PN-ABH-375
70430

MAPPING AND REMOTE SENSING

OF THE RESOURCES OF THE REPUBLIC OF SENEGAL

A STUDY OF THE

GEOLOGY, HYDROLOGY, SOILS, VEGETATION AND LAND USE POTENTIAL

SDSU-RSI-86-01

DIRECTION DE
L'AMENAGEMENT
DU TERRITOIRE

Agency for
International
Development

REMOTE SENSING INSTITUTE

PN-AEH-375

MAPPING AND REMOTE SENSING OF THE RESOURCES OF THE REPUBLIC OF SENEGAL

A STUDY OF THE GEOLOGY, HYDROLOGY, SOILS, VEGETATION AND LAND USE POTENTIAL

For

THE REPUBLIC OF SENEGAL
LE MINISTERE DE L'INTERIEUR
SECRETARIAT D'ETAT A LA DECENTRALISATION

Prepared by

THE REMOTE SENSING INSTITUTE
SOUTH DAKOTA STATE UNIVERSITY
BROOKINGS, SOUTH DAKOTA 57007, USA

Project Director - Victor I. Myers
Chief of Party - Andrew S. Stancioff

Authors
Geology and Hydrology - Andrew Stancioff
Soils/Land Capability - Marc Staljanssens
Vegetation/Land Use - Gray Tappan

Under Contract To

THE UNITED STATED AGENCY FOR INTERNATIONAL DEVELOPMENT
MAPPING AND REMOTE SENSING PROJECT
CONTRACT N°-AID/afr-685-0233-C-00-2013-00

Cover Photographs

Top Left: A pasture among baobabs on the Bargny Plateau.
Top Right: Rice fields and swamp priaires of Basse Casamance.
Bottom Left: A portion of a Landsat image of Basse Casamance taken on February 21, 1973 (dry season).
Bottom Right: A low altitude, oblique aerial photograph of a series of niayes northeast of Fâs Boye. Altitude: 700 m; Date: April 27, 1984.

PREFACE

Science's only hope of escaping a Tower of Babel calamity is the preparation from time to time of works which summarize and which popularize the endless series of disconnected technical contributions.

Carl L. Hubbs
1935

This report contains the results of a 1982-1985 survey of the resources of Senegal for the National Plan for Land Use and Development. The more descriptive title, Mapping and Remote Sensing of the Natural Resources of Senegal, was adopted to describe this project, the final report of which fulfills the requirements of USAID contract AID/afr 685-0233-C-00-2013-00, applicable during the period of February 19, 1982 through May 31, 1985 and of USAID/Senegal contract, applicable June 1, 1985. The first contract required the delivery of materials and equipment, the collection of data and the training of Senegalese counterparts to project scientists. The second contract required the preparation and delivery of maps and reports describing the resources of Senegal.

The delivery of materials and equipment took place during 1982 and 1983, and the collection of data by teams of both non-Senegalese and Senegalese experts began in 1982 and ended in 1985. Training activities also began in 1982 and terminated in 1985. The above subjects are treated in a previous report entitled Final Management Report, SDSU-RSI-85-04.

The current report provides Senegalese governmental planning agencies and cooperating international agencies with the following products and supporting evidence.

Resource Maps:

Hydrogeologic map of Senegal showing geologic and hydrologic units as interpreted from Landsat imagery and field work. Scale 1:500,000. Four map sheets and a one-sheet legend with annotations. In color.

Soils map of Senegal showing morphologic units as interpreted from Landsat imagery and field work. Scale 1:500,000. Four map sheets and a one-sheet legend with annotations. In color.

Vegetation map of Senegal showing phytogeographic units. Scale 1:500,000. Four map sheets and a one-sheet legend with annotations. In color.

Thematic Maps:

Land use map of Senegal showing present use of land in terms of major crops, forestry and/or rangeland. Scale 1:500,000. Four map sheets and a one-sheet legend with annotations. Black and white.

Groundwater table and well location map of Senegal showing depth to groundwater and wells measured by the Project. Scale 1:500,000. Four map sheets and a legend with annotations. Black and white.

Synthesis Maps (cartes de synthèse):

Land/soil capability map of Senegal showing potential for agriculture, forestry and grazing. This map indicates three to five levels of suitability. Scale 1:500,000. Four map sheets with a legend and annotations. Black and white with patterns.

Tectonic map of Senegal showing major structural units and their relationship to mineral and groundwater potential. Scale 1:1,000,000. One map sheet with a legend and annotations. Black and white.

Soil degradation map of Senegal showing areas of wind and water erosion, saline incursion and areas under ecologic pressure due to human degradation. Scale 1:1,000,000. One map sheet with legend and annotations. Black and white.

Vegetation degradation map of Senegal showing pressure on phytogeographic units due to lack of water and/or soils degradation, etc. Scale 1:1,000,000. One map sheet with legend and annotations. Black and white.

Water and mineral map of Senegal showing areas of high probability for water at indicated depths and the country's mineral potential. Scale 1:1,000,000. One map sheet with legend and annotations. Black and white.

ACKNOWLEDGEMENTS

After four years of work it is very difficult to know where to begin to thank those responsible for the success of this effort. We are deeply indebted to many in Senegal, the United States and other parts of the world. We sincerely hope that our debt will be in part repaid by the utility of our work.

Special recognition is given to the Senegalese government for its interest in the project. The support of his excellency the Minister of the Secretariat of Decentralization, Moussa Ndoye, and his staff was particularly gratifying. Our thanks also goes to the members of the Bureau d'Organization et Methode at the Presidency of the Republic for their concern and interest. We would like to thank the director and staff of the Direction de l'Aménagement du Territoire for their interest and criticism. We are also most grateful to all the government agencies' workers who assisted, giving of their time and in many cases, their friendship.

We should be remiss if we did not individually name those members of the various agencies who strove with us to improve our knowledge of Senegal. Our special thanks go to Alioun Badian, DAT; Luc Dubois, PNUD; A.K. Fahem, PNUD; Dr. P. Michel, Strasbourg; A. Hadj, ENEA; B. Dieng, J. Le Priol and P. Curretti, Direction d'Etudes Hydrauliques. Very heartfelt thanks are due to the Geography Department of the University of Dakar and all its members for the patience, understanding help and friendship shown to the project. Our thanks are due particularly to Dr. Diop, who helped us catalog our samples and the Direction des Mines et Géologie where help and friendship were generously proffered by Mr. Cheirrk Faye and the staff of the library. The assistance of IFAN and ORSTOM were also much appreciated.

At USAID we are especially grateful to Mrs. Littlefield, the Director, and her predecessor, Mr. Shear; the project officer, Mr. Harvey, and his predecessor, Mr. Larry Harms; and particularly to David Diop and Angélique who kept the project going with their good humor, hard work and patience. Of course we are also indebted to many other AID employees, Senegalese and American, for their assistance and support, particularly consulting ecologist Dr. Gene Eulert for his valuable insight into field methods and mapping. Upon our return to RSI, the arduous task of completing maps and reports fell upon a most cooperative staff. We thank Lisa, Melanie, Rick, Barb, Lillian, Jan, Bob, Russ, Rahim, Hamid, Joanne, Paul, Janet, Mary and Kevin for their hard work. Special thanks are extended to Doug "Waldo" Van Driel for drafting the figures, Bob Markowitz for his pen and ink interpretations of the Senegalese landscape, Sheryl Bolton for typing the manuscript, Shirley Lyons for typesetting, Tom Coblentz for map preparation, Anne Gellner for a gifted translation and Jeanne Lesinski for patience in editing the manuscript.

Our work could never have been accomplished without our project staff in Dakar. We would like to recognize its members for their hard work and cooperation during some difficult and some very good times; we hope that the memories they have will be as good as those we cherish of our time together. We thank:

M. Cisse - guard
M. Coli - guard
M. Diaga - guard
A. Diallo - guard
S. Diallo - chauffeur
M. Darboe - guard
S. Darboe - chauffeur
M. Da Silva - chauffeur
I. Diop - draftsman
M. Gadiaga - draftsman
L. Hulten - administrative assistant
D. Ka - administrative assistant
C. Lamotte - accountant
A. Ouattara - secretary
M. Ndiaye - cleaning personnel
I. Thior - gardener

All our work would have been for naught had it not been for the assistance we received from innumerable people in the Senegalese countryside. We are most thankful to those who pushed our cars when we were stuck, those who generously fed us and those who received us in their homes when we were tired, dirty and in need of moral support, which they gave so thoughtfully. We thank in this regard our friends in Thiel, Linguère, Bakel, Koumpentoum and at the "Hotel Diouf" in Tambacounda.

Finally, we would like to acknowledge our debt of gratitude to those who will carry on in remote sensing in Senegal and with whom we shared much more than professional concerns. These individuals gave much to the project's success. They worked hard and sacrificed much so that the results would make life better for their compatriots. They gave to their country and to us. For this we thank the following friends and scientists:

A.K. Cisse - Homologue au chef du projet, DAT
A. Bodian - Botaniste, Dir. des Eaux et Forêts
A. Sow - Géologue, Dir. des Mines et Géologie
K. Diatta - Géographe, DAT
B. Diouf - Géographe, Prof.
A. Niang - Aménagiste, DAT

We would like to dedicate this work to two men who have long worked to bring remote sensing to its rightful place in the scheme of global resource development, monitoring and planning. For their foresight, fortitude and unflagging support, we dedicate this work to Dr. Mamadou Sall of the Geograhy Department of the University of Dakar and Dr. Charles Paul, USAID, Office of Science and Technology, Washington, DC.

EXECUTIVE SUMMARY

Date - January 1, 1986
Project - National Plan for Land Use and Development
Country - Senegal
Cost - Authorized - $2,000,000

PROJECT PURPOSE

1. To provide baseline resource maps and interpretations for development potential.
2. To transfer technology and develop an appreciation and operational capability by GOS officials for use and application of remote sensing.
3. To initiate a pilot institution-building effort to identify and assess longer term institutional needs of Senegal in remote sensing.

ACCOMPLISHMENTS

1. PREPARATION OF MAPS

-Soil map of Senegal at 1:500,000 in color
-Vegetation map of Senegal at 1:500,000 in color
-Geohydrology map of Senegal at 1:500,000 in color
-Land use map of Senegal at 1:500,000 in black and white
-Land suitability/capability map of Senegal at 1:500,000 in black & white
-Soil degradation map of Senegal at 1:1,000,000 in black & white
-Vegetation degradation map of Senegal at 1:1,000,000 in black & white
-Tectonic map of Senegal at 1:1,000,000 in black & white
-Mineral & water potential map of Senegal at 1:1,000,000 in black & white
-Water resources/well location map at 1:500,000 in black & white

2. THE HYDROGEOLOGIC SURVEY

The hydrogeologic survey had 3 major goals: to define the hydrologic potential of Senegal, to ascertain the level of degradation of the aquifer of Senegal due to desertification and human pressure, and to map and evaluate the geology and mineral potential of Senegal. Our survey used Landsat and other data, as well as fieldwork, to establish new, improved maps which unequivocally show that the underground water potential of Senegal is good but deserves further study. Our survey measured hundreds of wells throughout Senegal and indicates that some minor lowering of the water table has occurred in certain specific overpopulated areas and that measures can be taken to counter this effect. The survey also showed that Senegal has a fossil fuel and mineral potential exceeding that which has been previously attributed to this country.

3. THE SOILS SURVEY

The soils survey accomplished its three major goals: to map the soils of Senegal at our scale (1:500,000), to sample and evaluate the soils potential of certain poorly mapped areas of Senegal and to provide the government of Senegal with a land capability map showing the potential of the Senegalese territory for agriculture, animal husbandry and forestry.

4. THE VEGETATION AND LAND USE SURVEY

The vegetation and land use survey was conducted in response to a need by the Government of Senegal (GOS) for an up-to-date inventory of the vegetation and land use of Senegal. The survey used a multistage remote sensing approach to produce detailed maps of the vegetation cover, vegetation degradation and land use/land cover of Senegal. The maps are based on 1:250,000 multitemporal Landsat interpretations, analysis of aerial photographs over selected areas, and extensive field data collected between 1982 and 1985.

Presented in this report is a description of the mapping procedures including interpretation of Landsat imagery, field data collection, vegetation and land use classification strategies and structure of the map legends. To be used in conjuction with the maps, a detailed description of each vegetation cover type is also presented, containing information on physiognomy, species composition and the general vegetation condition.

5. CONCLUSION

This report and the accompanying maps, figures and appendices document the extent and present status of the natural resources of Senegal. This information, although not definitive, should provide the Senegalese government, its people and the agencies involved with development a much clearer view of the natural resources of Senegal and should provide the tools necessary for more effective planning and development.

CONTENTS

PAGE

Preface i
Acknowledgements iii
Executive Summary vi
Table of Contents viii
List of Maps xii
List of Tables xiii
List of Figures xiv

CHAPTER I: SCOPE, OBJECTIVES AND METHODOLOGY OF THE REMOTE SENSING SURVEY OF SENEGAL

1.1 Introduction 3
1.2 Application of Remote Sensing to the Senegal Resource Survey 5
1.3 Utilization of the Resource Maps and Data 9
1.4 Map Format 11
1.4.1 Map Products Prepared in Senegal 11
1.4.2 Map Production at RSI 12
1.4.3 Map Format 13
1.4.4 Map Accuracy 14
1.5 References 15

CHAPTER II: CLIMATE AND PHYSIOGRAPHY

2.1 General 19
2.2 Physical Environment 20
2.3 Climate 23
2.3.1 Atmospheric Influences 23
2.3.2 The Trade Winds of Alizé Maritime 23
2.3.3 The Harmattan 23
2.3.4 The Monsoon 23
2.3.5 Seasons 23
2.3.6 Rainfall Characteristics 24
2.3.7 Climatic Regions 24
2.3.8 Temperature and Evaporation Rates 30

CHAPTER III: HYDROGEOLOGY

3.1 Introduction 41
3.2 Mapping Procedures 42
3.3 Literature Consulted 43
3.4 Interpretation Methodology 43
3.5 Characteristics of Available Landsat Imagery 45
3.6 Field Work 46
3.6.1 General 46
3.6.2 Methods 47

CONTENTS (CONT.)

PAGE

3.7 Other Means of Verification..... 50
3.7.1 General..... 50
3.7.2 Aerial Overflights..... 50
3.7.3 Aerial Photography..... 52
3.8 Legend and Map Format..... 54
3.8.1 Geohydrology Map..... 54
3.8.2 Tectonic Map..... 55
3.8.3 Hydrologic Map..... 55
3.8.4 Mineral and Water Potential Map..... 55
3.8.5 Map Format and Supporting Documentation..... 56
3.9 The Geology of Senegal..... 56
3.9.1 Introduction..... 56
3.9.2 Geology of Senegal Oriental--The Precambrian and Paleozoic..... 58
3.9.3 The Sedimentary Basin of Senegal..... 67
3.9.4 Landsat Interpretation..... 78
3.9.5 Tectonic Interpretation of Landsat and Other Data.... 124
3.9.6 Economic Geology..... 135
3.10 Hydrology..... 156
3.10.1 Introduction..... 156
3.10.2 Overview..... 157
3.10.3 Literature Review..... 158
3.10.4 Major Hydrologic Characteristics of Senegal..... 158
3.10.5 Conclusions on the Hydrology of Senegal..... 179
3.10.6 Senegal's Water Potential..... 180
3.11 Appendix A: Hydrogeology..... 185
3.12 Bibliography..... 266

CHAPTER IV: SOILS AND LAND CAPABILITY

4.1 Introduction..... 279
4.2 Mapping Procedure..... 279
4.2.1 Introduction..... 279
4.2.2 Acquisition of Remotely Sensed Data..... 280
4.2.3 Literature Consulted..... 280
4.2.4 Interpretation..... 280
4.2.5 Fieldwork..... 281
4.2.6 Finalization..... 285
4.2.7 Other Means of Verification..... 285
4.3 Map Production (Morphopedology)..... 285
4.3.1 Introduction..... 285
4.3.2 Legend..... 285
4.3.3 Mapping Units Description..... 290
4.4 Production of Derived Maps..... 399
4.4.1 Introduction..... 399

CONTENTS (CONT.)

PAGE

4.4.2 Land Capability Map..... 423
4.4.3 Soils Degradation Map..... 423
4.5 Appendix B: Soils and Land Capability..... 425
4.6 Bibliography..... 472

CHAPTER V: VEGETATION AND LAND USE

5.1 Introduction..... 485
5.2 Literature Consulted..... 485
5.3 Mapping Procedure..... 486
5.3.1 Vegetation and Land Use Reconaissance Surveys..... 486
5.3.2 Vegetation Classification..... 487
5.3.3 Land Use/Land Cover Classification..... 488
5.3.4 Interpretation..... 489
5.3.5 Field Data Collection..... 490
5.3.6 Other Means of Verification..... 493
5.3.7 The Vegetation Legend..... 493
5.3.8 The Land Use/Land Cover Legend..... 494
5.4 Description of Cover Types..... 494
5.4.1 The Sahelian Phytogeographic Region..... 495
5.4.2 The Sudanian Phytogeographic Region..... 588
5.4.3 The Guinean Phytogeograh'que Region..... 613
5.5 The Vegetation Degradation Map..... 619
5.6 Appendix C: Vegetation and Land Use..... 622
5.7 Bibliography..... 629

CHAPTER VI: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction..... 637
6.2 Summary and Conclusions of the Hydrogeological Mapping of Senegal..... 638
6.2.1 Summary of the Hydrogeologic Mapping..... 638
6.2.2 Conclusions Drawn from the Hydrogeologic Mapping Effort..... 638
6.3 Summary and Conclusions of the Soils Mapping of Senegal..... 639
6.3.1 Summary of the Soils Mapping..... 639
6.3.2 Conclusions Drawn from the Soils Mapping Effort..... 640
6.3.3 Recommendations Based on the Soils Mapping Effort.... 640
6.4 Summary and Conclusions of the Vegetation Mappng of Senegal. 641
6.4.1 Summary of the Vegetation Mapping..... 641
6.4.2 Observations and Conclusions Drawn from the Vegetation Effort..... 642

6.5 Recommendations 649
6.5.1 Recommendations Based on the Hydrogeologic Work of the Project 650
6.5.2 Recommendations Based on the Soils Work of the Project 652
6.5.3 Recommendations Based on the Vegetation Work of the Project 653
6.6 References 655

MAPS

CHAPTER I

MAP		PAGE
1.1	Index to Landsat Coverage--Senegal and The Gambia.....	6
1.2	Natural Regions of Senegal.....	7
	CHAPTER II	
2.1	Generalized Portrayal of Climate Zones of Senegal.....	22
2.2	Isoheytal Map of Senegal.....	25
2.3	Average Annual Rainfall.....	26
2.4	Comparison of Rainfall Patterns.....	28
2.5	Phytogeographic Regions of Senegal.....	29
	CHAPTER III	
3.1	Hydrogeologic Survey Routes.....	48
3.2	Aerial Overflights.....	51
3.3	Map of the Senegalo Mauritanian Basin.....	57
3.4	Gravimetric Map of Senegal.....	127
3.5	Aeromatic Map of the Senegal Basin.....	128
	CHAPTER IV	
4.1	Geologic Subdivisions.....	286
4.2	Formations.....	287
4.3	Formations A & L (partim).....	289
4.4	Formation P (partim).....	351
4.5	Formation S (folded rocks).....	361
4.6	Formations M, G, I, Q, S (partim).....	362
4.7	Soil Climate Zones.....	417
	CHAPTER V	
5.1	Vegetation Survey Routes.....	492
5.2	Ecogeographical Environments (cited from another source).	498

TABLES

TABLE		PAGE
	CHAPTER II	
2.1	Rainfall Measurements 1974-1983	27
2.2	Temperature Gradients	30
2.3	Evaporation Rates	31
	CHAPTER III	
3.1	Compagnie Sénégalaise des Phosphates de Taïba: Production and Export Statistics, 1960-1982 (total)	144
3.2	Compagnie Sénégalaise des Phosphates de Taïba: Production and Export Statistics, 1960-1982 (breakdown)	145
3.3	Comparison of Wells and Water Depth in Senegal--1962	177
3.4	Comparison of Wells and Water Depth in Senegal--1967	178
3.5	Comparison of Wells and Water Depth in Senegal--1981	178
	APPENDIX A: HYDROGEOLOGY	
III-1	Characteristics of Landsat Imagery	185
III-2	Hydrology Table	200
III-3	Rock Sample Identification	235
III-4	Samples by Mass Spectrometer	245
III-5a	Field Activities	249
III-5b	Field Activities	250
III-6a	Overflights	251
III-6b	Overflights	252
III-7	Aerial Photograph Analysis	253
	CHAPTER IV	
4.1	Textural Triangle	404
4.2	Conversion Table	419
	APPENDIX B: SOILS AND LAND CAPABILITY	
IV-1	Soil Survey Routes	425
IV-2	Examples of Soils Profiles	427
IV-3	Soils Characteristics: First Order Parameters	447
IV-4	Soils Characteristics: Second Order Parameters	459
IV-5	Land Capability	469
	APPENDIX C· VEGETATION AND LAND USE	
V-1	Vegetation Types	623
V-2	Vegetation Tables	627

FIGURES

FIGURE PAGE

CHAPTER III

3.1 Schematic cross section of Senegal (Dakar-Bakel)..... 75
3.2 Landscape of Senegal Oriental..... 80
3.3 Landsat image of Senegal Oriental..... 81
3.4 Banded shaley and siliceous limestone/marble, Ibel..... 84
3.5 Tightly folded calcareous rocks of the Dialé Series near Bandafassi..... 85
3.6 Erosional remnant of tightly folded, thin bedded, calcareous cherty shale and limestone east of Ibel..... 85
3.7 Kink-fold schistose rocks east of Kossanto..... 86
3.8 Landsat image of eastern Senegal..... 89
3.9 Landsat image of Senegal Oriental..... 95
3.10 Landsat image of the Haute Casamance..... 100
3.11 Tillite horizon in a small stream east of Marsa..... 101
3.12 Dolerite boulders on a scree slope west of Bandafassi... 103
3.13 Dolerite caping and talus covering the Birrimean Dialé Series west of Bandafassi..... 103
3.14 Sandstones at Cap Skirring..... 111
3.15 A low angle thrust fault..... 116
3.16 Landsat image of the Diourbel-Thiès Groundnut Basin region..... 118
3.17 Aerial view of the niayes..... 139
3.18 The bed of the Falémé River as seen from Mali in April.. 141
3.19 A fold-bearing horizon between Kédougou and Saraya..... 147
3.20 A fold-bearing conglomerate from the banks of the Diaguéri River..... 149
3.21 Shallow gully erosion south of Mboune..... 161
3.22 Well at Ndiaganiao Catholic Mission..... 166
3.23 A group of trainees and instructors..... 167
3.24 Karst features in Paleocene limestone at Keur Ndiogue Ndiaye..... 167
3.25 Well being dug in the "Continental Terminal" near Koutia Ba..... 171
3.26 A saline delta in Lake Retba..... 172
3.27 A typical céane in Senegal Oriental..... 174

CHAPTER IV

4.1 Augering..... 282
4.2 A mini-pit..... 282
4.3 A mini-pit..... 283
4.4 A profile pit..... 284

FIGURES (CONT.)

FIGURE		PAGE
4.5	Low-oblique aerial photograph of units La2, La3 and La4	291
4.6	Functional valley bottom in the Haute Casamance	306
4.7	Mushroom-shaped termite mound on hydromorphic soil	307
4.8	Glazed surface and residual microrelief left by sheet erosion	310
4.9	A firebreak in the Sandy Ferlo	317
4.10	A firebreak in the Ferlo Boundou	330
4.11	Indurated, ferruginous material exposed to air by erosion	332
4.12	Termite mounds on deep, ferruginous tropical soils	337
4.13	Cuirasse pavement	339
4.14	Erosional surface: Massif de Ndiass	358
4.15	Close-up view of a carapace layer in sandstone	367
4.16	Mushroom-shaped termite mound on gravelly soil	368
4.17	A cuesta (sandstone)	378
4.18	The backslope of a cuesta	379
4.19	Hardcap pavement with boulders	387
4.20	Close-up view of a cuirasse pavement	387

CHAPTER V

5.1	A view east of the Senegal River Valley	498
5.2	Shrub steppes of the Senegal River Valley	499
5.3	Aerial view of an *Acacia nilotica* riverine woodland	501
5.4	A degraded *Acacia nilotica* riverine woodland	501
5.5	Landsat image of the Sandy Ferlo, the Lac de Guiers and the Senegal River Delta	503
5.6	An aerial view of the niayes near Fâs Boye	506
5.7	An aerial view of coastal dunes	507
5.8	A view of a large *niaye*	509
5.9	An aerial view of the Groundnut Basin in the Khombole area	515
5.10	An aerial view of open shrub and tree pseudo-steppes in the northern Groundnut Basin	517
5.11	Ephemeral summer rangeland at the end of the wet season	518
5.12	*Euphorbia balsamifera* used as live fences	519
5.13	*Guiera senegalensis* in a sandy, fallow field	523
5.14	Dry season scene east of Ndangalma	524
5.15	Wet season scene east of Ndangalma	524
5.16	Remnants of an exploited *Borassus aethiopium* grove	527
5.17	An aerial view of a narrow valley near Noto	530
5.18	An aerial view of a striped savanna (*savane tigrée*)	533
5.19	An open shrub pseudo-steppe on *diéri* soils	535

FIGURES (CONT.)

FIGURE		PAGE
5.20	An open shrub pseudo-steppe in the northern Sandy Ferlo	537
5.21	An open shrub pseudo-steppe with sparsely scattered trees	538
5.22	Relatively dense vegetation in interdunal depressions	540
5.23	A dry season view of the Ferlo Valley west of Linguère.	547
5.24	A wet season view of the Ferlo Valley west of Linguère.	547
5.25	A dry season view of the Pterocarpus lucens shrub savanna near Lonoféré	549
5.26	A wet season view of the Pterocarpus lucens shrub savanna near Lonoféré	549
5.27	An aerial view of the Pterocarpus lucens-dominated shrub savanna near Revane	551
5.28	Densely wooded channels within a fossil valley east of Mboule	556
5.29	An aerial view of the groundnut-millet-cotton growing region south of Nioro du Rip	565
5.30	Landsat image of the Department of Kaffrine	567
5.31	A dry season view of agricultural lands east of Koungheul	568
5.32	A wet season view of agricultural lands east of Koungheul	568
5.33	An aerial view of termite mounds	570
5.34	An aerial view of the Sine Saloum estuaries north of Toubakouta	575
5.35	A degraded vegetation landscape in the Forêt Classée de Mbegne	578
5.36	An aerial view of the boundary between the Forêt Classée de Mbegne and the cropland of the Groundnut Basin	579
5.37	A view of an upland savanna-woodland south of Toubéré Bafal	584
5.38	A dense savanna-woodland north of Tambacounda	587
5.39	Scattered shrubs and small trees on buttes and residual hills between Bakel and Kidira	590
5.40	A typical bowal, or iron pan, near Saraya	596
5.41	Landsat image of the southern portion of the Parc National du Niokolo Koba	597
5.42	Riparian vegetation of the Gambia River near Gue de Wassadou	601
5.43	An aerial view of cropland within the extensive woodlands of Moyenne Casamance	603
5.44	A wet season view of a wide, shallow valley in Moyenne Casamance	608
5.45	A dry season view of a wide, shallow valley in Moyenne Casamance	608
5.46	An aerial view of rice paddies, mangrove communities and denuded tidal swamps near Séléki	612

FIGURES (CONT.)

FIGURE		PAGE
5.47	An aerial view of deforested uplands in Basse Casamance	614
5.48	An aerial view of the complex of moist woodlands and oil palm groves that border low, wide valleys in Basse Casamance.....	616
5.49	Landsat image of Basse Casamance.....	618

CHAPTER I

SCOPE, OBJECTIVES AND METHODOLOGY OF THE REMOTE SENSING SURVEY OF SENEGAL

CHAPTER I: SCOPE, OBJECTIVES AND METHODOLOGY OF THE REMOTE SENSING SURVEY OF SENEGAL

1.1 Introduction..... 3
1.2 Application of Remote Sensing to the Senegal Resource Survey..... 5
1.3 Utilization of the Resource Maps and Data..... 9
1.4 Map Format..... 11
1.4.1 Map Products Prepared in Senegal..... 11
1.4.2 Map Production at RSI..... 12
1.4.3 Map Format..... 13
1.4.4 Map Accuracy..... 14
1.5 References..... 15

CHAPTER I

SCOPE, OBJECTIVES AND CARTOGRAPHIC METHODOLOGY OF THE REMOTE SENSING SURVEY OF SENEGAL

1.1 INTRODUCTION

Senegal, which covers an area of about 196,700 km^2, and The Gambia, whose area is nearly 10,000 km^2, lie in the Sudano-Sahelian zone. The population of Senegal is estimated (in 1985) at 6.1 million and its annual growth rate at 2.5%. About 70% of the population lives in rural areas. Notwithstanding the massive pressure of the rural population on Dakar and other urban centers, the rural population continues to grow. Of this latter group, over 55% lives in the central Groundnut Basin, which covers less than 20% of the country's area.

The combined effects of an increasing population, declining soil fertility and a prolonged period of below normal rainfall continue to pose major obstacles to Senegal's development. The threat is particularly felt in the Groundnut Basin. It is estimated that only half of Senegal's arable land (4.6 million ha) is presently under cultivation, and productivity figures for crops such as millet and rice are significantly below those of other African countries.

The Senegalese are not fully exploiting their nation's few known mineral resources, such as phosphates, and little effort has been made to properly explore for gas in the west, other mineral commodities in the southeast and east and oil throughout Senegal.

The availability of water has been the chief problem for Senegal at every level. Over the last ten years, low rainfalls have resulted in the depletion of water supplies in many villages; however, no country-wide effort has yet been made to evaluate the underground potential of the various aquifers. The damming of Lac de Guiers and the annual replenishment of fresh water to the lake has eased shortages in Dakar and other population centers. The construction of dams at Diama and Manantali will also help by regulating Senegal's water flow and by bringing new land into production. Efforts by middle eastern investors to drill deep wells in the Groundnut Basin should also locally alleviate problems. Nevertheless, in large parts of the overpopulated western portion of the country there is little hope for improved conditions without adequate water supplies, particularly as decreasing supplies of water have caused the elimination of small herds of sheep and goats, as well as curtailing vegetable production.

Forestry and grazing resources are poorly mapped, and while in certain areas they are under stress due to overexploitation and burning, in other regions they remain underdeveloped.

Serious deterioration of soils occurs throughout much of Senegal due to population pressure, deforestation, extensive cash cropping of

peanuts, poor land management practices, chronic drought, and heavy winds and occasional torrential rains that remove top soils. Declining productivity due to land degradation poses serious problems. An initial approach to solving these problems is to arrive at a better understanding of Senegal's soils resource and its potential.

Senegal thus faces two major problems in its effort toward developing agricultural self-sufficiency. The first is a lack of knowledge concerning its resources; the second is the degradation of its land due to the combination of drought and poor agricultural practices, which have depleted its soils, destroyed its rangeland and abused its forests.

This project is an effort to increase the knowledge of the Senegalese environment through a systematic inventory of its resources and an evaluation of the effects of degradation by natural or human causes.

Innumerable specific and special site studies have been conducted and are ongoing in Senegal. Many of these investigations are, however, restrictive by design, age, and specific purpose. While these studies can be used to corroborate other small-scale surveys, they cannot be easily incorporated into a nationwide resource data base. Synchronous collection of resource data is needed to assure uniformity in the establishment of baseline conditions. The extent and condition of various resource parameters are needed to furnish a foundation which can be the base for national planning, implementation of remedial actions and future updating of resource characteristics.

In large area surveys, small-scale mapping (1:1,000,000 or 1:500,000) provides the best compromise between the level of detail and the expense and time needed to complete the survey. Landsat satellite data have been used successfully in several small-scale, country- or region-wide resource surveys. Generally, multistage approaches are used in Landsat-based surveys; these stages or levels include Landsat Multispectral Scanner (MSS) data, Landsat Return Beam Vidicon (RBV) imagery, aerial photography and ground observations, and sampling in the field. Landsat images, though limited by their small scale, offer synoptic, nearly orthographic, multispectral coverage. The multidate coverage by Landsat (which, if available by means of aerial photography, would be more expensive) further provides the potential for updating changes in resource variables, such as rangeland trends, land use, wetness and erosion.

Nationwide inventories of Senegalese resources are virtually non-existent. For instance, the existing soils map of Senegal at a scale of 1:1,000,000 is based on piecemeal surveys at different scales and on limited field information for much of the all-important central Groundnut Basin. Similarly, the geologic maps of Senegal at 1:500,000 because of their composite nature, show few structures and little or no information concerning the tectonic evolution of the country;

structural data (folds, faults, fractures) are most important when searching for water, minerals and combustible resources. It was therefore the aim of this project to establish baseline data for a national resources plan in the context of the needs of the Plan National de l'Amenagement du Territoire (National Plan for Land Use and Development). This goal was achieved through the use of a Landsat-based, multistage reconnaissance resource survey. The resource inventories in this 206,700 km^2 survey of Senegal and the Gambia include mineral and water resources, vegetation (forests, pastures and arable land) and soils. Additional interpretations of degradation and maps of resource potential were also prepared.

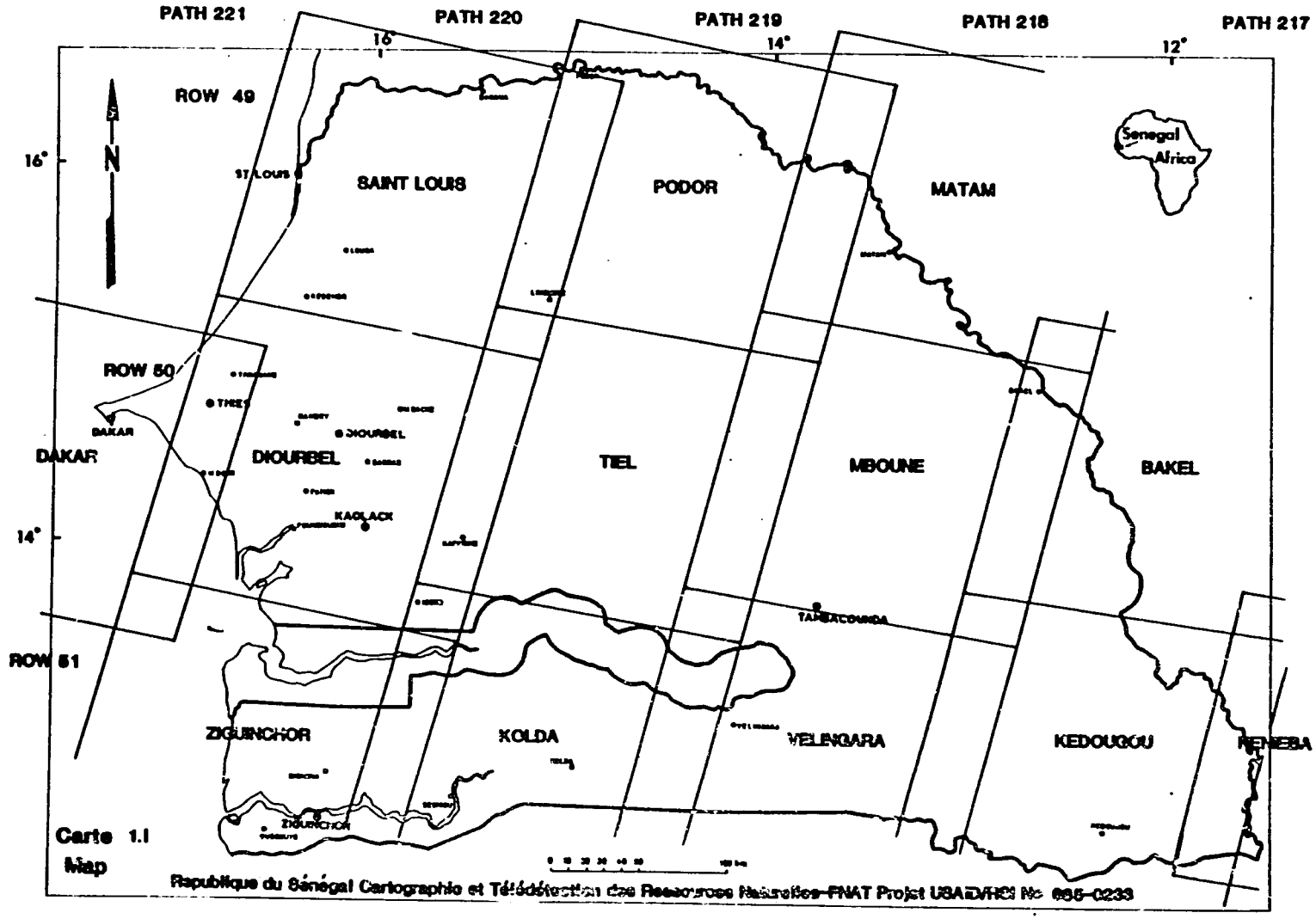
1.2 APPLICATION OF REMOTE SENSING TO THE SENEGAL RESOURCE SURVEY

Remote sensing is defined as the science and art of acquiring information about material objects without coming into physical contact with those objects.

In conducting the reconnaissance resource surveys, the Mapping and Remote Sensing Project employed near-infrared and visible spectrum imagery, as well as digitally enhanced Landsat satellite imagery and aerial photography.

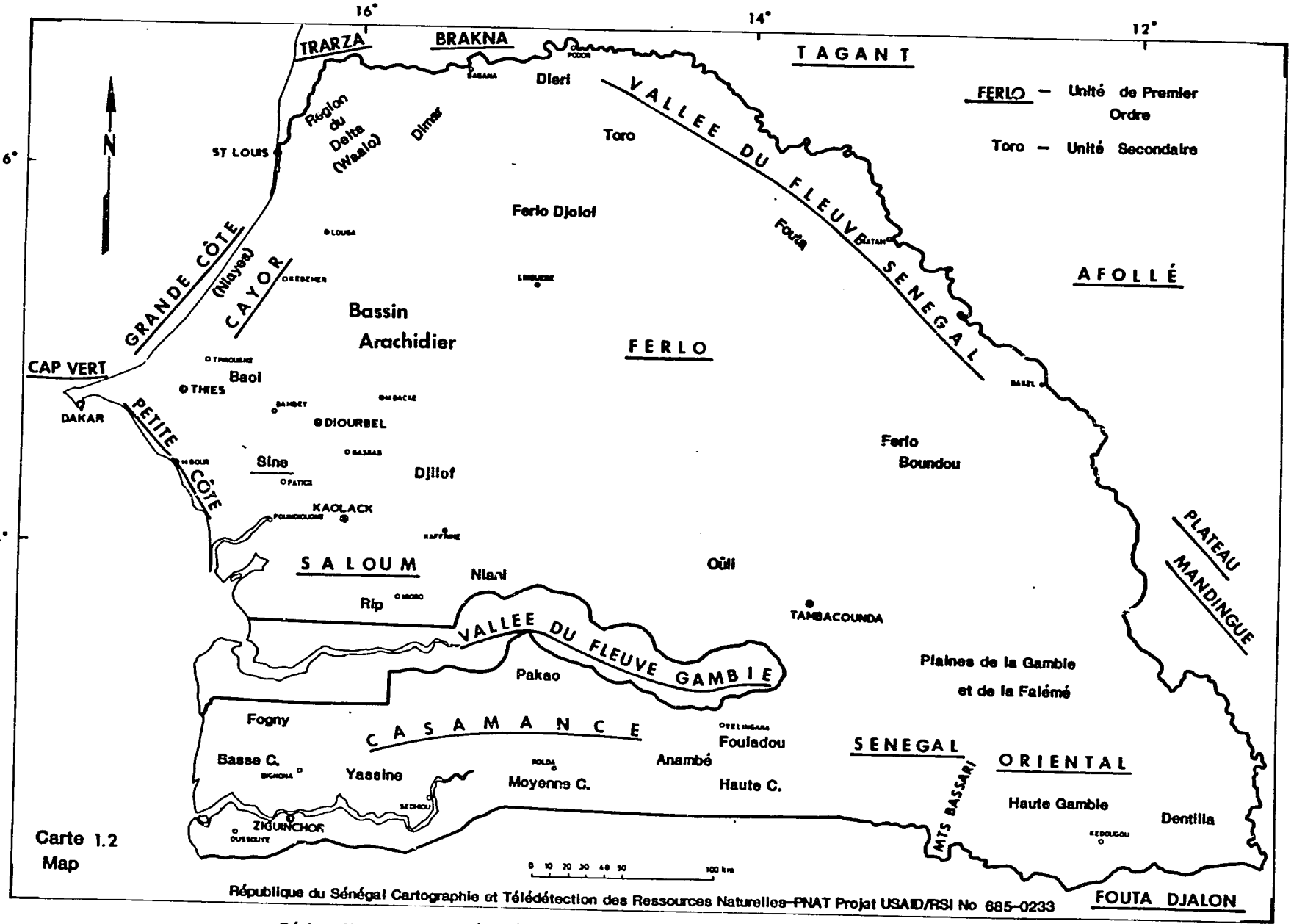
The Landsat satellite imagery consisted of MSS and RBV data. The MSS data are collected in four spectral "bands": band 4, 0.5 to 0.6 µm (green); band 5, 0.6 to 0.7 µm (red); band 6, 0.7 to 0.8 µm (near-infrared); and band 7, 0.8 to 1.1 µm (near-infrared). The RBV imagery (Landsat 3) is collected by a two-camera system that records data in the 0.505 to 0.750 µm spectral region. Scene coverage for a Landsat MSS scene is 185 by 185 km, whereas RBV coverage is 98 by 98 km (4 RBV scenes per MSS scene). The instantaneous ground resolution (i.e., the ground spot viewed at any instant by the optical system) is 0.45 ha for Landsat MSS and 0.10 ha for RBV. The Landsat satellite completely covers the earth every 18 days from an altitude of 917 km, (coverage for Senegal is shown in Map 1.1); however, recording and data handling facilities are limited, and as a result MSS and RBV data are not transmitted continuously over all the land surface of the earth.

As with color infrared film, Landsat MSS data is sensitive to radiation in the visible and near-infrared portions of the electromagnetic spectrum. Growing vegetation absorbs radiation in the blue and red portions of the spectrum and reflects radiation in the green and near-infrared portion. The Landsat system differentiates between portions of the spectrum and the imagery derived allows us to see and define growing, stressed and dead vegetation. The creation of color images by the compositing of Landsat MSS bands 4, 5 and 7 allows us to map healthy or stressed vegetation by tonal comparison. Thus, by inference or deduction, we can map productive soils, wetness, agricultural management practices (land use) and healthy vegetative growth, as well as areas that are stressed by natural or human variables.



INDEX TO LANDSAT COVERAGE–SENEGAL AND GAMBIA

INDICE DE LA COUVERTURE LANDSAT DU SENEGAL ET DE LA GAMBIE



Carte 1.2
Map

République du Sénégal Cartographie et Télédétection des Ressources Naturelles–PNAT Projet USAID/RSI No 685-0233

Régions Naturelles et Unités Géographiques du Sénégal

Natural Regions and Geographic Units of Senegal

Although a large amount of imagery is available for Senegal, no group of high quality images (13 in all to cover Senegal) could be found to cover Senegal during a particular month or season. Therefore, analyses were based on a mosaic of images from different years and different seasons. In addition, no particular set of images were found to be optimal by the three groups of mappers (soils, hydrogeology, and vegetation). Thus no unified base could be created. This lack of imagery of Senegal, particularly for recent years (1982-1984), has precluded any overall evaluation of the progressive desertification of Senegal. The reason for this lack of imagery is that the earth-orbiting Landsat satellites all suffered functional problems from 1982 to 1984; the latest in the series, Landsat TM (Thematic Mapper), which could have provided the needed information, suffered a malfunction, was seldom operated over Senegal and initially produced poor results.

A hierarchical, multistage, approach was used by each resource scientist in completing his respective map. This approach was based on photointerpretation and analyses of multidate (seasonal and different years) Landsat imagery. Preliminary photointerpretative delineations were completed on the Landsat MSS imagery at various scales before field work was begun. Background materials, including site-specific studies, small-scale maps and the experience of the project's Senegalese counterparts, were used in the preparation of the preliminary interpretation.

Ground verification trips were of one to two weeks duration, and the resource teams generally worked separately due to the disparity of sampling techniques, i.e., type and number of ground observations. Collecting plant samples of mountable quality, determining the quantity of species per unit area, collecting rock samples, sampling soil, describing soil profiles, mapping slopes and estimating the amount of ground cover were some of the methods used to verify mapping unit boundaries and descriptions. Specifics of the various resource sampling schemes are detailed in the appropriate chapters. After the collection of the field data and samples, further analyses and collation took place in the project office in Dakar and at RSI in Brookings, SD.

The finalization of mapping unit boundaries took place after studying the results of the field observations, re-analyzing the Landsat imagery, and describing the mapping units in such a way that significant differences excluded any further grouping or separating of delineations. The actual placement of boundaries was subjective and depended upon the experience and knowledge of each resource specialist and the analysis and integration of many sets of data.

Remote sensing technology was used in this project to provide a basis for locating and describing the natural resources of Senegal. This baseline resource information was collected and analyzed for immediate and future use by resource managers, planning personnel and

appropriate government officials. Remote sensing technology should also be considered in designing future activities that result from these survey data, and examining in detail (i.e., larger scale surveys) some of the more promising land areas.

The late 1980's and 1990's will see rapid improvement in most aspects of satellite remote sensing capability: new satellites will have smaller instantaneous fields of view and better spectral differentiation, cartographic application and "turn-around" time. As satellite sensors improve and the types of available spectral information expand, remote sensing applications to resource monitoring will provide the potential for more precision.

1.3 UTILIZATION OF THE RESOURCE MAPS AND DATA

Before the data in this report can be fully applied, an understanding of the term "reconnaissance survey" is required, together with an awareness of the relationships of and between soil, vegetation, and geohydrologic units. The inherent strengths and shortcomings of a reconnaissance survey determine the types of uses and decisions that can be based upon it. Likewise, similarities and disparities among the mapping units of the different resources should be understood, if integrated programs are to be undertaken on the basis of this survey.

The level of detail in a resource survey is usually dictated by the scale of the base map and concomitantly by the density of ground observations. A scale of 1:500,000 was chosen for this survey because it provided the optimum amalgamation of detail, extent of the project area and time required from project beginning to report completion. At the 1:500,000 scale, mapping units consist of associations and have a minimum, prescribed size of 100 ha. As an example of the scale limitations for mapping units, a line of 1 mm width on the base map corresponds to an on-ground width of 0.5 km. As a consequence, the survey results should be used only for general activities, such as broad planning and management uses, or in determining the locales for more detailed surveys.

In Senegal, geologic features, soil types and vegetation tend to correspond to one another and therefore could be mapped as singular features. This situation would dictate the use of land mapping units, i.e., composite units, each having reasonably similar attributes of climate, geology, hydrology, soil, flora, and fauna. However, the differences in dynamics, or resistance to change, among the various resources and in the climate/land use interplay in Senegal lead the remote sensing scientists to use individualized resource surveys. Consequently, there are three resource maps for the project area instead of just one, and a general understanding of the similarities and differences between these maps will lead to more effective use of the survey results.

Two variables should be recognized before working with the various resource maps: 1) the relationship of mapping unit boundaries to the appearance of the specific resource on Landsat imagery and aerial photographs and 2) the methods or levels of partitioning the project area into associations, or mapping units. Soils, geology and vegetation are the major features that influence the Landsat-recorded, spectral reflectance in Senegal. In many places, herbaceous ground cover influences spectral signatures, especially sandy areas in the more favorable rainfall zones. In other areas, vegetation tends to mask the soils and geology; therefore, interpretation must depend on more complex analysis or combinations of second order factors such as plant vigor or topography. In some heavily forested areas with little or no topography, soils and geologic interpretations depend heavily on pre-exiting maps and other data, such as aerial photographs.

A similar approach was used by each resource survey team in arriving at the final delineation of mapping units, but individual criteria for mapping unit definition differ substantially. Similarities among survey approaches include 1) elimination of those cover types or soil units not likely to occur in a given locale and 2) a listing of expected associations in a given locale, based on imagery representations and known ecologic interactions. The various hierarchical criteria used in mapping are listed as follows by the resource and in order, from highest to lowest levels:

1. Soils--soil climate zones, landform groupings and soil associations, which are based on soil slope and other measurable soil properties and include composition of differing, but nonseparable, soil groups.

2. Vegetation and land use--soil and landform groupings and dominance of major plant associations and occurrence of minor plant associations, density of trees per hectare, average height, level of exploitation, regeneration, field patterns, etc.

3. Hydrogeology--wetness, texture of landscape (topographic variation), drainage, vegetation cover, geometric discordance or concordance of surface features.

Each resource chapter discusses the specifics of the mapping units' definitions and interpretations as they apply to that discipline. Utilization of a resource map alone requires little explanation, short of the previously mentioned limitations associated with reconnaissance maps. If an integrated approach is taken in which all the mapped natural resources are considered, some care must be taken in order to fully utilize and avoid discounting map differences. The manner in which the various resource maps are combined should be related to the specific purpose of a given project. Therefore, approximation of general levels of animal-carrying capacities, for example, could involve mapping unit interpretations from the soil map (erosion and erosion hazard) and the vegetation and land use maps

(level of exploitation and regeneration). To effectively integrate these data, the project area must first be defined; second, the necessary mapping units extracted; third, the pertinent or contributing interpretations selected; fourth, the hierarchy of the mapping units determined; fifth, the various resource map unit boundaries (via overlays) over the project area should be compared and the appropriate boundaries selected; and lastly, the hectares per defined unit tallied. The last process is more easily accomplished with a computerized Geographic Information System (GIS).

To effectively use the land capability map, it must be remembered that as in the individual maps each cartographic unit represents a unique aspect, even though it has been established by combining vegetation, land use, soils, hydrologic, geomorphic and geologic criteria. Each user must define his requirements before areas with suitable potentials for his needs and related activities can be located on the appropriate resource map. Conversely, areas unsuitable for certain activities can also be located.

Uses of the resource data are numerous and include the following incomplete listing: environmental monitoring of any of the measured dynamic variables; selection of areas that appear promising for development (detailed or intensive surveys or further specialized ground characterization); use in other on-going projects; use in the development of management objectives and applications, extension activities and student education. The resource data represented on the various maps and described in the following chapters provide a generalized, synoptic representation of the current state (1985) of the selected resources of Senegal.

1.4 MAP PRODUCTION AND FORMAT

This section summarizes the major steps involved in the map production effort undertaken by the Project and describes the format of the map products.

1.4.1 Map Products Prepared in Senegal

a. While the initial Landsat interpretations and field work were still in progress, the drafting of a full complement of 21 base maps at 1:250,000 scale was begun by the project draftsman. They were prepared from the Joint Operations Graphic (JOG) 1501 series of topographic maps of the U.S. Army Map Service, 1:250,000 scale; the drafting was done on translucent film overlays; topographical and cultural features to be included on the final Project maps were extracted from this map series, including towns, roads, drainage, political boundaries and geographical coordinates. The JOG maps were used instead of the topographic maps of the Institut Geographique National (IGN) primarily because the scale of the JOG sheets corresponded to that of our Landsat interpretation sheets and because fewer JOG sheets were needed to cover Senegal (21 JOG versus 28 IGN sheets).

b. Upon completion, multiple copies of each translucent base map were photographically made, one for each set of basic resource maps and thematic maps (hydrogeology, soils, vegetation, land-use, and groundwater maps).

c. After the completion of field work and the finalization of the Landsat interpretations by the resource survey teams, the map units were transferred to the duplicate base maps, using towns, roads, drainage and other control points as a means of registering the interpretation sheets to the base maps. Registration proved to be more problematic than anticipated since the Landsat imagery varied slightly in scale from image to image and the translucent film used in the base map reproductions was found to be dimensionally unstable, a problem later rectified. The transfer of linework was done on a sectional basis corresponding to areas of approximately 1/2 degree of longitude and latitude. The linework had to be matched from section to section and sheet to sheet. Codes were used to label each map unit.

d. Paper copies of each of the resource and thematic maps (21 sheets each, 1:250,000 scale) were reproduced from the originals. They were hand colored and delivered to the DAT to serve as preliminary map products for the PNAT. The originals were sent to the Remote Sensing Institute for the final map production phase.

1.4.2 Map Production at RSI

a. The set of 21 translucent base maps containing cultural and topographic features were photographically reduced to 1:500,000 scale. Most of the scale inconsistencies resulting from the dimensionally unstable sheets were rectified by adjustments made during the reduction process. The 21 reduced base sheets, were then mosaicked into four quadrants, using the 1:500,000 IGN "Carte Routière et Touristique, République du Sénégal" as a guide for format.

b. Each set of resource and thematic maps was also photographically reduced to 1:500,000; these maps were made to match the reduced base map mosaic.

c. Detailed annotations and other map format requirements were then made. They included placement of the frame, title, legend and credits, as well as ensuring proper balance and selecting of line widths, type styles, etc. Specific colors and patterns were selected to represent each areal map unit.

d. Final drafting of the maps began with the base map mosaic of topographic and cultural features. All drafting of linear map features was done on large (30" x 36") scribe sheets, using rigid and swivel gravers to prepare the map artwork in negative form. Linear features to be printed in different colors (e.g., drainage: blue, roads: red, administrative boundaries: black) had to be engraved or scribed on separate sheets, one for each color.

e. A 1:1,000,000 scale base map was scribed for the four synthesis maps to be printed at that scale. The source for this base was the IGN roadmap "Senegal, Carte au 1:1,000,000". Several of the synthesis maps required reducing the 1:500,000 resource map sheets to 1:1,000,000. A mosaic at 1:1,000,000 was then constructed and used as a guideline for final scribing.

f. Upon completion of the scribe sheets of the 1:500,000 and 1:1,000,000 base maps, scribing began on the map units from each resource, thematic and synthesis map, using mosaics as source material. All map units were registered to the completed base scribes.

g. Lettering plates were prepared for each map. Type styles and point sizes were selected for all lettering to appear on the maps. All textual material, including place names, map codes and credits, was printed, photographically converted into negatives, reproduced as film positives, manually affixed to transparent flaps registered to the base maps and finally reprinted onto large negative plates.

h. Peelcoats, or open-window negatives used for laying tints and patterns into a given area, were exposed and etched from the appropriate scribe sheets. Each map unit to which a unique color or pattern is assigned (including shades of gray) required a peelcoat, though often it was possible to combine several map units onto one peelcoat.

i. Each completed peelcoat had to be masked to remove extraneous linework.

j. Several phases of proofing of the artwork (scribes, peelcoats, lettering plates) were required, including making preliminary color or black-and-white proofs so that the final map products could be seen and corrections made

k. All artwork was then sent to the printer for final proof-making and printing.

Each color map sheet required 7 to 9 scribe sheets and film negative separations and 12 to 20 peelcoats. The black and white map sheets generally required slightly fewer separations and peelcoats.

The full set of three resource maps, two thematic maps, and five synthesis maps comprises 32 sheets, including the legend sheets. The total number of sheets of artwork (scribes, film negative separations and peelcoats) submitted to the printer was approximately 470.

1.4.3 Map Format

All of the maps are conventional as opposed to being photomaps which are based on Landsat or other forms of photographic or image products. The decision to produce conventional maps rather than

photomaps was based on several limitations inherent in the Landsat imagery available for Senegal:

a. There was no nation-wide coverage within a given season and year, with limited cloud coverage, from which an acceptable image mosaic could be made. One such possibility was considered: From February through March of 1973, a set of thirteen images were acquired over Senegal; however they were rejected because of their early date and their relatively low contrast.

b. Bush fires sweep across much of Senegal each year, producing very dark, irregular patches on the Landsat imagery. These patches tend to mask the map units that are traced over a photomap, making it incomprehensible.

c. A photomap tends to emphasize a specific date and season as a function of the dates of image acquisition. Seasonal and year to year changes tend to be very pronounced both on the imagery and in the field. A conventional map allows one to take all seasons into consideration and portray the recent environmental developments by relying on the most recent imagery and field data.

Although considerable exchanges of ideas, techniques and information occurred between the three resource survey teams, each team produced its own Landsat interpretations. Thus, while certain landscape units were of interest to and mapped by all three teams (e.g. fossil valleys), the map boundaries of the same feature tend to vary from one map to another. This variation can be attributed to the fact that no two photo-interpreters will produce the same interpretation. Furthermore, certain dates of Landsat imagery were more favorable for extracting geologic data, while others were particularly useful for vegetation analyses. Additional discrepancies between resource maps arise from the way in which a particular feature is illustrated. For example, in the vegetation map the vegetation within a given valley of eastern Senegal is mapped as a single unit: No cartographic distinction is made between slope vegetation and bottomland vegetation, though the distinction is made in the cover type descriptions. On the soils map, however, the soils team chose to map valley slopes separately from the valley bottoms.

1.4.4 Map Accuracy

The locational accuracy of the map unit boundaries as depicted on the maps relative to the true position of the unit is estimated to generally fall within ±1 mm (equivalent to ±500 m at 1:500,000 scale). Positional errors of ±2 mm may occur (equal to ±1 km at 1:500,000) in some areas, particularly along the edges of adjoining basemaps. In a few cases, positional errors may exceed 2 mm.

Although every attempt was made to maintain spatial accuracy, several sources of error can be identified:

a. Slight scale variations in the Landsat imagery (1 to 2%).

b. Slight distortion introduced in the transferral of interpretations to the basemaps.

c. Problems encountered in producing an accurate mosaic of basemaps.

Nevertheless, spatial error was kept to a minimum by reducing the 1:250,000 working scale; the final map scales are 1:500,000 and 1:1,000,000.

1.5 REFERENCES

Arnaud, G. (1952) Note sur l'hydrologie de la région de Dakar. Bull. de la Dir. des Min. 10:61-74.

Breusse, J. (1952) Prospection électrique appliquée aux recherches hydrologiques dans la presqu'île du Cap Vert. Bull. de la Dir. des Min. 10:77-91.

Church, R. (1980) "West Africa." Geographies for advanced study, 8th ed.

Dubresson, A. (1979) La Géographie de l'Afrique. Dakar: Nouvelles Editions Africaines.

Fauck, R., et al. (n.d.) Etudes sénégalaises. No. 9. Fas. 3. CRDS-Sénégal, St. Louis de Sénégal. 214 p.

Giffard, P. (1974) L'Arbre dans le paysage sénégalais: Sylviculture en zone tropical sèche. Centre Technique Forestier Tropical, Dakar. 431 p.

IGN (1977) Atlas national du Sénégal. Paris. 147 p.

Michel, P. (1973) Les Bassins des fleuves Sénégal et Gambie: Etudes géomorphiques. Mém. ORSTOM. No. 63. Tomes I et II.

Nelson, H. (1974) Area handbook for Senegal, 2nd ed. DA.Pam. 550-70. pp. 269-71.

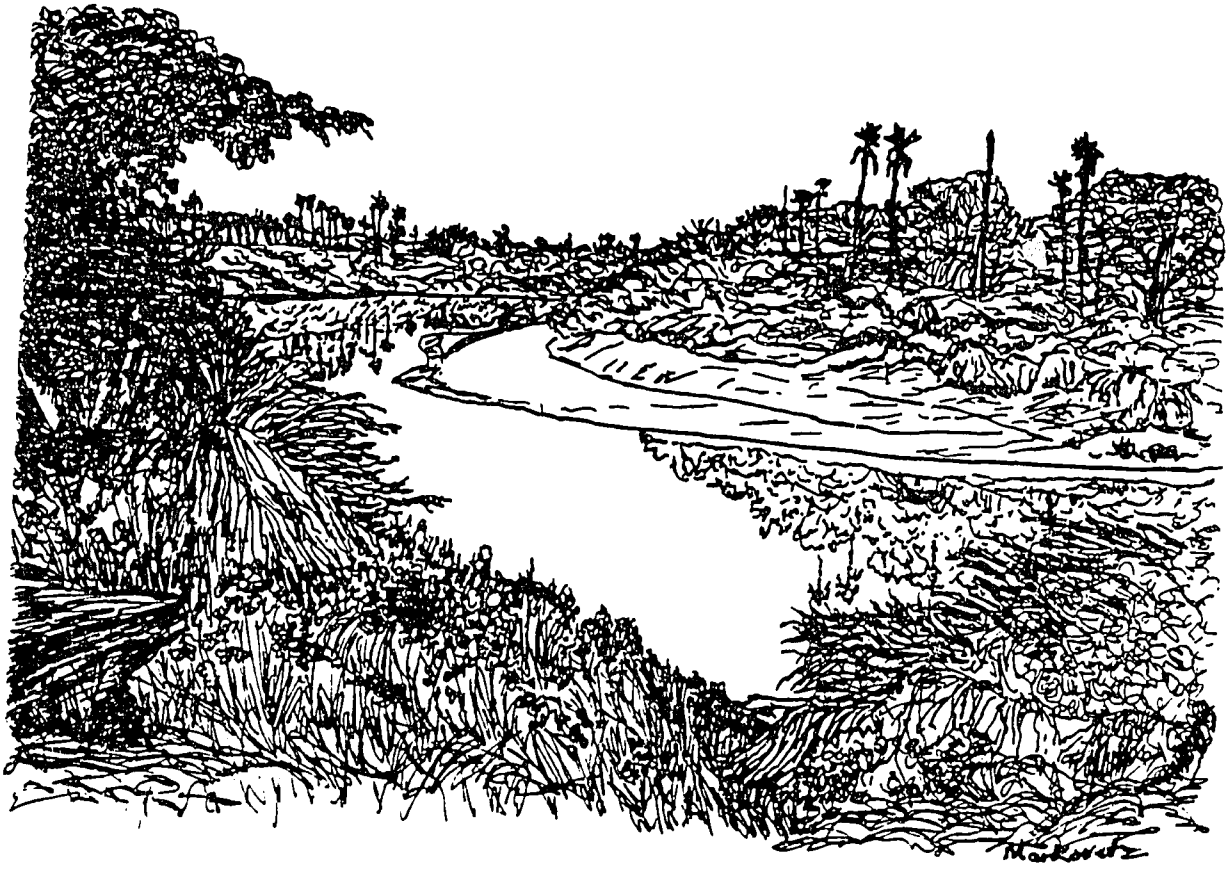
Seck, O., ed. (1977) Atlas pour l'aménagement du territoire. Dakar-Abidjan: Les Nouvelles Editions Africaines. 159 p.

Stoner, B., et al. (1981) USAID-project authorization document.

USAID (1980) Environmental report on Sénégal (draft). Office of Arid Lands Studies. USAID. 105 p.

CHAPTER II

CLIMATE AND PHYSIOGRAPHY



Previous Page Blank

CHAPTER II: CLIMATE AND PHYSIOGRAPHY

2.1 General..... 19
2.2 Physical Environment..... 20
2.3 Climate..... 23
2.3.1 Atmospheric Influences..... 23
2.3.2 The Trade Winds of Alizé Maritime..... 23
2.3.3 The Harmattan..... 23
2.3.4 The Monsoon..... 23
2.3.5 Seasons..... 23
2.3.6 Rainfall Characteristics..... 24
2.3.7 Climatic Regions..... 24
2.3.8 Temperature and Evaporation Rates..... 30

CHAPTER II

CLIMATE AND PHYSIOGRAPHY

2.1 GENERAL

Senegal is the most westerly state of West Africa. Composed primarily of a gently sloping, poorly dissected plain, it has low relief. Its total land area is 196,192 km^2. The northern border, which is shared with Mauritania, is defined by the Senegal River; the Faleme River delineates the eastern border with Mali; Guinea and Guinea-Bissau are Senegal's southern neighbors, and The Gambia (part of the project area) forms an enclave of 11,295 km^2 along the Gambia River in the southern part of Senegal.

As all of Senegal lies south of the 17°N latitude--well within the tropics--temperatures are high throughout the year. Annual rainfall is almost entirely limited to the summer wet season, which lasts up to six months in the south and decreases to three months in the north. Like all areas near the northern limits of the Southwesterlies, Senegal suffers from extremely variable rainfall. St. Louis had 127 mm of rain in 1903 and 660 mm in 1912. Dakar had 381 mm in 1937 and 686 mm the following year. Average rainfall varies from over 1500 mm in the southwest to just under 300 mm in the northwest.

The project area encompasses 207,487 km^2, including all of Senegal and The Gambia. The majority of the population of Senegal lives in the western portion or the Groundnut Basin in the populated centers of Dakar, Thies, St. Louis, Diourbel, Kaolack, Louga, Tambacounda and Ziguinchor. About 30% of the population is concentrated in these cities and another 40% in the aforementioned Groundnut Basin. Over 60% of the population lives within a 330 km radius of Dakar. About 70% of the population belongs to the rural sector of the Senegalese economy and is active in crop production, stock raising, fishing, and forestry. Roughly 61% is dependent upon cultivation alone and another 7% upon the combination of stock raising and cultivation. Only 2% is wholly dependent upon herding for its livelihood and about 1% on full-time fishing.

The majority of agriculture consists of dry farming in the Groundnut Basin, with increasing amounts of irrigated lands in Casamance and especially the lower Senegal River region, where flood-recessional agriculture has been the practice. The major crops grown are peanuts, sugar cane, millet, sorghum, cassava, paddy rice, maize, cotton, vegetables, fruits and pulses.

The country (including The Gambia) is drained by four major rivers. The Senegal River is intermittently navigable as far as Kayes in Mali, the Gambia River for about 470 km. The Saloum River and its major affluent, the Sine River, are sluggish streams feeding into the extensive tidal swamps of a drowned estuary. The Casamance River

drains a narrow basin between The Gambia and Guinea-Bissau. A number of smaller streams, such as the Ferlo, flow intermittently during the rainy season, but are in fact relics of a more humid past climate.

The transportation network is good and consists of over 13,000 km of roads, of which over 2500 km are paved. Rail services extend east and north of Dakar and consist of 1186 km of rail. River traffic is negligible and has decreased markedly on the Senegal River because of improved roads and decreased navigability due to lower rainfall in the basin. Air transport is good within the country and serves fifteen cities besides Dakar.

2.2 PHYSICAL ENVIRONMENT

Senegal is composed of two primary relief features, a sedimentary basin of Tertiary and Quaternary rocks and sediments occupying the western and northeastern part of the country, and a more dissected, elevated region of Paleozoic and Precambrian folded and faulted rocks occupying the southeastern part of the country.

Senegal can further be subdivided into four regions (see Map 2.1):

A. The first is a dissected, laterized mountain region, which comprises part of Ferlo Boundou, the plains of the Gambia and Falémé rivers, the Bassari Mts., Haute Gambie (Niokolo Koba) and Dentilia. The rocks here are highly folded and fractured formations of the lower Paleozoic age, resting unconformably on Precambrian rocks of Birrimian age.

B. The second region occupies most of the remaining area and consists of a low plateau and plains of geologically younger sedimentary rocks overlain by wind-blown sediments, alluvial deposits and intermittent laterite hardcap. This region comprises Ferlo, Cayor, Sine, Saloum and Casamance. Ferlo consists of Dimar, Toro, Ferlo Djolof, Ouli and parts of Fouta, Diéri and Ferlo Boundou. Cayor and Sine Saloum, which make up the Groundnut Basin, consist of the following subregions: Baol, Rip, Djolof and Niani. Casamance is separated into Basse, Moyenne and Haute Casamance and includes such geographic subregions as Fouladou, the Anambé basin, Pakoa, Yassine and Fogny.

C. The third region consists of the fluvial and alluvial plains of the Senegal River, the Sine Saloum Delta, the Gambia River Valley and the Casamance River Valley. The Senegal River Valley is often separated into three units--the upper or Fouta, the middle or Diéri and the lower (delta) or Walo. These regions are composed of alluvial deposits, terraces and temporary lacustrine deposits, as well as levees and deltaic deposits. Much of the Senegal, Sine Saloum, Gambia and Casamance delta areas are affected by marine tides and thus

provide the environment for large areas of mangrove swamps.

D. The fourth and smallest region consists of a narrow coastal belt which extends from St. Louis in the north to the Sine Saloum estuary in the south. This belt is subdivided from north to south into the Grande Côte from St. Louis to Kayar, Cap Vert, which includes the peninsula of Dakar (Cap Vert) and the Petite Côte which extends south from Cap Vert to the Sine Saloum estuary. Grande Côte is composed of a gently sloping beach backed by high dunes of irregular direction, separated by marshy depressions called Niayes. The Cap Vert is composed of a large body of Quaternary and Tertiary intrusive and volcanic rocks connected to the mainland by sands transported by longshore currents from the north. Petite Côte is narrow, with a sandy coastline backed by cliffs and irregular headlands caused by folding and faulting.

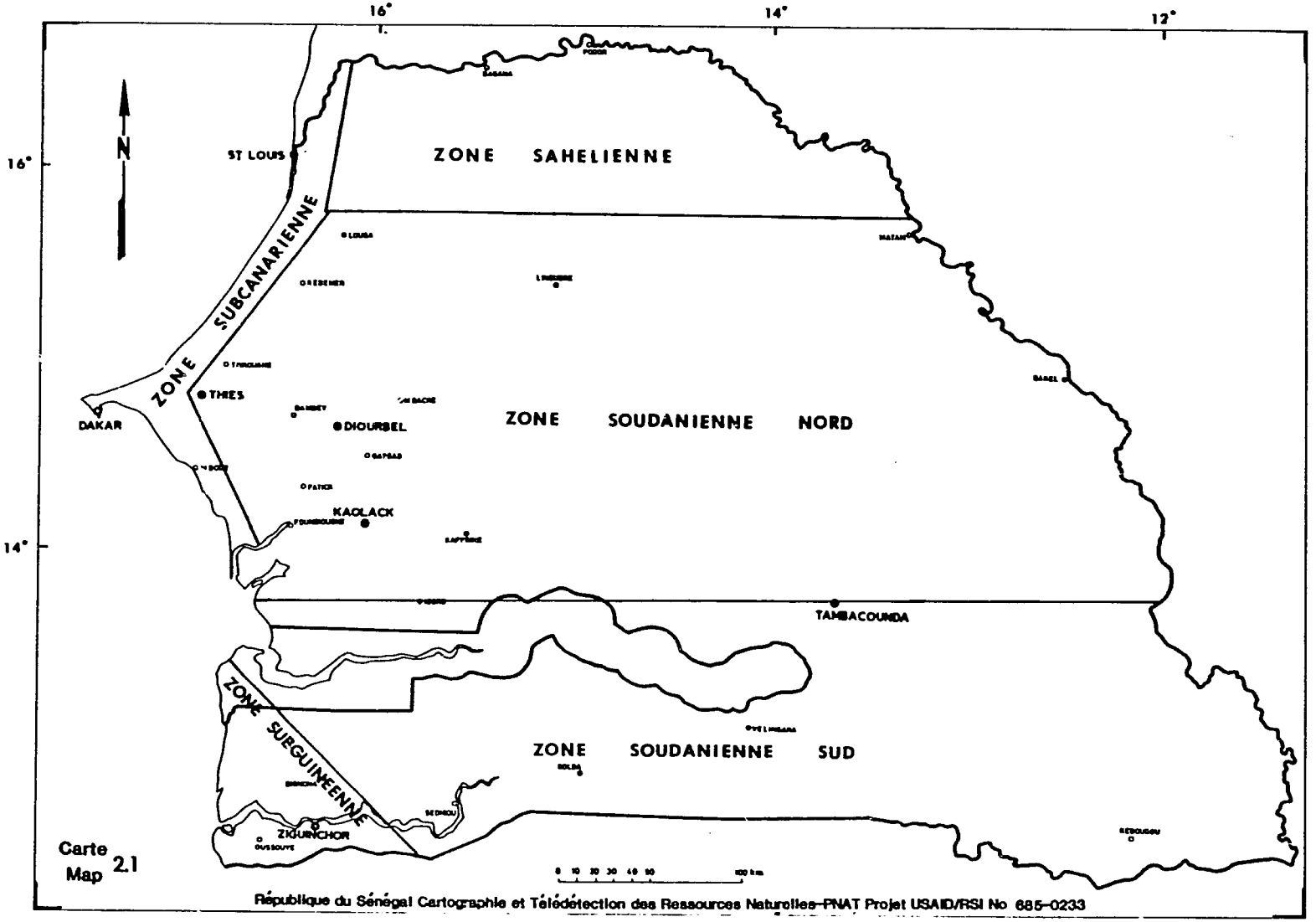
Four additional geomorphic units deserve mention:

E. Just east of Cap Vert is an escarpment of Paleocene and Eocene sedimentary rocks which form a striking boundary between Cap Vert and the rest of Senegal.

F. The Lac de Guiers occupies the valley of the Bounoum River. Prior to damming activities, which have created a manmade impoundment of Lac de Guiers, the Senegal River would annually flood the Bounoum Valley and as much as 70 km up the Ferlo River toward Linguère.

G. The Ferlo, Sine and Saloum rivers are fossil remnants of streams which flowed permanently across the Senegalese landscape during more humid periods. Their valleys are broad and meandering and constitute only a small portion of a much more extensive drainage in previous times.

H. The offshore continental shelf of Senegal is an important resource extension of its land mass. It covers an area of 29,580 km^2 and extends about 45 km offshore from St. Louis and decreases southward to 10 km north of Dakar. It is from 50 to 75 km wide off Mbour, The Gambia and Casamance. It is composed mainly of sediments, muds, sands and hard rock benches. The latter tend to be concentrated south of Dakar and off St. Louis. A very important canyon occurs offshore of Kayar where a 200 m deep indentation in the shelf occurs within 10 km of the coast. This feature is probably a remnant of a more extensive drainage system predating the uplift of the Thies escarpment.



Région Climatique du Sénégal Schématisée / Generalized Portrayal of Climatic Zones of Senegal

2.3 CLIMATE

Due to its position between 12° and 17° north latitude, Senegal is entirely within the tropics. Because of its long coastline and low relief, it is strongly, if intermittently, affected by both oceanic and continental climatic influences.

2.3.1 Atmospheric Influences

Three types of atmospheric actions control the Senegalese climate: the Azores anticyclone, the high pressure centers of North Africa and the Saint Helens anticyclone. The corresponding climatic currents are known respectively as the trade winds, the harmattan and the monsoon.

2.3.2 The Trade Winds or Alize Maritime

These are north to northwest winds which affect the coastal region from the Saloum estuary to St. Louis and areas as far as 15 km inland. The winds are fresh and humid, bringing lower temperatures, fog, dew and occasional rains (drizzle), which are called heug in Wolof.

2.3.3 The Harmattan

These winds originate in the Magrebian region of the Sahara. They are hot and dry and responsible for the extremely hot temperatures and high evaporation rates found in most of Senegal. These winds generally blow from the northeast and are the cause of the parallel dunes throughout north and north-central Senegal.

2.3.4 The Monsoon

The monsoon, or south Atlantic humid anticyclone, moves progressively northward to displace the harmattan as the African continental mass is subjected to the hotter and constant temperatures of summer. These winds bring massive quantities of humid air over West Africa, which result in isolated, intense thunderstorms, very intense widespread storms and occasional continuous rains. A monsoon front's thickness and extent determine the type of rain received.

2.3.5 Seasons

From the end of the month of August, when the sun is at its zenith over Senegal, to its return in May, colder air from the north influences Senegal and provides for the atmospheric conditions which result in the harmattan. This period is known as the dry season. As the position of the earth shifts and the sun's influence returns to the northern tropics, this shift moves the intertropical front northward, bringing with it moist air and the resulting monsoon rains which define the wet season of hivernage (navet in Wolof).

2.3.6 Rainfall Characteristics

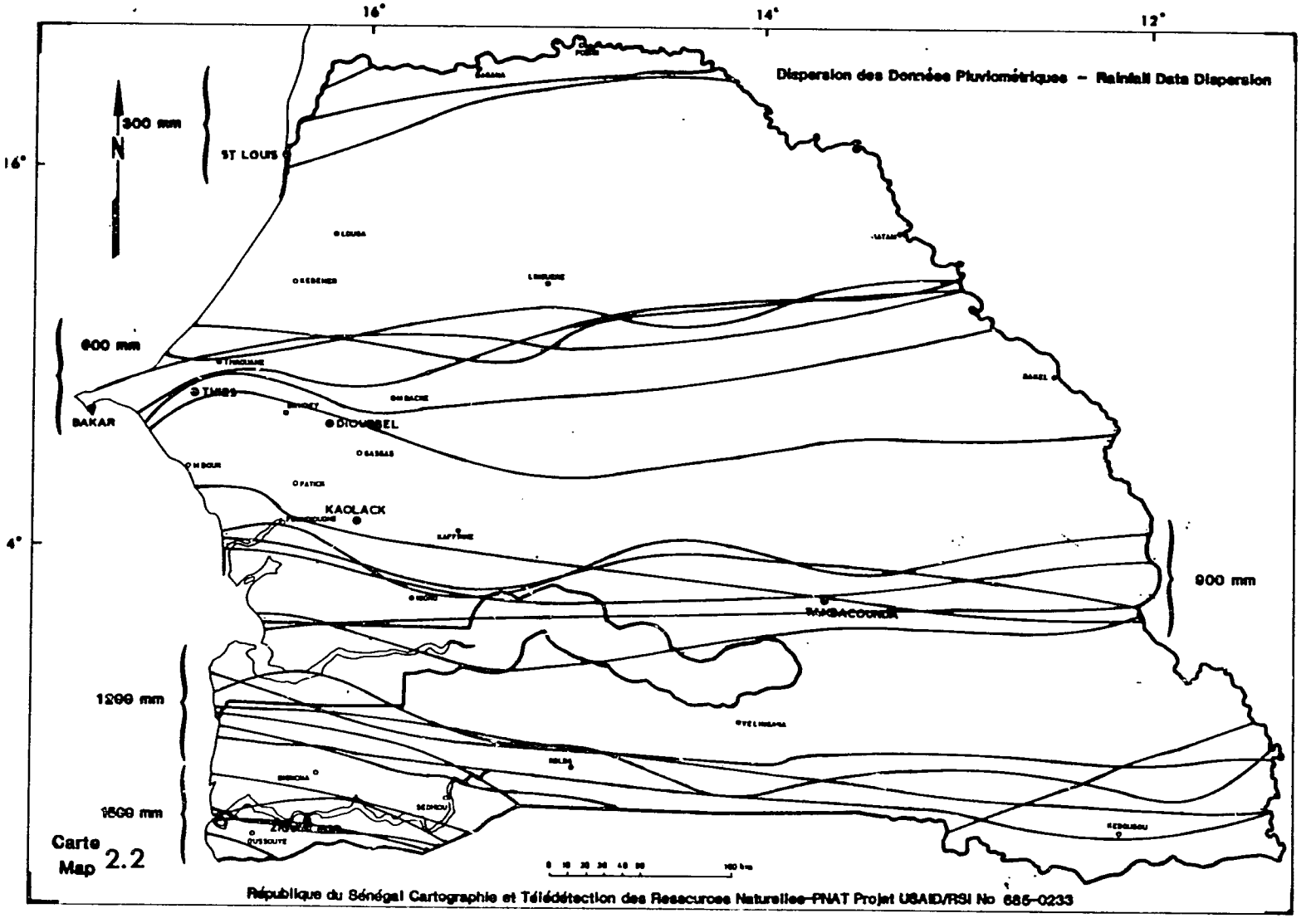
Excluding the occasional dry season coastal rains called heug, the majority of rainfall occurs during the wet season.

The isohyetal map of Senegal (Map 2.2) indicates a relative decrease of rainfall from south to north. The average length of the rainy season is 5.5 months for Kédougou, 5 months in coastal Casamance, 4 months at Nioro du Rip, 2.5 months at Louga and 2 months in the lower Senegal Valley. In decreasing order the rainiest months are August, September and July. Rainfall is highly variable from year to year or even longer periods of time, as can be seen on Map 2.3. This variation may be much greater than 100%, as recorded in St. Louis in 1903 during which 127 mm of rain fell and in 1912 during which 660 mm fell. Furthermore, while rainfall for a certain year may seem normal in amount, it varies greatly in its onset, periodicity and termination, especially in central and northern Senegal. Such variations play havoc with agricultural practices and may result in the disastrously low production of crops.

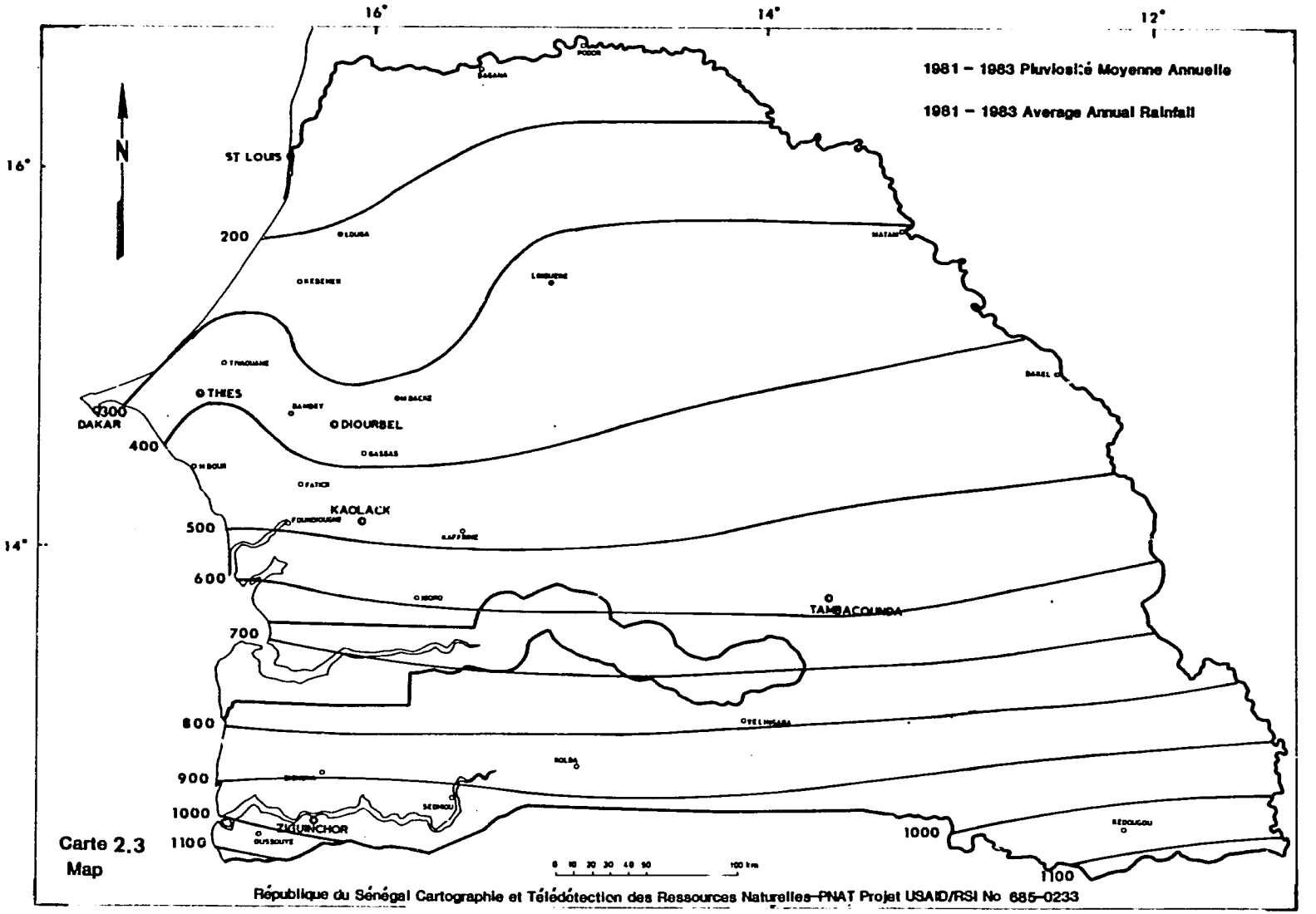
The drought years of 1967 to 1973 prompted speculation that a climatic shift toward drier conditions was in progress. However, an examination of recent records and historical documents has shown that there has been no major change in climate, only minor fluctuations that have occurred and can be expected due to the geographic position of Senegal within the climatological framework of West Africa and its position on the edge of the Sahel. Table 2.1 shows rainfall data for the 12 major stations in Senegal for the years 1974 to 1983. No conclusions indicating a shift to a progressivley drier climate can be drawn by studying this or preceeding data.

2.3.7 Climatic Regions

The amount of precipitation has, of course, a direct effect on the climate of Senegal and the corresponding growth of vegetation. These variations have been defined throughout North Africa and their equivalents in Senegal are shown on Map 2.4. A more detailed zonation, referred to as phytogeographic or biogeographical zones, is shown on Map 2.5 and will be further discussed in Chapter V, Vegetation and Land Use.


Dispersion des Données Pluviométriques - Rainfall Data Dispersion
16°
14°
12°
16°
4°
N
300 mm
600 mm
900 mm
1200 mm
1500 mm
ST LOUIS
DAKAR
TIVAOUANE
DIOURBEL
KAOLACK
TAMBACOUNDA
ZIGUINCHOR
République du Sénégal Cartographie et Télédétection des Ressources Naturelles-PNAT Projet USAID/RSI No 685-0233

Carte
Map 2.2

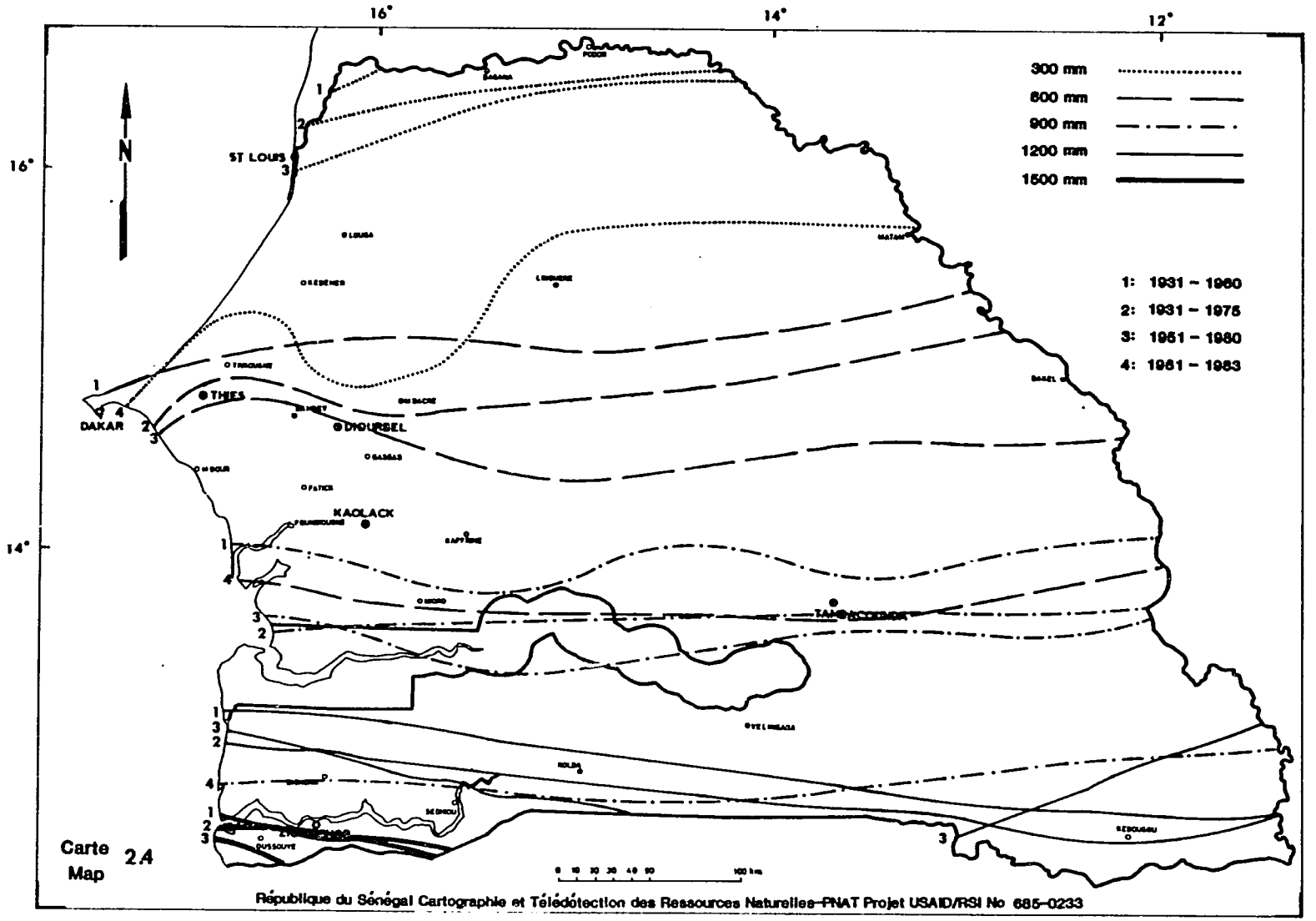

1981 – 1983 Pluviosité Moyenne Annuelle
1981 – 1983 Average Annual Rainfall
16°
14°
12°
N
ST LOUIS
200
THIES
300
DAKAR
400
DIOURBEL
KAOLACK
500
600
700
800
900
1000
1100
TAMBACOUNDA
ZIGUINCHOR
1000
1100
0 10 20 30 40 50 100 km
République du Sénégal Cartographie et Télédétection des Ressources Naturelles–PNAT Projet USAID/RSI No 685–0233

Carte 2.3
Map

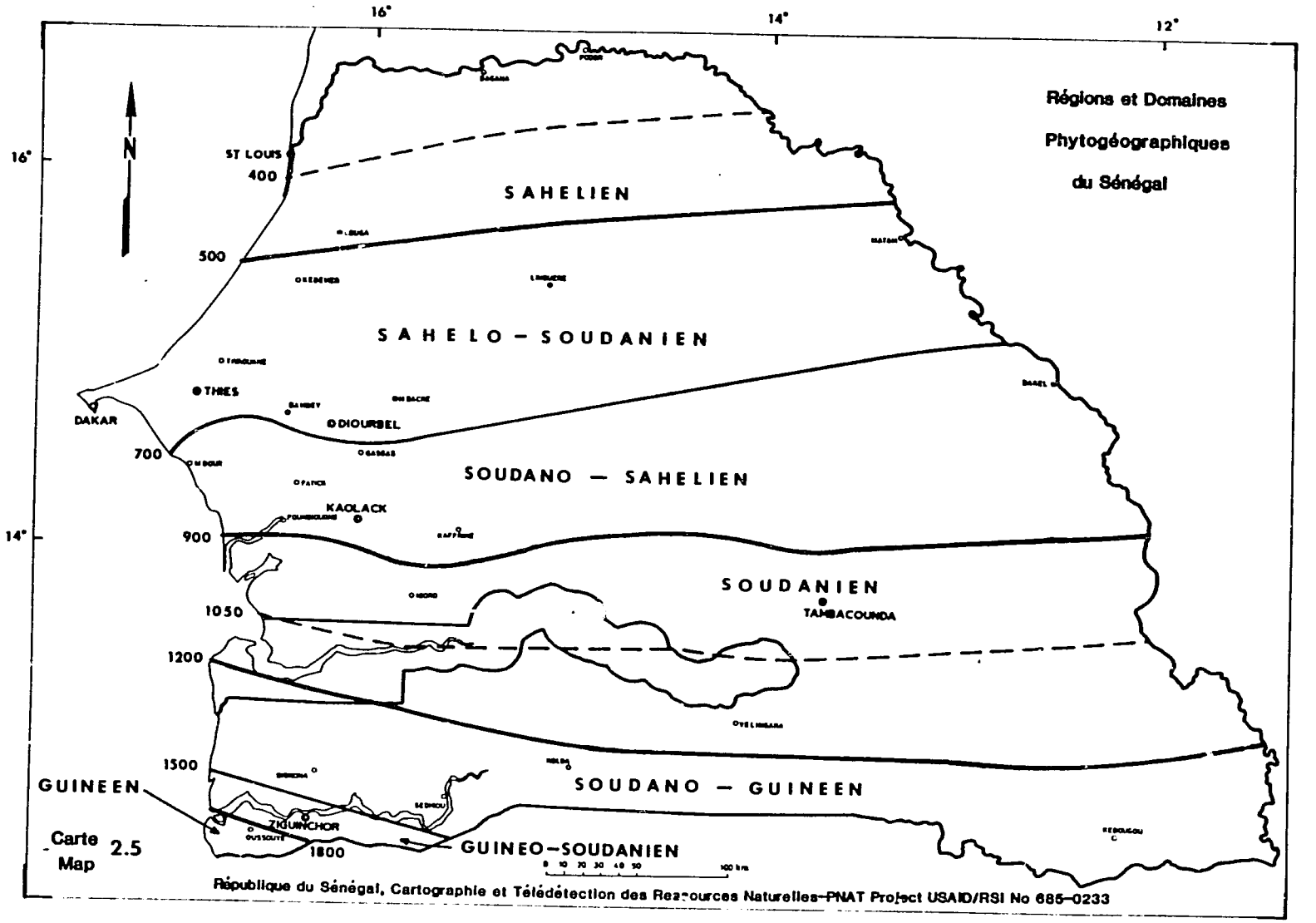
Table 2.1

RAINFALL QUANTITIES FOR MAIN
WEATHER STATIONS FROM 1974 TO 1983 (in mm)

STATIONS	YEARS									
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Dakar Yoff	366.3	564.0	387.3	171.2	323.4	341.1	377.8	338.2	305.5	154.9
Kédougou	1296.21	1271.9	1111.8	1109.3	1595.3	958.3	1116.1	1305.5	957.4	879.8
Kaolack	548.5	553.7	472.4	461.1		510.5	418.1	457.9	654.3	302.5
Linguère	330.0	478.9	378.7	340.0	316.0	393.3	380.9	376.7	480.0	189.4
Louga	408.5	308.3			308.0	252.4		259.1		145.4
Tambacounda	943.0	892.9	665.6	602.3	725.6	737.0	523.9	762.8	457.9	488.7
Diourbel	598.9	505.2	497.1	351.8	651.2	527.3	340.6	370.8	328.5	285.0
Thiès	655.4			288.1	605.6	626.5	409.1	482.7	459.9	250.7
Kolda	1019.0	1187.8	920.4	644.6	991.9	823.2	565.9	1001.9	848.4	726.4
Podor	150.9	225.5	264.0	132.4	303.9	226.6	219.6	139.5	169.4	94.2
Matam	327.5	407.5	392.5	194.0	318.7	259.0	217.5	370.8	275.9	265.0
Ziguinchor	1240.4	1417.2	1296.5	790.3	1513.4	1194.1	698.5	1221.4	897.9	818.5



Comparaison de Données Pluviométriques / Comparison of Rainfall Patterns


Régions et Domaines
Phytogéographiques
du Sénégal
16°
14°
12°
N
ST LOUIS
400
500
700
900
1050
1200
1500
1800
SAHELIEN
SAHELO – SOUDANIEN
SOUDANO – SAHELIEN
SOUDANIEN
SOUDANO – GUINEEN
GUINEO–SOUDANIEN
GUINEEN
DAKAR
THIES
DIOURBEL
KAOLACK
TAMBACOUNDA
ZIGUINCHOR
République du Sénégal, Cartographie et Télédétection des Ressources Naturelles–PNAT Project USAID/RSI No 685–0233

Carte 2.5
Map

2.3.8 Temperature and Evaporation Rates

Analysis of temperature gradients from a number of stations in Senegal (Table 2.2) shows that mean annual temperatures and daily means are higher for the interior than the coast. The highest temperatures occur in April, May and June.

Evaporation rates are very high in Senegal, especially in the areas north of Louga, Linguère and Matam. Minimum evaporation rates occur in March and April and maximum rates occur from August to September, as can be seen on Table 2.3.

Table 2.2 AVERAGE MONTHLY TEMPERATURES, °C
Draft Environmental Report, Univ. of Arizona, 1980.

	J	F	M	A	M	J	J	A	S	O	N	D	Year Avg.
Dakar*	12	21	21	22	23	26	27	27	28	27	26	23	24.3
Diourbel**	24	25	28	29	30	30	29	28	28	29	27	24	27.5
Kaolack+	25	27	29	30	30	30	29	28	28	29	28	25	28.0
Kedougou++	24	27	30	32	32	28	27	27	27	28	27	25	27.7
Kolda	24	27	29	31	31	30	28	27	27	28	27	24	27.7
Linguere	24	26	28	30	31	31	29	28	28	29	28	24	28.2
Matam	23	26	29	31	34	33	30	29	29	30	28	24	28.7
Podor	23	25	28	30	32	32	31	30	30	30	28	23	28.5
St. Louis+++	22	22	22	22	22	26	28	28	29	28	26	23	28.2
Tambacounda	25	28	30	32	33	30	27	27	27	28	27	25	28.2
Ziguinchor	24	26	27	28	29	28	27	26	27	28	27	25	25.8

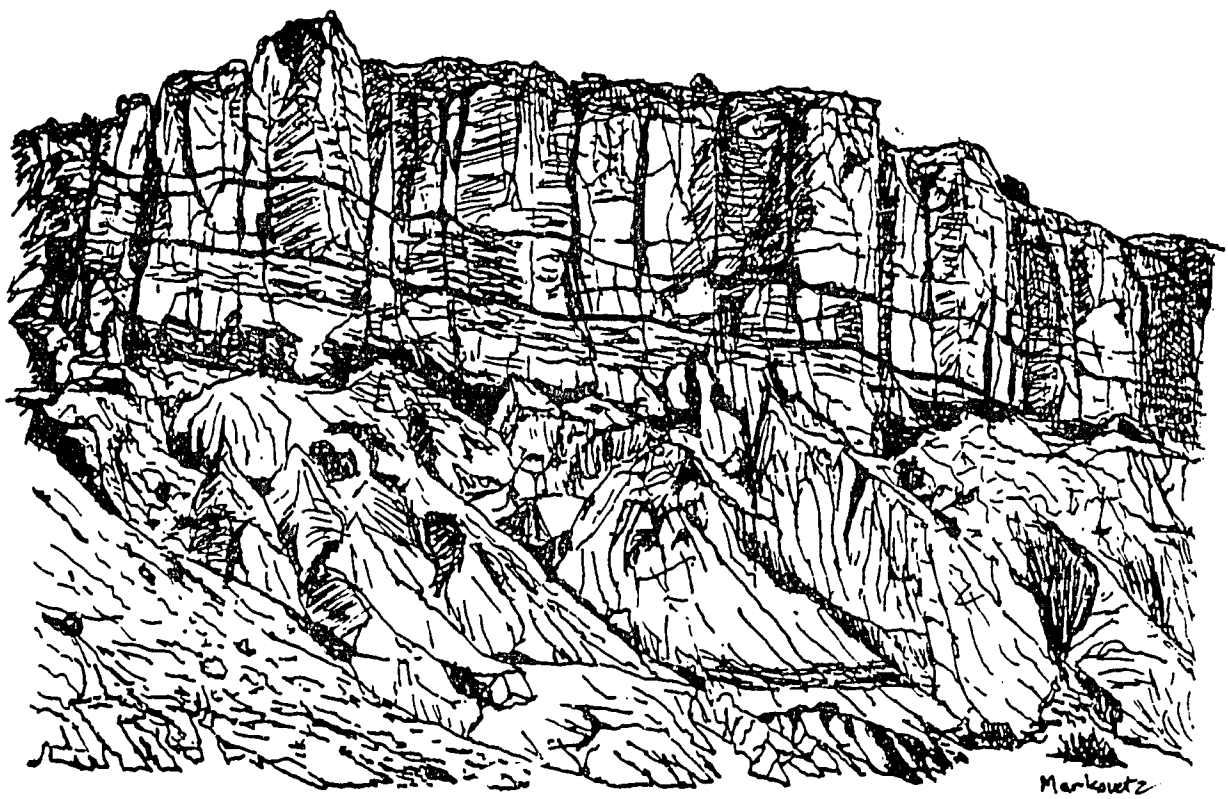
* Years 1947-70 ++ Years 1953-65
** Years 1951-70 +++ Years 1931 -70
\+ Years 1931-60

Table 2.3 AVERAGE EVAPORATION RATES FOR 4 STATIONS IN SENEGAL (A. Danes et al, 1965) (in mm)

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Matam	260	270	383	424	412	345	215	121	121	172	182	220	3.127
Linguere	449	457	572	580	484	317	206	123	109	193	359	384	4.233
Kaolack	276	289	354	344	264	173	107	65	52	97	152	222	2.395
Diourbel	255	268	337	318	252	172	116	65	67	116	168	208	2.342

CHAPTER III

HYDROGEOLOGY



Previous Page Blank

CHAPTER III: HYDROGEOLOGY

3.1 Introduction..... 41
3.2 Mapping Procedures..... 42
3.3 Literature Consulted..... 43
3.4 Interpretation Methodology..... 43
3.5 Characteristics of Available Landsat Imagery..... 45
3.6 Field Work..... 46
3.6.1 General..... 46
3.6.2 Methods..... 47
3.7 Other Means of Verification..... 50
3.7.1 General..... 50
3.7.2 Aerial Overflights..... 50
3.7.3 Aerial Photography..... 52
3.7.3.1 General..... 52
3.7.3.2 Aerial Photograph Analysis..... 53
3.8 Legend and Map Format..... 54
3.8.1 Geohydrology Map..... 54
3.8.2 Tectonic Map..... 55
3.8.3 Hydrologic Map..... 55
3.8.4 Mineral and Water Potential Map..... 55
3.8.5 Map Format and Supporting Documentation..... 56
3.9 The Geology of Senegal..... 56
3.9.1 Introduction..... 56
3.9.2 Geology of Senegal Oriental--The Precambrian and Paleozoic..... 58
3.9.2.1 Birrimian..... 58
A. The Mako Series..... 58
B. The Dialé Series..... 59
C. The Daléma Series..... 60
D. Baoulé-Type Granites..... 61
E. Boboti-Type Granites..... 61
F. Boudoukou Granites..... 61
3.9.2.2 Late Precambrian and Paleozoic Rocks..... 62
A. The Ségou-Madina Kouta Series..... 62
B. The Mali Series..... 63
C. The Falémé Series..... 64
D. The Bassari Series..... 64
E. The Younkounkoun Series..... 65
F. The Koulountou Series..... 66
G. The Bakel Series..... 66
3.9.2.3 Conclusions..... 66
3.9.3 The Sedimentary Basin of Senegal..... 67
3.9.3.1 Geologic Periods..... 67
A. The Paleozoic..... 67
B. The Triassic and Liassic..... 68
C. The Jurassic..... 68
D. The Cretaceous..... 68
E. The Tertiary..... 69
1. The Lower Eocene..... 69
2. The Middle Eocene..... 69

3. The Upper Eocene..... 70
4. The Oligocene..... 70
5. The Miocene..... 70
6. The Pliocene..... 71
F. The Quaternary (Pleistocene-Holocene)... 71
3.9.3.2 Tectonics, Magmatism and Geologic History of the Senegalo-Mauritanian Basin..... 73
A. Tectonics of the Senegalo-Mauritanian Basin..... 73
1. Structural Overview of the Basin..... 73
2. Fracture Analysis..... 73
B. Magmatism of the Senegalo-Mauritania Basin..... 76
C. Geologic History of the Senegalo-Mauritanian Basin..... 76
1. Pre-Mesozoic History of the Basin..... 76
2. Origin of the Basin..... 77
3. Development of the Continental Margin..... 77
4. Cretaceous to Mid-Eocene Events..... 77
5. The Pyrenese Phase (Middle to Upper Eocene)..... 78
6. From the Upper Eocene to the Quaternary..... 78
3.9.4 Landsat Interpretation..... 79
3.9.4.1 Introduction..... 79
3.9.4.2 Descriptive Approach..... 79
A. The Birrimian Shield Rocks..... 80
1. The Mako Series (βB)..... 80
a. Description of the Unit..... 80
b. Structure and Interformational Relationships..... 82
c. Anomalous Features Interpreted from Landsat..... 82
d. Conclusion..... 83
2. The Dialé and Daléma Series of Rocks (Bvs, Bs, Bv, AB)..... 83
a. Description of the Units..... 83
b. Structure and Interformational Relationships..... 88
3. The Baoulé- and Boboti-Type Granites (Big)..... 88
a. Description of the Unit..... 88
b. Structure and Interformational Relationships..... 90

4. The Bondoukou Granites (GPB)..... 91
a. Description of the Unit..... 91
b. Structure and Interformational Relationships..... 91
B. Birrimian Rocks: Summary and Conclusions..... 91
C. Late Precambrian and Paleozoic Rocks of Eastern Senegal..... 92
1. Introduction..... 92
2. The Ségou-Madina Kouta Series (C^1)..... 92
a. Description of the Unit..... 92
b. Structure and Interformational Relationships..... 92
3. The Mali Series..... 93
4. The Falémé Series (C^2, C^3, Ci)..... 93
a. General..... 93
b. Description of Unit C^2..... 94
c. Structures and Interformational Relationships..... 94
d. Description of Unit C^3..... 94
e. Structures and Interformational Relationships..... 96
f. Description of Unit Ci..... 96
g. Structures and Interformational Relationships..... 96
5. The Bassari Series (Cim)..... 97
a. Description of the Unit..... 97
b. Structures and Interformational Relationships..... 97
6. The Younkounkoun Series (Ci, C^3).... 98
7. The Koulountou Series (Caiv, Cvt, Cig)..... 98
a. Description of the Units..... 98
b. Structures and Interformational Relationships..... 99
8. The Bakel Series (C^2m, βC)..... 99
a. Description of the Units..... 99
b. Structures and Interformational Relationships..... 101
9. The Dolerites of Senegal Oriental (Dol)..... 102
a. Description of the Unit..... 102
b. Structures and Stratigraphic Relationships..... 104
D. Conclusions Concerning the Landsat Analysis of the Precambrian and Paleozoic Rocks of Eastern Senegal..... 104

E. The Sedimentary Basin of Senegal..... 105
1. Introduction..... 105
2. Approach Used in Mapping Lithologic Units..... 106
3. Description of the Units..... 106
a. Cretaceous Maestrichtian Rocks (Cr)..... 106
i. Description of Unit..... 106
ii. Structure and Interformational Relationships..... 107
b. Tertiary-Paleocene (e^{iv})..... 107
i. Description of the Unit..... 107
ii. Structures of the Paleocene... 107
c. Tertiary-Eocene (e^{iii}, e^{ii}, e^{i}, ei)..... 107
i. Introduction..... 107
ii. Description of Unit e^{iii}-- Lower Eocene, Ypresian..... 108
iii. Description of Unit e^{ii}-- Middle Eocene, Lower Lutetian. 109
iv. Description of Unit e^{i}-- Middle Eocene, Upper Lutetian. 109
v. Structures and Interformational Relationships..... 109
vi. Description of Unit ei-- Differentiated Eocene..... 110
d. Tertiary-Oligo-Miocene (om)..... 111
e. Tertiary "Continental Terminal" (Ct)..... 112
f. Tertiary (and Quaternary) Lateritic Cap (cf)..... 112
g. Other Tertiary Formations (ad^1, aff)..... 113
F. Structural Geology of the Sedimentary Basin..... 114
G. Description of the Quaternary Units of the Senegal Basin..... 114
1. Introduction..... 114
2. Volcanic Rocks (β)..... 115
a. Description of the Unit..... 115
b. Structures and Interformational Relationships..... 115
3. Lake Deposits (a, ae^1, aei)..... 116
a. Description of the Units..... 117
b. Structural Relationships..... 117

4. Fossil River Channels (aff)..... 117
a. Description of the Unit..... 119
b. Structural Relationships..... 119
5. Fossil Dunes of the Ogolian (Red Dunes--ad[1])..... 119
a. Description of the Unit..... 119
b. Structural Controls..... 120
6. Recent Fluvial Deposits (af)..... 120
a. Description of the Unit..... 120
b. Structural Relationships..... 121
7. Recent Marine Depostis (am)..... 122
a. Description of the Unit..... 122
b. Structural Relationships..... 123
8. Recent Dunes (white and yellow--ad[2])..... 123
H. Conclusion to the Descriptive Approach.. 123
3.9.5 Tectonic Interpretation of Landsat and Other Data.... 124
3.9.5.1 Introduction..... 124
3.9.5.2 Interpretation of Landsat Imagery and Tectonic Analysis..... 125
A. The Interpretation of Landsat Mosaics... 125
B. Conclusions Drawn from Tectonic Interpretation and Analysis..... 126
1. Conclusions Drawn from Landsat Interpretation..... 126
2. Conclusions Drawn from Combining Landsat Interpretations with Other Data..... 130
3. Conclusions Based on Data Other than Landsat..... 131
3.9.5.3 Summary of the Tectonic Development of Senegal..... 133
3.9.6 Economic Geology..... 135
3.9.6.1 Introduction..... 135
3.9.6.2 Description of the Mineral (and Hydrocarbon) Potential of Senegal..... 136
A. Hydrocarbons and Energy Sources..... 136
1. Oil and Gas..... 136
2. Lignite and Coal..... 137
3. Geothermal Sources of Energy..... 138
4. Peat Resources..... 138
B. Nonmetallic Mineral Resources..... 140
1. Building Materials..... 140
2. Phosphates..... 142

C. Metallic Minerals, Precious Metals and Other Economically Viable Substances.... 145
1. Introduction..... 145
2. Summary of the Project's Discoveries 146
a. Gold..... 146
b. Chrome..... 150
c. Lead, Zinc, Silver Mineralization 152
d. Tin, Tungsten, Molybdenum, Lithium, Niobium, Tantalum and Other Rare Earth and Exotic Minerals..... 154
3. Conclusions..... 155
3.10 Hydrology..... 156
3.10.1 Introduction..... 156
3.10.2 Overview..... 157
3.10.3 Literature Consulted..... 158
3.10.4 Major Hydrologic Characteristics of Senegal..... 158
3.10.4.1 Surficial Water..... 158
A. Precipitation..... 158
B. Evaporation..... 159
C. Runoff..... 160
D. Conclusions Concerning Surfical Water... 162
3.10.4.2 Underground Water..... 163
A. Deep Aquifers..... 163
1. The Maestrichtian Aquifer..... 163
2. The Paleocene Aquifer..... 164
3. Eocene Aquifer(s)..... 168
B. "Shallow" Aquifers..... 169
1. The Uppermost Eocene..... 169
2. The Mio-Pliocene Sediments of the Casamance..... 170
3. The "Continental Terminal" (Mio-Pliocene of the Internal Part of the Sedimentary Basin)..... 170
4. The Aquifer of the Niayes Region.... 170
5. The Subvolcanic (nappe infrabalsatique) Aquifer..... 172
6. The Alluvial Deposits of the Senegal and Other Rivers..... 172
7. The Fossil Valleys of Senegal..... 173
8. Other Aquifers in Crystalline Rocks. 174
3.10.4.3 Structural Controls of Aquifers..... 175
3.10.4.4 Landsat Interpretation of Hydrologic Features and Verification..... 175
3.10.4.5 Well Measurements Made by the Project..... 176
3.10.5 Conclusions on the Hydrology of Senegal..... 179
3.10.6 Senegal's Water Potential..... 180
3.11 Appendix A: Hydrogeology..... 185
3.12 Bibliography..... 269

CHAPTER III

HYDROGEOLOGY

3.1 INTRODUCTION

The purpose of mapping the geology and hydrology of Senegal on the basis of Landsat interpretation was to provide new insights into these two important aspects of Senegalese natural resources. Little has been done in recent years in the mineral sector. Although some attention has been given to phosphates in particular, exploration activities have been limited to uranium, gold and iron ore deposits. Most of the deposits presently under study were discovered before or in the early 1960's. Mr. Serigne Lamine Diop, Minister of Industrial Development, recently defined in part the problem in the forward of the Plan minéral de la République du Sénégal (1985):

> Previously in the avant garde of West African geology, Senegal has perhaps suffered from over-diagnosis by too many geologists more interested at that time in basic geology than in proving the existence of an economic mineral deposit.

The lack of development of Senegalese mineral resources and particularly the continued disinterest demonstrated by investors proves this point. However, another factor that has retarded Senegalese mineral development should be mentioned. It is well known that numerous efforts were made in the early 1960's, especially through the UN Special Fund to investigate the mineral potential of Senegal Oriental. Although much of this work is of excellent quality, it was unfortunately conducted before the revolutionary changes wrought in exploration methods by the introduction and acceptance of the theory of plate tectonics. In addition, new systems and tools were introduced particularly during the 1960's and 1970's which have been responsible for about 40% of the new mines in the world. These tools, such as geochemistry and ground geophysical and airborne geophysical instruments have been invaluable not only in locating mineral deposits on a stochastic basis and on the basis of exploration models developed prior to 1965, but have been most effective when merged into a common approach with exploration models based on plate tectonics.

Since 1972, satellites have provided an additional tool for exploration. The most remarkable advantage provided by Landsat satellite imagery is that it has allowed us to view large portions of the earth simultaneously. We can now view entire geological provinces, mountain ranges, plateaus and other geomorphic features. Adding scattered information painstakingly acquired by inductive methods, we can integrate these data into the Landsat-provided "big picture" and deduce the potential of an area with much greater ease.

Previous Page Blank

The development of Senegal's mineral industry, including water, has been retarded by a limited number of geophysical surveys. In addition, very little has been written until very recently on the tectonic and metallogenic framework of Senegal. In fact, few mineral exploration efforts have been mounted in recent years and only a few geologic or hydrologic syntheses of Senegal have been presented since 1966, (Bassot) with the exception of a thesis at the University of Marseille (Villeneuve, 1984) and the Plan minéral (1985).

It should be noted that in the last two or three years an awareness of Senegal's potential has produced a very effective effort by the Geology Department of the University of Dakar in cooperation with a few French geologists. Unfortunately this group is overworked and underfinanced.

The effort made by the Remote Sensing project cannot be expected to have immediate results. What it attempts to provide is a new approach, which we hope will be the vehicle for the development of new models and the impetus to revitalize exploration in Senegal. Although no immediate benefits can be derived from our survey, we believe that our Landsat-based interpretative mapping has taken a very important step toward defining new mineral and water resources. What we have done in a very elementary way is to redefine the tectonic framework of Senegal and have on this basis and through partial verification in the field provided new "ground" for exploration for water and mineral deposits.

We hope that this new model will assist the workers in the field in finding ways to solve Senegal's critical water and mineral shortages.

3.2 MAPPING PROCEDURES

The methodology used for mapping the hydrogeologic units of Senegal differs from that used to map vegetation, land use or soils. These differences result from methods inherently dissimilar to each discipline or because greater or less emphasis was placed on acquiring detailed results in one or the other of those fields. For example, it is clearly evident in the project documents that geology (i.e. mineral exploration), was not considered as important as land use. Again, it was the wish of the Ministry of Decentralization that more emphasis be placed on water resources than minerals. Finally, less time and money were allocated to hydrology and mineral resources.

No specific method was defined in the project paper and other documents to direct either hydrologic or geologic investigations. Due to of this lack of direction, a methodology was developed which made the best use of time, money, vehicles, fuel and the critical lack of Senegalese counterparts.

It should be noted that a much more thorough job could have been done had a hydrologist and mineral expert been detached by the government to the project and, of course, had the project geologist himself been freed of administrative duties.

3.3 LITERATURE REVIEW

Generally, a project of this kind begins its effort by making a thorough literature search and acquiring as much available material as possible. This includes books, articles, scientific publications, maps, aerial photographs, and other documents useful in providing a background on the hydrology, climate, geology, mineral industry, and other aspects of geohydrology.

The literature on Senegalese geology and hydrology is abundant, although often difficult to locate, purchase or borrow. Frequently references are not available in Senegal and must be ordered from France at great expense. In other cases, documents are hard to find because there remain few extant copies, and often they are not available.

The basic search for background documents took place in June, July and August of 1983 immediately upon the arrival of the hydrogeologist. At this time, only the most general texts were acquired along with all the available publicly disseminated maps. This documentation provided the basis for the first level of interpretation conducted on the Landsat imagery. Later, much more detailed literature was collected along with aerial photographs and the more recondite and less easily obtainable scientific journals. These journals and material were used in the second phase of the interpretation and as supporting documents in the preparation of this report.

The literature on the geology and hydrology of Senegal is vast and growing (especially material on well drilling and water quality). If there are lacunae found in our bibliography, we must be forgiven because to collect all the literature, not to mention trying to read it all, would have been impossible in the 22 months available.

We have attempted to assemble, evaluate and integrate a representative body of pertinent literature. This material is noted in the bibliography following this chapter.

3.4 INTERPRETATION METHODOLOGY

The methodology used in our survey is relatively simple and consisted of the following steps:

A. Choosing the best available imagery as a base for interpretation.

B. Conducting a rapid literature review to understand the basic geological and hydrological aspects of the country.

C. Conducting a rapid interpretation of the major lithological and structural entities of the country at a scale of 1:1,000,000 on individual images and on a black-and-white mosaic at the same scale.

D. Comparing initial interpretation results to available maps to verify our ability to identify known rock units as well as faults, fractures and folds, and correcting the initial interpretation and redefining our approach if necessary.

E. Making short field trips to establish spectral characteristics of the land surface and the relationship of various morphological features.

F. Interpreting the geomorphology and geology of Senegal at a scale of 1:250,000 using available maps and aerial photographs. Completing first order interpretation beginning with the least complex areas. Using all available imagery including RBV and multidate (multiseason, multiyear) imagery. The interpretation is conducted by placing the Landsat imagery on a light table and overlaying a clear acetate or frosted transparent material (mylar) on which definable units or features are drawn. Once interpretation is complete on one image (for example, a color composite), comparison is made by using either a color image of a different date or by using a black-and-white image of the same or different date. Better results are also achieved by using RBV imagery or aerial photographs. Usually transparencies of topographic maps (if available) at the same scale are used to locate the features interpreted as they relate to roads or towns. Sometimes roads and towns are preplotted on the interpretation sheets; however, these tend to be distracting. Available geologic or other maps are also used in order to maintain consistency and assist the interpreter where the lithologic units are masked by thick vegetation (as in the Casamance) or by brush fires (as is often the case in Senegal). Generally, dry season imagery is used for hydrogeologic interpretation. Preparation of a first legend follows this step.

G. Preparing field work by choosing areas or specific points on the Landsat interpretation where disagreement exists with published results. Defining anomolous areas which may not have been previously noted for verification. Choosing areas or points which are difficult to interpret. Preparing final traverse maps to cross the maximum number of anomalies, geologic or hydrologic boundaries or other distinguishable features.

H. Conducting field work to verify the above.

I. Correcting interpretations to agree with the field-collected data and preparing the second order legend.

J. Conducting aerial overflights to better understand the relationships between ground and interpreted features.

K. Making final corrections to interpretations.

L. Transferring interpretations to base maps and assuring unit continuity between Landsat images.

M. Preparing final legend and defining unit relationships, (i.e., age, geometry, etc.).

N. Correcting and coloring base maps to assure coherent relationships, refining legend by means of this step.

O. Scribing and/or drafting the final map for publication.

P. Preparing additional maps based on interpretation results (e.g., tectonic, mineral potential, water availability, water degradation, etc.).

Note: It must be noted that both geologic and hydrologic surveys are not usually conducted by the same individuals for an area as large as Senegal.

3.5 CHARACTERISTICS OF AVAILABLE LANDSAT IMAGERY (see Map 1.1)

Numerous parameters are considered in the acquisition of space imagery for resource applications. They include, but are not limited to, the following: year and date, quality, cloud cover, resolution, scale, type (MSS or RBV, Radar, Thematic Mapper), bulk versus corrected or enhanced, color versus black and white, etc.

The Landsat imagery acquired by the project is described in Table III-1 in Appendix A. The main constraints placed on effective up-to-date use of the imagery in mapping Senegal were: a lack of recent imagery (since 1981), which would have been useful in evaluating dessication rates in the Sahel and by deduction would have been useful in establishing hydrologic trends; a lack of geometrically corrected imagery, which guarantees duplication of scale from one image to the other; and the lack of available imagery for all of Senegal (13 scenes) for the same date(s), which would have permitted the evaluation of degradation for particular periods since 1972 when Landsat imagery was first acquired. Finally, the scale chosen, 1:250,000, was not as useful as 1:200,000 scale imagery would have been, since most published maps in Senegal are at the latter scale. Nevertheless, excellent and good quality Landsat imagery was available for the period 1972 to 1981. This imagery had little or no cloud cover. Thirteen scenes covering all of Senegal were enhanced, and some higher resolution RBV was

available; comparative imagery was available from different dates for the same scenes, and imagery was available at various scales including, 1:1,000,000, 1:500,000 and 1:250,000. In addition, four 13-scene mosaics of Senegal were produced in color, color transparency and two in black and white (one each for channels 5 and 7).

3.6 FIELD WORK

3.6.1 General

Field work in support of a satellite remote sensing project has not, to our knowledge, been defined to include methods different from those applied in other conventional surveys. Generally, however, remote sensing field surveys are curtailed because, by their very nature, they are meant to reduce the amount of field checking required. This is done by describing all units of homogeneous aspects by interpretations and defining the parameters within each of these units that have to be field checked. For example, a geologically homogeneous unit in the Senegalese Sedimentary Basin will have a set of textural and tonal aspects which are characteristic of that unit. In field checking this unit, each of these textural and tonal aspects must be verified. However, every example within the same unit need not be verified, since units can be clearly recognized as being the same on the satellite image. Thus, to be effective, a field survey in support of a satellite mapping effort will attempt to field check a statistically valid number of similar tonal or textural features representing geomorphic, structural, lithologic or hydrologic units that have been identified by interpretation on the satellite imagery.

Two further aspects remain to be considered when conducting supporting field work for geology or hydrology. The first involves change and is particularly applicable to hydrologic surveys in which the dynamic forces acting on the earth often change the positions of streams, sand bars, dunes, etc., thereby affecting both the quantity and quality of the water available. To study such changes and provide useful hydrologic conclusions as they relate to these changes, multidate satellite imagery is used to detect change or impending change, and a field survey is tailored to measure such effects or the potential for change. Because satellite remote sensing interpretation has provided us with a view of the earth as we had never before seen it, we are able to see singular, previously unnoted features; these features can be structural, less often are lithologic and in most cases represent botanic or chemical variations which are not visible on the ground, but are noted on the synoptic format of Landsat imagery. These anomalous features require explanation and therefore field verification.

Finally, field checking is done simply because in many areas little or no field work has been conducted and additional field work is always useful.

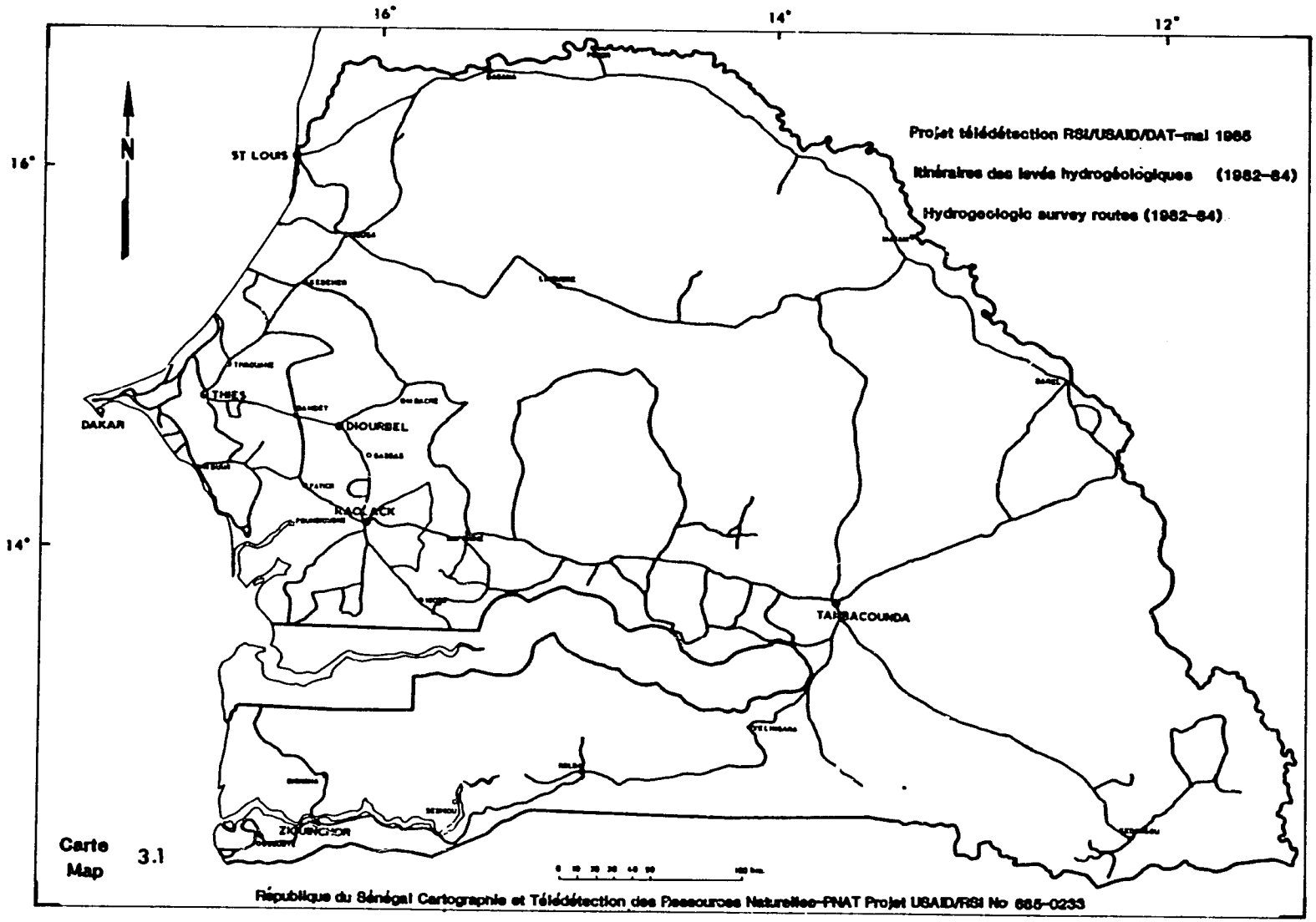
3.6.2 Methods

Field work was carried on simultaneously for geology (lithology, structures, tectonics, fuel and mineral deposits) and hydrology (extent, quantity, quality and potential). In spite of numerous levels of correspondence between these two sciences, it was difficult to gather supportive evidence in the field in adequate amounts and by proper means to do justice to both. Map 3.1 indicates the routes traveled and the sample areas visited.

A total of 9 field trips were taken during a total of 50 days. All were conducted in 1984: 2 in March, 2 in April, 1 in May, 2 in June and 2 in September. The total mileage was over 12,000 km.

Trip No.	Date	Area
1	March 5-9	Petite Côte, Thiès, Sine Saloum
2	March 13-17	Louga, Thiès, Linguère, Fleuve (Ouro Sogui), St. Louis, Dakar
3	April 3-7	Cap Vert, Thiès, Diourbel, Louga, Sine Saloum
4	April 12-20	Sine Saloum, Louga, Senegal Oriental, Fleuve
5	May 17-28	Senegal Oriental
6	June 15-20	Sine Saloum, Senegal Oriental
7	June 28-July 3	Casamance
8	Sept. 4	Thiès
9	Sept. 9-10	Cap Vert, Thiès

The first day of the first field trip was used to train counterparts in the methods of geological field verification, as well as setting up a methodology for hydrologic field verification. The team designed its sampling method to maximize geologic data acquisition, while at the same time acquiring large amounts of information on ground water levels. This was done by sampling (measuring) wells at intervals of from 5 to 10 km on every transect (with the exception of the region of Moyenne Casamance where lack of water is no problem). Simultaneously, geological samples were described either at the well site or from materials dug from the wells during the original excavation. In as many cases as possible, the team tried to locate recently dug wells or wells which were being dug in order to establish stratigraphic relationships and determine the potential of the aquifers being tapped by the wells sampled. These wells often had freshly dug material displayed at the surface and allowed us to describe the sequence of materials down to the water-bearing aquifer.


16°
14°
12°
16°
14°
N
ST LOUIS
DAKAR
THIES
DIOURBEL
KAOLACK
TAMBACOUNDA
ZIGUINCHOR
Projet télédétection RSI/USAID/DAT-mai 1985
Itinéraires des levés hydrogéologiques (1982-84)
Hydrogeologic survey routes (1982-84)
Carte
Map
3.1
République du Sénégal Cartographie et Télédétection des Ressources Naturelles-PNAT Projet USAID/RSI No 685-0233

The collection of hydrologic data was accomplished by means of a weighted tape measure. The suspended weight was dropped until it touched water, at which point a reading was taken of the length of the tape to the surface. Then the metered and weighted tape was dropped until it touched bottom and a second reading was made. Over 530 wells were measured and recorded in this manner (see Appendix A, Table III-2 and the Hydrologic Map for results).

Geological field work was accomplished by describing the lithology, stratigraphy, geomorphology and structure of an observation site. These sites were chosen before our departure. Typically our choice of observation points were related to features interpreted on Landsat imagery where they were intersected by existing roads. Observation points were noted on blueprint copies of the topographic maps of Senegal. All available geologic and mineral occurrence maps were also taken in the field, as well as Landsat imagery at 1:1,000,000 and 1:500,000. The team attempted to verify the geologic contacts, faults and other features noted on existing maps. Other observations were made in areas which were neither notable on the existing geologic maps nor chosen on the basis of Landsat imagery but were found to be of interest during the field work.

Rock samples were described at numerous locations but few were brought back for identification (see Appendix A, Table III-3 for sampling results). One hundred and seven samples were collected and identified. Thirteen samples were analyzed by mass spectrometer (see Appendix A, Table III-4). Typical summaries of field activities can be found in Tables III-5a, III-5b, III-6a and III-6b of Appendix A.

In summary, our field work varied depending on the nature of the area being sampled but, in spite of these variations, our work always consisted of collecting and identifying rock types and measuring the geometric relationships of outcropping rock units by means of a Brunton Compass to establish tectonic relationships, including folds, fractures, joints and faults. To better understand the recent geologic evolution of Senegal, particularly that of Senegal Oriental where such analysis may suggest targets for mineral exploration, we attempted to describe such geomorphic features as dunes, rivers, terraces, cuestas and other landforms.

Finally, it must be added that, although our methods were valid, our time in the field was at best very limited, though adequate to verify the majority of features interpreted on Landsat imagery. It was, nevertheless, disappointing not to have more time to document certain ideas or collect enough data to prove hypotheses which we will propose in the later sections of this report.

3.7 OTHER MEANS OF VERIFICATION (OVERFLIGHTS, AERIAL PHOTOGRAPHS

3.7.1 General

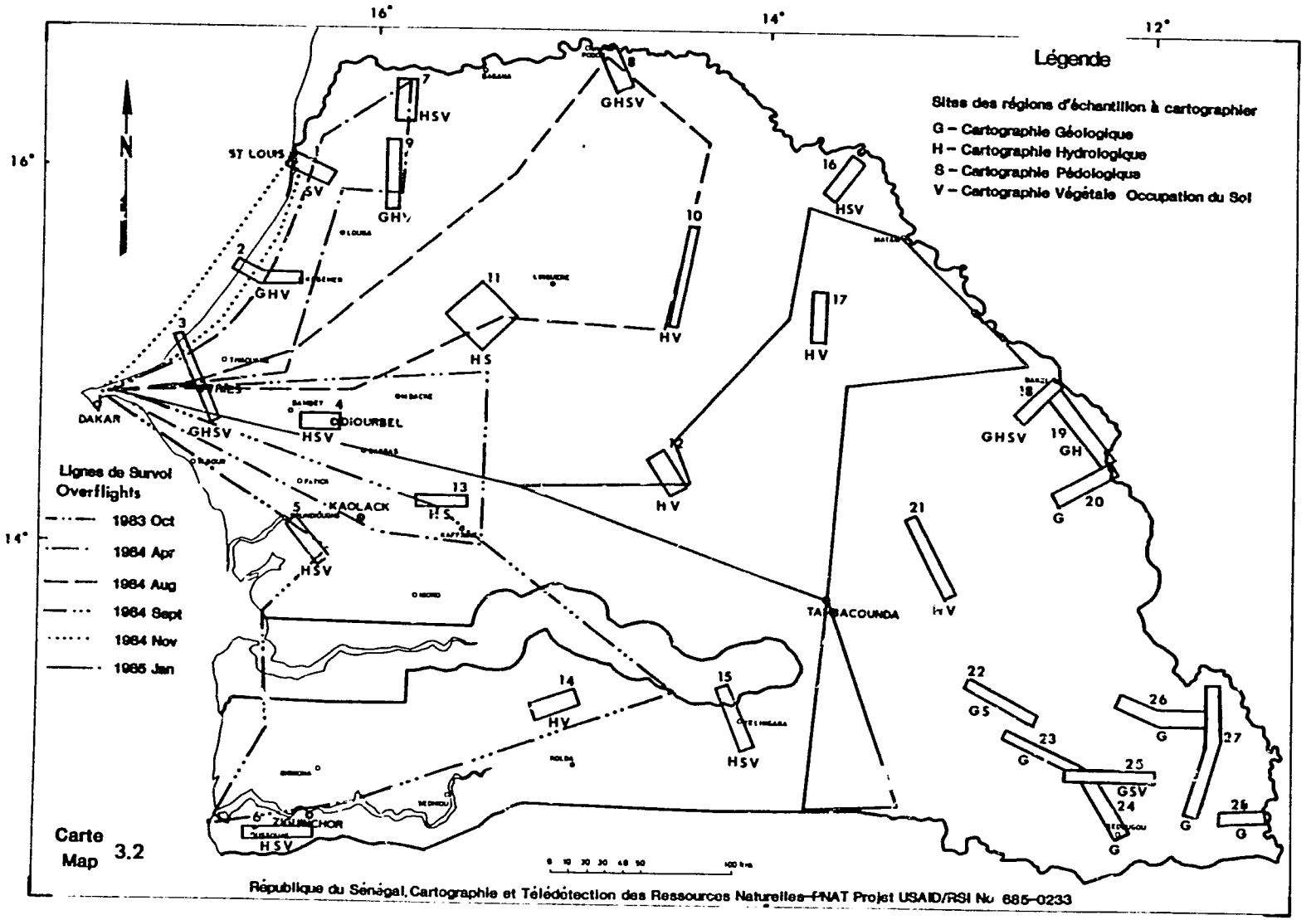
Two additional means of rapid verification are often used in the multilevel approach in support of Landsat projects: aerial overflights by means of a light plane and the use of aerial photographs taken on previous mapping missions. Both of these means are extremely useful in gaining a better understanding of ground features. However, aerial overflights tend to be more efficient than aerial photographs in that they permit the observer in the plane to assimilate large amounts of information and correlate them to previously interpreted data. Aerial photographs taken at specific altitudes provide better ground control than overflights and therefore provide excellent detailed information for the intermediate scales between ground surveys and satellites.

3.7.2 Aerial Overflights (see Map 3.2)

Six overflights were conducted for examples (see Appendix A, Tables III-6a and III-6b). They were generally successful but were on four occassions either curtailed or affected by poor visibility. Usually a six-seater, fixed-wing aircraft was used. It was hired from a local company at a cost of approximately 125,000 CFA/hr. Unfortunately, the available aircraft had low, rather than high wing profiles, a characteristic that impeded air to ground observations for some of the passengers. The normal practice was to have one scientist taking pictures, while a second would observe the plane's relative position on a 1:1,000,000 Landsat image or 1:250,000 topographic map and simultaneously record the location of each photograph taken.

The geological group participated in three overflights and was particularly disappointed by poor visibility on the Senegal Oriental overflight. This overflight was conducted with the cooperation of Dr. Sall, Geographer at the University of Dakar and P. Michel (of the University Louis Pasteur in Strasbourg, France), author of Les Bassins des fleuves des Sénégal et Gambie: Etude géomorphologique (1973).

The photography on those overflights was taken to coincide with previously chosen sample areas or to verify questionable interpretations. The photographs were usually taken as transparencies, which allow projection and detailed analysis. The altitude at which these pictures were taken varied from 500 to 1500 m, but haze from sandstorms or brush fires usually forced lower altitude flights, thus hampering geologic (large feature) observations. Optimal altitude for geologic observations is between 1500 and 2000 m.


Légende
Sites des régions d'échantillon à cartographier
G – Cartographie Géologique
H – Cartographie Hydrologique
S – Cartographie Pédologique
V – Cartographie Végétale Occupation du Sol
Lignes de Survol
Overflights
1983 Oct
1984 Apr
1984 Aug
1984 Sept
1984 Nov
1985 Jan
N
16°
14°
12°
ST LOUIS
DAKAR
DIOURBEL
KAOLACK
TAMBACOUNDA
ZIGUINCHOR
HSV
GHSV
GHV
HS
HV
GH
G
GSV
Carte
Map 3.2
République du Sénégal, Cartographie et Télédétection des Ressources Naturelles-FNAT Projet USAID/RSI No 685-0233

Low altitude flights with a camera fixed in the belly of the plane and with predetermined flight lines, provide real-time, continuous "strip" photography which can allow for crop inventories and, through stereoscopic analysis, careful geologic interpretation. These surveys have been conducted in Zaire (Stancioff, et al., 1981) and were useful in predicting corn production as well as making inventories of other resources. This advantageous method was not used in Senegal because the required aircraft was not available.

The overflights were extremely useful in confirming or denying the existence of features interpreted on Landsat, in establishing major geomorphic and structural units and in confirming the existence of fossil channels, faults, linear features, fractures and joint patterns. The following table shows the date and areas overflown by the project. The first, second and sixth overflights were flown by the hydrogeological team. Photographs from other missions were viewed by the team as well.

Flight No.	Date	Area
1	Oct. 1984	Mbour-Koalack-Sadio-Diourbel-Thiès
2	Apr. 1984	Thiès-Koki-Guier-Rosso-St. Louis-Louga-Meka-Tanma
3	Aug. 1984	Dakar-Diourbel-Darha, Linguère, Yonoféré, Tiaski, Tilogne, Podor, Koki, Dakar
4	Sept. 1984	Dakar, Nioro du Rip, Kolda, Zinguinchor, Foundioungne, Dakar
5	Nov. 1984	Dakar-St. Louis-Dakar (dune stabilization)
6	Jan. 1985	Dakar, Diourbel-Payar-Loumbol, Liou, Ouro Sougi-Matam-Woumpou-Fête Bowé-Tambacounda-Kalifourou Simenti-Tambacounda-Dakar

3.7.3 Aerial Photography

3.7.3.1 General

Twenty-eight areas were chosen as sample test sites for the various disciplines. Not all of the areas were of geological or hydrological interest. The areas of interest are shown on Map 3.2. Fourteen areas were chosen for geological aerial photographic interpretation and verification of Landsat interpretation, and nineteen areas were chosen for hydrology. Detailed photographic interpretation was not conducted for all these areas for the following reasons:

- Areas 8, 11, 16, 17, 18, 19, 20, 21, 22 and 26 were not available from IGN in Dakar; of these 8, 11, 16, 17, 18, 19 and 21 were hydrologic sample sites and 8, 18, 19 and 26 were geologic sample sites.

-Detailed aerial photograph analysis, at scales of 1:50,000 or 1:40,000, requires time and concentration. Both of these commodities were in short supply due to management problems at the project.

-The quality of many photographs was poor.

-In the case of area 2, the photographs taken by the project fully satisfied our verification requirements.

-In the case of areas 4, 5, 6 and 13, agricultural patterns tend to mask geologic and hydrologic features at this scale (1:50,000).

3.7.3.2 Aerial Photograph Analysis (see Appendix A, Table III-7)

All the aerial photographs analyzed either casually (areas 2, 4, 5, 6, 7, 9) or in detail (3, 10, 23, 24, 25, 28) definitely support the Landsat interpretation. Lithologic boundaries are clearly more visible on aerial photographs, but their position on these was not always transferred to the Landsat interpretation as this would have resulted in far too much detail and a "cluttered" map. Structural features located on Landsat were verified on the aerial photographs and approximately 80% agreement was found. This was especially true of the simpler structural provinces of the Sedimentary Basin and the Thiès-Cap Vert axis.

Interestingly, such features as fossil channels appear as unexplainable trends on the aerial photographs, whereas their identification as an important geomorphic feature ubiquitious to the Senegalese landscape was only possible by use of Landsat imagery. Their verification was, however, made easy through the use of aerial photographs.

Effective verification of Landsat imagery by the use of aerial photographs rests on the photographs being able to be viewed stereoscopically. This three dimensional aspect naturally depends on height variations. Unfortunately, a good part of Senegal is very flat; many streams are incised only 1 or 2 m below the general topography. Because of this, aerial photographic analysis for geological/hydrological purposes was of little use in much of the Groundnut Basin and Ferlo. In fact, fractures and lineaments are more apparent on the Landsat imagery than on aerial photographs because they are enhanced by different spectral responses recorded on Landsat and the availability of color imagery, repetitive imagery, as well as the synoptic view from Landsat.

The aerial photographs were particularly useful in Senegal Oriental, where rock units and structures occur in a variety and complexity impossible to decipher on Landsat imagery, which lacks the

necessary ground resolution. Whereas aerial photographs in this area provide detail, the plethora of such detail often masks the larger trends which are only visible on Landsat. Thus, the two techniques are especially useful in establishing geologic relationships in such areas. A complete photogeologic analysis should be conducted over Senegal Oriental with better quality photographs at a scale of 1:40,000 and preferably in color. Even this approach, however, would have limits because of the abundance of lateritic crust, which probably obscures over 40% of the geology, and the additional hindrance of vegetation cover. Thus, a photoanalysis including Landsat is not adequate to effectively establish geologic relationships in Senegal Oriental. The only effective way to provide good maps of Senegal Oriental, those on the basis of which exploration programs can be planned, is to use a combination of the above methods coupled with an aero-magnetic survey and a more detailed gravimetric survey. This approach would permit the interpreter to map the continuities or discontinuities of geological structures beneath the vegetative and lateritic cover.

A number of specific and detailed aerial photographic analyses were conducted, and they are shown and annotated in Appendix A, Table III-7. These analyses unquestionably show that this method of interpretation, i.e., Landsat, aerial photographs and ground follow-up, has definite advantages over traditional photogeologic interpretation. Nevertheless, it has also shown that it has its limits in regions similar to Senegal Oriental.

3.8 LEGEND AND MAP FORMAT

Four maps were prepared by the geohydrology group, each with its own legend. These maps are as follows:

A. Geohydrology map in color at 1:500,000.

B. Tectonic map in black and white at 1:1,000,000.

C. Hydrologic map in black and white at 1:500,000.

D. Mineral and water potential map in black and white at 1:1,000,000.

3.8.1 Geohydrology Map

This map was produced to correspond in as many ways as possible to the existing geologic map of Senegal ("Carte géologique de la République du Sénégal et de la Gambie", BRGM, 1962) and to incorporate, wherever possible the salient features of the 1:200,000 series of geologic maps published by the Service des Mines et de la Geologie, J.P. Bassot, et al., 1963.

Our map differs from those already published in that it incorporates a variety of previously unmapped features visible on Landsat imagery and attempts to show certain hydrologic features or accentuate

certain geologic features that relate directly or indirectly to the hydrologic potential of the country. In that sense, then, our legend departs from the norms established for the maps previously mentioned.

We have used wherever possible the same lithologic designations as are found on pre-existing maps. Differences occur, however, and will be explained in the text of this report. We have also attempted to use a similar color code to simplify reading the map and comparing it to pre-existing maps.

3.8.2 Tectonic Map

Our tectonic map is, as far as we know, the first such effort at this scale (1:1,000,000) for Senegal. This map used wherever possible pre-existing lithologic and structural designations. It does, however, incorporate certain new elements which we have attempted to describe in the legend. This map also shows lithologic units in a generalized manner and attempts to show the structural components of the crust in Senegal to provide economic geologists and hydrologists with a framework for exploration and development models.

3.8.3 Hydrologic Map

The hydrologic map, prepared by the project at a scale of 1:500,000, shows the location of the wells measured by the project, the assumed position of the uppermost levels of three geologic formations known to be productive aquifers and the location of alluvial-filled channels of Tertiary, Quaternary and Recent origins.

The location of the well measurements is self-explanatory. The method used to denote the measured data follows as closely as possible the method used by SODEFITEX (1981). The contours showing the relative depth to the Maestrichtian, Paleocene and Late Eocene aquifers are taken directly from C. Monciardini (1966). The faults, fractures and linears are taken from the Landsat interpretation, as are the fossil channels and other alluvial, mapped units. There are few norms that exist for the creation of legends for this type of map, so we developed what we believe to be an adequate and self-explanatory legend.

3.8.4 Mineral and Water Potential Map

This map has been prepared on the basis of the "Carte des Gites Mineraux de la Republique du Senegal" (1985), the Plan minéral (1985), C. Monciardini (1966) and the work of this project. The scale of this map (1:1,000,000) does not permit detailed definition of prospects, mines and other important characteristics of the mineral, water, and combustible resources of Senegal. We have, however, attempted to show the locations of known deposits and the areas in which this potential is high or low. The main aim is to provide the resource manager with a rapid means of evaluating the potential of Senegal's mineral, water and combustible resources.

3.8.5 Map Format and Supporting Documentation

The map format used for the geohydrology map was four sheets, each at a scale of 1:500,000 and one sheet for the legend. The maps were made by transferring Landsat interpretations from Landsat 1:250,000 imagery to 1:250,000 United States Army Map Service base UTM projections which were prepared on the basis of IGN aerial photographs. These maps were then composited and reduced to a scale of 1:500,000. The supporting documentation used is cited in the bibliography following this chapter.

The map format for hydrologic data is the same as above, but consists only of four sheets, with the legend on Sheet No. 2, the northeast quadrant.

The map format for the 1:1,000,000 scale Tectonic, Mineral and Water Potential maps is a reduced version of the above two maps and consists of one sheet.

The map format preparation and production methods are further described in section 1.4.

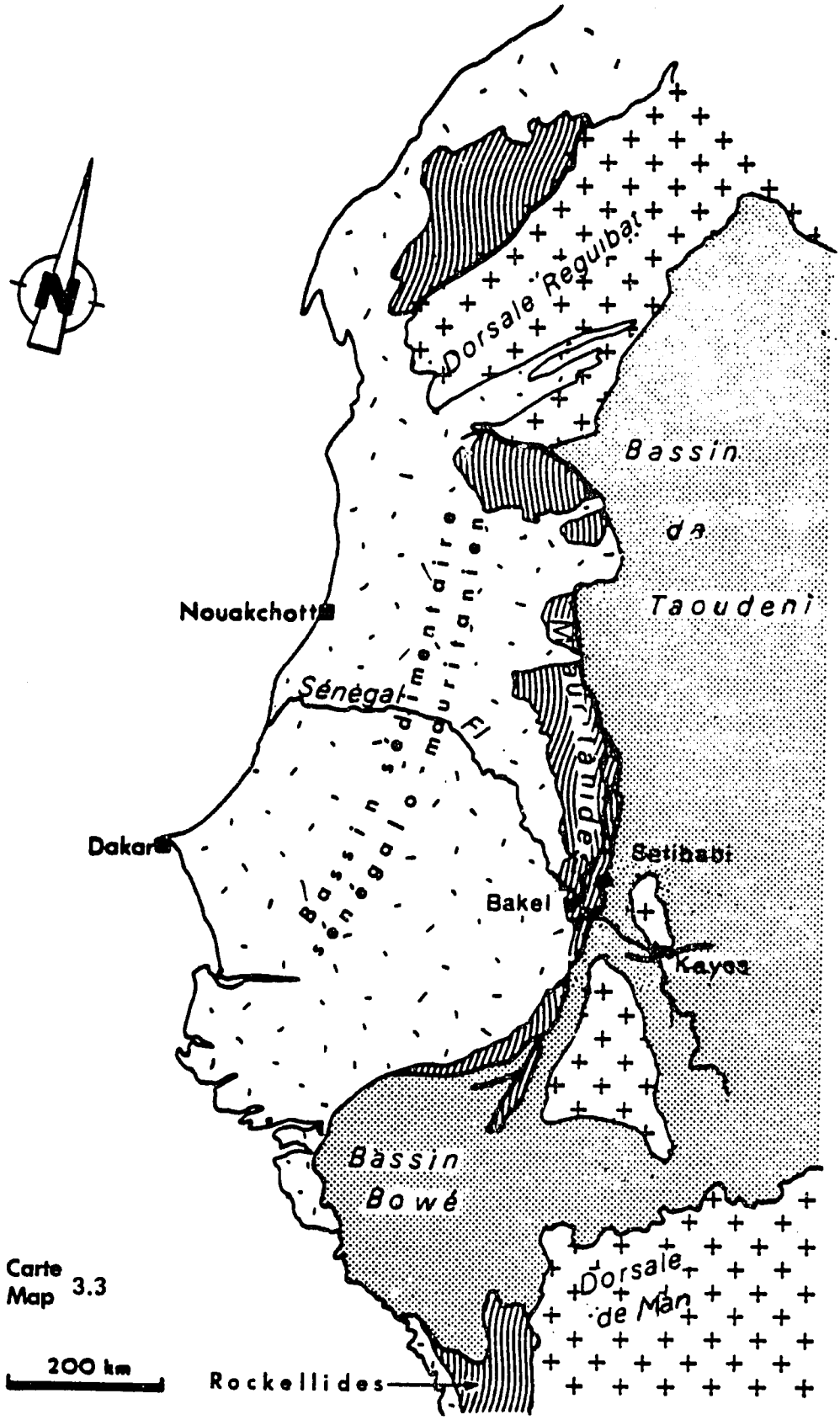
3.9 THE HYDROGEOLOGY OF SENEGAL

3.9.1 Introduction

This portion of the report will attempt first to give a short overview or summary of the geology of Senegal and second to describe the project results. Five recent works have been used as the basis for this summary; J.P. Bassot (1966), P. Michel (1973), M. Villeneuve (1984), Plan minéral, (1985) and A. Le Page (1980).

Although nearly one hundred years of mapping have provided much data to the overall geologic view of Senegal, two major problems remain to be solved. In the case of Senegal Oriental, which is composed of Paleozoic and Precambrian rocks, the main problem is that of stratigraphic succession, which is intimately related to the tectonic evolution of the region. Thus has a great deal of bearing on the potential for and location of mineral deposits in that region. The second problem involves the post-Paleozoic sedimentary basin of western Senegal (see Map 3.3), where structural relationships are poorly understood and affect the search for hydrocarbons and water.

This survey and report cannot attempt to resolve these problems. It may, however, provide some clues to the structural and tectonic evolution of Senegal and thereby suggest possible avenues for research as well as permitting future efforts to focus on specific mapping projects.



The Senegalo-Mauritanian Basin

Sections 3.9 through 3.9.3 summarize existing data, whereas sections 3.9.4 through 3.9.6 summarize Landsat interpretation, supporting field work and aerial photograph analysis.

The sections describing the geology of Senegal follow the format used by previous authors, who have usually subdivided their analyses into two parts--the first (3.9.2) describes the Precambrian and Paleozoic shield region of eastern Senegal and the second (3.9.3) the sedimentary basin of the central and western part of the country.

3.9.2 GEOLOGY OF SENEGAL ORIENTAL--THE PRECAMBRIAN AND PALEOZOIC

The Paleozoic and Precambrian rocks of eastern Senegal form an orogenic nucleus upon which more recent rocks have been deposited. These ancient rocks consist of the following:

A Precambrian (early Proterozoic) shield, fenster of ophiolitic and granitized rocks of Birriman age which are also found in Mali. These rocks have been dated ±2000 M.Y., which makes them equivalent in age to similar sequences in Ghana from whence their name is derived (Birrim).

A late Precambrian (Grenvillian) Series of volcano-sedimentary rocks named "Serie de Ségou-Madina Kouta", found in southernmost Senegal and Guinea. It comprises the rocks of the Plateau of Tambaoura in Mali. The basal sequence has been dated at ±1000 M.Y.

A series of tightly folded volcanic and sedimentary rocks of varying grades of metamorphism which have been poorly defined structurally and are globally referred to as the Mauritanids. They date from the late Precambrian to possibly the Silurian.

The Plan mineral (1985) summarizes the work done by previous authors in this area and should be referred to for additional information.

3.9.2.1 The Birrimian

J.P. Bassot (1966) separates the Birrimian into six groups as follows.

A. The Mako Series

The Mako Series is a generally metamorphosed series of ophiolitic rocks. It is composed mainly of basic rocks, including, gabbros, dolerites, basalts (of submarine origin), audesites, rhyolites, pyroxenites, dunites, amphibolites, volcanic breccias, graywackes, argilites, schists and micas schists. The basic and ultrabasic rocks form elevated relief features because of their resistance to erosion. Between these relief feature occur less resistant volcanic and

meta-sedimentary rocks.

The degree of metamorphism appears to be in the greenschist to amphibolite focies. On the other hand, possible higher grade metamorphism has been noted in the ultrabasic sequences and the conclusion is that much work remains to establish metamorphic rank and tectonic relationships.

J.P. Bassot (1966) proposes the following sequence of events for the Mako Series:

- submarine emplacement of basic rocks under ophiolitic conditions.
- formation of a mountain range and the concommitant deposition of flysch and andesitic volcanism, producing rhyolites and volcanic breccias.
- acceleration of flysch deposits along with deposition of graywackes and conglomerates.
- major orogenic cycle, and emplacement of granites.
- tensional emplacement of a system of basic dykes and veins.

B. <u>The Dialé Series</u>

This series of rocks is found east of the Mako Series and west of the Saraya "granite". These rocks are essentially lightly metamorphosed sedimentary rocks, (greenschists and phyllites)and tend to be steeply dipping, northeast-striking units consisting of from east to west:

- schists and quartzites.
- graywackes and mudstones (sericite and chlorite schist metamorphic equivalents).
- conglomerates, basalts, jasperoidal sequence (the conglomerates contain granitic and metavolcanic pebbles).
- additional schists and graywackes of dark greenish hue which resemble the tuffaceous rocks of the Mako Series.

In addition, marbles have been found locally at Ibel in the southwest, along with tightly folded interlayered calcareous and pelitic sequences. These marbles are also found near the village of Missira, northwest of the Saraya granite.

J.P. Bassot believes that the Diale Series is younger than the Mako Series and suggests the following sequence:

- quartzite/marble sequence, conglomeratic schists, graphitic schists.

- flysch sequence at the base of which occur conglomerates in the western portion of the series.

However, J.P. Bassot suggests that the marbles may be equivalent to the Mako Series.

Other work (Plan minéral, 1985) suggests that the Dialé Series can be divided into two parts--a lower dominantly arkosic sequence and an upper predominantly graywacke sequence. In addition, it is thought that the upper (younger) part of the sequence is situated in the west and the older in the east. Estimates of the total thickness of this series would be nearly 8 km.

Work by COGEMA has located graphite schists near the top of the Dialé Series, and they have been proposed with qualification as being equivalent in age to similar rocks in the Mako Series. The authors of the Plan minéral (1985) feel that these two series could be synchronous, one oceanic and volcanic, the other littoral and sedimentary.

C. The Daléma Series

This series is found to the east of the "granite" of Saraya and extends eastward to the Falémé River and beyond into Mali where it is overlain by the Ségou-Madina Kouta Series. The following rocks described by J.P. Bassot (1966) as comprising this series lie from west to east:

- a steeply dipping series of yellow to grey-black schists with minor beds of graywackes.

- a graywacke sequence which becomes progressively more calcareous going eastward where marbles occur.

These two series are, however, quite varied and include conglomeratic, quartzitic, calcareous and arkosic graywackes as well as sericitic and brotite mica schists.

More extensive work (Walter and Chartraine, 1976) indicates two major provinces separated by a granodioritic sequence named Boboti by J.P. Bassot. These two rock types are a western schisto-graywacke group and an eastern group in which several types of volcanics can be identified in a sequence of volcano-sedimentary rocks. The volcanics exhibit intermediate to acid characteristics and are typically andesitic. It is with these rocks that we find associated the important bedded and massive iron deposits of the Falémé River. According to the above sources, low grade metamorphism affects these two series, although more profoundly in the volcanic sequences. These

authors also state that the granodioritic intrusive rocks have produced a contact metamorphism which extends 1 km into the surrounding country rock.

D. Baoulé-Type Granites

These granites, according to J.P. Bassot, are intrusif batholiths, which are concordant with the country rock and syntectonic, or related to late tectonic activity. They are either metasomatic in the Massif de Kakadian from north of Mako north to the Falémé River, or supposedly magmatic as in the case of the Saraya type granites. The ages of these granites vary from 2200 to 2000 M.A. (Rb/Sr).

The Baoulé-Kakadian granites are described as being extremely varied in composition. The massif includes diorites, granodiorites, and calcalkalin and alkalin syenities. The fact that these bodies are tectonically oriented suggests a syntectonic origin.

The Saraya-type granites (including Saraya-2000 km^2 and Lamoussa-10 km^2) are much more leucocratic, and although they contain numerous petrographic variations, are generally homogeneous and considered syntectonic because their general trend corresponds to the overall strike of the enclosing Birrimian rocks. They are also considered to be within "anticlinal" structures.

E. Boboti-Type Granites

These granites occur east of Saraya and are named for a small stream which transects them from east to west. These granites are also aligned in the general direction of the Birrimian rocks and so are considered syntectonic, or perhaps part of a late tectonic phase. According to J. Walter and J. Chartraine (1976), they are orthopyroxene granodiorites.

F. Bondoukou Granites

Typically homogeneous, these rocks are circular to elliptical bodies of small size (a few kilometers in diameter). They tend to be akeritic (oversaturated with silica) and are nonalkalic. Their emplacement seems to be related to deep seated, post tectonic activity in the Birrimian rocks.

These rocks all seem to have been profoundly affected by orogenesis. Folding is isoclinal, dipping steeply northwest. Strikes vary but tend to average about 45°E of N.

J.P. Bassot proposes two major periods of tectonism and granitization in the Birrimian rocks described above, one at about 2200 M.A. and the other at 2000 M.A. Both of these periods are nonetheless contained within the Eburnean orogenic cycle.

J.P. Bassot concludes his summary of the Birrimian in Senegal by proposing a geosynclinal environment as the site for the deposition of these rocks. He proposes that the Mako Series was deposited in a eugeosyncline, the Dialé and Daléma series occurred as miogeosynclinal trough deposits. Flysch deposits began to be deposited eastward of the Mako Series as this series became elevated and folded due to compression from the northwest. He adds that during these initial orogenic pulses, the granites (Kakadian, Saraya and Boboti) were emplaced. Finally, he proposes a late-stage tectonic compression, which produced major structural breaks (fissure system) and the emplacement of the circular type granites. J.P. Bassot finds analogous rocks in Mali (Kayes), Guinea, Sierra Leone, Ghana, Mauritania (Guidimaka) and in the Reguibat Shield area. Although he proposes a rejuvenation process for Proterozoic granites in Mauritania, he does not suggest this possibility for Birrimian granites in Senegal perhaps because pre-Birrimian shield is unknown in Senegal.

3.9.2.2 Late Precambrian and Paleozoic Rocks

Based on the numerous works cited by the Plan minéral (1985), this sequence of rocks is composed of two large and distinct series, or groups, of rocks: a basal series known as Ségou-Madina Kouta and a highly diverse series of rocks named the Mali, Falémé, Younkounkoun, Bassari, Koulountou and Bakel. This last group of rocks has not been well defined and due to its structural complexity and diversity of origin, poses considerable problems.

Due to the structural complexity of this area, arguments concerning the relative ages of these series continue. M. Villeueuve (1984), who has worked mainly in Guinea, and A. Le Page (1983), who has worked mainly in northern Senegal and Mauritania, have shown that imbricate thrust faulting has taken place and could well be responsible for the repetitions and truncations of the various series and thus suggest that relative ages cannot be decided purely on the basis of superposition or simple stratigraphic relationships.

A. The Ségou-Madina Kouta Series

This rock series is unconformable to the underlying Birrimian Shield rocks and is unconformably overlain by the Mali Series at the base of which is found a marker horizon of tillite. Tillite is used throughout West African, but its age is still undetermined. The Ségou-Madina Kouta Series id dated at 1022 M.Y.

According to J.P. Bassot, this group contains a mixed succession of volcano-sedimentary rocks about 2500 m thick. More recent work (COGEMA 1976-1977) has two series:

- a volcaniclastic sequence known as the Ségou Series, which thickens westward.

- a marine deltaic sequence, which marks the transgressive stage of the late Precambrian. This sequence is unconformable to the Ségou Series and is defined as the Madina Kouta Series.

These rocks are confined to the area bordering Mali and Guinea.

The Ségou Series is thought to have been deposited in a rapidly developing basin along the edges of the more stable cratonic portions where stromatolithic reef deposits accumulated. After a short period of denudation and erosion of the above series, the finer marine sediments of the Madina Kouta Series were deposited. This sequence begins with a thin bed of reworked or in situ stromatolites and is particularly notable due to the occurrence of a yellowish calcareous pelite which is high in uranium, copper (malachite) and manganese. This heavy metal bed is continuous from east to west and is an excellent marker bed. The rest of this sequence is rather monotonous and consists of coarse-grained sandstones with occasional calcareous beds and is terminated by a limestone unit that becomes more evident as one moves southward into Guinea.

It is thought that a late or post-Birrimian tectonic event was responsible for the basinal development which provoked the depositional sequences described above. Apparently, the various granitic units, Yamoussa, Saraya and Boboti, remained as topographic highs, while the intragranitic areas slowly collapsed and provided the depositional basins, where the materials described above accumulated.

Very little tectonic activity is noted in these rocks; they tend to dip southward very gently and are crisscrossed by three fracture systems--N30-40°, N140-160° and N70°. The only additional visible orogenic effects are indicated by the appearance of the overlying dolerite sequences, which shall be further discussed.

B. <u>The Mali Series</u>

This series occupies only a very small part of Senegal but is extensive southward in Guinea. It lies conformably on the Ségou-Madina Kouta Series. The essentially sedimentary succession is described as follows:

- basal tillite marker horizon
- mudstones
- sandstones
- calcareous dolomites
- jaspers

- upper mudstone member which contains arkosic sands, graywackes and conglomerates.

This sequence ranges from 500 to 700 m thick, with most of the accumulation in the upper pelitic formations. It is said to be very gently deformed and westward dipping.

C. The Falémé Series

This sequence is a continuation of the Mali Series and narrows as it follows the Mauritanid trend northward. It lies unconformably on Birrimian rocks to the east and has a complex nonconformable relationship with the Bassari Series to the west. This sequence is composed of folded and horizontal nonmetamorphic rocks. It is thought to have been deposited in a nearshore depositional environment in the east and a deeper basinal environment in the west. The only major difference between the rocks of this series and those of the Mali Series is that its basal member tends to be an acid volcanic member composed of rhyodacites and tuffs followed by the tillitic marker horizon and the typical sequence described for the Mali Series. Farther west, the basal volcanic formation becomes more basic and is composed of a volcano-sedimentary sequence of diabases and spilites. The succession then returns to the tillite and other previously described members, which in the west tend to be much thicker. Finally, unlike the Mali Series, the Falémé Series is capped by a thick sequence of red sandstones (±1000 m).

J.P. Bassot and A. Le Page both see minor folding as influencing the Faleme Series. In the northern portion of this series, near Kidira and Marsa, A. Le Page has described a series of eastwardly-imbricated thrust sheets (Le Page 1978, 1980, 1981, 1982) and a much more complex structural history.

D. The Bassari Series

The Bassari Series occupies a 25 to 5 km wide (from south to north) highland area. This series of rocks is metamorphosed and broadens southward in Guinea, where it splits into two bands (Villeneuve 1980, 1984). The Bassari Series is nonconformable to the Faleme rocks to the east and the Younkounkoun rocks to the west, from which it is separated by a major fault.

Age relationships for this series have not been established, although at least three authors (Bassot, 1966; Chiron, 1964; and Villeneuve, 1980, 1984) suggest that the Bassari Series may be in part coeval with the Faleme Series, though probably somewhat older.

These rocks are variously described as sequences of schists, basic effussive rocks and diabases underlain by quartzites and green schists. The upper sequence resembles in part the Mali and Falémé series, but no marker beds have been found, and for the basal series any correlation

appears to be tentative at best.

The estimated thickness of this series is 1500 m (Chiron 1964). To the north, where it narrows, this series appears to "join" the Koulountou Series.

The rocks are described as crushed and mylonitized throughout and strongly tectonized. Although their structural relationships with neighboring rocks are poorly understood, it is thought that they are transported from west to east and nonconformable with the Falémé Series along a major fault. Similarly, the rocks to the west are thrust upon the Bassari Series and lie unconformably upon them. It is also suggested by the Plan minéral (1985) that the Bassari Series might represent an anticlinal zone within this area.

E. The Younkounkoun Series

The Younkounkoun Series occupies a large basinal depression which parallels the Bassari Series to the east and is separated from it by a major structural discontinuity, which is assumed to be a thrust fault. To the west, this series passes discordantly into the Koulountou Series by a series of faults and granitic intrusions. The intruded rocks give an age of 683 ±18 M.A., suggesting a Pan-African or Hadrynian origin. This series of rocks is described from bottom to top by J.P. Bassot (1966) as follows:

- an acid volcanic complex
- mudstones and argillites with graywacke and sandstone beds
- red arkosic sandstones
- white sandstones

The total thickness of this sequence is 4500 m.

The Younkounkoun Series is thought to have been emplaced along a series of deep fractures which provided the venue for the acid volcanics. These acid volcanics were partially deposited in a marine environment. Continued basinal collapse allowed for a mixed volcano-sedimentary sequence to be deposited, which was followed by typical shallow to deep sedimentary sequences. These events are followed by orogeny, the shallowing of the seas in certain areas and the deposition of the red sandstones. This sequence is followed by renewed orogeny, including strong folding. A final marine transgressive stage provides the depositional environment for graptolitic schists. Sedimentation in this area continues until at least the late Ordovician/Silurian, but in Guinea it continues into the Devonian. Another orogeny produces folding in the uppermost part of the series (Hercynian). J.P. Bassot does not explain why he combines rocks affected by the Pan-African orogeny in the same series with rocks

of obvious early to mid-Paleozoic age (Gothlandian).

F. The Koulountou Series

The Koulountou Series is a complex acid volcano-sedimentary sequence which occurs to the west of the Younkounkoun Series and appears to be separated from it by a series of faults and fractures. It is probably an "anticlinal equivalent" of the series to the east. To the west, it is unconformably overlain by Tertiary and Quaternary rocks.

The Koulountou rocks are highly metamorphosed and in some places nearly mylonitized, often recrystallized and stretched. J.P. Bassot believes that this series is the metamorphic equivalent of the Younkounkoun Series, although he was not able to find any continuous cross section where the two series join. Dating of the Koulountou Series suggests an age of 433 M.Y. (Caledonian) and is thought to represent post-depositional metamorphic "rejunvenation". J.P. Bassot also notes a gravimetric (positive) anomaly situated beneath this acid complex and estimates without explanation that ultrabasic rocks occur 3000 m below the Koulountou Series. He interprets geophysical data as providing evidence for NE/SW as well as NW faults, trending 300°-330°. Finally, he suggests that compressive forces acted in two directions on the Koulountou Series of rocks--one from the NW and the other from the SW.

G. The Bakel Series

Recent authors have shown that the Bakel Series is composed of a volcano-sedimentary sequence of acid submarine volcanic and sedimentary rocks, quartzites, schists, acid subaquenous equivalents of spilitic rocks, jaspers, serpentinites, keratophyres quartz keratophyres and gabbroic rocks, including partially serpentinized harzburgite and dunite (Petkovic, 1971).

This typical ophiolitic sequence is structurally affected by extreme tangential tectonism and subsequent horizontal dislocation of thin slices of the Bakel Series from west to east (Le Page 1981, 1982).

3.9.2.3 Conclusions

Although J.P. Bassot, A. Le Page, and M. Villineuve, among others, have provided us with a general framework for the Proterozoic, Precambrian and Paleozoic rocks of eastern Senegal, it appears that the structural complexity of this region requires much additional work before we can have a clear understanding of its stratigraphic relationships and mineral potential. A. Le Page has shown that the region from Kidira to Bakel is highly complex, but that careful analysis of Landsat imagery followed by conventional photogeology and field work will allow us to slowly decipher the geology of this region.

3.9.3 The Sedimentary Basin of Senegal

A large sedimentary basin with sediments and sedimentary rocks of Cratce ..s to Recent age covers more than two-thirds of Senegal. This basin is referred to as the Senegalo-Mauritanian Basin and extends south from Morocco to Guinea (see Map 3.3). Although this basin appears to have a simple structural makeup, its simplicity is belied by the volcanic activity manifested in the Cap Vert Peninsula and various faults known to affect the region, such as those paralleling the Horst of Ndiass. In fact, large folds and faults control the position of the Lac de Guiers and its Mauritanian analog, the Lac de Rkiz. Gravity and magnetic maps also clearly show that the Sedimentary Basin has nonuniform substrate that are probably controlled by variations inherent to the basement rocks, and tectonic effects, which have more recently affected both the basement and the overlying sedimentary sequence.

In general, the Senegalo-Mauritanian Basin extends a maximum of 500 km from the coast to the shield area of Senegal Oriental. It is composed at the surface of mostly Tertiary and Quaternary sediments and sedimentary rocks, with the exception of a small wedge of Upper Cretaceous sediments in Cap Vert. The entire sequence is thought to be underlain by sediments and sedimentary rocks of Precambrian to Devonian age and it is intruded, particularly in the west, by ophiolitic and intrusive rocks of varying ages, though mostly of Tertiary age. The basin is much faulted, particularly in a NE/SW direction and is gently folded or simply downwarped in places.

The sedimentary sequence in Senegal is very well described by numerous authors and is quite clearly summarized in the Plan minéral (1985). This report will only recapitulate the previously presented basic outline and add information wherever our work showed noteworthy results.

3.9.3.1 Geologic Periods

A. The Paleozoic

The sedimentary sequence rests unconformably on quartzitic sandstones attributed to the Devonian (Paleozoic). This information comes from deep wells drilled for oil in the Casamance (Diama Malari). In other places, Dabo and Haute Casamance, drilling has encountered folded schistose rocks of probable Paleozoic origin. During petroleum exploration by the Shell Oil Company, folded schistose rocks were reached at Linguere. In addition, granitic rocks of probable Precambrian age were reached in drill holes at Korkol, (southeast of Linguère) at a depth of 620 m and at a similar depth at Dioumanan, east-southeast of Linguère. Not far to the west, at Kolobane, drills reached a metamorphic aureole the existence of which suggests an igneous, intrusive body at this site and a rapidly developing basin as one moves westward.

It is obvious from the above description that the Senegalese Sedimentary Basin is extremely variable in depth, although it does have a general tendency to dip and thicken westward.

B. The Triassic and Liassic

The post-Paleozoic sedimentary sequences begin with saline, gypsiferous and anhydrite deposits with which are associated green and black pyritic and sulfur bearing shales. These rocks are found in diapiric structures offshore of Casamance, and some of them have been drilled for oil, gas and sulfur. Offshore drilling has also located pure salt in diapiric offshore structures with similar anhydrite, shale and dolomitic sequences. Near Dakar, offshore drilling located (at 4050 m) anhydrite/dolomite sequences characteristic of intertidal depositional environments.

C. The Jurassic

Jurassic sediments have been penetrated by a number of drill holes offshore and onshore. The large number of fossils suggests a neritic environment for these essentially carbonate rocks. The total thickness of these sediments probably exceeds 1800 m.

D. The Cretaceous

The Cretaceous in Senegal is represented by a very complete stratigraphic column. The main stages represented are the Neocomian, Aptian, Cenomanian, Turonian, Senonian and Maestrichtian. This succession is dominated from its base to its top by continental sands and occasional argillaceous sands. However, as one approaches the coast, these sediments become more calcareous. In the interior, the lignitic material found in the mid-Cretaceous suggests near shore lagoonal and interdunal depressions. Coarse sands and gravels in the Senonian sediments of the western platform indicate a possible uplift of the eastern highlands of Senegal. In the coastal area, this stage is represented by erosional breaks and suggests uplift throughout the basin concomitant with the emplacement of the Leona syenite dome south of St. Louis.

The uppermost Cretaceous is homogeneous in eastern and central Senegal, where it consists mostly of shaley sands. Variations in sediment types occur, notably the existence of a number of lignite beds which are present in the uppermost part of the Maestrichtian succession. Westward, this series of beds becomes more argillaceous and thickens to about 2000 m. This variation is observed as one moves from east to west in the region of the Horst de Ndiass, where this formation outcrops. The Maestrichtian is very important as an aquifer and will be discussed further.

E. The Tertiary

The Paleocene outcrops both east and west of the Horst de Ndiass, in the Falaise de Thies and at Dakar. During the Paleocene, the depositional environment became increasingly calcareous, developing reef environments which include limestones, marls and calcareous shales. The Paleocene is rich in fossils in the east as far as the Ferlo and Tambacounda, whereas westward (present offshore Casamance), it becomes argillaceous and much thicker (+300 m). At the end of the Paleocene, the Horst de Ndiass began to emerge and resulted in the formation of karst topography in the adjacent Paleocene limestones. This limestone sequence is a major aquifer in the western region of Senegal.

1. The Lower Eocene

During the Lower Eocene, the ocean had transgressed over the entire sedimentary basin, and argillaceous and marly deposition predominate, except at the base and top of the stratigraphic sequence. Resting generally conformably on the Paleocene, we find calcareous and sandy horizons of limited thickness. These horizons sometimes contain chert, phosphates and glauconites, which in the area of the Horst de Ndiass fill Paleocene karstic features. Above these lowermost horizons, thick successions of attapulgites argiles papyracées, and marls occupy most of the basin but are particularly noteworthy near Rufisque and Lake Retba. The Lower Eocene ends with a succession of marly limestones and limestones.

2. The Middle Eocene

During this stage the ocean covered all or almost all of the Senegalo-Mauritanian Basin. The base of this stage is defined by the reappearance of microfauna. Though marls predominate, typical facies include phosphatic horizons, sands and limestones. This series of rocks, known as the Lutetian, is unconformably overlain by the Upper Eocene Series, which appears to have been deposited after a short erosional cycle. This sequence varies in thickness from 40 m in the Bambey-Linguère axis to 150 m in Casamance and to more than 200 m in the Senegal River Delta.

It is during the Middle Eocene that the main phosphatic deposits were formed. They occur at various levels throughout this sequence and are presently being mined at a number of locations in Senegal, particularly at Taiba. This series ends with a sandy and calcareous sequence, that at its summit consists of a "yellow formation" which in turn generally grades into the continental deposits of the Upper Eocene.

3. Upper Eocene

According to the summary (Plan minéral, 1985) of the geology of Senegal, the Upper Eocene is only represented in the westernmost part of Senegal. The geologic map of Senegal (1962) shows Upper Eocene sediments covering a somewhat broader region, which includes Sakal, Louga, Mbédiène, Niakhène and Baba Garage. In and off Casamance, the Upper Eocene has been identified in drill holes where the series is represented by marls and calcareous marls, which are often phosphatic. This series has also been identified at Kolda and Tambacounda, where it consists of argillites and calcareous argillites of perhaps 10 to 20 m.

Incipient volcanism has been noted in the region of Thiès near Bandia. This activity and the limited marine transgression of the Upper Eocene in western Senegal suggest that orogenesis (uplift) began in western Senegal at this time. Concurrent to the volcanism, broad anticlinal and step-faulted structures were being emplaced west of Mbour and the Lac de Guiers. At this time also the collapse of the Casamance Basin began with a synchronous marine transgression.

4. The Oligocene

The Oligocene in Senegal is represented by limestones in the Casamance shelf area. Gray and brown marls appear at the base of this series and are intercallated with the limestones, which sometimes provide phosphatic characteristics. The series thins rapidly as one moves eastward and at Ziguinchor it takes on a sandy aspect. Oligocene offshore facies are also identified at Dakar, while phosphatic, nearshore, marine sediments have been identified at Lam-Lam and at Thies. It is during the Oligocene that volcanic activity becomes important and is first noted in the Dakar region and the offshore islands.

5. The Miocene

Recent work has identified Miocene marine sediments throughout much of the Senegalese Sedimentary Basin. Nevertheless, because of the lack of fossils in many areas, some controversy exists as to their origin and exact identification.

The best developed sequence of Miocene marine sediments occurs offshore of the Casamance, where Miocene sediments succeed the Oligocene without a break and consist of argillites dated by means of microfossils. This sequence is 300 to 600 m thick and grades upward into marly limestones, marls, and argillaceous limestones. Marine fossils are not identified in sediments of equivalent age farther east. These unfossiliferous sediments, which have been identified as far as Tambacounda and have been affected by subareal erosion and diagenesis, consist of silty sands about 110 m thick. Palynological evidence has permitted the dating of these sediments, and they are attributed to the marine and lagoonal transgressive stages of the Middle to Upper

Miocene.

A very large portion of the Senegalese Basin is covered by a clay-sand formation, which has traditionally been called the "Continental Terminal". This formation is the thickest in Ferlo where it may reach 130 m. Recent work by J.R. L'Appartient (1978) has shown that parts of this formation (at Nioro du Rip) are highly fossiliferous and belong to the marine Middle Miocene transgression. Further east and north, this same formation--though no longer fossiliferous and often surmounted by laterites--is an altered equivalent of the Middle Miocene sequence described above.

Sections cut during offshore drilling near Dakar show the existence of over 100 m of marls and clays attributed to the Middle Miocene, although no paleontological proof is available.

Volcanism becomes very important during the Miocene, not only on the Cap Vert Peninsula and in the Thies region, but also in the offshore region of Senegal's continental shelf.

6. The Pliocene

No marine formations have yet been found in Senegal which can definitely be attributed to the Pliocene. However, it is quite obvious that such deposits must exist on the continental shelf off Senegal. P. Michel (1973) attributes the formation of most of the iron-rich laterites of Senegal to a pluvial period at the end of the Pliocene. Since laterites do not form at the surface, but at some depth where iron accumulates due to solution and infiltration, it can be suggested that a general basinal emergence took place during the Pliocene. It is also probable that such emergence created downcutting by streams with valleys 10 to 50 m below present levels, especially in the Ferlo. This downcutting probably continued into the early Pleistocene.

F. The Quaternary (Pleistocene-Holocene)

Quaternary deposits of marine continental and volcanic origin cover much of the surface of the Senegalo-Mauritanian Basin. P. Michel (1973) has best summarized work dealing with these Quarternary deposits and is widely accepted as the authority on this subject.

Quaternary marine sediments representing transgressive stages at about 32,000, 5000, 3000 and 2000 B.P. have left unmistakable evidence of higher sea levels along the Senegalese coast and along the lower courses of the major river valleys, including the Senegal, Ferlo, Sine Saloum, Gambia and Casamance. Two major transgressive episodes, the Inchirian and the Nouakchotian, produced beach (sand and coquina) accumulations during these stages. The main deposition occurred during the Nouakchotian, particularly in the Senegal Delta. These deposits are, however, of limited thickness and do not exceed five m. Furthermore, thick marine and continental deposits in what are

considered fossil valleys along the Senegalese coast have been found to exceed 30 m and reach 50 m, indicating marine and continental deposition. These transgressive episodes probably filled valleys cut during Pliocene and early Pleistocene low sea level (glacial) stands. These low sea levels also produced the downcutting of the Kayar Canyon, which has a depth of 200 m a few kilometers offshore. The most recent of these erosional cycles, created deep valleys during or just before the Ogolian. Various terraces and erosional surfaces represented by continental deposits testify to Pleistocene terrestrial depositional cycles related to changes in climate and sea level.

A highly accentuated marine regression is dated at about 20,000 to 30,000 B.P. It was responsible for the downcutting, deepening and headward eroding of the major stream systems of northern, central, and eastern Senegal. It was during this period that the Senegal River captured many streams to the east and changed the morphological development of Senegal. This action effectively produced dams and ponds in various areas and is probably responsible for extensive lacustrine deposits throughout central, northern and north-eastern Senegal.

During the Ogolian, eolian deposits covered extensive areas in western Senegal, extending as far south as the Gambia River, and produced damming and deflection of weakened streams that could no longer carry their loads.

Three sets of dunes, each of different periods, have been noted in Senegal. A ENE/WSW set of broad dunes occurs in the northern Ferlo region and is referred to as Akcharian (pre-Ogolian). A NE/SW set of reddish dunes, which occurs in the Sine Saloum and the Senegal River Delta, suggests the erosion, mobilization and deposition of Pliocene lateritic materials. These latter dunes are attributed to the Ogolian. A geometrically heterogeneous set of dunes, varying in color from white to yellow and generally trending NW/SE, occurs along the coast from Dakar to St. Louis.

In this coastal area and below these dunes are found peat deposits which date from a more humid period between 8000 and 10,000 B.P. These deposits are associated with all littoral deposits of the late Quaternary (Holocene) and are typically associated with lagoonal environments in present estuaries or in similar conditions along the coastal district of Cayor or the Niayes.

The late Pleistocene to Recent (Holocene) tectonic development of Senegal has been marked by a period of relative inaction. With some exceptions this inactivity is particularly true of the coastal areas where longshore currents have transported sediments from north to south and have, due to stable sea levels, permitted the winnowing (segregation) of the heavy fraction of the beach sands; thus, accumulations of zircon, rutile, monazite and ilmenite exist along the entire coast of Senegal.

3.9.3.2 Tectonics, Magmatism and Geologic History of the Senegalo-Mauritanian Basin

A. Tectonics of the Senegalo-Mauritanian Basin

The relatively flat terrain, visible throughout this geomorphic province, and the flat to gently dipping succession of sediments and sedimentary rocks, belie the facts concerning the complex structures and tectonic diversity evidenced by gravimetric, magnetic and drill hole data.

1. Structural Overview of the Basin

Tertiary and Quaternary volcanism in the Thies-Dakar region provides proof of extensive tectonic activity in this area and implies the existence of an extensive and deep-seated fracture system. The most obvious examples are evidenced in the Horst de Ndiass, the Dakar Horst, the Lake Rkiz/Guiers depression, and the Rufisque graben. Other structures have been identified by drilling or geophysical surveys and include salt diapirs off Casamance and a horst offshore of Mbour. A number of recent authors, including Y. Bellion and R. Guiraud (1984) and A. de Spengler et. al. (1966), have produced cross sections on the basis of data collected primarily by oil companies. These data indicate a very complicated structural province composed of en echelon faults that trend generally north to south or subparallel to the coast. Faulting offshore along and on the continental platform seems to be simple in that it suggests long, generally continuous faults. Within the actual landmass, the faulting becomes more complex and may include abnormal or reverse faults, some doming, folding and finally cross-faulting, orthogonal to the nearly north-south trends noted above.

Such structures have complicated oil and gas exploration and make the search for and evaluation of aquifers a difficult and frustrating task.

2. Fracture Analysis

The major fracture direction, as exemplified in the Horst de Ndiass, strikes from NS to $\pm 20°$ E of N. These fractures and associated faults define vertical or nearly vertical movement. The faulting is both normal and reverse, and some observations suggest strike-slip movement as well.

Field studies and aerial and satellite photointerpretation suggest that there exist numerous other fracture systems, though possibly of lesser importance. The Plan mineral (1985) provides the following information regarding directions of fracture.

a. West Central Senegal--N25°-N35°E, N60°-N65°E, N125°-N130°E, and N160°-175°E

b. Region of Mbour--N30°-N50°E, N80°E, and N120°-N140°E

c. Western and southern region of the Dome de Guiers--N40°E, N130°E

d. Casamance--N50° to N55°E, N130° and N160°E

e. Northern Guinea-Bissau--N50° to N60°E

Finally, and of great importance, are the transform faults whose extension from the Atlantic Ocean into the Senegalo-Mauritanian Basin can be assumed. It is postulated that they continue eastward into the prebasinal rocks (see Map 3.3). These faults are interpretable from magnetic and gravimetric data and are notable in the following areas (Fig. 3.1):

a. The 20th parallel fault which offsets the Mauritanian chain north of Akjoujt.

b. Cap Verde Archipelago faults or fracture zones which appear to be related to the Cayar Seamount and the Dome of Leona (positive gravity anomaly south of St. Louis).

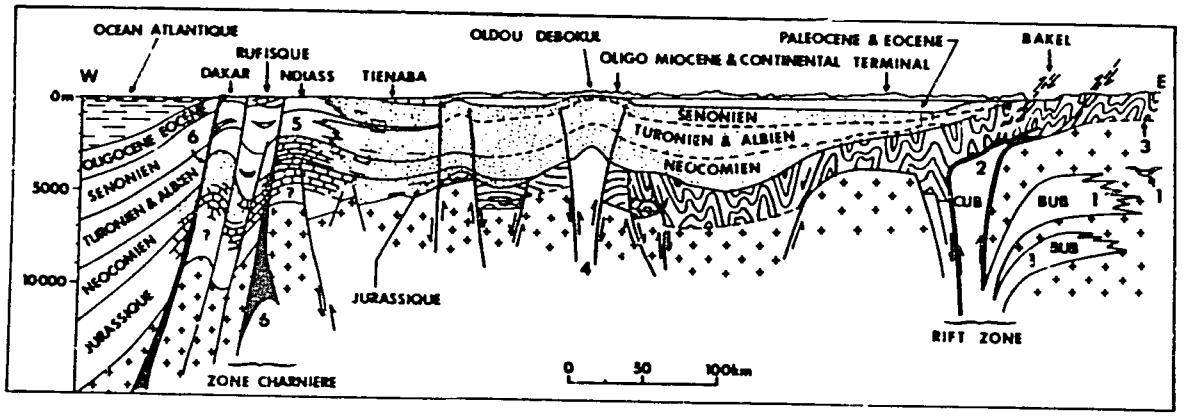
c. The Gambian fracture zone which strikes east for a considerable distance and is clearly noted on the available geophysical maps.

d. The Guinea fracture zone.

Magmatic activity from the late Paleozoic to the Recent has provided for the extrusion of dolerites throughout eastern Senegal, the emplacement of the syenite Dome of Leona and the more recent Eocene to Holocene intrusive and extrusive activity of the Cap Vert Peninsula. The first two magmatic events can probably be tied to movement along east-west transform faults, whereas the Cap Vert magmatism does not appear to be directly related to such faulting.

Viewing the stratigraphic record, we can clearly see a number of major tectonic events defined by unconformities, depositional lacunae and rapid sedimentologic changes. These changes have been recorded within the Cretaceous (in the Aptian, and Lower Senonian); between the Cretaceous and the Paleocene; between the Paleocene and the Eocene, and by a major tectonic event at the base of the Upper Eocene; finally, in a minor way in the Quaternary.

In conclusion, it should be noted that the tectonic history of the Senegalo-Mauritanian Basin is defined by the predominance of tensional events resulting in horsts and grabens, with some compressional events and a complex multiphase development. The project has attempted to summarize the available information on the Tectonic Map.



Legend		Légende
Clay		Argiles
Carbonates		Calcaires
Sandy carbonates		Calcaires gréseux
Dolomitic sands		Grès dolomitiques
Sands		Sables ou grès
Sand and clay (alternating facies)		Alternance de sables et d'argiles
Volcanic rocks		Roches volcaniques
Paleozoic metamorphic rocks		Roches métamorphiques du Paléozoique
Late Precambrian and Cambrian Ophiolites	CUB	Roches ophiolitiques de l'Infracambrien et du Cambrien
Birrimian ophiolites	BUB	Roches ophiolitiques du Birrimien
Crystalline and metamorphic rocks		Roches cristallines et métamorphiques

1. Fermeture du Rift Birrimien et charriage vers l'est (± 2.000 million)
2. Fermeture du Rift Infracambrien et Cambrien charriage vers l'est
3. Plissement Hercynien et Caledonien
4. Intrusion Cretacée d'Oldou Debokol
5. Compression Oligocène - Horst de Ndiass
6. Volcanisme du Tertiaire et Quaternaire

1. Closure and eastward overthrust of Birrimian (± 2.000 million)
2. Closure and eastward overthrust of late Precambrian and Cambrian
3. Hercynian folding and Caledonian folding
4. Cretaceous intrusion of Oldou Debokol
5. Oligocene compression - Horst de Ndiass
6. Tertiary and Quaternary volcanism

Figure 3.1

Coupe schématique du Sénégal(Dakar – Bakel) d'après A. de Spengler et al 1966(partim)

Modifié d'après interprétation Landsat et Tectoniques: Project Télédétection 1985

Schematic cross section of Senegal(Dakar – Bakel) from A. de Spengler et al 1966(in partim)

Modified on a basis of Landsat and Tectonic interpretation: Mapping and Remote Sensing Project 1985

B. Magmatism of the Senegalo-Mauritanian Basin

The evidence from outcrops in the Dakar-Thiès region of magmatic activity represents only the visible but a very minor part of a large magmatic province that includes the Cayar Seamount and the Dome of Léona. This activity begins in the Cretaceous and ends in volcanic paroxisms less than a million years ago in the region of Cap Vert.

The first evidence of post-Triassic magmatic activity known in Senegal is from drill holes 40 km south of St. Louis near the town of Leona, where a microsyenite was reached at a depth of 463 m. This body, capped by Maestrichtian sands, appears as a +90 milligal anomaly on the gravity map of Senegal. The intrusive body is flanked by gently dipping Senonian rocks, which are unconformably overlain by Maestrichtian sands.

More recent Tertiary volcanism has been found as far east as 16°30'W longitude northeast of Khombole and as far north as Taïba. West of this area and as far south as the Cap de Naz, lavas and tuffs have been found disseminated throughout the region as small outcrops or in wells. Offshore seismic work and sampling (Domain, 1977) also indicate basaltic rocks which are attributed to this period of magmatic activity. Although this activity has been dated from its origin at about 35 M.A. to about 5.3 M.A. before the present, or from the end of the Eocene to about the Pliocene, most of the activity is thought to have occurred in the Miocene.

Onshore Quaternary volcanism is confined to the Cap Vert Peninsula. This activity is demonstrated by the volcanic complex of the Mamelles, just north of Dakar. These rocks represent a complex volcanic cone and consist of tuffs, flows and breccias interstratified with sediments.

The general concensus is that the magmatism and volcanism of the Senegalo-Mauritanian Basin is of an intermediate variety or transitional between continental and oceanic. The magmatism began in mid to late Cretaceous and reached its appogee during the Miocene. The most recent events occurred as little as one million years ago.

C. Geologic History of the Senegalo-Mauritanian Basin

1. Pre-Mesozoic History of the Basin

The pre-Mesozoic history of the basin is little known because of a limited amount of deep drilling in this area. It is supposed that the Paleozoic Bové Basin, which existed in Guinea and in which were accumulated thick sequences of Silurian and Devonian rocks, continued northward into Senegal. The Senegalese extension of this Paleozoic basin must have collapsed along the major tectonic lines that strike along the Gambia River and underwent orogenesis during both the Taconic and Hercynian orogenies. Drill hole data supports these suppositions,

particularly in Casamance where Devonian sandstones are separated from Mesozoic sequences by an angular unconformity.

2. Origin of the Basin

Very little is known about the origin of the basin. It can be assumed, however, that movement along transform faults during the opening of the Atlantic Ocean provided for the collapse. Depression occurred both in a north-south and in an east-west direction in a series of graben-like structures, which produced differential marine sedimentation by the incipient Atlantic transgression.

Based on the distribution of Triassic to Jurassic evaporite facies, it is thought that two primary troughs exist and are separated by a topographic high parallel to and between the present Gambia and Senegal rivers.

3. Development of the Continental Margin

From the Lower Jurassic (Liassic) to the mid-Cretaceous (Aptian), the continental margin continued to collapse, but a hinge line developed east of which continental, detrital sedimentation occurred and west of which marine sedimentation was predominant. This hinge line provided a beneficial environment for reef building and may be the locus for hydrocarbon accumulation.

4. Cretaceous to Mid-Eocene Events

Toward the end of the Aptian, a renewal of widespread continental detrital deposition took place, suggesting an elevation and denudation of the eastern highlands. This is attributed by the authors of the Plan minéral (1985) to the first compressive phase of the Alpine Orogeny. This detrital-period deposition was followed by alternating marine transgressions and regressions representing the uppermost Aptian and Cenomanian.

Toward the end of the Cretaceous, especially during the Maestrichtian, detrital sedimentation again prevailed in the basin and suggests a renewed elevation of the shield areas to the east, possibly due to isostatic (tensional) readjustment. During this period, the Horst de Ndiass also began its development along a series of subparallel north-south faults. Just before the Maestrichtian, the Dome of Léona was emplaced. The end of the Cretaceous is marked by the definite, though partial, emergence of the Horst de Ndiass.

During the Paleocene, the newly emerged or raised portions of the continental shelf led to the establishment of new reef facies along the continental margin. Notwithstanding this localized emergence, a major transgression deposited marine sediments as far as eastern Senegal and beyond into Mauritania. This transgressive stage is represented mainly by biochemical deposition, which continued into the mid-Eocene and was

responsible for the phosphatic deposits of Taïba, Lam-Lam and Matam.

5. The Pyrenese Phase (Middle to Upper Eocene)

Toward the end of the Middle Eocene, the entire Senegalo-Mauritanian Basin underwent fracturing, probably by compression, and a general regression of the seas of that time. The Gulf of Casamance is an exception and was fractured in the Upper Eocene. Faulting was general and multidirectional; however, most faults are normal and show little displacement.

6. From the Upper Eocene to the Quaternary

Although marine transgressions are recorded in the Upper Eocene, the Oligocene and the Miocene, they are limited in duration, extent and thickness. During this time the area progressively took on its present form, and from the Upper Eocene onward a continental environment pervaded the basin. No major marine trangressions occurred after the Miocene transgressive phase. During this progressively continental influence, Miocene marine sediments were profoundly altered by diagenesis and surface and subsurface fresh water movement. This alteration could have occurred during a lower ocean level in late Miocene time or, due to a general isostatic adjustment, at this time. The resulting altered and ill-defined sedimentary sequence, which covers most of the Senegalese Basin, is referred to as the "Continental Terminal". The iron-rich laterites of the latest Pliocene imply a humid, tropical climate.

During the Quaternary, glacial (eustatic) effects provide evidence of changes in sea level along the coast and were responsible for deposition of various terraces and erosion surfaces throughout Senegal.

Changing (drier) climates also provided for the denudation and transportation of large masses of sediments by northeast winds. The resultant eolian features cover much of northcentral and northwestern Senegal.

Magmatic and resultant volcanic activity began again in mid-Tertiary time and continued through the Quaternary. This activity began at the end of the Pyrenean mountain building cycle or phase and is largely confined to the Dakar-Thiès region. The magmatic and volcanic activity took place near the edge of the continental shelf in a zone of crustal thinning and along nearly north-south fractures parallel to the shelf edge. This activity appears to be contained within a broad east-west zone that is limited by transform faults and extends to and includes the Cape Verde Islands.

The history of the Senegalo-Mauritanian Basin and its development is related to the opening and closing of the Atlantic Ocean and the occasional movement of the African plate in collision with South America and Europe.

3.9.4 Landsat Interpretation

3.9.4.1 Introduction (see Map 3.3)

Section 3.4 describes the methodology used to conduct the Landsat interpretation. Two additional points should be mentioned before we proceed to the description of the units on the Geohydrology maps. The first point is that a large amount of interpretable data does not appear on these maps because the scale used (1:500,000) limits the amount of information that can be shown. For instance, a number of thrust faults visible on the Landsat imagery in the region south of Bakel were not mapped. Some of them have been interpreted from Landsat imagery by A. Le Page (1978, 1980, 1982). Secondly, our interpretative effort attempted to break new ground in geology and hydrology. To do this, we purposely avoided references to previous work in conducting our initial interpreations. This arrangement effectively permitted us to view the geology of Senegal with an untarnished eye, and the results of this unbiased view later provided us with unqualified verification of our interpretation. On the other hand, it also forced us to review and revise our interpretation when field data or previous work contradicted the interpretation. Some examples of this approach are notable and will be discussed further. The most positive proof of the effectiveness of our interpretation came much after its completion, when the project was able to acquire the gravimetric and magnetic anomaly maps of Senegal. These maps clearly show a striking positive gravity and magnetic anomaly south of St. Louis at Leona. The anomaly is due to a late Jurassic, early Cretaceous igneous intrusive body of syenitic rocks. Although there is no visible surface expression of this feature and no existing geologic maps suggest its existence, Landsat analysis delineated its position and extent. The Landsat imagery shows some subtle variations in vegetation. These differences define a series of faults or fractures which circumscribe this intrusive body and provide evidence of recent movement along the faults; or, they may imply the possibility of continued igneous activity.

Finally, we would like to make the following caveat. Those who use these maps should be fully aware of their interpretative nature and be reminded that today's apparent truth may be found wanting upon closer investigation.

3.9.4.2 Descriptive Approach

The approach used to describe the geohydrologic map and the results of our interpretation will follow the same method used in the sections 3.9 through 3.9.3.2. Each mapped unit will be defined by its name and its legend designation. Wherever differences occur and we diverge from the published data, an explanation will be provided. A short explanation will be given wherever possible in an attempt to explain how we arrived at the unit limits.

A. The Birrimian Shield Rocks

1. The Mako Series (βB on map and legend)

a. Description of the Unit

This series of rocks appears in relatively bold relief and in darker tones than surrounding rocks. It is marked on the Landsat imagery by the breadth and length of outcrops whose tones appear much darker than those of surrounding rocks. The persistently greater width and length of the units probably best define this series on Landsat imagery.

Based on our interpretation, two main bands of this rock unit have been defined (Figs. 3.2 and 3.3). These bands generally trend NE/SW but are slightly convex eastward. The more westernly band is generally more persistent and broader, and it splits into a series of discontinuous, but generally parallel units near the Falémé River from where it continues into Mali.

Fig. 3.2. Landscape of Sénégal Oriental north of Missira. The foreground is composed of rocks of the Dialé Series. The hills in the background probably represent erosion resistant rocks of the Mako Series.

Fig. 3.3. Landsat image of Senegal Oriental. The scale is 1:1 000 000; the date of acquisition is 27/12/77. The spectral band is channel 7. Mako is at the bottom center of the photograph (M). The Falémé River is in the top right corner. The linear feature between the triangles at left is the Mont Bassari metamorphic series. The arcuate sequence between the arrows, represented by the darkest tones, is the surface expression of the ophiolotic Birrimian Mako Series. The area at the upper right between the open arrows represents a typical sequence of the Dialé Series rocks of Birrimian age.

Although this unit is well defined on the map, it is not in reality as homogeneous as it appears. In fact, both satellite imagery and aerial phototographs suggest that in many areas the ultrabasic and ophiolitic rocks of the Mako Series are intercalated with thinner bedded, lighter-toned rocks of a different petrographic and stratigraphic nature. The boundaries of the Mako Series are defined at the limit of the more massive, thicker sequences of erosion resistant basalts and ultrabasic rocks.

b. Structure and Interformational Relationships

The Mako Series appears to have steep to subvertical dips. Plotting of visible outcrops fails to provide definite evidence of closures that are suggestive of folds. Aerial photography analysis in the Mako-Kanoum area suggests that such folding exists but proof awaits more thorough photoanalysis and field work.

The major structural trend of the Mako Series is N30° to N65°E, although in the area north and west of Laminea on the Falémé River the strike turns northward and varies from N5° to N25°E.

The general trend of this series appears conformable to that of the contiguous rocks of other Birrimian series; however, this series is often separated from other series by faults, fractures and linears. Faults, fractures and linears tend to follow the course of the outcrops and are thus curvilinear, and they often display features common to mylonitized or crushed zones, such as those found southwest of Tourokhoto on the Falémé. These relatively linear, interformational crush zones are suggestive of thrust fronts, and it is proposed (though not shown on the map) that the contact between the volcano sedimentary sequence (Bvs) described as the Dialé Series and the Mako Series (βB) is almost everywhere a thrust contact. This conclusion is also implied by the numerous flysch deposits found in association with both these series.

Linear features in the Mako Series which represent fractures and faults vary a great deal in direction, distribution and intensity. The most prevalent direction of fracturing appears to be from N45° to N75°E; a second commonly found direction is N30° to N75°W; a third, and least common direction, found particularly south of Mako, is N15°W to N15°E.

c. Anomalous Features Interpreted from Landsat

Two elongate and one circular body of Mako Series rocks have been interpreted and mapped in an area south of Touré Kounda at 13°30'N and 12°15W. These bodies are mapped as Birrimian Mako Series rocks, although in two cases they occur at least at some distance from other rocks of their age. They are so identified because the trends in these rocks are not parallel to the strike of the late-Precambrian and early-Cambrian rocks that enclose them. They also appear to have coarser texture, darker tone and a more massive (less foliate) appearance. No field work was conducted in this area, and no aerial photographs were available; therefore, verification awaits further work.

d. Conclusion

The Mako Series appears to be a thick-bedded sequence of ultrabasic and ophiolitic rocks that is associated with flysch deposits whose structural relationship with other rocks to the northwest and southeast suggests an imbricate thrust-faulted sequence or sequences. The arcuate shape of the bands of rocks and their convexity southeastward implies compression from the northwest with a focal point of pressure somewhere between Bransan and Mako.

2. The Dialé and Daléma Series of Rocks (Bvs, Bs, Bv and AB on map and legend) (Figs. 3.4, 3.5, 3.6 and 3.7)

a. Description of the Units

No distinguishing features were noted during the Landsat interpretation which would have permitted differentiation between these two series. J.P. Bassot differentiates them mostly on the basis of their relative positions and their separation by the so-called granite of Saraya. Although some structural variations exist, no tonal or textural differences were seen on Landsat imagery. Therefore, these rocks are mapped as one unit (Bvs) unless otherwise noted.

The two series of rocks show a thin-bedded aspect and generally form the lowlands between the harder granitized rocks and the thicker-bedded Mako Series. In many places contacts are visible and, where they can be plotted, show evidence of closures. These units are generally a lighter tone than the Mako Series but are darker and less homogeneous than the granitized rocks of the Saraya "granite".

These rock units also outcrop east of the Falémé River, south of Kidira and north of Laminea. Their appearance in the last area is variable and suggests a complex depositional and tectonic environment. On the basis of tonal variations, texture and structural differences, we have mapped three distinct units in this area: a sedimentary unit (Bs); a less homogeneous unit, which we assume is predominantly volcanic (Bv); and a more uniform and darker unit (AB), which appears to be more highly metamorphosed than the more easterly age-related rocks. In using the available 1:200,000 and 1:500,000 maps as guides, we found little or no correlation between what is visible on the Landsat imagery and the units as previously mapped. In order to maintain some continuity with available maps, we have retained the existing nomenclature. In addition, we have found little evidence for mapping large granitic bodies as indicated on the geologic maps. Rather, we have found that sedimentary- or volcanic-bedded features are more in evidence throughout this region than the proposed granites. We do not deny the existence of granitization phenomena, but we have failed to find any definitive evidence of the existence of large batholithic granite bodies. Rather, we have found clear evidence of parallel and sinuous contacts, which suggest a general low grade metamorphism imposed on a volcano-sedimentary sequence. We have mapped

Fig. 3.4. Banded shaley and siliceous limestone/marble, Ibel, Senegal Oriental. The white veins are calcite, the gray bands crystalline limestones, the dark bands shaley layers with siliceous nodules. The dark massive blocky material is brecciated silica. This rock was fluidized during metamorphism. After folding in kink bands, segregation and recrystallization the rock was further folded and brecciated. Finally calcite was deposited as vein filling.

Fig. 3.5 Tightly folded calcareous rocks of the Dialé Series near Bandafassi showing shale, chert and calcareous beds.

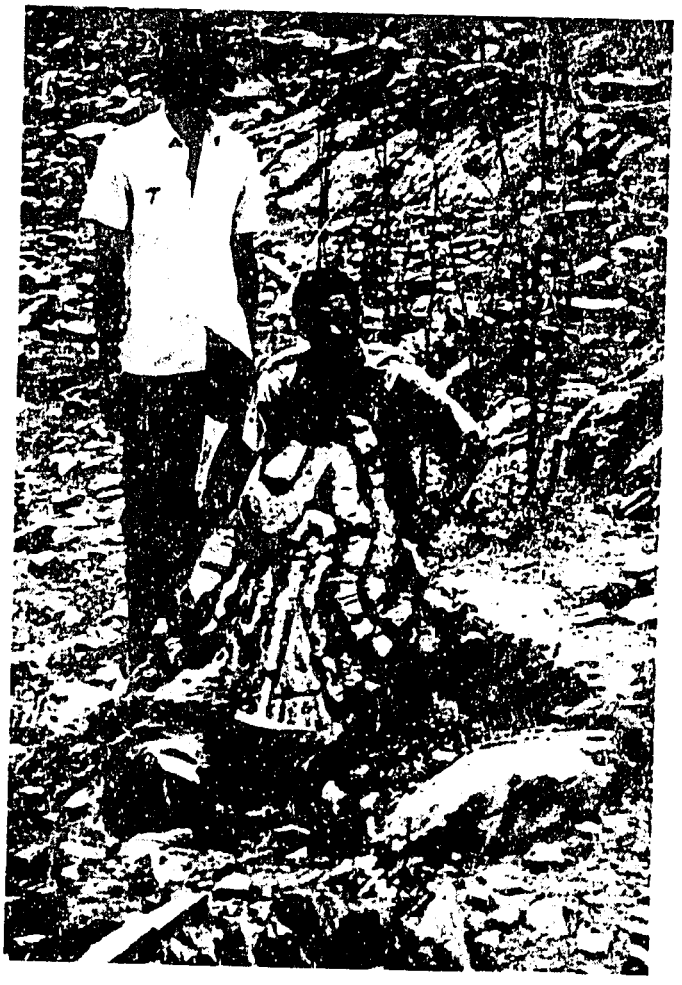


Fig. 3.6. Erosional remnant of tightly folded, thin-bedded calcareous cherty shale and limestone 1 km east of Ibel. These rocks belong to the Dialé Series and occur very near the boudinaged limestone of the Ibel marble quarry. The tight folding (microfolding) exhibited here implies that this sequence was a fluid medium which could have acted as a lubricant for thrusting of more compact rock units.

Fig. 3.7. Kink-folded schistose rocks 4 km east of Kassanto. These rocks probably belong to the Dialé Series and have otherwise undergone light metamorphism and have been isoclinally folded.

as Birrimian sedimentary rocks those areas that clearly show numerous linear or sinuous topographic features which provide evidence of differential erosion of steeply dipping strata. Darker areas with a more mottled appearance and with less evidence of stratification we have mapped as Birrimian volcanics. We have designated as Birrimian amphibolites those rocks having darker tones and fewer visible surface features that indicate bedding. We have chosen this designation (AB) only on the basis of previous work (Bassot et. al., 1963: Dalafi, Bakel, and Kossanto 1:200,000 map sheets).

We have also chosen to differentiate the Birrimian iron-rich rocks from their coeval equivalents simply because the iron-rich rocks tend to be easily mapped due to their tonal characteristics. These units are denoted by the symbol Fe. We had originally hoped that by plotting their size, position and shape, we might gain some insight into the relationships between the Boboti style of granitization and the enclosing Daléma Series. Unfortunately, no definitive conclusions can be made regarding these relationships. The only possible significant

observation made is that tonal characteristics suggesting the existence of iron and its erosional products at or near the surface are not restricted to Birrimian volcano-sedimentary sequences as mapped and that these iron ore deposits occur in the Boboti granitized series. It has not been possible to establish if the relationship between iron deposits and granitized series is conformable, which might imply a similar age and origin for the two, or whether different ages are more probable. Based on previous work (Plan minéral, 1985), the relationship between iron ore and granitized materials (or andesites and granodiorites) is everywhere discordant, whereas some iron ore deposits are overlain unconformably, and occasionally nearly conformably, by limestones and marbles. This relationship would suggest that the iron ores are older than the carbonate units and younger than the Boboti granitic rocks.

b. Structure and Interformational Relationships

Numerous folds have been mapped in the Dialé and Daléma series based on the plotting of contacts and closures. These structures trend NE/SW but have also been mapped as NW/SE trends at 12°50'N and 11°40'W in an area 20 to 25 km east of Saraya. Evidence of folding is particularly clear east of the Falémé River (east of Sansandé and Tomboura).

The most prevalent direction of fractures, faults and linears in this Birrimian volcano-sedimentary sequence is N40° to N60°E. Other directions include: N30° to N60°E, N30° to N60°W, N80° to N105°E and N0° to N20°E. At least two strike-slip faults have been mapped between Kanoumering and Kédougou, with differential movement indicated along NE/SW and NW/SE faults.

The broadest band of Birrimian volcano-sedimentary, Dialé and Daléma series of rocks extends northeastward from Ségou in the south to Sainsoutou on the Falémé River. This trend is contiguous to and parallels the tholeiitic rocks of the Mako Series and has a strike of N45°E. The two other smaller belts of Birrimian volcano-sedimentary rocks, those of Diakha Madina to the south and Tomboura-Falémé, to the north, trend nearly north-south.

The relationships between these units appear to be complex. Differences in the direction of trends (as seen on Landsat) and rock types (as described by previous authors) suggests that the volcano-sedimentary series of the Dialé-Daléma series and similar rocks on the east bank of the Falémé River have undergone different tectonic histories. We believe that during the Birrimian orogenic episode (Eburnean orogeny), the Dialé volcano-sedimentary sequence was compressed and thrust eastward over the so-called Saraya granite. These orogenic events also produced the emplacement of the Mako Series, which we believe to be an allochtonous, though nearly synchronous, sequence. To the east of the Saraya granite the age equivalent Daléma Series was simply compressed, and if transported, it was displaced in a

conformable fashion and by a telescoping mechanism. The main body of the volcano-sedimentary sequence on the east bank of the Faleme appears to lie just north of the main compressive zone of the Birrimian tectonic thrust, and though some transport and thrusting is probable, especially in the southern portion of this sequence (north of Kondoko), Landsat analysis suggests that these highly folded and faulted rocks are autochtonous.

3. The Baoulé- and Boboti-Type Granites ("Big" on map and legend)

The contacts between these granites and the surrounding Birrimian rocks are poorly reflected on the Landsat imagery. The Saraya granitized mass is much more homogeneous in tonal aspect than the Kakadian or Boboti types. In fact the Kakadian Massif, as it is called, is so heterogeneous that mapping it as a unit must be considered as a concession to previous mapping efforts. On the basis of tone and texture, our interpretation suggests that these rocks represent metamorphosed and sometimes recrystallized equivalents of the Mako Series and that careful mapping of this area will show a volcano-sedimentary origin for some of these rocks and an overwhelming concentration of ophiolitic rocks characteristic of plate junctures or rift suture zones. The Kakadian area shows some linear parallel features suggestive of interformational contacts. It does not show extensive jointing that might indicate quasi-total recrystallization, which would imply the granitization proposed by other authors. Such jointing and fracturing occurs only 15 to 25 km north-northeast of Mako, where it seems to be associated with post-Birrimian intrusive activity.

a. Description of the Unit

The Saraya granite (Fig. 3.8) has a very homogeneous aspect on Landsat imagery; it is light colored and, at first glance, has distinct boundaries. However, more careful analysis of multi-seasonal and multi-year imagery indicates less clear relationships, especially in the area from Bembou to just east of Missira. Careful analysis of this tonally distinct body has provided evidence suggesting relic sedimentary structures in the region from Saraya to Koudokhou and 3 to 5 km north of Fodikounda. Aerial photograph analysis supports this interpretation. Three domes have been defined in the Saraya granite which in two cases appear to have internal or concentric structures; they are, however, interpreted as resulting from more recent tectonic events rather than those responsible for the emplacement of the Saraya body (see photointerpretation in Appendix A, Table III-7).

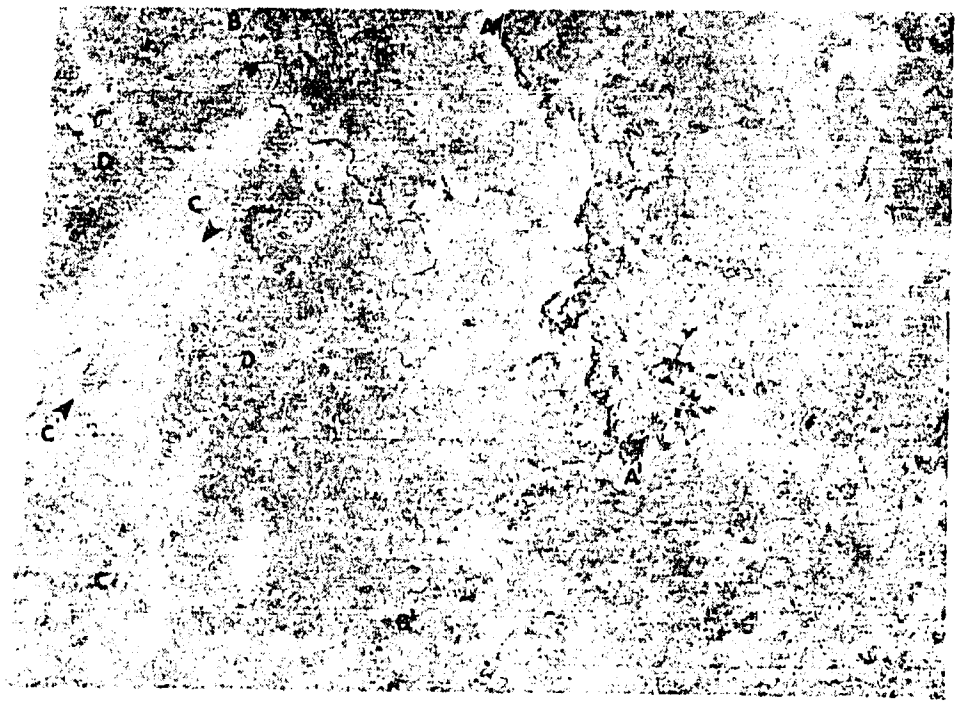


Fig. 3.8. Landsat image of eastern Senegal. The scale is 1: 1 000 000; the date of this view is 07/03/73. The spectral channel is 7 (infrared). The Tambaoura escarpment is visible between A and A^1. The Falémé River can be traced from B to B^1. The Saraya granite is clearly distinguishable in the left of the picture as a lighter toned entity (C). The Dialé and Daléma Series (D) surround the granite. The internal pregranitic structure of the Saraya granite is visible between the arrow heads.

The Boboti granites, or granodiorites as they are sometimes called (Witschard, 1965), are very difficult to define and map as distinct from the surrounding volcano-sedimentary rocks of Birrimian age. They are generally conformable to the sedimentary rocks and appear to be magmatized versions of the surrounding Birrimian rocks. Aerial photograph analysis of these series from Nagadji to Satadougou Bafé does not give clear evidence of an intrusive relationship (see photointerpretation in Appendix A, Table III-7).

b. Structure and Interformational Relationships

Fractures in the Kakadian Massif consist of linear trends which strike in the following directions: N45° to N50°W, N10 to N20°W, N75° to N85°W, and N45° to N55°E. Few of these fractures continue into the Mako Series and so suggests an earlier tectonic phase of activity for the Kakadian granites.

The predominant direction of fracturing, faulting and linears in the Saraya granitic terrain is N45° to N60°E; a lesser but still important direction is N40° to N65°W. In addition, short north to south and east to west fractures have been mapped, particularly on the eastern side of the granitic body where it is in contact with Birrimian volcano to sedimentary rocks and where these fractures cross the boundary between the two units. Very few structures cross the western limit of the granitized rocks and they tend to be NW/SE trends. These observations tend to indicate a more conformable contact between the granitic rocks and the Dialé Series in the west and possibly provide evidence of a thrust contact along at least a portion of this boundary. The eastern contact is much more irregular and many fractures and linears cross the boundary between these two groups of rocks.

The Boboti granitized sequence also tends to provide examples of numerous fractures and linear trends which continue into the adjacent Dalema Series. These trends are N45° to N60°E, N70° to N100°E, and N45° to N60°W.

The project proposes a different origin than that suggested by J.P. Bassot (1966) for these varied granitized terrains. We postulate that the Kakadian intermediate to basic crystalline rocks are synchronous in origin with Birrimian rocks and represent a plate edge or rift edge depositional environment. These rocks have undergone compressional stresses from the northwest and mylonitization during overthrusting by the ophiolitic (rift) sequence that comprises the Mako Series. The Mako Series of rocks is thought to originate in the area of the large linear positive gravity anomaly, which occurs to the west and strikes N30° to N45°E. Such a hypothesis would account for the lack of petrographic and structural homogeneity of the Mako Series and the Kakadian sequence of rocks.

In the field, the Saraya granites were found to have xenoliths of hornblend-rich rocks and gneisses, and they show relic structures, including folds, bedding contacts and differences in grain size, that imply graded bedding in a nearshore environment. The combination of these factors suggests a metasedimentary origin for the Saraya granites. Although these rocks give an age indicative of Eburnean tectonism, it is thought to be due to recrystallization. It is postulated that these granitized and relatively homogeneous rocks represent recrystallized pre-Birrimian rocks of possible Archean age and of a nearshore basinal environment. These rocks could be the equivalent to Precambrian D-1 age rocks of the Dorsal (Shield) of Reguibat.

Finally, we propose a similar tectonic development for the Boboti granitic terrain. Its depositional area, however, was probably situated farther offshore and thus the intermediate nature of the rocks (andesites, etc.) can be accounted for by a mixed volcano-sedimentary environment in a zone more tectonically active. These hypotheses are highly speculative, but may provide a plausible explanation for the occurrences of such divergent rock types in such close proximity.

4. Bondoukou Granites (GPB on map and legend)

a. Description of the Unit

These granites are circular to ovoid and relatively easily identified on Landsat imagery and aerial photographs due to their geometric configuration and lack of internal features. They are grouped in the region of Mako and intrude Birrimian rocks; thus, they are considered post tectonic (post Eburnean). It is probable that more but smaller intrusions and apophyses of this type will be mapped as detailed field work proceeds in Senegal.

b. Structure and Interformational Relationships

No structural features distinguish the Bondoukou granites from the surrounding rocks. A few fractures have been noted which pass through these granites into the enclosing rocks and so must be post Birrimian. Few NE/SW fractures have been noted in these granites. Most fractures trend from N30° to N60°W.

B. Birrimian Rocks: Summary and Conclusions

Combining Landsat interpretation, aerial photograph analysis and field work with existing data has permitted us to postulate the following sequence of events for the Birrimian of eastern Senegal.

1. A broad basinal depression and rift alaucogen forms between the Dorsal de Man and the Dorsal de Reguibat, striking southwest from Kayes to Sansandé (±2600 M.Y.).

2. A narrow, rapidly deepening rift forms nearly perpendicular to the alaucogen (above) and occupies the location of the present positive gravity anomaly, which parallels the present Mauritanian chain of folded mountains.

3. Post-rift isostatic rebound of the pre-existing Archean terrain to the east--postulated to have existed at Saraya and eastward--provides nearshore and deeper sediments to the basinal rift.

4. Ophiolitic sequences are deposited in the rift and volcano-sedimentary intermediate rocks are deposited in the region of the Kakadian Massif while nearshore sediments are deposited in the Dialé and Daléma troughs.

5. Closure of the rifts begins, and the ophiolitic series are uplifted, folded and overthrust eastward toward the Saraya metasedimentary nucleus. Deposition of flysch occurs at the base of the thrust sheets and is partially interstratified with continuing nearshore sedimentation in the Dialé basin.

6. Compression continues and creates isoclinally folded sequences and allochtonous overthrust sheets, possibly in the form of nappe structures. These sheets drive the thin Archean crust (at Saraya) downward, producing a recrystallization of the Saraya granitic rocks and the younger coeval Kakadian granitized sequence (2100 M.Y.).

7. Compressive Eburnean forces cease and erosion begins. Tensional response provides for the emplacement of batholithic-complex, Bondoukou type granites (900-2000 M.Y.).

C. Late Precambrian and Paleozoic Rocks of Eastern Senegal

1. Introduction

In view of the continued lack of agreement regarding the late Precambrian and Cambrian succession, we have decided for the purpose of simplicity to group these rocks under the Cambrian. Some of these units have radiogenic ages that indicate definite Precambrian age; nevertheless, because ages and exact relationships are so poorly known we feel that valid differentiation should await further field evidence.

2. The Segou Madina Kouta Series (C^1 on map and legend)

a. Description of the Unit

This rock series is relatively easy to map on Landsat because it forms the high terrain of the Guinea-Senegal boundary. Because of its relatively flat-lying nature and unconformable relationship to the underlying Birrimian rocks, it is relatively easy to distinguish from older rocks. Its relationship to the overlying dolerite flows is also clearly distinguishable since the latter are more homogeneous and darker in tone.

b. Structure and Interformational Relationships

No folding is evident in this series. Fracturing and faulting are restricted to two main directions, a N20° to N40°E group and a north-south to N10°E group.

It is interesting to note that this series is not found in outliers to the north, which implies that if this unit had greater aerial extent it has been completely removed by erosion. This explanation appears unlikely. More probable is that its present extent represents perhaps the near totality of the depositional environment of this unit in Senegal. If the latter is true, then it can be assumed that the area of Birrimian rocks to the north represented a mountainous region which supplied coarse erosional products (Bassot, 1966) to a limited basin forming to the south and east during a Ségou-Madina Kouta period of deposition.

This series is composed of a lower volcano-sedimentary sequence followed by a sulfide-rich horizon associated with stromatolites and overlain by more typical basinal sedimentary deposits. In western Africa this series strikes parallel to the Taoudeni Basin or Gourma aulacogen. Thus, it is postulated that the deposition of this series was due to the reactivation of the breakup of the West Africa shield during an early phase of the development of the Atlantic. Subsequent closure of the proto-Atlantic provided a tectonic impulse attributable to the Kibaran orogeny. This activity caused very little orogenic disturbance in the Ségou-Madina Kouta Series in Senegal, where this series is essentially flat lying. Volcanic activity was probably induced along NE/SW faults parallel to the Toaudeni Basin and Gourma aulacogen. This activity was probably caused by reactivation of deep-seated fractures and provided the metal-rich materials found at the base of Medina Kouta Series. On the other hand, it is possible that the source of the metals is the Birrimian ophiolitic sequence, which eroded, dissolved and was redeposited in a nearshore environment, where these metals were enriched by biogenic activity or by intermittent flooding and dehydration in a sebkha-type environment. Notwithstanding their origin, these metal-rich sediments are of interest because of their lateral extent and lack of deformation.

A small area east of Takoutala on the east bank of the Faleme River is attributed to the Ségou-Madina Kouta Series (Bassot, 1966). Although this unit is visible on Landsat, we have mapped it as (Ci), Cambrian undifferentiated material.

3. The Mali Series

The Mali Series was not differentiated and so not mapped from the Landsat imagery.

4. The Falémé Series (C2, C3 and Ci on map and legend)

a. General

Although these three units are thought to be of the same age, they are found to differ on the basis of lithologic and structural relationships, as seen on Landsat. Unit C2, the base unit, appears to be thinner bedded, more tightly folded and more frequently faulted than

the material represented by the other units in this series. On this basis, and because they are petrographically distinct (Bassot, 1966), these three units have been mapped as separate entities.

b. Description of Unit C2 (Fig. 3.9)

This unit, which is contemporaneous with and similar to the Mali Series mapped in the south, occurs in a north-south band 225 km long that ranges from the Guinea border to just south of Kidira. It varies from 10 to 20 km in width and tends to be narrowest near Kayan and west of Mako.

On Landsat imagery this unit is almost always distinguishable from the Birrimian rocks to the east, on which it lies unconformably. Its contrast with younger rocks to the west is indefinite except where faulted. Especially in the northern and central portion, it internally consists of thin-bedded, sedimentary sequences with clearly visible bedding-plain contacts, which often form closures.

c. Structures and Interformational Relationships

This unit strikes almost due north and probably consists of a series of isoclinally (where compression was strongest) to open folded units. In view of its relationship to younger, but less elevated rocks to the west, it is assumed that this band of rocks forms an anticlinorium.

Between Kidira and Sitabanta, the main fracture and fault direction is NE/SW. This system continues southward, but a more prevalent direction of N80° to N100°E becomes evident between Sitabanta and Touré Kounda. South of Touré Kounda, a NW/SE system is added to the NE/SW direction. Finally, a north-south system is notable, particularly at what is thought to be a fault contact between the Falémé Series and younger rocks to the west. In view of the last observation, it is possible that at least some portion of the contact between the upper and lower Falémé units C2 and C3 is fault controlled and possibly thrust faulted, for example, west of Sitabanta and east of Tiankaye.

d. Description of Unit C3

This unit occupies the largest area covered by Paleozoic rocks in Senegal Oriental and occupies two quasi-parallel belts from Kidira in the north to the Guinean border in the south. In the north, a few outliers can be found nearly as far north as Yafera on the Senegal River. These rocks are also thought to occur in a small area east of the Falémé River. This interpretation may, however, be erroneous; this area may represent rocks of the earlier C2 Falémé Series. At the surface, unit C3 is basically composed of reddish sandstones which are much less folded and disturbed than those of the C2 unit to the east.

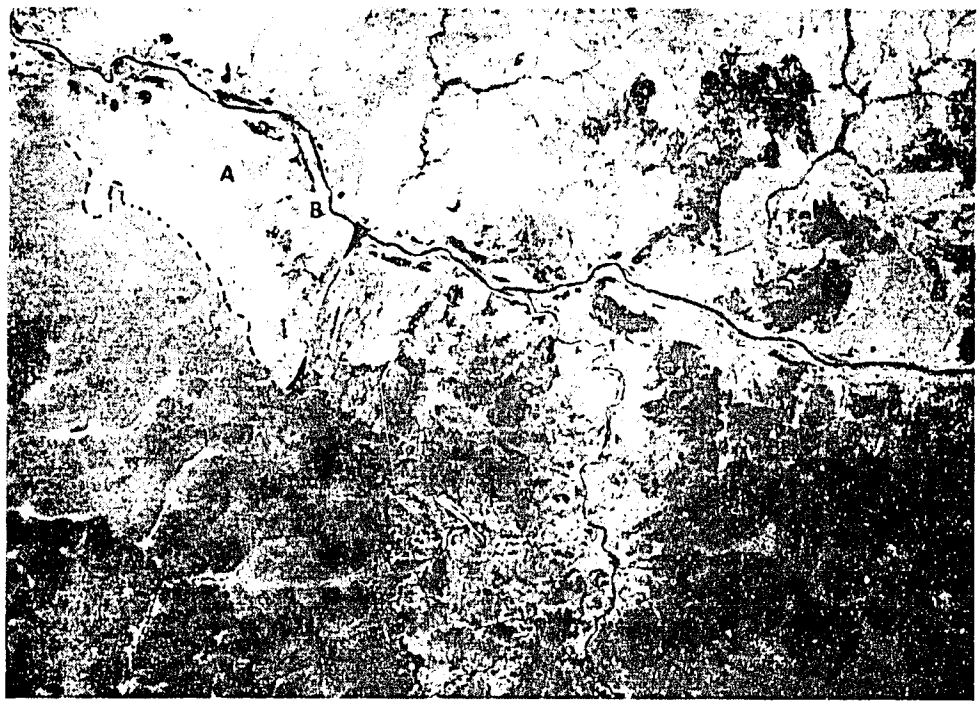


Fig. 3.9. Landsat image of Senegal Oriental. The scale is 1:1 000 000; the date of acquisition is 21/11/77. The spectral band is channel 5, representing the visible part of the spectrum. The Senegal River flows from east to west (right to left) in this picture. The Falémé River flows north; Bakel is at point B. The dashed line separates the westward dipping sediments of the Senegalese Basin from the underlying, tightly folded Paleozoic and Precambrian rocks. The light spots along the drainage system at the left are barren areas around villages; the darker tones represent grasses and other vegetation. The lightest toned area (A) repesents quartizites and schists of the Bakel Series. The area to the southeast (F) represents red sandstones and other rocks of the Falémé Series. The dark tone between the pointers is probably the contact along a thrust fault.

In the area between Sambakola and Touré Kounda, stratification is evident on the Landsat imagery and suggests that this northern area underwent more profound tectonism than in the south, where contacts and marker beds are not as visible. However, this may not be the case, since major tectonic activity has been shown to have had a profound effect in the south where at least two major thrust and reverse faults are know to have affected this formation, and where metamorphism has reached a relatively high level in the Bassari mountain range. Perhaps this paradox can be explained by assuming that the C3 sediments in the

north were thinner and therefore more readily folded than those in the south, which appear to represent thick, basinal successions and presently occupy broad synclinorial belts which would be less susceptible to tight folding.

e. Structure and Interformational Relationships

It was noted above that the C3 unit is composed of a thick sequence of red sandstones and occupies two broad basinal depressions. These depressions are assumed to have become broad synclinoria when tectonic activity from the northwest compressed them. The most prevalent strike direction visible on Landsat is N10° to N30°E in the eastern synclinal belt. To the west of Salemata and Niokolo Koba strikes vary from N40° to N60°E. Relationships between this unit and units to the east and west are not clear. The wedge mapped as C3 to the west and south of Niokolo Koba is clearly limited on the east by what is probably a thrust fault but could be a low-angle reverse fault. To the west there is clear evidence of faulting. Faults extend approximately 100 km in a NE/SW direction; this fault is assumed to be and was mapped as a thrust. However, this fault's very straight aspect may indicate a reverse fault. Fractures trend N30° to N60°E, N30° to N60°W, N to N20°W and NS.

f. Description of Unit Ci

Unit Ci (Cambrian undifferentiated) is mapped separately from the other C units because it appears to have undergone some metamorphism and appears to occur in at least two anticlinal belts which merge west of Boutougou Fara. In spite of heavy lateritic cover, these rocks are visibly steeply folded and show closures and numerous outcrops indicative of parallel bedding. According to J.P. Bassot (1966), this unit differs from the Falemian rocks to the east in that it contains a thicker sequence of volcanic rocks, which tend to be more basic and include spillites and diabases. These rocks are probably equivalent in age to the C2 rocks to the east, but represent the offshore plate boundary depositional equivalents. A small occurrence of these rocks is found at Oussoumkala, southwest of Mako.

g. Structure and Interformational Relationship

If these rocks (Ci) are correctly interpreted by J.P. Bassot (1966) as being older than the red sandstones (C3), then clearly they occur in uplifted belts and are probably equivalent in age to the C2 rocks (as noted above) which rest unconformably on the Birrimian rocks to the east.

Fractures are variable and strike parallel to the regional trends, especially at the boundaries between units, but also follow the main directions imposed on units C3 and C2 namely, N30° to N60°E, N30° to N60°W, N to N20°W and NS. In the westernmost area of Ci, the most prevalent trend is N30° to N50°W. These features are particularly

visible northeast and southwest of Simenti.

The relationship between units in this area remains a moot point. Landsat analysis of this complex area did not yield enough information to unravel the complexities inherent in these sequences of rocks. Solutions will have to await additional field work and/or the higher resolution and wider spectral range of the Thematic Mapper or SPOT satellites.

5. The Bassari Series (Cim on map and legend) (Fig. 3.3)

a. Description of the Unit

This series trends just east of north and occupies a belt 35 km long and from 5 to 15 km wide. It has a mottled but homogeneous appearance on Landsat imagery, which differentiates it from the smoother (less broken) units to the east and west. The main geometric aspect that differentiates the Bassari rocks from their neighbors are the numerous parallel, but non-linear, topographic expressions suggestive of folded and indurated (metamorphosed) rock units. The northern limit of this unit is unclear, and the series may plunge beneath what are probably younger units.

b. Structures and Interformational Relationships

The Bassari range appears to form a large arch-like mass. Its western boundary is definitely unconformable and is thought to be defined by a continuous fault, along which unit C3 rocks have been thrust upon the Bassari rocks. Other shorter fractures or faults provide the limit between the Bassari range and unit Ci to the east.

Fractures and faults within this unit are perhaps more limited in length than in the contiguous rocks to the east and are highly variable. They include a N15° to N30°E system, a N45° to N60°E system and a N30° to N45°W system.

The Bassari Series appears to be a metamorphosed equivalent of the Falémé Series or perhaps a slightly older mylonitized, crushed and arched version of the Ségou-Madina Kouta Series.

South and east of Gouta, an elliptically shaped body (Cim) of relatively homogeneous rocks appears as a separate entity. Its boundaries are indefinite on the Landsat imagery: this unit measures 35 km from north to south and 20 km at its widest. The unit is characterized on Landsat imagery by the distinct nature of its outcrop and the length and width of its mappable units. J.P. Bassot (1966) has described some rocks from this area as being quartzitic, of uncertain age, but of probable Paleozoic age and metamorphically overprinted. This description may be correct, but does not establish this unit's relationship to others.

The main structural trend of this unit is northeast-southwest. Fractures and/or stratigraphic boundaries show up distinctly and strike about N50°E. Other fracture systems are N20°E and N45° to N55°W.

This unit is bounded on the east, north, south and southwest by undifferentiated Cambrian rocks and appears to have the same relationship to these rocks as does the Bassari Series to the south and may represent a more terrigenous facies of this same series, one that has undergone a lesser degree of metamorphism. This unit and the Bassari Series may be the equivalent of the Bakel Series to the north.

6. The Younkounkoun Series (Ci and C3 on map and legend)

According to J.P. Bassot (1966), this series is of volcanic-sedimentary origin and is discordantly related to both the Bassari Series to the east and the Koulountou Series to the west. As noted earlier under the description of units Ci and C3, we believe unit C3 to be the younger of the two units in view of its synclinal position and suggest an early Falemian age (equivalent to C2). We also propose that Ci, Caiv and Cvt are coeval.

7. The Koulountou Series (Caiv, Cvt and Cig on map and legend)

a. Description of the Units

Landsat analysis has permitted us to define, on the basis of their complex structural and stratigraphic relationships, these three units as distinct from the rocks to the east and west. The imagery clearly shows tightly folded, non-rectilinear, but parallel outcrops and contacts within unit Caiv. The main trend of the unit is N60°E, but strikes of outcrops within the unit vary north-south to N80°E. Unit Cvt is a much more homogeneous unit with indistinct internal lithologic boundaries or contacts, and may represent a thrust wedge of allochtonous rocks. The 1:200,000 series of geologic maps of Senegal (Younkounkoun sheet) shows this unit as composed of tuffs and agglomerates.

Between Mahsa Dala and the Gambia River southeast of Simenti, two elongate bodies of granitized rocks have been mapped (Cig). Their boundaries appear to be tectonically induced and are probably fault controlled, particularly on their northwest limits.

Although only two areas within this group of units are shown to be laterized, these units are, in fact, capped by laterites in an almost continuous fashion. Nevertheless, this cap must be relatively thin and differential erosion has permitted the mapping of unit boundaries and structural relationships in spite of the ubiquitous cover of lateritic cap rock.

b. Structures and Interformational Relationships

Fractures and faults are numerous in these units. The most prevalent direction noted on Landsat is N40° to N50°W; a second important direction is N60° to N70°E. A number of folds have been mapped on the basis of contact closures, particularly in the area between the Koulountou and Gambia rivers. This broad belt of lightly metamorphosed volcano-sedimentary rocks and their granitized equivalents appear to have been emplaced in a basin that responded to tensional stress. Subsequent compression of these heterogeneous, submarine volcanic and sedimentary sequences produced the highly irregular appearance visible on Landsat imagery.

The relationship between units Caiv and Ci appears to be relatively simple. We believe, based on structural analysis, that Caiv is older than Ci and occurs in the core of two large anticlinorial fold systems. The relationship between these two units appears to be conformable. This interpretation does not exclude the possibility that they are contemporaneous or nearly coeval. Thus, these rocks (Caiv, Cvt) and their granitized equivalents (Cig) are older than C3 and probably the same age or slightly older than C2; units Caiv and Cvt are the probable equivalents of C2m, which represents the Bakel Series.

We believe that this rather inaccessible area covered by acid volcanic rocks and sedimentary rocks is the key to establishing correct stratigraphic relationships and determining the relative ages of the so-called Infracambrian and Cambrian of eastern Senegal. Landsat analysis has shown that contacts, boundaries and outcrops can be mapped. These contacts might even be located on the ground, in spite of the lateritic overburden and could help to establish a better lithostratigraphic understanding of this region. This lithologic environment also offers potential for a wide variety of mineral deposits.

Recent work (Plan minéral, 1985) has also shown that early Paleozoic rocks have been located at very shallow depths in the Anambé Basin (Fig. 3.10). It is postulated that a NW/SE horst brings the Cambrian/Precambrian sequence to within a few meters of the surface in the Anambé region. Landsat analysis suggests that this phenomenon may be repeated in a number of locations from Goumbayel on the Niéri Ko to Kounkane and beyond (see Tectonic Map and section 3.9.5).

8. The Bakel Series (C2m and βC on map and legend) (Fig. 3.9)

a. Description of the Units

This series of rocks is perhaps the most interpretable of the units visible on Landsat. It is composed essentially of metamorphosed rocks, including erosion-resistant quartzites which make up the hills from Bakel to Kidira and which represent a series of folds between whose limbs are found less resistant schists, shales and phyllites.

Fig. 3.10. Landsat image of the Haute Casamance, including the Koulountou River (K) and the Anambé Basin (BA). The scale of the image is 1: 1 000 000; the date of acquisition is 10/02/75. The spectral channel 5 accentuates soil wetness. Since all of the drainage diverges from the Anambé Basin, the so-called basin is probably a dome rather than a basin, though in its central portion sediments are eroded and so give the appearance of a basin. The wetness of the central part of the Anambé depression is due to the fact that impervious crystalline rocks of Paleozoic and Precambrian age outcrop in the center and restrict drainage. A NE/SW trending lineament is clearly visible between the arrows and continues northeast to Médina Gounas (MG) and beyond. The line drawn between the triangles will separate sediments of Eocene and younger age from Paleozoic rocks to the southeast. This demarcation is quite clearly visible on the basis of changes in the drainage pattern.

Covering smaller areas, are outcrops of tillites, jaspers, and serpentinized ultrabasic rocks. On the basis of the erosional remnants found at the surface, most of these units can be traced on Landsat imagery. These units, however, take on a much more irregular form than the typical Cambrian sequences to the south and clearly have undergone compression, shearing, mylonitization and lateral transport from west to east.

b. Structure Features and Interformational Relationships

Until one reaches the latitude of the Senegal-Falémé confluence, the strike of the Bakel Series is similar to that of the rocks of the Falémé and Younkounkoun series to the south. From Yaféra northward, the strike is variable and other changes abruptly. A. Le Page (1981, 1982) has mapped a series of parallel thrust faults on the basis of Landsat imagery. Most of them were interpreted and mapped by the author before the existence of A. Le Page's work was known. Many of the thrusts strike northeast-southwest, but one supposed thrust that has been mapped southwest of Moudiéri strikes southeast and then turns southwest at a point 5 to 7 km west of Bakel. Along the edge of the more southerly thrusts, thin slices of serpentinized Cyprus-like ophiolitic ultrabasic sequences (Petkovic, 1971) have been located. Gabbros and dolerites were seen by our team south of Marsa and a thick tillite horizon (Fig. 3.11) was found at Marsa. Numerous parallel and

Fig. 3.11. Tillite horizon in a small stream east of Marsa, Senegal Oriental. This tillite belongs to the Falémé Series (coeval to the Bakel Series) and is composed of a schistose matrix with occasional erratic boulders and pebbles of various origins, including granite.

subparallel folds have been identified in this region and appear to represent a thin sequence of basal Cambrian sedimentary material. These folds were dislocated by westward compression and transported in small sheets to their present location. The ultrabasic serpentinized sequence of dunites, harzburgites and gabbros probably represent wedges of the ultrabasic rocks which produce the positive gravity anomally (see Tectonic map) to the west of Bakel and Kidira (The 10+ milligal contour passes through Bakel and east of Kidira).

The relationship between C3, or the upper Falemian red arkosic sandstone, and the Bakel Series (C2m) is relatively clear. The C3 series clearly overlies the Bakel Series as shown west of the Faleme River and south of Yafera. The relationship of the lower Falemian rocks and the Bakel Series is not as clear and it appears that they may be the same age but represent different depositional environments and lithologic facies. More important, it seems likely that the Kidira-Bakel area has undergone much greater metamorphism than the region to the south. It is probable that these two units are separated by a major, deep-seated, fracture zone that lies parallel to the Tambacounda-Kidira road and is located some 10 to 15 km to the south of the road. This fracture system would be associated with the formation of the Proterozoic Gourma aulacogen. It is thought that to the north of this fracture or fracture zone, the Bakel Series has been vertically displaced, uplifted and eroded to nearly the level of the Precambrian basement.

9. The Dolerites of Senegal Oriental (Dol on map and legend) (Figs. 3.12 and 3.13)

Although these rocks are not Paleozoic but probably Jurassic, we have included their desciption here because of their intimate relationship to Paleozoic, Precambrian and Birrimian rocks of Seneagal Oriental as well as their lack of occurrence as outcrops in the Sedimentary Basin to the west.

a. Description of the Unit.

These rocks occur as irregularly shaped erosional remnants in the southernmost portion of Senegal Oriental. Most of the mappable units show up clearly as dark masses or table lands with clear cliff-like features surrounding them. These dolerites are thought to have covered much of Senegal Oriental at one time and are still to be found as large sill-like bodies to the south in Guinea and east in Mali. Some dykes have also been noted, such as a 10 km long body trending about N40°E that was found about 7 km southeast of Oubadji. This dyke has been displaced along a N130°W fault, and the northern block appears to have moved from 300 to 700 m.

Fig. 3.12 Dolerite boulders on a scree slope 2 km west of Bandafassi on the road to Ibel. These rocks are of probable Mesozoic age. The roundness of the boulders is due to exfoliation. The rocks' dark tones provide dark spectral responses on Landsat imagery.

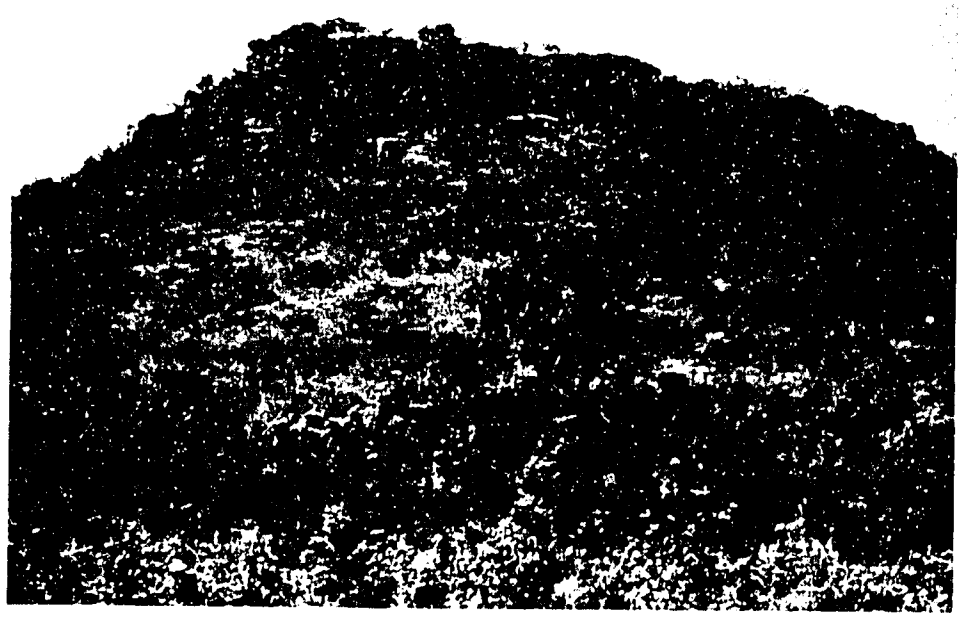


Fig. 3.13. Dolerite capping and talus covering Birrimian Dialé Series, west of Bandafassi in Senegal Oriental.

J.P. Bassot (1966) has proposed that these late Jurassic effusive rocks were emplaced along deep fractures and faults affecting the Birrimian basement. It is probable that they are the result of tensional stress caused by the break up of Gondwanaland which began at the end of the Jurassic.

b. Structures and Stratigraphic Relationships

Three sets of fractures which affect the dolerites are clearly visible on Landsat imagery: a N15° to N30°E trend, a north-south trend, a N60°E trend and a N10° to N20°W trend.

These sills usually blanketed pre-existing, eroded basement rock units in sheet-like masses. The dolerites are extensive throughout West Africa and occur especially in Mali, east of the Faleme River and southward in Guinea. They appear to have been eroded along a NW/SE direction which parallels the Senegal-Falémé drainage. This suggests an arching effect in a NW/SE direction and a possible set of fractures parallel to the Senegal-Falémé rivers' drainage system which provided for more rapid headward erosion and removal of the dolerites from the highest portion of the proposed arch.

D. Conclusions Concerning the Landsat Analysis of the Precambrian and Paleozoic Rocks of Eastern Senegal

Thirteen years of Landsat analysis have shown that lithologic boundaries are difficult to determine except in extremely arid terrains. Some recent work using Thematic Mapper data suggests that additional information can be drawn from the higher wavelength and higher resolution data available from that system (personal communication, USGS, 1985). The differentiation of rock units and the location of boundaries are more difficult than usual in Senegal Oriental due to the heavy cover of lateritic material, which masks many contacts. Nevertheless, Landsat analysis was relatively successful in this area because the available maps provided some guidelines. Additional analysis of the available aerial photographs would have been invaluable; however, the time to conduct such an extensive analysis was not available.

The results of our interpretation clearly show that Landsat has provided information indicating that Senegal Oriental is a much more complex structural domain than previously known. Our analysis shows many previously unknown structures. This analysis, combined with other available data, such as gravimetric data, permits us to deduce much concerning the tectonic history and the mineral potential of this region.

E. The Sedimentary Basin of Senegal

1. Introduction

A superficial glance at the Landsat imagery of the sedimentary basin of Senegal (see Map 3.3) suggests a homogeneous terrain with few topographic features and little or no evidence of tectonic activity. However, the closer the analysis, the more evidence one finds to indicate a complex tectonic terrain, masked by recent sediments, dunes and lateritic hardcap. Many of the features we were able to define on Landsat imagery are very subtle and have no apparent equivalents in the field. We spent many hours in the Groundnut Basin attempting to verify certain features noted on the Landsat imagery, and, more often than not, we failed. The level of confidence in our interpretation was at one point very low but two successes, one clearly demonstrated and the other (although not completely proven was logical), reaffirmed our belief in the interpretation.

The first case concerns the identification of some east-west and N70° to N90°W fractures noted in our interpretation, approximately 40 km south of St. Louis. These features, which occur in a grassy dune terrain, are subtle and appear only as differences in vegetation response to a possible variation in subsurface water supply. The features are not linear over great distances and are not visible on the ground or on aerial photographs. Their strike, or trend, is neither shown on previous maps, nor discussed in the literature, and clearly their features are not representative of tectonic trends considered prevalent in western Senegal. Since no available data suggested their validity, the existence of these trends was disturbing. The identification of these trends was made in October 1983. In March 1985 we saw for the first time a gravimetric map of Senegal which clearly shows a positive gravity anomaly of a size and shape indicating a definite relationship between the features mapped on Landsat and the underlying anomalous mass. In April 1985, a reference was noted in the Plan minéral (1985) to a nepheline syenite intrusive body, called the Léona Dome, which has been located by deep drilling (at 463 m below the surface) by oil companies. The location of this body and its anomalous gravimetric characteristic are defined at the surface by the fractures we have mapped on Landsat imagery, thereby illustrating the viability of such interpretation.

The second example involves the mapping on the basis of Landsat of a large number of channels that cross the Senegalese Sedimentary Basin. Plotting these channels focused our attention on the possibility that Holocene drainage may have been very different from current drainage. The interpretation shows that a large number of streams flowed across the central Groundnut Basin toward Thiès and beyond. It suggests that many of the streams flowing south and southeast into the Saloum River have been reversed and that before the uplift of the Thiès escarpment and the formation of the Horst de Ndiass, a major river system probably drained this area and emptied into the ocean near Kayar. This

hypothesis appeared to gain merit when it was discovered that there exists a large deep canyon off Kayar which could not have formed any other way than by fluvial erosion on an exposed continental shelf.

These two examples provided some evidence that our interpretative methodology was valid. Further support came when we found a high level of agreement between our work and that of Y. Bellion and R. Guiraud (1979) in which they conducted fracture analysis of the Diourbel Landsat scene. M. Sall (1979) studied the Anambé Basin, and based on Landsat analysis, postulated an eroded dome in that area. Work by J.Y. Trenous and P. Michel (1971) in the Dôme de Guiers area also shows agreement with our interpretation.

Finally, the work of C. Monciardini (1966) who plotted well data in order to establish the locations and depths of various aquifers in the Senegalese Sedimentary Basin, was useful in providing evidence of fractures and faults. His work shows steep slopes in certain aquifers, as evidenced by the close spacing of the contours that mark the contact between formations. This close spacing suggests probable faults. In many cases, the fractures we had plotted on the basis of Landsat interpretation, parallel and often occur on or very near the probable faults shown by the work of C. Monciardini.

2. Approach Used in Mapping Lithological Units

Within the Senegalese Sedimentary Basin, only a few units are clearly definable and mappable on Landsat. This limitation is due to three factors--the extensive superficial deposits of wind blown materials, the lack of topographic variation of the region and the homogeneous nature of the marine and non-marine sequences found in the area.

Wherever it was possible to distinguish lithologic features, we have mapped them as distinct units and followed the lithologic and stratigraphic descriptive usage presented in previous published work. Where boundaries are indistinct, we have shown them as such and have used the limits as shown on pre-existing documents.

3. Description of the Units

a. Cretaceous Maestrichtian rocks (Cr on map and legend)

i. Description of the Unit

These rocks or sediments are clearly visible on Landsat imagery in a broad north-south band (15 to 20 km wide at Ndiass) which tapers northward, where it dips beneath the sediments of Lake Tanma. The weathered appearance of this greenish-yellow unit is due to the high iron content of its sands. Heavy laterization of the formation also makes it distinguishable from adjacent units. These rocks occur in an arched horst structure.

ii. Structure and Interformational Relationships

This unit is highly faulted internally and its contact with adjacent units is fault controlled. The most prevalent direction of faulting is north-south; however, N45° to N70°E faults and fractures are common. In addition, a few N60° to N80°W faults and fractures have been noted. To the east, the contact of Maestrichtian and Paleocene rocks is probably fault controlled, although in some areas it may be conformable. To the west, the Maestrichtian is found juxtaposed to Lower Eocene rocks of Ypresian age which have been downfaulted and occur as the east limb of an Eocene syncline.

b. Tertiary-Paleocene (e^{iv} on map and legend)

i. Description of the Unit

This unit is generally uniform in appearance on Landsat and tends to be heavily tree covered by small acacia, a characteristic which distinguishes it from its neighbors. The Paleocene contact with Maestrichtian rocks is generally clear, but relationships to eastward units are not as clear. This uncertainty is in part due to the fact that the Paleocene forms much of the high ground west of Thies, and its erosional products thus mask the downslope contact with younger rocks. Paleocene rocks also produce different soils, which provide for vegetation common to the Paleocene rather than that prevalent on the underlying younger rocks, and make accurate delineation of these rock units difficult.

ii. Structures of the Paleocene

Most of the major fractures is the Paleocene strike N40° to N50°E. In the area between Pout and Thies, a few short fractures have been defined and trend N75° to N90°E, with some minor fractures striking N50°W.

c. Tertiary-Eocene (e^{iii}, e^{ii}, e^{i}, ei on map and legend)

i. Introduction

A very large part of northwestern Senegal north of the Gambia River consists of Eocene rocks. Such rocks or sediments are often covered by more recent sand dunes, alluvial and lacustrine sediments, and laterites. Such superficial sediments make it almost impossible to distinguish one unit from another. Furthermore, Upper and Lower Eocene rocks are not characteristically different and so create further interpretative difficulties.

Because of these problems, we have chosen to use pre-existing boundaries for Eocene units, except where distinction is possible by

means of Landsat. In certain areas, the geologic relationships, as proposed by previous mappers or those represented by our first interpretation, appeared questionable, unlikely, or even incongrous. We, therefore, chose to designate these units (areas) as undifferentiated Eocene (ei). An example of this problem occurs in a highly block-faulted area from north of St. Louis to the Sine Saloum River.

It is very probable that TM, SPOT and SIR-B (Side Imaging Radar-B) data would have, had they been available, resolved many of these problems and permitted us to produce much more precise maps of the sedimentary units of the Senegalese Basin.

ii. Description of the Unit e^{iii}--Lower Eocene (Ypresian)

This unit, according to the geologic map of Senegal (1962), outcrops in a wide band from Nianing to Fimela on the Sine Saloum estuary and then recurs in a narrow strip at Foundiougne. This band is said to curve northwestward to Fissel, Thiès and Ndiassane south of Tivaouane. Our interpretation and field work does support these findings, except for an area between Nianing and Ngazobil along the coast and extending northward as far as Thiès where we believe block faulting may bring to the surface some Paleocene materials and exposes some younger Eocene rocks in graben structures. Because of the large number of parallel NE/SW faults in this area, and in view of rapid lateral changes of materials found during the field work, we have felt it necessary to designate part of this area as undifferentiated Eocene.

The Lower Eocene (unit e^{iii}) is clearly mappable in the region between Lake Tanma to north of Mboro. This lower Eocene unit also occurs at Lam-Lam and extends southward to Thiès. The predominance of greenish hues on Landsat imagery of this area implies a laterized terrain, which we have shown as such. Additional outcrops of unit e^{iii} occur west of the Horst de Ndiass in the east limb of the Bargny syncline.

The predominant fractures in the northern outcrop areas of the Ypresian rocks is N60°E, whereas southward in the Saloum estuary area, two other important directions were noted, and the N60°E direction becomes N70°E. The other two fracture directions are N30°E and N25°W. These fractures are seen as 20-to-40-km-long features which control the direction of flow of the Sine River and other tributaries of the Sine Saloum Delta area. Based on the pattern of occurrence of this formation, it is probable that the lowermost Eocene rocks are folded in a shallow structure, which forms a syncline trending from Palmarin to Fatick. At Fatick, this trend veers northwestward and is defined by a gravimetric law (see Tectonic map). In the Bargny syncline area, fracture directions are variable and profuse. Clearly visible on Landsat imagery and aerial photographs, they were noted during overflights. They act as strong drainage controls.

iii. Description of the Unit e^{ii}--Middle Eocene, Lower Lutetian

This unit occupies a very broad area of western Senegal from Sokone in the south, it passes through Kaolack and 15 km east of Kolobane, continues east of Linde through Lagbar and Yaré Lao and then sweeps southeastward east of Guirvas, Odealdou, Nandenam to just east of Madina Diaka, where it sweeps southwestward toward the border of Guinea Bissau (just east of Koumbakara). Of course, this formation is indistinguishable from any other Eocene or, for that matter, other rock or sediment types of the Sedimentary Basin because of heavy eolian, lacustrine, lateritic and alluvial cover.

One area where this unit is relatively easy to map is found along the Senegal River from Fadaria to Bodé in the north. Here the sedimentary sequence tends to have a distinct tonal aspect from the alluvial sediments to the east and the typically laterite covered rocks of the same age which are located to the west. Similarly, the Lower Eocene, Lutetian rocks can be mapped along a number of the tributaries of the Ferlo River. Although at these locations the Eocene is often masked by younger deposits, including large amounts of wind-blown sand and lateritic rubble and alluvium, distinct tonal characteristics permit delineation

iv. Description of the Unit e^{i}--Middle Eocene, Upper Lutetian

According to previous mappers, this unit occupies much of the central portion of the Senegal Basin. We have only been able to distinguish it from other units in western Senegal in a relatively narrow, 30-to-50-km-wide band which extends from just south of Tivaouane to 30 km northeast of Louga. It is best displayed on Landsat color composite imagery in the region west of the Tivaouane-Louga highway, where it is recognizable due to its slightly roseate hue.

v. Structures and Interformational Relationships

The Middle Eocene, Upper Ypresian series is exposed in the Senegal Basin in two large depressions. The first is a 30-to-50-km-wide, north-south striking synclinal feature, which extends from northeast of Louga to just north of Thiès. This feature, although shallow and much faulted, nevertheless exemplifies a plunging syncline. It is bounded on the west by the compound, anticlinally folded Horst de Ndiass, and it is limited on the east by the Lac de Guiers anticline or dome (Trenous and Michel, 1971). The fracture system of this Eocene series is complex, and, because of its pervasive nature, will be discussed globally with the remaining formations of the basin.

vi. Description of the Unit ei--Undifferentiated Eocene

A number of areas have been mapped as undifferentiated Eocene sediments or sedimentary rocks because the number of structures in these areas implies a more complex geology than that proposed by previous mappers and because superficial cover precludes the likelihood of correct stratigraphic assignment.

The first such area is located in the Bargny syncline, which is a fault bounded unit in which numerous faults and fractures have been noted. Although this area has been relatively well mapped, it is thought that block-faulting may well complicate this structure. Another area where incertitude did not permit definitive lithologic assignment is found in the sector of Tiénaba, Ndiaganiao, Tiadiaye and Ngazobil. This area has been mapped as Lower Eocene Ypresian (e^{iii}) by previous authors (Geologic Map of Senegal, 1962). Landsat imagery suggests that in this area the Paleocene (e^{iv}) may well outcrop in a number of narrow fault blocks (which strike N40°E and N65°E). West of Mekke, from 5 km north of Siné Kane, to as far north as Ndiougo on the Senegal River we have mapped a 10-to-35-km strip as ad^1/ei because the very heavy multidirectional white and yellow dune system (ad^1) does not permit mapping with any assurance. Another reason for this designation is that a significant number of southeast-to-east-striking fractures associated particularly--but not exclusively--with the Leona Dome, suggest that some block faulting may disturb the normal stratigraphic sequence along the coast. This is particularly true of the following areas: Siné Kane and Make Gayé; from Toundé Maléyé on the coast to Taïba Amaria Mberi; between Sag and Léona Ndiaye and in the probably block-faulted deltaic region of Makhana; Ndiougo and Ndiol northeast of St. Louis. In western Senegal, other areas which pose categorization/interpretation problems are those which appear to have been occupied by lakes and over which a thin venier of lacustrine deposits has been left. These areas, for example, in the region between Diourbel and Kolokane, are nearly impossible to place lithologically within the Eocene sequence. This difficulty is particularly experienced where lacustrine deposits are associated with fracture zones, as is the case in the vicinity of Ndande.

Another area mapped as "ei" is located in Senegal Oriental and extends from the Guinea-Bissau border northward along the Anambé River. It broadens where it crosses the Koulountou and the Gambia rivers; then it continues northward to within 6 km west of Diarra. This region is heavily laterized and supposedly covered by superficial terrigenous sediments of the "Continental Terminal". Many closely spaced, linear outcrop patterns suggest a nonhorizontal sequence in this area, and it is possible that these "outcrops" are pre-Tertiary. The discovery that the Anambé depression represents a domed Paleozoic/Precambrian area (Plan minéral, 1985) suggests that the latter may be the case; however, it is just as possible that these "outcrop" areas represent a slightly tilted sequence of early Eocene rocks which may have been tilted due to northwestern basinal development toward Tambacounda. It

is also possible that en echelon block faulting is responsible for the surface expression of Eocene outcrops seen on the imagery.

d. Tertiary-Oligo-Miocene (OM on map and legend)

Oligo-Miocene sediments occupy a broad basin which extends from 30 km north of the Gambia River mouth to some distance into Guinea-Bissau. This marine transgression phase is thought by previous authors (Geologic Map of Senegal, 1962) to extend nearly as far as the Anambé River, whereas other sources (see Plan minéral, 1985), suggest that the Oligo-Miocene transgression was far more extensive and covered much of east-central Senegal, including large parts of the Ferlo region north of Tambacounda. The Landsat imagery does not provide clear evidence of a homogeneous unit extending east beyond Ziguinchor. Typical iron-stained, nearshore, sandy facies of Oligo-Miocene age were seen at Cap Skirring (Fig. 3.14) and in well cuttings at Oussouye, Kabrousse and Essaout. East of Ziguinchor and Bignona, surficial sands and laterites mask any evidence of a marine sequence. Thus, we were again forced to apply designations to our map units by using boundaries from previous mapping. These boundaries are particularly misleading in the Casamance, where outcrops are few.

Fig. 3.14. This occurrence is located at the beach face ± 7 m at Cap Skirring. The basal gray homogeneous formation is composed of Miocene red cross-bedded, sometimes graded sandstones. The dark shadowy area is void. Above this occurs ± 1 m of laterites which it can be seen have slumped under their own weight. The light colored topmost layer is arenaceous tropical soil.

e. Tertiary "Continental Terminal" (Ct on map and legend) (Fig. 3.9)

Since the term "Continental Terminal" has been used as a catch-all classification, this title is no longer considered valid. We feel that a more appropriate term should be found and careful field work conducted to identify the various superficial sediments that have been grouped under this heading. As indicated earlier in this report, L'Appartient (1983) has shown that large areas mapped as "Continental Terminal" actually contain marine fossils and form part of the transgressive sequence of the Middle Miocene. Based on this work, it has been suggested by the Plan minéral (1985) that extensive areas of Senegal in the Ferlo and Senegal Oriental regions are in fact reworked or altered equivalents of the so-called Continental Terminal. Nevertheless, this formation has been mapped by the project as if it were in fact a continental erosional product (of nonmarine origin). It is everywhere nonhomogeneous, if only because it is nearly always at least partly laterized, or covered by surficial, eolian, lacustrine or alluvial sediments. In summarizing, we have defined (mapped) everything under "Ct" which we were unable to clearly map as a distinguishable unit in the entire eastern region of the Senegalese Sedimentary Basin.

f. Tertiary (and Quaternary) Lateritic Cap (cf on map and legend)

This lateritic material seldom appears extensively at the surface and is usually only clearly visible in cliffs along river valleys; nevertheless, because of its erosion-resistant nature, it often forms a piedmont-like, nearly horizontal surface (bowal) which in many areas is covered by little or no sediment. Wherever this is the case, the iron-rich erosion products, including colluvium, elluvium and alluvium, are clear indicators of its presence near the surface. As much as half the Sedimentary Basin of Senegal is underlain by laterite under less than 2 m of wind-blown sands or sediments of other origin. On Landsat imagery the areas where laterites occur near the surface, tend to have a deep brown, or reddish brown and sometimes brownish-black or greenish tonal response on Landsat imagery. These tones are hardly ever visible in river valleys, nearly always dominate the interfluvial heights and are clearly defined when they are exposed as darker cliffs; thus, these laterites are relatively easy to delineate on Landsat imagery.

In western Senegal, the laterites are intermittent but were only mapped where they clearly appear as the dominant surface rock type. Although much of the Horst de Ndiass has a laterite cap (as do some of the areas south as far as Nianing), it was felt that mapping the units of primary importance, in this context the Maestrichtian and Paleocene, would have greater value.

In some parts of the Casamance, block faulting has brought laterites close to or to the surface. Our interpretation indicates that little or no laterite occurs at the surface in the region of Sindian and Bignona (mapped as ct), while to the northeast laterites do

appear at the surface. This apparent anomally can be explained by the fact that the Bignona-Sindian area represents a down-faulted block, which accounts for the laterites being found at depth in the region. Conversely, the area to the northeast (mapped as cf) appears to be an upthrown block in which laterites are faulted to or near the surface. In eastern Senegal lateritic materials are pervasive, but because they are of lesser economic interest than the underlying rocks, they have not been mapped unless they reflect some structural or tectonic effect or if their presence may affect the economic potential of the region.

It is difficult enough to discriminate between flat-lying lithologic units; it becomes much more difficult when a unit occurs in a discontinuous manner at or near the surface. Though it is certain that many errors exist in the mapping of the lateritic cap, we have generally followed the pre-existing geotechnical map of Senegal (Carte Geotechnique de la Republique du Senegal, Service des Mines et de la Geologie, BRGM, 1963).

g. Other Tertiary Formations (ad^1 and aff on map and legend)

Large areas of Senegal are overlain by dunes. These linear dune systems are usually considered to be Quaternary, interglacial features and late Quaternary and recent results of the desertification of the Sahel-Sahara region. We suggest, however, that some of the major dune systems in the northern Ferlo may well date from earlier periods of uplift, erosion and eolian activity. Two such periods of uplift and erosion are documented (Michel, 1973), one at the end of the Oligocene and a more likely dry period at the beginning of the Pliocene. We propose that considerable uplift occurred in northeastern Senegal and adjoining regions of Mauritania and that a typical desert regime was prevalent during that time.

Uplift and emergence of the Senegalese Sedimentary Basin, at least in part, would have resulted in a continuous topographic divide somewhere east of the present Senegal River and would have included large parts of western Mali and southeastern Mauritania. This large drainage basin was probably traversed by numerous deep valleys, whose rivers crossed the Senegalo-Mauritanian Basin from east to west. The result was a major river system which drained the Guinean highlands, western Mali, and large parts of southern Mauritania, and its ultimate point of outflow could well have been at Kayar. The depth of the offshore canyon suggests a drainage system of large carrying capacity and some duration such as that described above. After uplift of the Horst de Ndiass, the valleys which carried the erosion products from east to west began to fill with alluvial, eolian and marine deposits. We propose that many of these valleys which are visible today on Landsat imagery are of Tertiary origin and probably contain as much as 50 m of post-Eocene terruginous and marine deposits.

F. Structural Geology of the Sedimentary Basin

The Sedimentary Basin of Senegal is replete with evidence of fractures and faulting. There are three levels of fractures visible and at least two main directions of fracturing.

The most apparent direction of fracturing is a N60°E trend; the second is nearly orthogonal to the above and traverses the basin from northwest to southeast. Although these fractures are discontinuous, they do appear to form major trends. For example, one discontinuous trend that begins just south of Bakel was intermittently mapped to Kabrousse. Another such trend is traceable from north of Bakel through Koupentoum and Kougheul to Dar Salam and Diana. A major northwest-southeast trend is nearly continuous from Dagana to Goudiri and a second from Dahra via Tiel to Koussanar, another parallels the Senegal River from east of Ndioum to Bakel and beyond.

In the westernmost portion of Senegal, fracture directions tend to change. This is prevalent especially in Basse Casamance, from Kaolack to Dakar and in the Lac de Guiers-Léona sector. In the Cap Vert-Petite Côte region, the fractures are numerous and trend N40° to N50°E as well as N30° to N60°W. In the Cayor, the trends become N60° to N85°W. The trends nearly all follow magnetic and gravity trends. Their relationships and relative movement are discussed in section 3.9.5. Because these fractures tend to correlate with the limits of gravity anomalies, we suggest that they represent complex horst and graben systems for most of the basin, as well as probable en echelon-faulted grabens, such as those centered on the mouth of the Senegal River, the Bignona-Koussanar-Bakel trend and the Ross Bethio-Linguère-Tambacounda trend. In some cases, it is believed that these trends are also the sites for upwarping and gentle folding, such as is the case for the Lac de Guiers auticline (Trenous and Michel, 1971) and the Koussanar syncline (see Tectonic map).

It is thought that a number of other broad folds occur throughout the basin and are due to compressional forces and intrusive activity related to the opening and closing of the Atlantic Ocean. These possibilities are discussed in section 3.9.5.

G. Description of the Quaternary Units of the Senegal Basin

1. Introduction

Early Quaternary and late Tertiary units are difficult to differentiate on Landsat imagery and thus it is even more difficult to accurately attribute ages to these formations. Hence, many deposits which we have mapped as Quaternary may well be, at least in part, Tertiary in origin.

2. Volcanic Rocks (β on map and legend)

a. Description of the Unit

Effusive and intrusive rocks of basic composition are clearly visible on and mappable from Landsat imagery. They occur in the Cap Vert Peninsula and at least at one location southeast of Thies at Diak. At the latter location, a very strong greenish tone, indicating iron rich laterites, surrounds a darker tone comparable to that found in the Dakar-Yoff area. To the northeast, two areas, one north and one south of the town of Keur Samba Kane are heavily discolored by laterization. Because this surficial evidence is so similar to the Diak occurrence, we mapped both these tonally characteristic areas as alteration haloes over basic intrusive bodies. Partial confirmation of this interpretation comes from the Plan minéral (1985), which indicates two sill-like accumulations of basic tuffaceous rocks at the villages Bare Diam and Beaufi. Field work attempted to correlate apparent tonal anomalies to actual outcrops of Tertiary-Quaternary basic volcanic rocks which might be found to occur as intrusives in the Sedimentary Basin. This effort was unsuccessful, except at Diak, because most outcrops were of insignificant size and therefore not visible, or because no outcrops exist (or were not found) and finally because laterites produce spectral signatures similar to those of the basic volcanics in this region.

b. Structures and Interformational Relationships

Structural relationships of the intrusive and extrusive rocks of western Senegal indicate a variety of types of activity, which include subaerial and subaqueous lava flows, scoraceous, tuffaceous and cineritic accumulations as well as sills, dykes and pipes of various sizes and compositions. None of these differences are directly evident on Landsat imagery. What is evident on the imagery is that the activity is related to N40° to N50°E faulting. This relationship is true of the Diak and Keur Samba Kane occurrences and can also be deduced when plotting the known occurrences of Tertiary volcanic rocks (Plan minéral, 1985) on the Landsat linear/fracture map. This map shows that all the occurrences of magmatic or volcanic rocks occur on structural trends of N40° to N50°E.

At the Mamelles (Fig. 3.15), a fault was noted during landing at Dakar airport and confirmed on the ground. This fault was interpreted as a thrust fault as indicated on the map. The Plan minéral (1985) suggests that it is a crater collapse fault. We saw no evidence to support this suggestion and believe that a thrust fault can be traced inland and east southeast for some distance across the peninsula.

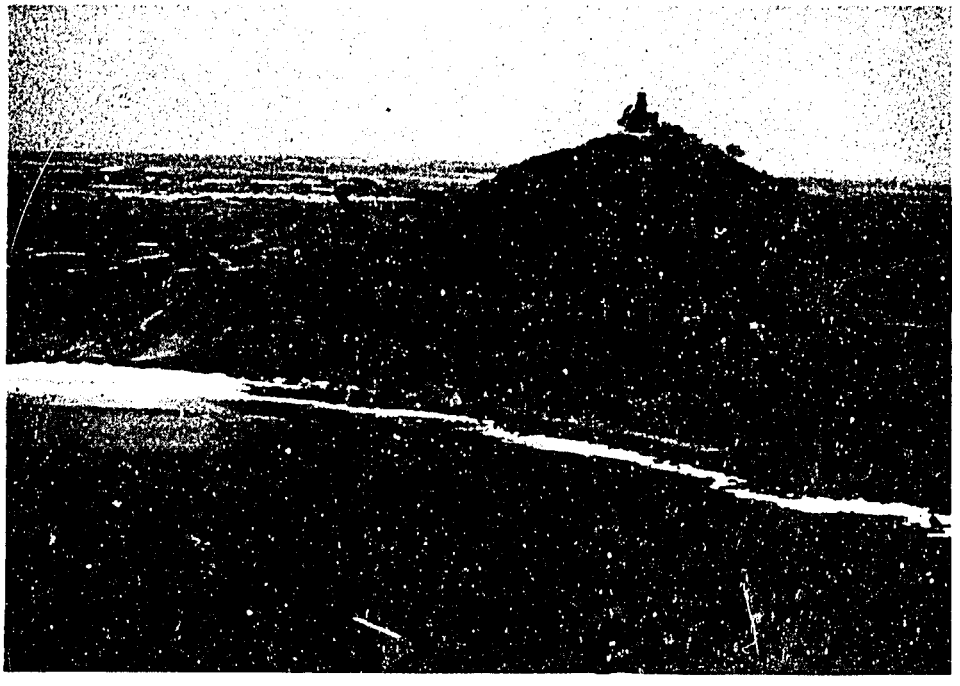


Fig. 3.15. A low angle thrust fault in Quaternary volcanics below the lighthouse of the Mamelle. The fault is the dark arcuate line which begins at the point indicated by the arrow.

3. Lake Deposits (a, ae^1 and aei on map and legend)

Lacustrine deposits have been noted in many parts of Senegal by previous authors (see Geologic Map of Senegal, 1962). We have also noted what we believe to be lacustrine deposits on the Landsat imagery. The most obvious deposits occur in the Ferlo east of Linguere to the edge of the Tertiary plateau and the valley of the Senegal River. These lakebeds are intermittent (seasonal) and continue to act as catchment basins much as they have for most of Quaternary time. Most of them are circular or subcircular and occupy depressions in the lateritic crust. Their extent is quite large, up to 150 km^2, but they average 15 to 25 km^2. T. Monod (1965) misinterpreted these features as being possible meteor impact craters.

a. Description of the Units

Large areas of apparent lacustrine origin have been noted in western and west-central Senegal. These areas show up in extremely light colored tones on the Landsat imagery and contrast with the darker tones of the vegetated river channels usually associated with them. Significant areas of lacustrine deposits have been mapped in the Linguere-Dara-Sagata area, between Mekhe and Kébémer, in the Diourbel-Kolobane area and east of Baba Garage. We believe that the lake deposits in the Diourbel area are related to the damming of the east-west drainage system which entered the Atlantic Ocean at Kayar and was blocked by the elevation of the Horst de Ndiass. This east-west system probably emptied at various points along the coast from Kayar to Loumpol after the Kayar Canyon effluence was no longer possible and before the collapse of the Gambia-Casamance trough.

It is believed that similar, but later, uplift affected the course of the Ferlo River. It is postulated that the Ferlo flowed in a direct line from Linguere into the Atlantic at St. Louis. Landsat imagery suggests a complex drainage history for the area from Pal to St. Louis where small, meandering channels and wet areas have been mapped. If we accept this postulate, then we can understand how the elevation of the Lac de Guiers anticline would easily have affected, (possibly on more than one occasion) drainage development in this area. Thus, we would propose that the lake deposits west of Linguère may be due to intermittent damming of the Ferlo River mouth near St. Louis that dates from perhaps as long ago as the late Jurassic to as recently (and more probably) the Middle Quaternary.

b. Structural Relationships

Few structures (fractures or linears) interrupt the lacustrine deposits, except north and south of Ndande, where a number of fractures can be seen in the area mapped as lake deposits and may well have controlled the site of lacustrine deposition.

4. Fossil River Channels (aff on map and legend) (Fig. 3.16)

We know (Michel, 1973) that during the Wurm glacial period (30,000 B.P.) a major marine regression occurred during which time the Senegal and Gambia rivers incised their channels to bedrock. P. Michel (1973) states that the Senegal River cut its channel to 28 m below the present surface at Richard Toll and the Gambia River 38 m at its mouth. It was probably during this period that headward erosion by the Senegal River captured the numerous streams of the Ferlo and Mauritania rivers, first via the Bounoum Valley and then due east via its present channel. Most of these river channels are no longer active, but remnant valleys of great width attest to a much more humid climate, as indicated above. These valleys cut deep channels which have long since filled with alluvial sediments and eolian sands. It is impossible to know which of

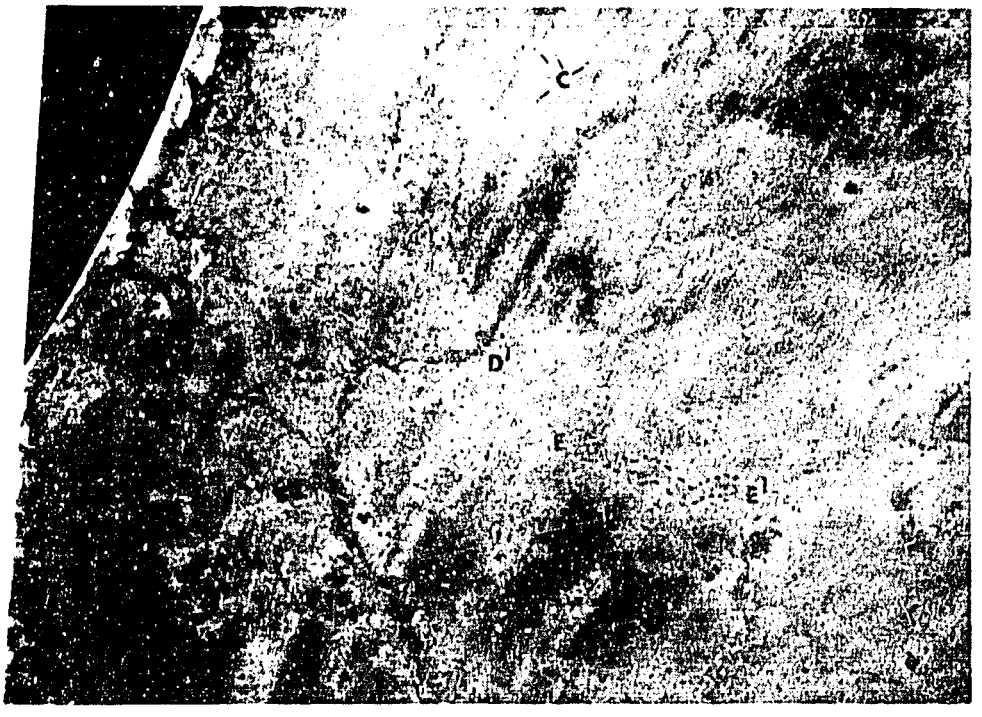


Fig. 3.16. Landsat image of the Diourbel-Thiès Groundnut Basin region. The scale is 1:1 000 000; the date of acquisition is 21/02/73. The spectral channel 5 enhances the humid characteristics of the soils. Diourbel is located at point A, Thiès at point B. The black and gray dots represent towns (C). The trace between D and D^1 is the location of a major east-west fault. The sinuous dark tone between E and E^1 (emphasized by the dashed line) is one of the many such features interpreted as a fossil channel. The area between the arrows shows numerous NE/SW parallel trends which represent the surface expression of faults and fractures in the Paleocene/Eocene rocks in that area.

these channels was the main branch or a minor branch of a fossil system, when these river valleys were active, or whether they represent erosional activity that occurred on a number of occasions, and whether some or all of the valleys were drowned by salt water ingression at the last highest oceanic stillstand (Nouakchotian). Notwithstanding, it can be said with some certainty that many of the fossil channels mapped from Landsat imagery probably carry fresh water. In many areas of the Ferlo, as well as west-central and western Senegal, these channels could yield large quantities of fresh water for village use. Based on a sea level of -74 m at the end of the Ogolian (±14,000 B.P.; Michel, 1973) and a subsequent wet period (12,000-7,300 B.P.; Michel, 1973), it is clear that thick sections of fossil sands and gravels could well be expected to carry significant volumes of water. In some cases, the

fossil channels may well have cut into the Maestrichtian aquifer and could be recharged from that source. The reverse could be true, and it is possible, for example, that the Maestrichtian is being replenished by the waters of the Senegal River at Dagana, where it is known to occur within 20 m of the surface.

a. Description of the Unit

Fossil channels in Senegal Oriental were mapped from Landsat imagery along the course of the Falémé River. There, channels are of interest because of their potential for alluvial gold, tin, tungsten and diamonds.

Other pre-Tertiary fossil drainage channels are believed to exist on the Falémé River between Kédougou and Tourokoto. These channels parallel the drainage of the Diguinkili and Dialé rivers and probably represent pre-Tertiary, northeast-directed drainage of the headwaters of the Gambia River. It is postulated that the headwaters of the Gambia River flowed from the Guinean highlands northeast to Kédougou and north along the Dinodiang drainage into the Diale before the new Gambia River was able to break through the highlands of the Kakadian Mountains and the Mako Series and capture the drainage of southeastern Senegal and in this manner encompassing the total extent of its present drainage basin. This event probably occurred at the end of the Wurm glacial period, when sea levels were as much as 70 m below present levels and rainfall began to increase.

The project located a Quaternary terrace with high gold values at about 3 m above present river levels. The potential for gold deposits in higher terraces between Kédougou and the Falémé River is very good. The terraces being mined at Kossanto and other locations are about 35 m above the present river level which corresponds to the difference between the present mouth of the Gambia River and the -35 m lower sea level still stand mentioned by P. Michel (1973).

b. Structural Relationships

Many of the fossil channels in the Ferlo follow rectilinear trends which form trellis patterns. The main trend is N60°W and the secondary trend is N45° to N50°E. These two directions of drainage are particularly evident in the Ferlo and central Senegal but become less frequent in western Senegal.

5. Fossil Dunes of the Ogolian ("Red dunes"--ad^1 on map and legend)

a. Description of the Unit

Dunes cover much of western, central and northern Senegal from Matam to St. Louis and as far south as the Sine Saloum River. These dunes are clearly visible on aerial photographs and Landsat imagery. Very large dunes, such as those in the northern Ferlo and all of

northern Senegal, provide evidence of continuous atmospheric conditions over many thousands of years. We have noted earlier that we believe that some of the larger dune systems represent pre-Quaternary, eolian activity. Clearly, the numerous smaller dunes of the central Groundnut Basin appear to be of relatively recent origin. Their size and direction differ from those in northern Ferlo, which strike N60° to N70°E, whereas those of the Groundnut Basin strike N45° to 60°E and the latter are superposed upon the former. The larger north Ferlo dunes have a maximum length of over 125 km and are often more than 5 km wide. They are clearly restricted to an area east of the Lac de Guiers and north of the Ferlo River. South and west of the Ferlo River typical dunes have the following characteristics: a maximum length of 50 km, a width of less than 2 km, a strike of N45°E and an elevation of only a few meters (as opposed to the dunes of the northern Ferlo). To the west of these dunes in an area representing the Cayor and Niaye from St. Louis to Dakar, dunes of more yellowish, but often red or white, color represent the results of eolian transport by the alizé winds. These dunes are often multi-directional, but usually trend north-south, or nearly so. They may be more than 10 m in height. Such dunes control the location of the niayes.

b. Structural Controls

The dune fields of Senegal generally parallel those of Mauritania, which in turn often follow and sometimes fill river valleys whose beds follow linear fractures. This relationship is quite obvious in the barren bedrock provinces of Mauritania (Aftout, Tagant, Aouku and Idjibiten), but is less evident in Senegal. Nevertheless, this direction (N60° to 70°E) is parallel to a series of major gravimetric trends (see Tectonic map). Thus we conclude that the largest Senegalese dunes tend to follow preferential directions established by drainage, which in turn follows the major tectonic trend of N60° to N70°E. This we believe is the case for the extension of the Gorgol River in Senegal, which we believe trends, as indicated above. We propose that before capture by the Senegal River at Hore Fonde, the Gorgol River flowed wouthwest and joined the Ferlo River drainage at Mbeuleukhe. Since the capture of the Gorgol, the Senegalese portion of the channel has been filled with eolian sands.

6. Recent Fluvial Deposits (af on map and legend)

a. Description of Unit

These deposits are visible on Landsat imagery because they are often covered by vegetation. This vegetation is either red on the Landsat imagery taken during the rainy season or dark gray in the dry season imagery.

Many streams in Senegal are inactive for a number of years only to be revived by uncommonly heavy rains. When in flood, these streams cannot be contained by their valleys and create braided channels and

temporary meanders and leave the residual fluvial geomorphic features typical of a dry climate. These streams include the Ferlo River and many of its larger tributaries, as well as the Sine and the Saloum rivers.

It is not certain which streams have been active recently and how much material they are moving. Nor can one call a stream a fossil stream because no recent flow has been recorded. Nevertheless, certain streams had to be denoted as recent (af) which was done on the basis of whether or not a stream showed signs of erosion. Those streams which showed small active tributaries, vegetation patterns or visible fluvial geomorphic features in imagery from different years were considered as active and not fossil channels. Some channels were designated af/aff. This denotation was ascribed to them because it is believed that these valleys, usually wide and showing signs of geomorphic maturity, represent alluvial action and deposition of two types; the deeper materials in the beds of these valleys must be fossil or pre-Recent, whereas the surficial sediments of these valleys have been recently reworked and so represent Recent to present sedimentation.

Many active streams show signs of recent capture by younger streams with increased gradients. This is particularly true in southern Casamance, southeast of Kolda, where capture has probably taken place at Makon Ousman. Other streams have been captured by the Gambia River and its tributaries at the expense of the Saloum. For example, it is supposed that the drainage of the Sandougou north of the Tambacounda-Kougheul road flowed to the Saloum River at Kaffrine. This system has been progressively captured by the Gambia River because of the continued collapse of the Casamance trough and increased gradients caused by this collapse. Additional captures have occurred west of Kedougou where a southeast flowing stream, the Fongoli, now flows northeast toward The Gambia. It also appears that the Falémé River's course has been lengthened by capture at Faricounda. It is proposed that instead of flowing directly to Durali-Diaranke, the Falémé River now flows south to Segoto, then flows north again past Sekounkou to rejoin its former bed at Durali-Diaranke. In both the above cases, capture was achieved by tributaries flowing on softer rock types.

b. Structural Relationships

Most of the streams draining the Senegal Basin flow westward and are defined as consequent streams. In Senegal Oriental, drainage is east and north into the Falémé and Senegal rivers. Of the streams draining the sedimentary rocks of the basin most are consequent and flow west along the dip slope. Other streams, however, have developed along visibly obvious, linear directions, such as N50° to 60°E and N50° to 70°W. The direction and flow of many rivers, including the Gambia and Senegal, are controlled by other types of structural features. The Senegal River has created a wide delta because the river flows over very weak basement which is collapsing under the weight of the superposed sediments. This collapse is due to continued movement along

a number of faults which have created a complex graben-like structure at the mouth of the river. The Senegal River is thought to follow its present course from Pate Galo to Yafera because it has been eroding headward in a southeastern direction along the crest of an arch. The Gambia River makes a major bend east of Madina Sabak. Here, it flows north-south for at least 30 km. The simplest explanation for this divergence is that the Gambia River is and has been affected by uplift in this area. The Tectonic map indicates a strong positive gravity anomaly between Madina Sabak and the Gambia River to the east. If this anomaly is related to uplift as at Léona, which seems probable, then it is quite conceivable that the reason for the major bend in the river is the emplacement and subsequent gentle uplift of the area in question, which would have diverted the river.

Because of epeirogenic collapse of the Senegalese Sedimentary Basin and rising sea levels since late-Pliocene times, the mouths of many major rivers are drowned and marine sediments can be found eastward and inland. Such marine transgression is found on the Casamance River as far as Diattakounda, on the Gambia as far as Maka Gouye and on the Saloum as far as Keur Mbouki. Saline incursions on the Senegal River vary depending on tidal fluctuations and changes of the shore bars due to longshore currents, but the large scale incursions which affect the delta are due to structural collapse and the formation of complex grabens and en echelon faulting in the delta area.

7. Recent Marine Deposits (am on map and legend)

a. Description of the Unit

Marine and/or estuarine deposits are readily mapped from Landsat imagery. In the estuarine areas, heavy mangrove growth is clearly visible in the near-infrared part of the spectrum; other estuarine features, such as tidal flats, marshes and littoral salt deposits, show up very clearly and delimit the most recent transgressive stage of marine waters in Senegal. The four largest areas of marine transgression are the Senegal delta area, and the drowned river valleys of the Sine Saloum, Gambia and Casamance rivers. Small segments of drowned coast can be found between Ngazobil and Nianing along the Petite Côte, at Thiaroye, Malika and Retba on the Cap Vert Peninsula, and from Tanma to Mboro along the Cayor. In the case of the Cayor, the coast is growing by accretion, and what were in many cases drowned valleys filled with marine sediment are now freshwater-filled depressions referred to as Niayes.

In the Senegal River Delta, marine waters have risen to points beyond Richard Toll. In late Pliocene, and as recently as the late Pleistocene, marine waters rose as far as Dioum and Bogue. Because marine and fresh waters mix intermittently (seasonally) in the delta, no line of demarkation can properly be made. Each rainy season, marine and fluvial waters deposit their loads, dividing the delta according to

the fluctuation of the tides, the movement of longshore currents and the erratic rainfalls of the Sahel.

b. Structural Relationships

The structural controls of the estuarine areas of the Casamance, Sine Saloum and Senegal rivers are not in doubt; linear analysis of Landsat imagery supports the proposition that these deltas are composed of a series of en echelon faults or composite grabens which have permitted marine ingressions. The fractures and faults in the Sine Saloum trend N10° to N15°E, N55° to N65°E and N45° to N55°W. The mouth of the Gambia River does not seem to be composed of similar blocks, and its drowned aspect probably relates to the general basinal development of this region. The Senegal River Delta is a complex graben structure which is limited by numerous en echelon faults trending N45° to N55°E and a similar more or less orthogonal set of fractures/faults that trend N55° to N60°W.

8. Recent Dunes (white and yellow--ad^2 on map and legend)

These dunes are found mostly along the Atlantic coast from St. Louis to Dakar. They are indistinguishable from typical beach sands along the same coast and beach sands southward in the Casamance and The Gambia. Additional deposits of recent dunes or reactivated Plio-Pleistocene dunes have been mapped in the northern Ferlo at Revane, Dodji, Diouguel Sanarabé, west of Mbouba and Doumga and from Dioum to Ndiayène. These dunes are of two types: those of the northern Ferlo where Ogolian and earlier dunes have been reworked (these dunes trend parallel to the pre-existing dunes, or about N60° to N70°E); dunes of the second type are actually dune fields which have filled old river valleys, as at Dodji, or seem to occupy fault-induced depressions on either side of a horst, such as at Revane and Diougé Sanarabé. These dunes are very similar to those of the more extensive, but older, system which occupies the 150 km long depression from Horé Fôndé to Mbeuleukhe on the Ferlo.

H. Conclusion to the Descriptive Approach

Various authors (Robineau, 1985; Sal, 1978; Le Priol, 1985; Le Page, 1978, 1980, 1982) have by now conducted Landsat interpretations of Senegal and have shown this technique to be very helpful in providing improved maps of many kinds. Use of Landsat imagery in Senegal still poses a number of problems because of poor imagery, lack of repetitive imagery, lack of complete quasi-simultaneous coverage, poor resolution and the difficulty inherent to the imagery for differentiating lithology. The lack of topographic variation of the Senegalese landscape, heavy lateritic and vegetal cover and the ubiquitous fire scars from slash and burn practices exacerbate the problems listed above. Nevertheless, the results indicate that satellite-aided interpretation improves geologic maps, especially those indicating linear fracture systems and faults. Our work with Landsat

imagery has clarified two significant aspects of Senegalese geology which were previously poorly understood. The first observation made by Landsat that contributes to the geology of Senegal is the definition and explanation of the relationship of faults and fractures; the second is the location of an extensive fossil drainage system. Landsat imagery and its interpretation is, in the final analysis, most useful when it is integrated with existing data and when it is used to help provide a synthesis. Such a synthesis should permit us to derive new exploration models for hydrocarbons, water and other minerals. We believe that our effort has done this.

3.9.5 Tectonic Interpretation of Landsat and Other Data

3.9.5.1 Introduction

In attempting to establish a tectonic history for Senegal, we must recall Senegal's situation in the framework of West African geology and tectonics. Senegal is composed of three geotectonic units which include the following:

a. A window of the West African craton which consists of a granitized basement of Proerozoic or earlier rocks and an overlying late Proterozoic to Paleozoic volcano-sedimentary sequence.

b. Paleozoic volcano-sedimentary sequences which border the shield.

c. A Mesozoic and Cenozoic volcano-sedimentary province which borders on the above.

This area has been affected by at least three, and possibly four, major orogenies:

a. The Eburnian, 2,000 M.Y.

b. The Pan-African, 500-700 M.Y.

c. The Hercynian, 300 M.Y.

Although not enough evidence exists to define a fourth mountain-building episode. According to J.P. Bassot (1966), the fourth orogeny may well have been the Caledonian (Katangan/Damaran), which would have affected the region about 400 M.Y. More recent orogenic activity of lesser consequence, but nevertheless of a significant level of activity, occurred after the Visean (Carboniferous) and before the Jurassic (Bellion and Giraud, 1979), when the doleritic sheet basalts were deposited in eastern Senegal; during the Cretaceous (Senonian) the Léona syenite was injected; and finally, but almost continuously, since the mid-Eocene, activity began in western Senegal which included broad folding (Lac de Guiers), block

faulting (Horst de Ndiass), and magmatism {Cap Vert, Mamelles (Fig. 3.16) etc.} (Bellion and Giraud, 1979).

This report can in no way recapitulate the extensive work done by numerous geologists in West Africa to establish the existing tectonic model. What we will attempt to do is to describe the project's work in tectonic analysis, including the interpretations conducted on Landsat imagery, the conclusions to be drawn from our work and previous work, and the hypothesis to be presented.

3.9.5.2 Interpretation of Landsat Imagery and Tectonic Analysis

We have already described the manner in which project geologists conducted the geologic/structural analyses of the Landsat imagery available to us. Such an analysis is really useful only after a tectonic framework is developed, so that the detailed work involved in analyzing the parts (separate images) can be seen in the context of a more complete analysis of the whole region, which in turn, permits the geologist to arrive at conclusions regarding the hydrocarbon and mineral potential of the region. To prepare a tectonic analysis of Senegal, the project interpreted 3 mosaics of 13 Landsat scenes of Senegal. The Tectonic map prepared on the basis of this work combined with some previous work, shows the main lithologic, structural and geophysical elements within the boundaries of Senegal.

A. The Interpretation of Landsat Mosaics

The project's two geologists each interpreted Landsat imagery of Senegal in the following manner:

a. Conducted Landsat interpretation on 1:1,000,000 scale mosaics of Senegal using Landsat channels 5 and 7 to define linear elements.

b. Similarly interpreted individual color composites of Senegal at a scale of 1:1,000,000.

c. Conducted interpretation on color mosaic at a scale of 1,000,000 of 13 image areas covering Senegal and parts of Mali, Mauritania, Guinea and Guinea-Bissau.

d. Compared the results of the two interpretations.

e. Eliminated invalid interpretations (where agreement was lacking).

f. Plotted data common to two interpretations.

g. Compared results to previous interpretations at 1:250,000 and added significant linear features from above.

h. Compared our results to other available data (Bellion and Giraud, 1979 and Le Page 1978, 1980, 1982).

i. Compared interpreted data to available magnetic maps, gravimetric maps and isopach maps (Monciardini, 1966 and Le Priol, 1984) to provide evidence as to the validity of the existence of faults, fractures, basins and domes. Wherever interpreted linears corresponded to rapid changes in sediment thickness or the edges of gravity or magnetic anomalies, we concluded that such correspondence could well mean the existence of a fracture or fault and possible movement along such features (see maps 3.4 and 3.5).

j. We reviewed our interpretations on the basis of all of the above and either added or deleted linear features.

k. Plotted the largest lithologic units from previous sources onto our tectonic base map.

l. Plotted elevated areas on map.

m. Based on a combination of the above, suggested directional displacement along faults.

n. Based on above, plotted fold axes and dips.

B. Conclusions Drawn from Tectonic Interpretation and Analysis

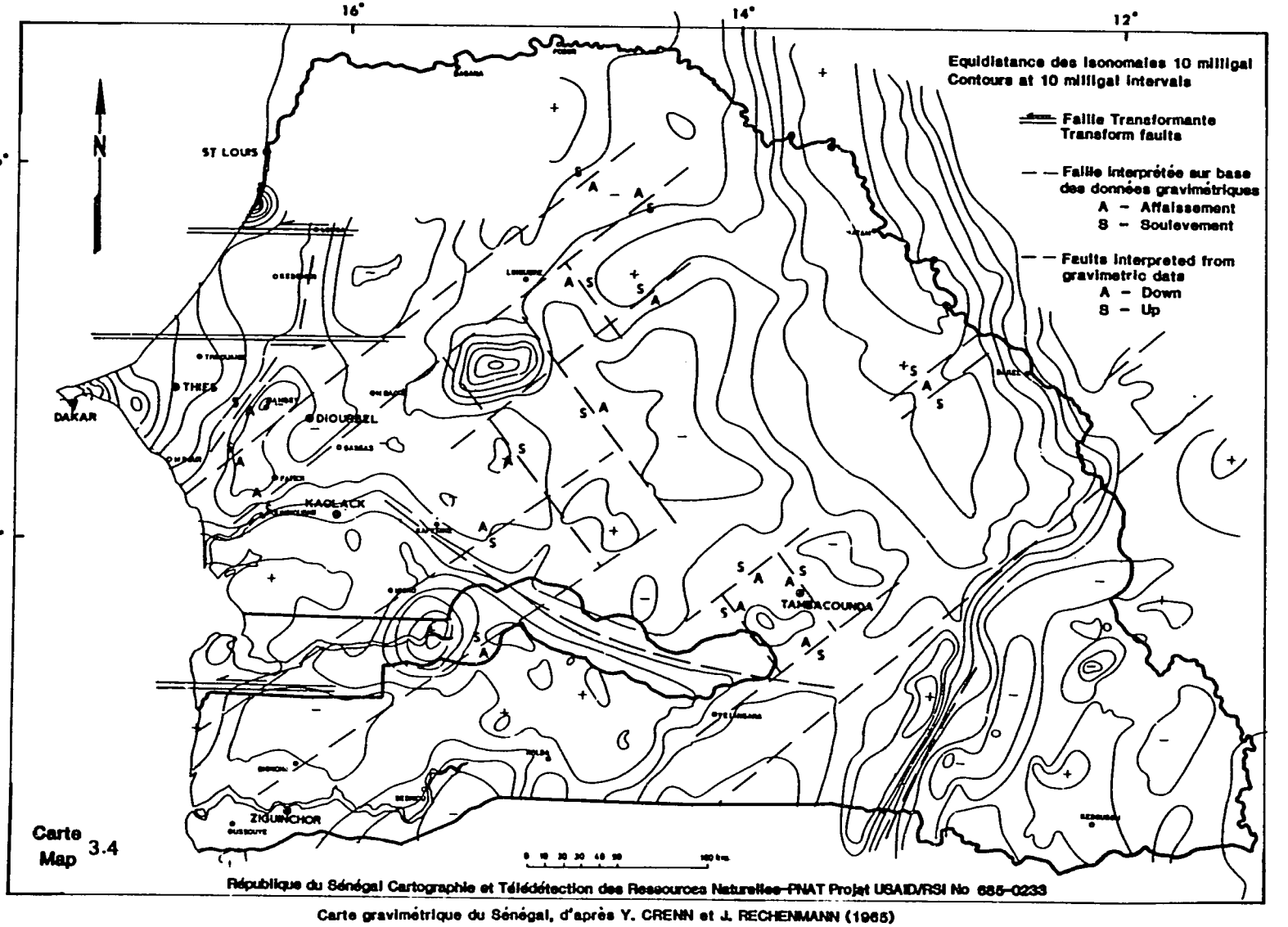
The conclusions to be drawn fall into three categories: those that are directly related to the Landsat interpretation and those related to other data which lend support to the Landsat interpretation or allow us to make some useful conclusions regarding the tectonic development of the region. Finally, we may draw some conclusions by re-interpreting existing data unrelated to Landsat but of significance in the context of the tectonic development of the region.

1. Conclusions Drawn from Landsat Interpretation

- Linear trends in the Senegal Basin are

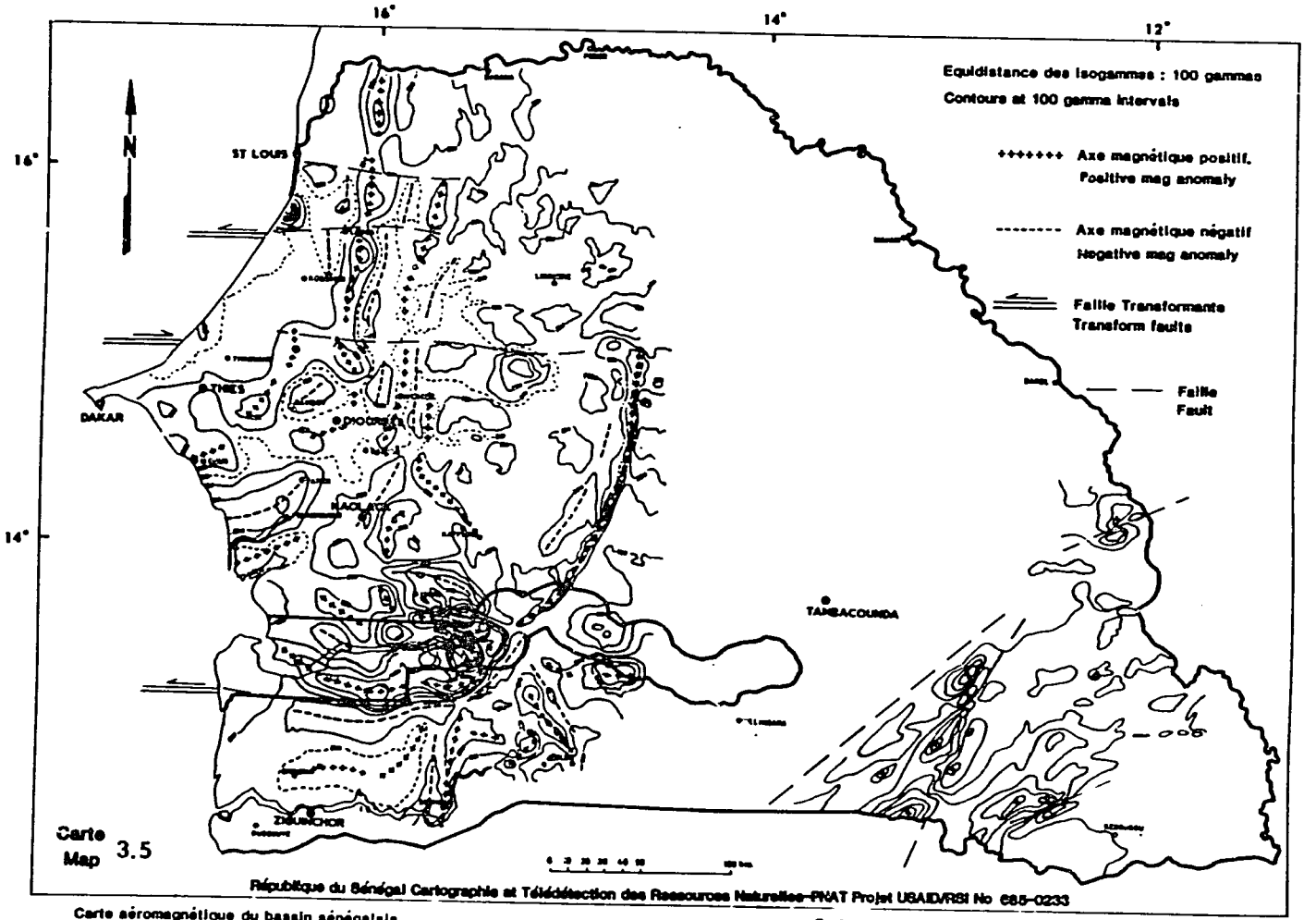
  N45°-N60°E (Major Trends)
  N40°-N55°W (Major Trends)

These two trends cross the entire country.



Carte gravimétrique du Sénégal, d'après Y. CRENN et J. RECHENMANN (1965)

Gravimetric map of Senegal, from Y. CRENN and J. RECHENMANN (1965)



Carte aéromagnétique du bassin sénégalais
(champ total réduit au pôle : d'après BRP, 1956)

Aeromagnetic map of the Senegal Basin
(total field reduced to pole : from BRP, 1956)

Carte composite des anomalies magnétiques au Sénégal Oriental,
d'après une compilation de Ponsard(1984)

Magnetic anomaly map of Senegal Oriental,
from a compilation by Ponsard(1984)

- Linear trends in the Senegal Oriental Paleozoic and Shield terrain are

  N45°-N60°E (Major Trends)
  N40°-N55°W (Major Trends)
  N0°-N15°E (Minor Trends)
  N60°-N80°E (Minor Trends)

- Numerous thrust faults were noted in the interpretation of Senegal Oriental (they could not all be shown on the 1:1,000,000 Tectonic Map) in the region from north of Bakel to 20 km north of Kidira. The trends of these faults are not consistent, although most appear to have originated due to compressive stress from the west or northwest.

- Some additional thrusts were mapped in the area between Salémata and Simenti. One of them is shown on the Tectonic Map. These thrust fronts are oriented a few degrees east of north.

- Linear trends in western Senegal (west of 15° west longitude) are

  N18°-N30°W (Major Trends)
  N30°-N45°E (Major Trends)
  N45°-N55°W (Secondary Trends)
  N60°-N70°E (Secondary Trends)
  N60°-N70°W (Secondary Trends)
  N/S (Minor Trends)
  E/W (Minor Trends)

- By accentuating the trends which are discontinuous but recurrent in linear or curvilinear patterns across Senegal, we find a number of northeast-southwest linears which can be traced from the Falémé and Senegal rivers in the east to the Gambia and Casamance river mouths in the southwest. The southernmost of these trends we have called the Kounkane trend. This trend acts as the southern limit of the Anambé Dome. The northern limit of this dome is the Niéri Ko-Velingara trend. This latter trend passes south of Kolda and continues to Ziguinchor and southeast to Kabrousse. The next trend is an arcuate, discontinuous composite of 15 linears which begin 10 km south of Bakel and trend southwest to pass 10 km south of Tambacounda and continue southwest to Bignona/Ziguinchor and Cap Skirring. Further north and beginning just south of Moudéri, about 50 km north of Bakel, we observe a discontinuous, but very obvious, trend which we can trace southwestward to Koumpentoum and beyond to the mouth of the Casamance River. In the Ferlo, south of Mboune, this trend is the divide between the Ferlo River and Gambia River drainage. To the north, another similar trend can be followed intermittently from Kanel on the Senegal River to Malem Hodar and Banjul on the Gambia River. Three other major

northeast-southwest trends have been mapped north of Matam, but they do not continue much beyond Kolobane. Linears in this area are somewhat suspect and are often confused with dunes that trend in the same direction.

- If we accentuate, as in the above case, linear trends which are more or less orthogonal to those above--that is those which strike northwest-southeast, we find a number of such parallel linears traversing the Senegalese landscape. These linears often define the course of streams in the Ferlo and the Haute Casamance. The main such trend is here referred to as the Dara-Tiel-Koussanar linear; another major trend with similar strike we have named the Dagana-Gandiu linear. A third linear of major length or continuity and one which controls the course of the Senegal River, extends from Pâté Galo to Sébou on the Falémé River. Other less extensive or easily definable northwest-southeast linears and trends traverse Senegal and are probably responsible for shifts in drainage direction along major streams.

2. Conclusions Drawn from Combining Landsat Interpretations with Other Data

- The Casamance-Gambia sedimentary trough as mapped by Montciardini (1966) and others is limited by major linear trends which probably define a graben.

- The Ferlo syncline and the Dara (Lac de Guiers) anticline (Dégallier, 1962) are both defined by orthogonal fractures (linear trends) seen on Landsat.

- Numerous magnetic and gravity anomalies are defined or circumscribed by linear features visible on Landsat, some of which have not been mentioned in the previous literature. Notable correlations between geophysical anomalies and Landsat linears are

  a. The Léona intrusive (known feature, previously drilled)

  b. The Doldou Dibokol "intrusive" ("new feature")

  c. The Farafenni-Medina Saback anomaly ("new feature")

  d. The Revane gravimetric anomaly ("new feature")

  e. The Mboune-Bakel gravimetric reentrant within the 40 millegal line ("new feature")

f. The Velingara-Kounkane trends which define the boundary between a smaller northeast striking, a more southerly, positive gravity anomaly straddling the Gambia River and a very large, broad, northwestern-trending anomaly. This latter anomaly begins at approximately Goudiri and extends north into Mauritania.

g. There exists a close relationship between gravity, magnetic anomalies and folds, particularly in western Senegal (i.e., the Joal syncline which is a negative magnetic anomaly and a negative gravity anomaly whereas the Lac de Guiers anticline is a positive magnetic and positive gravity anomaly) (See maps 3.4 and 3.5).

- An interpretation of the gravimetric and magnetic maps allows us to locate "faults" with a relative degree of confidence (see maps 3.4 and 3.5). We sometimes find that magnetically and gravimetrically interpreted faults are not exactly superimposed by the "equivalent" linear. We believe that this difference is due to the fact that we are measuring gravimetric or magnetic differences at some depth; thus the position of the fault as interpreted on the gravimetric or magnetic map corresponds to that fault's actual position at some depth below the surface. The difference in position between the two interpreted faults can then be attributed to inclination or dip along the fault. We may therefore make the following conclusions: it is possible to approximate the dip slope of the faults and it is possible by analogy to suggest relative displacement because most faults tend to be normal faults. We can certainly conclude that an intrusive body which has been faulted into place will be defined as a horst with down-thrown blocks surrounding it.

3. Conclusions Based on Data Other than Landsat

- On the gravity map of Senegal, three highly interesting and strong positive gravity anomalies occur in the western and central part of the country. Not only are they composed of denser material, but they are also composed of highly magnetic material (see maps 3.4 and 3.5). We know Plan minéral (1985) that the northernmost of these anomalies, located ±40 km south of St. Louis, is defined by a nepheline syenite plug; thus, it would not be too risky to suggest that the other two anomalies that have similar characteristics may also be igneous intrusive bodies. Based on the known depth of the Leona anomaly and its strength, and given that similar intrusives occur west of Tiel and on the Gambia River, we can assume that these bodies occur from 500 to 1,000 m from the surface. Such an assumption is supported by drill hole results which, it is reported, reached the Precambrian at 900 m some 10 km southwest of Tiel (Plan minéral, 1985).

- Two noteworthy, linear, positive gravity anomalies occur in eastern Senegal. One strikes a few degrees west of north and extends from Goudiri northward beyond Akjoujt in Mauritania. This anomaly is as much as 100 km wide and everywhere parallels the Mauritanian chain of folded mountains. More importantly, it subtends the massive, negative gravity anomaly of light granitic rocks of the Reguibat Shield and associated rocks and is apparently separated from them by one or more faults. The linearity, breadth, and location of this anomaly suggests a sutured rift system occupied by dense simatic rocks whose gravimetric response reaches 60 milligals at a number of locations in Mauritania. We conclude that ultrabasic sequences probably occur in this zone to within 750 m of the surface.

  The second and more southerly linear, positive gravity anomaly occurs west of Niokola Koba and strikes ±N30°E, plunging at Diama in the north and 30 km southwest of Younkounkoun in Guinea. The anomaly reaches 48 milligals. Its width does not exceed 35 km and its length ± 130 km. Positive values decrease very rapidly on the eastern limits of the anomaly, which suggests a major, deep-seated fault. Extension of this fault into Guinea places it directly over the town of Koumbia, the epicenter of an earthquake (6.2 on the Richter scale) which occurred in 1983 (Robineau, 1985; Dorbath et al., 1984). Magnetic data supports such a hypothesis (see maps 3.4 and 3.5). This anomaly is separated from the more northerly and larger, dense mass of rock by what is thought to be a major N45°E fault. A displacement along this fault of the southerly block from northeast to southwest is postulated (Villeneuve, 1984). Based on the gravimetric interpretation, we also postulate uplift of the southerly block from Timbedra in Mauritania to at least Lenikering and possibly beyond into Guinea-Bissau. Based on the compositing of magnetic and gravity data, we postulate a northwest dip on this fault. The fault on the eastern margin of the anomaly is probably vertical or a thrust boundary fault. This second anomaly is also believed to consist of basic and ultrabasic rocks typical of the ophiolitic environments found in rifts.

- Perhaps the most significant deduction to be made from the gravity and magnetic maps deals with the area near Mako. There well-exposed ultrabasic sequences should be yielding very high gravity and magnetic anomalies but have considerably lower than expected responses, which we believe are due to the fact that ultrabasic rocks do not exist at depth. The ultrabasic rocks exposed in this area probably represent allochtonous bodies which have been thrust into place from the northwest. This suggestion is similar to that made by A. Le Page (1978) for the area between Kidira and Bakel.

- Magnetic anomalies of large amplitude, length and breadth occupy the core of the Saraya "granite" (Witschard, 1965). A 4000 gamma anomaly in the core of a granitic body seems to preclude a plutonic batholithic mass. We believe that this anomaly reflects a nonmagmatic (sensu strictu) origin for the Saraya "granite". We would suggest that the Saraya granitic rocks are synkinematic granitized (recrystallized metamorphic rocks) rocks of pre-Birrimian age.

- A positive gravity anomaly of discordant aspect can be noted east of Linguère where the +20 millegal contour extends westward like a thumb from the quasi-north-south, Akjoujt-Goudiri anomaly. This anomaly cannot be properly attributed to either the north-south group of Birrimian rift-type anomalies or to the post-Triassic Atlantian plutons emplaced at the junctures of major pre-existing, deep seated trends and transoceanic fracture zones.

- A curvilinear positive magnetic anomaly can be traced from the Gambia River to some 30 km east of Tiel. Defying easy explanation, this anomaly could define a major fault or more probably, trace the axis of a anticlinal fold in basement rocks possibly accentuated by the accumulation of detrital heavy minerals or the seaward flank of the fold. Finally, it may be correlatable to an overthrust from west to east (Villeneuve, 1984).

3.9.5.3 Summary of the Tectonic Development of Senegal

Landsat analysis and interpretation supports existing conclusions which suggest that Senegal is essentially an unstable geologic area at the western edge of the West African Shield. It is composed of a relatively thin crust of metamorphosed Precambrian rocks of igneous and sedimentary origin which have for the most part been covered by sediments of Paleozoic to Recent age. The main conclusions to be drawn from our work and that of previous authors are as follows (Fig. 3.1):

- The stable, thick, cratonic areas of West Africa lie east of the 13°W longitude. Thus only a small corner of Senegal (east of Niokolo Koba) has a stable cratonic crust.

- Basement rocks do occur in western Senegal but are broken up and faulted segments of cratonic material that is being drawn toward the Atlantic during tensional periods and folded and overridden during periods of compression (Atlantic closure).

- Sometime during the Proterozoic, the West African craton in this area began to split into an aulacogen (Gold in Siegal et al., 1980). While one arm of the aulacogen extended into the Taoudeni Basin and joined with the Gourma aulacogen (Haggerty, 1984), the other formed a trough paralleling the Mauritanian

chain and the third extended southwest toward the Rokel Mountains of Sierra Leone.

- During the Birrimian, deposition of ophiolitic sequences took place in the developing rifts, and the Mako Series of rocks were emplaced in the deepest portions. The Daléma and the Dialé series were laid down on a foreshore composed of pre-existing Archean rocks (Saraya granites), which provided the detritus for both onshore and offshore deposits.

- During the Eburnean orogeny at the end of the Birrimian, compression took place and the Mako Series was thrust eastward over the foreshore deposits was produced nappe-like structures, isoclinal folding and recrystallization of the pre-existing rocks, including the Archean rocks in the Saraya "granite". During the last part of this orogeny and as compression ceased, tensional response allowed the intrusion of granitic stocks of the Bondoukou type (Bassot, 1966).

- During the mid to late Proterozoic, the Taoudeni basinal depression again responded to tensional stresses and deposition began along its "Atlantic" edge. First, foreshore deposits accumulated as the Ségou-Madina Kouta group and later the Mali group of rocks. Toward the end of the Proterozoic, a new rifting cycle began along the Mauritanian, Bassarian and Rokelian axis.

- This new cycle of rifting was more accentuated in the south and resulted in the deposition of the Bassari series. They were crushed, folded, faulted and metamorphosed locally during the Pan African orogeny and portions of these series were thrust eastward (Villeneuve, 1984).

- In the late Precambrian and early Cambrian renewal of rifting began along the Mauritanian-Bassarian rift. At this time, the Faleme, Bakel, Younkounkoun and Koulountou series were deposited.

- Renewed compression and intense folding and crushing took place first in the Caledonian (Taconic) (435 M.Y.) and later in the Hercynian (360 M.Y.). It resulted in the folding of the Mauritanian chain and the intense folding, faulting and thrusting of the rocks in the Bakel area and those of the Simenti-Niokolo Koba area.

- As the Atlantic began to open in the late Carboniferous, deep-seated faults were reactivated and fissure lavas of doleritic composition were deposited in the southeastern portion of Senegal. During this period, portions of the western Senegalese foreland began to collapse toward the Atlantic.

- During the mid to late Mesozoic, intrusives of intermediate to basic composition were emplaced in western Senegal (Léona, west of Tiel and on the Gambia River).

- In the mid to late Tertiary and since then, the African continent in collision with the European plate has produced the Atlas and Alps. In Senegal, this collision caused broad arching (the Lac de Guiers-Dara anticline, the Anambé Dome and the Horst de Ndiass) and faulting, as well as the introduction of basement magmatism in the Thiès-Dakar axis.

- During the late Tertiary and Quaternary, the Gambia trough has deepened, and some minor uplift has occurred in the Ferlo of Senegal and the Akjoyt of Mauritania.

For further details on the development of the tectonic history of Senegal, it is suggested that the discussion by M. Villeneuve (1984) be reviewed.

3.9.6 Economic Geology

3.9.6.1 Introduction

As the geologic potential of Senegal has been very thoroughly summarized by the BRGM in the Plan minéral (1985), this report will only summarize the findings of our project and attempt to put these results and the work conducted by previous authors into the perspective of the tectonic framework we have developed.

The project has prepared a map "Carte du Potentiel en Eau, des Gîtes ou Indices de Minéraux et du Potentiel Metallogénique" on which we show areas with potential for water (which will be discussed further in the section 3.10), the majority of known mineral deposits or prospects and the metallogenic potential of Senegal as it relates to the rock types in each region.

We have included metals, hydrocarbons and other sources of energy on this map, as well as gravels and important nonmetallic minerals, such as phosphates. We have not included such nonmetallic substances as marble, other decorative stones or sand deposits as they are well described in the Plan minéral (1985) and are, in our opinion, of minor immediate value in the development of Senegal.

Our analysis will treat the mineral potential of Senegal in three large categories--a) energy related, b) nonmetallic and c) metallic.

Before beginning this description, we might note the recent exploration activity in Senegal.

a. Energy related exploration continues in the offshore zone off the Casamance for oil and gas, in the central Groundnut Basin for lignite and in the coastal and estuarine areas for peat.

b. Nonmetallic mineral exploration and development is concentrated on phosphate deposits in western Senegal the Moyenne and Haute Casamance, as well as in the Matam area. Exploration and development continues in search of limestone, attapulgite, diatomaceous earth, silica sand, ceramic clays, ballast and construction grade rocks (basalts) and gravel.

c. Metallic mineral exploration and development has been limited in recent years to the search for uranium (COGEMA), nickel and copper (BRGM). Attempts at the development of iron ore (MIFERSO), gold (SABODALA), heavy minerals (ilmenite, rutile and zircon) of the littoral zone have been made. Occasional and dated exploration for chrome base metals, including lead, zinc, copper metal, chrome, tin, tungsten and molybdunum, has taken place.

3.9.6.2 Description of Mineral (and Hydrocarbon) Potential of Senegal

A. Hydrocarbons and Energy Sources

1. Oil and Gas

Oil and gas sources are generally restricted to the western portion of Senegal and its offshore continental shelf extension. It would be foolish to hazard any guesses concerning the offshore and coastal areas without the benefit of the data accumulated by the oil companies that have worked in Senegal. On the other hand, reports of oil seeps are numerous in Senegal, especially in the area between Bambey and Joal on the Petite Côte. Gas was found in the Cap Vert area and is known to occur offshore. An excellent summary of the oil and gas potential of Senegal can be found in a recent issue of The Oil and Gas Journal, (Dumestre, 1985). In this article, M. Dumestre divides Senegal into two basinal zones, one north of Dakar, the other south. Both appear to have potential. The southern zone has been partially explored and has been found to have potential. Salt domes and associated diapiric sediments were drilled and found to contain oil. In 1969, the Flore Dome was drilled and the presence of 600 million to 1 billion barilles of heavy crude oil was confirmed in Oligocene, Eocene and Paleocene carbonates. Furthermore, light oil was found in Paleocene and Maestrichtian sediments of predominantly arenaceous character. Gas/condensate was found but not evaluated in other Tertiary and Cretaceous reservoirs within the same structure. M. Dumestre also notes the potential for hydrocarbons in the northern offshore and onshore areas of the country and in Paleozoic sedimentary sections, hitherto not considered as having much potential and only recently identified by the interpretation of gravity, magnetic and seismic data. Based on available gravity and magnetic data, we believe

that hydrocarbon accumulations should be found on the west limb of a faulted Paleozoic trough that extends from approximately Pointe Sarene in the south to Tidem and Ross-Bethio in the north. Other possible targets in Paleozoic sediments of Silurian age occur in the Loumbol-Diourbel axis and the Barkédji-Boulel axis. Both these zones are underlain by block-faulted rocks represented by negative gravity anomalies.

Development of Senegalese oil and gas deposits depends on three factors: whether or not new richer fields are discovered, currently operating licensed companies decide that worldwide economic and political conditions warrant the exploration and development of existing showings and deposits, or Senegal with outside financing wishes to undertake its own national oil and gas development program.

The areas considered to have high potential for oil and gas (as well as for salt and sulfur) are outlined and numbered 17 on the project's mineral potential map. A small 20 by 30 km basin occurring southwest of Tambacounda is considered to have some potential for gas production. Another area of potential for gas and possibly oil is the western flank of the deep faulted synclinal depression which extends from Rosso to Tivaouane.

Without the benefit of seismic records, no further comments can be made concerning the potential for oil and gas either at the above sites or in the more promising offshore areas of Senegal.

2. Lignite and Coal

Since 1984, the Government of Senegal has begun the evaluation of lignite deposits in the central Groundnut Basin of Senegal. Specifically, two test borings have been made by a drilling company under the aegis of the Department of Mines and Geology and results should be forthcoming. In 1981, Dr. C. Bliss, Office of Energy, USAID, reviewed the work on lignite in Senegal. In his report, Dr. Bliss shows that most of the oil and gas wildcats drilled in Senegal penetrated a number of lignite seams of varying age and thickness. Drilled and hand dug water wells have also found lignite. The Plan minéral (1985) has summarized this data and produced a map and cross-sections showing that lignite occurs extensively in Senegal: it occurs at the uppermost levels of the Maestrichtian, as well in various lower horizons, and that it also occurs in the Oligo-Miocene (at lesser depth) in the Sine Saloum and Casamance regions.

These deposits' thickness vary as does their quality (B.T.U. content), and no evaluation of bulk samples has been made. Some samples were seen by project staff from the uppermost levels of a drill hole at Tiéneba which show carbonaceous material mixed with a high percentage of sand and clay.

The Plan minéral (1985) estimates that an exploitable seam of lignite with the following characteristics--a 5 km by 5 km zone, a thickness of 4 m and a caloric content of 4000 Kcal/kg--could be expected to produce 40,000,000 t of industrial fuel. Annual Senegalese fuel needs approximate 300,000 tons.

In 1984, efforts to evaluate this potential have focused at Tienéba and Kolobane, although at both these locations the lignite is found at depths exceeding 345 and 250 m, respectively. In view of the depths of the deposits at both these sites, their evaluation seems questionable. Exploration for phosphate deposits in the Lac de Guiers penetrated lignite seams in the uppermost Maestrichtian at depths less than 50 m. The lac de Guiers anticline would seem to be a better place to concentrate exploration efforts.

Structural analysis of Senegal by the project supports the highest potential for lignite and coal exists in the Lac de Guiers anticline, particularly southeast of Dara and south of Barkédji on the flanks of the positive gravity anomaly that centers on the Forêt Classée of Oldou-Debokol and an area just east of the anomaly at approximately Odiole, where a late-Cretaceous marine embayment is postulated to have existed. Another area of similar potential centers on a similar positive gravity anomaly that occurs on the Gambia River at Farafenni and on smaller but significant anomalies which extend eastward from the above.

We believe a number of crescent shaped embayments of Cretaceous marine/lagoonal sediments would have provided the proper conditions for the formation of lignite deposits. We can even expect some conversion of the lignites into low grade bituminuous coal in the area where the late Cretaceous intrusives penetrated this stratigraphic section.

3. Geothermal Sources of Energy

During the project's field work, hydrologic well measurements for water potential indicated much higher than normal water temperatures in certain wells in parts of the Ferlo (#277 Bélél Toufle, #297 Lofé, #326 Fété Bowé, #329 Namari). The exact temperature was not measured as a thermometer was not available. However, estimates place the water temperature at between 45 and 50° C (too hot to keep ones hand in it), with #326 possibly exceeding this level. These high temperatures are unexplained and exceed what is expected from such shallow wells but could be related to intrusive activity or movement of water along active faults. What they do imply is that much of the Ferlo may well have potential for geothermal sources. We suggest that there may be a correlation between hot water sources and northeast-southwest and northwest-southeast faults and intrusives indicated by gravity anomalies. We have thus designated two zones which we believe should be explored for geothermal energy sources.

4. Peat Resources

No effort was made by the project to evaluate the peat resources of Senegal for two reasons. First, the Senegalese Government in conjunction with and assisted by various international organizations has spent a number of years evaluating the peat potential of late Tertiary and Quaternary bogs in the Niayes (Fig. 3.17), the Petite Côte and Sine Saloum. The results of these investigations are not complete but well summarized by the Plan minéral (1985), especially for the Niayes area. Second, the Niayes now serve as the most secure and productive source of food for Senegal; thus, any major effort at development of the peat deposits, which in many places immediately underlie the truck gardens now being used to produce large quantities of fruits and vegetables, would, in effect, destroy one economic sector in order to develop another.

Fig. 3.17. Looking west toward the Atlantic. Fās Boye is below the wing at the upper left. Encroaching dunes are filling arable Niayes in the foreground. The dark linear feature in the upper left is a westerly striking fault visible on Landsat but too short to plot on the map at a scale of 1: 500 000. The extension of this fault is mapped south of Ndande. This photograph was taken as part of a USAID-funded project to evaluate the reforestation of the littoral dunes from Dakar to St. Louis. The Remote Sensing Project assisted the government of Senegal by designing this small program. Interpretation and overflights were conducted by Senegalese experts. Total cost of the project was $4000.00. Note the reforested dunes in the background.

The BRGM with the Compagnie des Tourbières du Sénégal (CTS) estimates (Plan minéral, 1985) that the Niayes from Kayar to St. Louis have the potential to produce 52 million m^3 of peat of which 23 million m^3 could be used to produce energy because of their low ash content (44%). The entire 23 million m^3 was defined by drilling in the Mboro to Lompoul sector. The estimates also include an additional 23 million m^3 allocated to agricultural usage for soil rehabilitation and 6 million m^3 for domestic consumption.

The advantages of peat production and use are thought to be great, since the expected capacity for electric generation would substantially decrease Senegal's import needs and fulfill the entire needs of the Taïba phosphate production facility. In addition, of course, the production of peat for home use would alleviate the pressure on the overexploited forests of Senegal. The production of peat for soil improvement appears to be less advantageous as transportation costs will increase the gasoline/diesel import requirements and severely affect the Senegalese balance of payments, as well as competing with national phosphate sales.

In order to avoid depleting Senegalese food production, peat exploitation should be limited to areas which are not presently under agricultural production or development. The decision to develop peat resources on a widespread basis in the Niayes region could have a disastrous effect on food production, relocation of people and generally therefore the entire economy.

Any development of peat should await exploration results from the Sine Saloum and Petite Côte area where ecologic and economic effects might be less severe.

B. Nonmetallic Mineral Resources

1. Building Materials

Most of the building materials used in the major centers of Senegal are produced locally. Of these, only Kédougou can boast access to all levels of construction materials.

However, thanks to the occurrence of basalts on the Cap Vert, limestones in the Rufisque-Bargny area and sands along the coast in Quaternary and recent dunes, Dakar has long managed to satisfy most of its construction and aggregate needs. Nevertheless, a need has always existed for gravel and coarse sand sources. In addition, so much sand is needed that little attention is paid to its quality and chemical characteristics. In many recent buildings, surficial decrepitation and structural defects are visible and often attributable to the high salt content in the sands used in the concrete.

Although the project did not concentrate on the search for building materials, some consideration was given to the search for

coarse sands and gravels. To this end Landsat imagery, aerial photographs and field work indicated some major sources whose potential is worth investigating along with the concomitant other economics, such as transportation.

During field work good quality gravels were observed on the Falémé River in the region of Kidira, #14 on the Water and Mineral map, (Fig. 3.18). This area is important because of its proximity to the Dakar-Bamako railway. Other sources of coarse sand and gravel occur in the Paleozoic/Precambrian metamorphic belt just south and west of Bakel. These sources are not as large as those at Kidira and transport would have to be by road, which would require additional capital investment for trucks and considerable upkeep for the road between Bakel and St. Louis. Other sources of lesser economic importance are the gravels of the middle Gambia River and those of the Koulountou River where these rivers flow parallel to each other. A careful analysis would have to be made of the economic potential of the Kidira gravels. However, it is certain that for specialized applications, such as well drilling or Terrazzo, the Kidira deposits would seem to be ideal.

Fig. 3.18. The bed of the Falémé River at Nayé as seen from Mali in April. Senegal is at the right side of the picture. The woman in the background is washing clothes with water from a céane.

Some concern exists regarding the reserves of basaltic rocks used in aggregate and for other construction in the Dakar area. The largest occurrence is found at Diak, but reserves are limited. Landsat analysis and field work by previous scientists suggests extensive intrusives in the Keur Samba Kane region, 10 to 12 km west-southwest of Baba Garage (at Bare Diarra and Beaufi). These occurrences are found on the same tectonic trend as that of Diak and since they might increase in size at depth, these deposits should be investigated.

The Plan minéral (1985) and the "Carte Géotechnique de la République du Sénégal" at a scale of 1:500,000 (Cornet, 1964) should be consulted for further information on the occurrence and potential of Senegalese construction materials.

2. Phosphates

Phosphate mining is a very important element in the economic life of Senegal. Exports of phosphates provide a major source of revenue, whereas local usage constitutes an important means for improving the depleted soils of the Groundnut Basin.

Phosphates were first discovered in 1897 in the area of Nianing in lower Eocene sediments. A volumunious documentation exists on the quantity, quality, occurrence and development of phosphates in Senegal. Phosphates are found in the Paleocene, the lower Eocene, but especially in the middle Eocene (Upper Lutetian) of Senegal. These deposits are located particularly in western Senegal from the Sine Saloum Estuary to the Senegal River in the north and from 15°30' to 17°W longitude. The most significant outcrops occur in an arch related to the uplift of the Horst de Ndiass from Thiès northward to Méouane. This zone includes the two presently operating phosphate mines of Lam-Lam and Taïba.

Hundreds of occurrences have been noted by previous authors and others were located by the project in the hydrologic well measurement program. The phosphates usually occur in lenses or beds of limited thickness (a few cm to a few m) and vary in composition from calcium phosphates to aluminum phosphates. At Taïba the occurrence averages 7 m and tenors vary from very low to as much as 30% P205.

In the Basse Casamance, phosphate occurrences have been noted during oil and phosphate exploration programs; however, they have been found at depths that exceed 40 m. These deposits have tenors of ±28% P205 but are relatively thin and too deep for consideration at present. In the Kolda-Vélingara sector, phosphates of similar tenor have also been found at depths of approximately 40 m. High calcium content and complex structures would add further economic constraints to the thick overburden and the thin bedded character of the deposits.

In the middle to upper Fleuve region, phosphates occur in middle Eocene outcrops from south of Semmé to north of Thilogne (see area #13 on map). This region has been prospected frequently since the

discovery of phosphates in 1916. Phosphatic beds and lenses exceeding 5 m in thickness have been tested and yield tenors of up to 30%. The known phosphates are concentrated in the area between Kanel and Semmé, near Matam and north of Thilogne. In this region, the phosphatic formations outcrop and are easily located on the ground (stratigraphically). Marker beds associated with the phosphates can be located on aerial photography as well as on Landsat. Recent work (Plan minéral, 1985) at Ouali-Diala and N'Diendouri indicate total reserves of ±40 million metric tons of 28.7% P205. Other discoveries in the Fleuve region at N'Douloum indicate phosphatic accumulation of up to 3 m under 9 m of overburden with tenors of 30 to 33% P205.

It would seem that this region, which is to undergo revolutionary agrarian changes due to the controlled influx of water to be made available from the Manantali Dam, will be in need of inexpensive sources of phosphates and thus deserves to be considered as a prime area for further exploration and development of its phosphate resources.

Phosphate fertilizers which are badly needed by Senegalese farmers remain out of their economic reach in spite of the widespread occurrence of rich deposits throughout Senegal. Research continues in an effort to find methods which will permit the direct use of chemically treated, crushed calcium phosphates. Such a discovery will presage the day of widespread usage of inexpensive phosphate fertilizers in Senegal and other parts of the world where soils are being depleted and crop yields are decreasing yearly.

Landsat imagery analysis suggests that Eocene formations outcrop quite extensively along the Anambé River and beyond to the Nieri Ko River. The project has mapped large areas of this terrain as undifferentiated Eocene sediments (ei). We have also noted stratigraphic "contacts" from as far in the southwest as the Anambé Dome to Noumayel in the northeast which we believe are suggestive of early to middle Tertiary contacts beneath the "Continental Terminal" and the lateritic cap. We believe that this area should be considered as an exploration target for phosphates although not a primary one. The primary areas are in the area immediately north of Taïba and in the Matam-Thilogne region.

The following tables taken from the Plan minéral (1985) show phosphate production since 1950, for the two major producing mines.

Table 3.1 Compagnie Sénégalaise des Phosphates de Taïba
Production and Export Statistics: 1960 to 1982

YEAR	PRODUCTION (t)	TOTAL SALES (t)
1. Aluminium Phosphate		
1950	11 910	9 383
1951	23 570	29 828
1952	43 388	38 862
1953	52 426	43 650
1954	73 237	47 213
1955	104 453	48 607
1956	68 222	29 295
1957	89 852	68 845
1958	104 581	70 220
1959	95 341	71 820
1960	105 292	98 999
1961	139 380	90 498
1962	141 426	77 030
1963	125 814	83 643
1964	120 939	97 065
1965	134 940	108 350
1966	144 781	81 100
1967	151 282	93 120
1968	160 398	99 470
1969	164 445	93 335
1970	130 388	94 150
1971	146 632	98 762
1972	165 646	106 765
1973	218 895	134 272
1974	405 362	223 768
1975	201 445	158 839
1976	207 682	147 069
1977	274 510	148 865
1978	203 921	115 930
1979	184 884	103 730
1980	224 141	77 430
1981	199 218	50 819
1982	279 181	76 538
1983	251 274	68 518
Total	5 148 856	2 990 788

YEAR	PRODUCTION (t)	TOTAL SALES (t)
2. Dewatere (calcinated) aluminum phosphate		
1954	17 160	11 450
1955	27 740	26 722
1956	41 697	35 238
1957	12 788	18 771
1958	15 304	10 233
1959	16 154	18 428
1960	23 622	22 130
1961	31 107	20 730
1962	41 682	33 940
1963	15 837	21 960
1964	32 254	17 830
1965	28 639	26 470
1966	51 908	31 635
1967	51 762	36 385
1968	43 638	38 913
1969	36 666	36 470
1970	38 323	33 165
1971	45 737	46 075
1972	52 338	39 580
1973	63 816	66 130
1974	96 798	88 174
1975	51 762	40 132
1976	88 165	55 731
1977	37 091	52 135
1978	47 859	54 221
1979	78 361	66 734
1980	131 838	111 825
1981	105 534	112 747
1982	136 130	126 105
1983	143 558	134 662
Total	1 605 358	1 434 638

YEAR	PRODUCTION (t)	TOTAL SALES (t)
3. Phospal		
1955	132	-
1956	1 256	1 375
1957	835	585
1958	2 815	3 062
1959	2 189	2 190
1960	947	790
1961	6 993	6 745
1962	5 669	3 978
1963	796	2 680
1964	9 805	9 805
1965	7 441	6 747
1966	18 904	16 270
1967	9 631	8 548
1968	6 335	9 349
1969	2 684	2 637
1970	5 985	5 887
1971	1 907	2 315
1972	6 238	6 123
1973	5 407	5 669
1974	4 914	4 501
1975	7 699	7 747
1976	6 084	5 846
1977	5 587	5 697
1978	6 419	7 144
1979	6 740	5 761
1980	6 567	5 256
1981	4 984	4 784
1982	2 339	1 498
1983	5	575
Total	147 307	133 572

YEAR	PRODUCTION (t)	TOTAL SALES (t)
4.		
1951	4 000	808
1952	22 695	5 000
1953	45 820	17 439
1954	0	5 270
1955	0	4 328
1956-1960	0	0
1961	0	301
1962	0	226
1963	5 500	0
1964-1973	0	0
1974	12 490	8 985
1975	49 971	44 897
1976	49 123	47 698
1977	67 985	65 530
1978	95 800	98 386
1979	127 718	120 919
1980	137 447	143 737
1981	68 291	78 865
1982	111 794	75 760
1983	40 655	44 950
Total	839 289	771 103

Table 3.2

Compagnie Sénégalaise des Phosphates de Taïba

Production and Export Statistics

From 1960 to 1982

YEAR	PRODUCTION (t)	TOTAL SALES (t)
1960	103 000	80 244
1961	390 000	340 205
1962	418 000	342 383
1963	446 000	459 983
1964	650 000	714 269
1965	867 000	824 787
1966	990 000	1 077 826
1967	1 115 000	815 567
1968	1 110 000	952 955
1970	998 000	1 002 419
1971	1 396 000	1 230 419
1972	1 250 000	1 515 859
1973	1 533 000	1 610 999
1974	1 472 000	1 650 999
1974 sic	1 472 000	1 650 724
1975	1 550 000	1 332 844
1976	1 542 000	1 322 566
1977	1 528 000	1 583 276
1978	1 460 000	1 541 322
1979	1 523 000	1 551 425
1980	1 288 000	1 230 226
1981	1 792 000	1 128 828
1982	840 000	1 184 820
1983	1 213 000	1 306 678
Total	26 946 000	26 451 623

C. Metallic Minerals, Precious Metals and Other Economically Viable Substances

1. Introduction

The objectives of our project did not include an extensive mineral exploration effort, and the limited duration of our time in the field precluded any in-depth sampling. In fact, one of our sorties (the last) into the mineral rich area of Senegal Oriental was cut short by transportation problems, and our last overflight over this same area had to be cancelled due to poor visibility. Nevertheless, the project visited some of the most important metallogenic areas, including Mako, Kossanto, Saraya, Gabou and Bandafassi. Some minor prospecting was done and new prospects were found which were previously noted in interim reports during the life of the project.

Because it was the main objective of the Plan minéral (1985) to summarize the mineral potential of Senegal, our report will only summarize our findings and attempt to provide suggestions for future exploration work. The basis for such recommendations includes the integration of previous work, our findings and the tectonic map we have developed. The combination of these elements can be seen on our map entitled, "Carte du Potentiel en Eau, des Gîtes et du Potentiel Métallogenique".

2. Summary of the Project's Discoveries

a. Gold

The project geologists made an effort to investigate the gold deposits of Senegal Oriental because of its history as a producer of gold.

Recent work by the BRGM at Sabodala has indicated ±5 grams g/tn or ±0.15 oz/tn in a quartz stockwork in Birrimian rocks. The total ore reserves are 11 million tons (BRGM, Dec. 1984). Other numerous exploration efforts have been carried out in Senegal Oriental, including work by the UNDP Special Fund and private companies.

Quoting from the colonial sources, P. Curtin (1975) puts the placer gold content or tenor of gold bearing sediments in eastern Senegal at 0.6 to 8.4 g/m^3. The project geologists visited numerous sites where gold was being panned either in the streams or in pits dug to bedrock. Based on these visits, an approximate average tenor for the gold produced from these sources was estimated to be 2.5 to 5 g/m^3. These tenors are not general but occur in stream gravels, sediments and terraces associated in particular with the Mako, Dialé and Daléma series.

The project visited a number of placer producing areas, among them Mako, Koulountou and Lamina-Sillacounda on the Gambia River, Daloto, Sambarabougou and Madina on the Dialé and Kossanto. At Mako, Lamina, Kossanto and Koulountou, project personnel saw individuals panning for gold. This entire region continues to produce placer gold during low water on the Gambia River and at various periods when such work does not interfere with agricultural activities.

South of Lamina on the Daguiri, project scientists were able to see panning in progress and to make an estimate of production. Here a panner washed 20 to 30 colors from 2 l of gravel from a 25 cm thick gravel bearing horizon found 3 m below the surrounding surface and about 50 cm above bedrock (Dialé schists). This amount would be equivalent to 8 to 15 gr/m^3 of gold or about \$100.00/m^3.

This figure would indicate that this area is a prolific gold producer. Unfortunately, this gold producing layer (Fig. 3.19) was identified by the project geologist in a road cut and is not normally

accessible to local "miners". Most panners work in the river gravels which are much less rich, although a few rich spots are occassionally discovered. Normal return from the river gravels is 2 colors from 1 l of sediment or about $14.00/m^3. It is estimated that an individual using a 5 l batea or pan, which is a calabas cut in half, can pan approximately 4 bateas or 20 l an hour, or a maximum of 200 l a day, providing the panner with about +0.2 g of gold a day or about $2.50 (approximately equal to 1000 CFA/day).

Fig. 3.19. This photograph shows outcrops of sand and gravel in a new road cut at the Daguéri River between Kédougou and Saraya. The gravel horizon at the laborer's left hand is a widespread gold-bearing horizon.

These figures are approximations but clearly indicate that gold mining from placer deposits is not a viable livelihood, not only due to the arduous labor involved, but also because of the intermittent availability of water.

Nevertheless, the local population continues to mine gold as it has for hundreds of years (Curtin, 1975). In Mako, the project visited a local gold buyer who estimated that approximately 2 kg of gold are bought each week by local purchasers to be resold to outsiders--mostly Malians. At Kossanto in the valley just below the village, over 50 gold mining pits were counted. These pits are 60 to 80 cm in width and usually reach bedrock at less than 2 m in depth where most of the gold is found. At Koulountou, most of the village was panning for gold during our visit, and at Lamina on the Gambia River (Fig. 3.20), we watched the village chief weigh a total of over 72 g of gold from the accumulated diggings of approximately 10 families. The largest nugget seen measured 1.2 cm x 1 cm x 0.3 cm. Generally, however, the gold is very fine to fine. The nugget described above was viewed through a 10x magnifying glass and showed subcrystalline to euhedral crystal faces indicative of short transport and a nearby source.

The UNDP (1963-1969) on several missions attempted to evaluate the placer gold deposits of Senegal Oriental, but the results were inconclusive. The most thorough effort was planned as part of a diamond prospecting program and so was carried out as a by-product. The BRGM has nevertheless taken out a large concession on the Falémé River from south of Limalo to Satadougou Bafé. This stretch of the Falémé River and others to the north and south have long been known as gold producing areas, and it is expected that deeper levels of the river gravels which are not attainable by manual methods may prove economical when dredges are used.

During its Landsat interpretation, the project was able to define a number of fossil channels of the Falémé River parallel to the present river. Most of these channels are on the Malian side, but a few are on Senegalese territory. These channels have good potential for placer gold.

As noted earlier in this chapter, the project has also proposed that the Gambia River south of Kédougou has been captured by its present downstream segment and that previously the upper Gambia River flowed north along the Dialé drainage. If this hypothesis is correct, then the entire Dialé River drainage basin which is underlain by gold bearing Dialé Series rocks becomes a significant target for placer gold deposits. We conclude that terraces and alluvial flats in the Kédougou-Ségoto axis have potential for placer gold.

Tin, tungsten and platinum could also be won from these deposits and have been reported at numerous locations throughout this sector (see Water and Mineral map).

Fig. 3.20. Gold-bearing conglomerate from the banks of the Diaguéri River, Senegal Oriental. The occurrence is located where a new bridge is being built on the Saraya to Kédougou road. The conglomerate occurs as a widespread layer 15 to 50 cm thick. This gold-bearing horizon rests on a saprolitized erosion surface of Dialé schists and is overlain by 2.5 m of gravel, 1 m of laterite and a few cm of sandy soil.

A rapid glance at the mineral location map of Senegal will show widespread occurrence of gold (both placer and hard rock, vein or disseminated) in Senegal. The ubiquitous nature of gold in Senegal Oriental is not surprising. Similar rocks in Mali and Guinea have been for many years producers of gold.

Rock types with potential for gold are indicated on our map as areas 1, 6, 7, 8, 9, 10, 11 and 12 and do not include any placer deposits. The areas with the highest potential are, in our opinion, 6, 9, 11 and 12. These choices are made on the basis of previous exploration results and the potential of the rocks as mapped.

Recent evaluation of the Sabodala gold deposit and the discovery of gold values in jasperoid rocks of the Bakel Series (personal communication 1985 Dir. des Mines et Géo., Dakar) would suggest that Senegal Oriental has not yet been fully explored and should provide the impetus for more exploration in this region.

It is improbable (though not impossible) that placer deposits will ever provide tenors and volumes to support a major gold mining operation. These deposits do nevertheless provide a partial means of support for many agriculturalists in Senegal Oriental and will continue to do so no matter what the price of gold. This local production can be an excellent means of locating hard rock deposits and could also provide Senegal with foreign exchange. However, it is estimated by local gold panners that 80% of the gold is sold to Malians and only 20% finds it way to Dakar.

To solve this problem and to help locate new hard rock deposits, it is suggested that the government of Senegal set up comptoir to buy placer gold at a fixed price. Each seller would be given a receipt showing name of seller, village of origin of gold, weight of gold, etc. Such a system would not only increase the government's hard currency, but would provide geologists with exact data on the source of gold and enable them to evaluate the potential of the associated source rocks. The areas (villages) with the highest production figures would become targets for hard rock exploration.

b. Chrome

Ultrabasic sequences of the Mako Series and younger serpentinized equivalents of the Bakel Series near Gabou have potential for nickel, copper, chromite, platinum and gold in podiform or vein-type deposits.

The obduction of the Mako Series of ophiolites and the associated ultrabasic sequences is Eburnean, whereas the serpentinized and smaller wedges of ultrabasic rocks in the Gabou area were probably emplaced either during the Taconic/Caledonian or the Hercynian orogeny. Various authors have described these rocks, but considerable work remains to be done to evaluate the potential of these deposits. The Gabou chromite deposits have been explored and described by various authors, including

M. Petkovic, 1967. In the case of the Mako Series, a limited amount of work has been done to explore the chrome potential. Rather, the exploration effort was directed toward establishing the nickel and copper potential of these rocks.

The Gabou area was sampled by the project at two sites. The first, on a large hill 7 km north of Gabou (Diabal), is composed almost entirely of ultrabasic rocks. These rocks are serpentinized, chromite and chrome related minerals (Williamsite and chromium antigorite) and are easily recognized in hand specimens. The hill is about 1 km in length and about 20 to 30 m above the surrounding terrain. Contacts with other rocks are slickensided and much faulted. The country rock is a fine bedded, much weathered, schist or phyllite. This occurrence resembles a thrust slice of basement rock such as those found in the Bay of Islands igneous complex in western Newfoundland (Smith, 1958).

Another ultrabasic body was sampled 1 km south of Gabou. At this site, the rocks are massive and very dense and appear to be metamorphosed equivalents of dunites. That this site has been much explored is attested to by numerous pits and trenches. Samples V-33, V-33-B and V-34 (Appendix A, Tables III-3 and III-4) were taken in this area and analyzed for chrome. The serpentinized deposits at Diabal yielded (#V-34) 2250 ppm Cr.

The Koulountou pyroxenites, which outcrop in a large hill just west of Koulountou, are massive, very dense and occasionally serpentinized in very thin layers. The entire hill appears mineralogically homogeneous. This area has been carefully studied by the BRGM (Plan minéral, 1985) and was evaluated for nickel and copper but not for chrome.

The Koulountou pyroxenite assemblage yielded as much as 14,000 ppm Cr. The project's identification of high chrome values in these rocks may be considered a new find.

Although the BRGM identified an ultrabasic sill which resembles a layered complex, it does not believe (Plan minéral, 1985) that this area holds any promise for nickel and copper. Nevertheless, the BRGM has taken a large concession over the Koulountou and Kaneméré area.

Although the above results cannot be considered very positive, they are interesting and should be viewed in the context of the region's tectonic framework. Our conclusions are that the ultramaphic/ophiolitic zone of Birrimian and Bakel Series rocks should be reviewed in an effort to find the source of the chrome and to locate typical ophiolitic sequences of rocks such as pillow lavas and associated fumarolic massive sulfides.

To do this, we suggest that

1. the structural/tectonic framework of the Bakel and Mako series be re-analyzed using aerial photographs, Landsat, TM, SPOT, and, if available, side imaging radar.

2. available magnetic and gravity data be re-analyzed to ascertain whether or not the Mako Series is allochtonous or autochtonous.

3. as a corollary to the above (2) the gravimetric and magnetic data be re-analyzed to locate the root zone of the ultrabasic rocks of the Bakel and Mako series.

4. the Mako Series be analyzed petrographically to determine its relative position in the typical sequence of magmatic differentiation of peridotites (i.e., do these rocks belong in the upper gabbroic sections of the differentiate or are they related to the harzburgite/lherzolite transition zone?) (Leblanc and Violette, 1983).

5. the Mako Series be reviewed with attention to the possible existence of platinum group metals and gold.

6. the marginal rocks of this series, namely, the Kakadian granitoid series be reviewed with particular attention given to searching for mineral deposits (volcano-sedimentary sequences) near spreading axes, such as those recently found in Oman (Alabaster and Pearce, 1985) in association with pillow basalts, rhyolite and obsidian lavas.

7. the regional magnetic and gravity data be re-analyzed in the Gabou area to identify the areas where ultrabasic rocks might occur.

8. the volcano-sedimentary stratigraphy of the Gabou region be reviewed in an effort to establish the relationships of the jasperoid rocks to volcanic centers and their potential for gold.

The potential for chrome and related minerals (Pt, Ni, Cu, Au) exists in areas 6 and 11 on the Mineral Potential Map.

c. Lead, Zinc, Silver Mineralization

This "family" of minerals is often associated with lava sequences and volcano-sedimentary deposits that are related to rift systems, such as the ophiolites of Senegal Oriental. A number of models have been proposed to explain the occurrence of mineral deposits along ocean-spreading centers (Hutchinson, 1983); however, no model seems to fulfill all of the requirements of Senegal Oriental because we still know too little about the exact rock chemistry, structure and stratigraphic succession of this region. Perhaps the most appropriate model for Senegal Oriental is a combination of the Oman ophiolite

(Alabaster and Pearce, 1985) and the Bay of Islands ultrabasic complex in Newfoundland (Smith, 1958). The important inference to draw from this combined model is that we should expect to find lead, zinc and silver, as well as copper and gold deposits, associated with zones of hydrothermal convection in basaltic pillow lavas deposited at a marginal basin spreading axis. These rocks would include part of the Diale Series and the partially contemporaneous Kakadian, the rocks of which were later recrystallized (granitized) during the compression and obduction of the Mako Series.

The ore-forming environment of the Kakadian Series is the most closely related to the primary, hydrothermal, massive sulfide type of environment inherent to the marginal basin spreading axis model. However, rocks of the Dialé Series also constitute potential ore-producing environments (Pb, Zn, Ag), especially where they are represented by metamorphosed equivalents of sebkha type environments. These we believe can be found in the shaley, calcareous and cherty environments of the Bandafassi-Ibel sector. It is possible that the fluidization of these rocks, evidenced by thin, tight folding and displacement, was a result of a high content of water and anhydrite, which acted as a lubricant during compression and thrusting. During deposition these rocks would have accumulated high levels of metal ions due to their proximity to the marginal basin spreading axis. The metals could have been concentrated either in brines or by biogenic activity, or both. In addition, Kuroko-type deposits should not be ruled out for units mapped as 2, 6, 8, 9 and 10.

During the project's field work, a new lead, zinc, silver prospect was found in the marble sequence northwest of Bandafassi. The first site, at a small marble quarry, was sampled where lead, zinc mineralization was visible in small veins. This sample (#35) yielded 11 ppm Zn, 105 ppm Pb and 1.2 ppm Ag. The second sample (#37) was collected as a chip sample across steeply dipping limestone beds along a stream on the western flank of a small monzonite intrusive 3 km northwest of Bandafassi. Samples V-37 through V37-V show low values of zinc (up to 62 ppm) and silver up to 1.7 ppm.

These two occurrences are not highly encouraging but do indicate that the district has a potential which deserves further investigation. Another area that may hold promise for base and precious metal accumulations occurs in the region bordering Guinea (area 4 on map). This area is underlain by the Ségou-Madina Kouta Series. At the base of this series, there has been described a metal-rich yellow bed (formation jaune) which deserves further evaluation in view of the possibilities for syngenetic, biogenically concentrated ore deposits like those of Daniels Harbor, Newfoundland and similar deposits in the copper belt of Zambia. It should be noted that stromalolitic sequences are excellent guides to ore deposits in the above examples and should be used to search for base metals in the Ségou-Madina Kouta Series.

d. Tin, Tungsten, Molybdenum, Lithium, Niobium, Tantalum and Other Rare Earth and Exotic Minerals (areas 1, 2, 3, 5, 7 and 12)

These elements usually occur in association with acid igneous plutons and their extrusive equivalents and granitized sequences, including, rhyolites, acid tuffs, pegmatites and other anorogenic suites. Subcrustal plume movement is thought to be responsible for the migmatization and granitization (Saraya and Boboti) phenomena in Senegal Oriental, as well as for the emplacement of postorogenic granites of the Bondoukou type.

In the case of the Saraya granitic rocks and their uranium mineralization, we can paraphrase M. Cuney (1978), who summarized the similar Bois Noir deposits in the Massif Central of France in the following manner: The Bois Noir granite resulted from anatexis of uranium-rich sediments near granulite-facies conditions. The temperature of anatexis is estimated at 800°C. The magma was syntectonically emplaced along an east-west structure into a nonmetamorphic, higher crustal environment. As the mass cooled, late phase magmatic fluids migrated upward, altering the uranium bearing minerals and dissolving and remobilizing the constituent uranium. This uranium was redeposited in a hydrothermal matrix as uraninite and was later greissenized. Such a scenario is supported by work done in Nova Scotia, where anatectic granites of Devonian age were found to carry high values of uranium. These uranium concentrations coincided with the extensions of linear magnetic anomalies found in the contiguous metamorphic terrains of the Paleozoic Meguma Group. The magnetic anomalies were interpreted (Stancioff, 1978) as concentrations of heavy minerals beach placers in the metasedimentary sequence. These concentrations tended to be greater wherever regional trends (NW/SE) intersected the magnetic anomalies (i.e., where streams flowing along these trends deposited their heavy minerals in basinal depressions).

Unfortunately no information was available to the project from COGEMA, so no evaluation of the uranium potential can be made other than to propose that the very high (4000 gamma) magnetic anomaly in the core of the Saraya syncline will probably yield tenors of 1 to 2% uranium for small deposits that should be located at the intersection of NW/SE faults related to pretectonic faults and drainage controls.

The Saraya granitized rocks and similar rocks in this area, particularly the Koulounton Series and the granites associated with them must be carefully explored for tin and tungsten mineralization. Major tin deposits have been found by Billiton and Shell in Nova Scotia and New Brunswick in similar terrains. The specific tin-tungsten bearing environments are difficult to locate but are typically associated with greissenized anatectic granitization, and in the case of Mt. Pleasant, New Brunswick they are associated with post-granitization hydrothermal enrichment resulting from Mississippian acid volcanism.

The search for tantalo-columbite and tin-tungsten should be pursued in the Boboti type granodiorites (area 5), as well as in the Birrimian rocks on the east bank of the Falémé River (area 10), where pegmatitization phenomena would have been most prevalent. The late stage monzonite-quartz diorite intrusions should continue to be the focus of moly-copper porphyry exploration.

Based on work done by numerous groups in Senegal Oriental, the search for diamonds in Senegal does not seem to have much future. However, the area should not be considered sterile in view of the economic extraction of diamonds from deposits associated with rocks of Birrimian age in the Ivory Coast and Ghana. In Mali at Kéniéba, Cretaceous kimberlites (Bardet, 1974) have yielded some diamonds. It is interesting to note that M.G. Bardet has suggested that the Kéniéba kimberlite may have been emplaced along an arch which corresponds to that proposed by the project geologist to explain the location of the Senegal and Faleme drainage axis and the dearth of plateau dolerites in this arch.

As it stands, the potential for diamonds in Senegal Oriental must clearly be considered of minor importance.

The Senegalese potential of beach sands for iron and other minerals has been more than adequately discussed in the Plan minéral (1985), and in view of the low economic return expected from the iron ore which is presently overabundant and the low tenors and high ratio of ilmenite vis-a-vis the more valuable heavy minerals (e.g., monazite, zircon), it would seem unjustified to explore these mineral deposits.

3. Conclusion

Any investment in the development of Senegalese mineral resources should concentrate on highly valuable minerals, particularly gold, silver, tungsten and chrome. Minerals that are in overabundant supply, such as iron, copper and nickel, should only secondarily occupy explorationists. If Senegal is to earn foreign exchange, it must locate marketable mineral deposits and not compete on the world market where depressed prices could negatively affect the economy of a country that has borrowed heavily to develop such a resource.

For the Senegalese mining sector to develop, it would be appropriate if new and better maps were produced of Senegal Oriental at a scale of 1:50,000 and if they were disseminated by international organizations which should be called upon to assist in this mapping effort.

3.10 HYDROLOGY

3.10.1 Introduction

A very large body of detailed work has been produced describing numerous aspects of the hydrology of Senegal. Unfortunately, few summary works exist which integrate this mass of data. Senegal still lacks a document which collates this information and derives from it an assessment of the availability of water, the real needs of the various sectors of the economy and the true potential of the Senegalese landmass as a water reservoir.

The work done by our project cannot provide final solutions to any of these problems. We have tried to evaluate the available information, collect new information, interpret old and new data (Landsat) and recommend what many others have suggested before us. The conclusion reached by workers in the field is that the aquifers in Senegal must be thoroughly and scientifically tested to establish their potential.

A recent work, Projet d'étude hydrogéologique de la bordure meridoniale du Ferlo entre Kaffrine et Tambacounda (1983) has proposed a Landsat analysis for the aforementioned region. This project is presently being supervised by the Director des Etudes Hydrauliques. An initial Landsat analysis has been conducted by J. Le Priol, consultant to the Ministère de l'Hydraulique. This study and others provide proof that much additional work needs to be done to evaluate the hydrologic resources of Senegal.

Aside from the fact that little or no integration of hydrologic data has been done, two other problem areas were considered significant. What has been the effect of the latest drought cycle on the water supplies of Senegal and what are the structural controls of the Senegalese aquifers? In an attempt to answer these two questions our project divided its hydrologic work into two categories, Landsat interpretation and collection of field data, and the comparison and analysis of this data.

The Landsat interpretation and the interpretation of pre-existing data yielded the following information:

1. The structure of the Senegalese Sedimentary Basin aquifers is complex, and by inference they cannot be considered as continuous nor as increasing in thickness from east to west.

2. A number of previously unidentified fossil river channels are now known.

3. Structures (fractures and faults) act as controls on the water reservoirs of the Sedimentary Basin.

The field data suggests that the following:

1. Some drawdown has occurred in certain areas and on specific aquifers.

2. In general, aquifer water levels have not dropped, but population demands have strained existing wells.

3. Wells are not cleaned often enough. With increasing use, cleaning should be done at least twice a year.

4. Wells are often dug only to the top of aquifers.

5. Some saline incursion has taken place, particularly in the Sine Saloum and Petite Côte.

3.10.2 Overview

Any assessment of previous work and the data collected by this project must take into account the Senegalese peasants' sum total of knowledge. The "collective unconscious" of the peoples of Senegal resulted in the settlement patterns that existed before colonial times. The Senegalese peasant knew where water was to be found not because he was scientifically able to understand its presence but because generations of Senegalese peasants from all the ethnic groups have (as have most Sahelian and Saharan peoples) for many thousands of years lived under the pressure of decreasing rainfall in northern Africa and so have through experience chosen the sites where underground or surface waters were certain to meet their needs.

Lacustrine deposits throughout Senegal have been dated by C-14 at between 12,000 and 7300 B.P. (Michel, 1973). The thick deposits of fern pollen from this same period located in the Senegal River Valley attest to a much more humid climate until 7000 B.P. (Desertification: its causes and consequences, 1972). Much of the fresh water found in Saharan and Sahelian surficial aquifers probably accumulated during this more humid period. At about 7000 B.P., began the renewal of a drier climate, which probably lasted until about 700 A.D. when a short period of humid climate permitted vegetation to stabilize many of the dunes that traverse northern and central Senegal. Since approximately 1000 A.D., the climate has become progressively drier and forced the peoples of the region to return to the security of the large river, the niayes and the intermittent streams which provide continuous near surface supplies. Clearly then, the indigenous populations of Senegal from at least the late Paleolithic ±8000 B.P. have been concerned with stable supplies of water and were aware of their existence.

If the Senegalese peasant is aware of his hydrologic environment, what then are the problems we face today? The "industrialization" of the agricultural sector of western Africa during the 19th and 20th centuries placed a heavy burden on water supplies in northern and

western Africa. Before the arrival of the Europeans, North and West Africans had achieved a stable relationship with their hydrologic environment through a historic knowledge of that environment. Agricultural industrialization and population increases largely due to the eradication of many diseases have produced a major population increase in the arable but relatively dry lands of west-central Senegal. This increased pressure has depleted the uppermost aquifers in this region and has forced the search for water even deeper into the subsoil.

Another area of concern is the development of deep wells in the Ferlo which have provided a year-round source of water for herds that in the past only spent short periods of time in this region. The normal period of grazing in the Ferlo depended on the length of time that temporary, rainfed lakes (mares) were available. In good (wet) years, they would last into early January and in dry years they would only last through November. The result of drilling these few wells in the Ferlo is that herd size has increased, so large areas of the very fragile northern Ferlo are being grazed year-round. They are therefore being depleted of their grass cover, thus creating new zones susceptible to eolian erosion. The areas particularly affected are those around the well sites where thousands of animals mill around, destroying ground cover and creating 5 to 10 km zones of wasteland. These factors, added to the recent lack of rainfall, are having a most dilatory effect on Senegalese man and his environment.

3.10.3 Literature Consulted

The hydrologic literature of Senegal is vast. The small part used by the project appears in the bibliography with the annotation "H". The works most often consulted by the project consist of some general texts and a few works to which we could compare our field work. The texts of major interest are P. Michel, 1973, Les Basins des fleuves Sénégal et Gambie, Etudes géomorphologiques; R. Dégallier, 1962, Hydrogéologie du Ferlo septentrional; P. Elouard, 1962, Etude géologique et hydrogéologique des formations sédimentaires du Guebla mauritanian et de la vallée du Senegal; M. Audibert, 1970, Etude hydro-agricole du bassin du fleuve Sénégal; C. Rochette, 1974, Le Bassin du fleuve Senegal, 1984; Schéma national d'aménagement du territoire (1984) and the J. Dépagne and H. Moussu Notice explicative de la carte hydrogéologique du Sénégal au 1:500,000.

3.10.4 Major Hydrologic Characteristics of Senegal

3.10.4.1 Surficial Water

A. Precipitation

The rainfall characteristics of Senegal have been discussed in Chapter II and can best be understood by reviewing the data in Maps 2.1 through 2.5 and Tables 2.1 through 2.3. A summary and analysis of

rainfall data permits the following general conclusions to be drawn:

2. Rainfall (map 2.3) in the area north of the 1000 mm isohyetal contour is probably insufficient to recharge near surface aquifers and certainly not adequate to recharge deeper aquifers.

2. Rainfall south of the 1000 mm contour provides adequate annual recharge to near surface and deeper aquifers.

3. Rainfall south of the 1000 mm contour is adequate to produce runoff and so add to the flow of the Gambia, Casamance, and Falémé-Senegal flood water volumes.

4. Rainfall in the areas south of the 1000 mm contour creates some surface erosion in the Senegal Oriental.

5. Rainfall north of the 1000 mm contour and south of the 500 mm contour provides sufficient water for agricultural (rainfed crops) purposes during years when rainfall is normal or above normal.

6. Rainfall north of the 500 mm contour is generally inadequate for normal agricultural practices and the areas north of this 500 mm limit are subject to heavy crop loss except when irrigated or flooded by the Senegal River.

7. Rainfall south of the 500 mm contour provides water in temporary ponds until early January (other than in exceptionally dry years), permitting the supply of water to the cattle herds.

8. Rainfall north of the 500 mm contour provides water in temporary ponds only until early December, permitting only a limited supply of water to cattle herds.

B. Evaporation

Table 2.3 shows evaporation rates for Senegal. They are particularly high for the areas north of the 500 mm isohyetal line. According to P. Michel (1973), evaporation rates vary daily from 3 to 8 mm in Senegal during December and January. Linguère is said to hold the record for evaporation rates which reach 10.2 mm/day in April. During the rainy season, evaporation rates decrease to 1.2 to 2.5 mm/day at Linguère. Along the coast, evaporation rates do not exceed 4 mm/day and decrease to 1.4 mm in May.

As can be seen form the above, annual evaporation rates for Senegal vary a great deal from place to place. For St. Louis, the annual rate is 900 mm, Tambacounda 1750, Podor 1770, Linguere 2400. These values are of course theoretical or potential evaporation rates

since there is little open water available for evaporation except in the Lac de Guiers, the Senegal River flood plain and a few ponds and niayes. These evaporation rates clearly indicate that any surface water remaining from the rainy season is very quickly lost to evaporation.

The total humidity lost to evaporation from the Senegalese landmass must also take into account transpiration from the vegetation cover; such losses can reach a theoretical annual high of 217 mm (Michel, 1973). A second and important means of humidity loss is evaporation due to brush fires. Approximately 60% of Senegal is subjected to bush fires. Fires are prevalent in areas of the Ferlo, eastern Saloum, Senegal Oriental and Haute Casamance, where 50 to 60% is burned annually. Brush fires dessicate the surface soils and draw water from the superficial water table, as well as increasing regional evaporation by increasing temperature levels.

C. Runoff

It is unnecessary for this report to discuss the runoff characteristics of the Senegal and Gambia rivers as this subject has been covered in exhaustive fashion by previous authors (Rochette, 1974; Michel, 1973, etc.). Suffice it to say that few streams entering the Senegal River north of Bakel provide sufficient runoff to maintain any flow at their confluence with the Senegal River. In fact, during flood periods the Senegal River enters the lower courses of its tributaries. The Senegal River (north of Bakel) receives little water from these tributaries except during torrential rains when tributaries flow for short periods. These conditions exist throughout Senegal north of the 750 mm isohyetal contour. In the region to the south of this line and particularly where the Senegal River flows over crystalline rocks (as do its tributaries), runoff is much heavier. Nevertheless, these streams are only intermittent, and no flow occurs during the dry season as can be noted in the photograph of the Falémé River taken at Nayé (Fig. 3.18).

During excessive rains, runoff occurs throughout Senegal but tends to be limited by the absorbent nature of the sandy soils and the localized nature of the rains. As soon as rain falls, most of it enters the ground or evaporates; the excess runoff joins dry (fossil) streambeds, where it quickly permeates the sediments to form water tables at various levels of these intermittent streambeds. In Senegal Oriental, this water occupies not only the old river beds but also permeates the fissures and fracture system of the Paleozoic and Precambrian bedrock, thus producing a water table that is exploitable but difficult to attain except by mechanical means. Similarly, in the Senegalese Sedimentary Basin the intermittant streams concentrate the runoff in their subsurface valleys which have been cut into the surrounding formations; they include the Continental Terminal (Oligo-Miocene), the Eocene, Paleocene and the Maestrichtian wherever it occurs near the surface. Thus, the main aquifers of the Senegalese

Sedimentary Basin that do not outcrop throughout most of the basin may be replenished or recharged by the percolation of runoff in fossil valleys (though the reverse may also be true). One area where such runoff may recharge the Maestrichtian aquifer is located north of Dagana where the Maestrichtian occurs within 20 m below the bed of the Senegal River.

Runoff causes some erosion, especially during heavy downpours (Fig. 3.21). It occurs particularly in the Gambia River Basin where small streams flowing south from the Ferlo River are retreating as a result of steeper gradients due to the downwarping of the Gambia-Casamance trough. Heavy to intermediate erosion also occurs in the upper Casamance River Basin and the upper Gambia Basin, as well as the Faleme River and its tributaries.

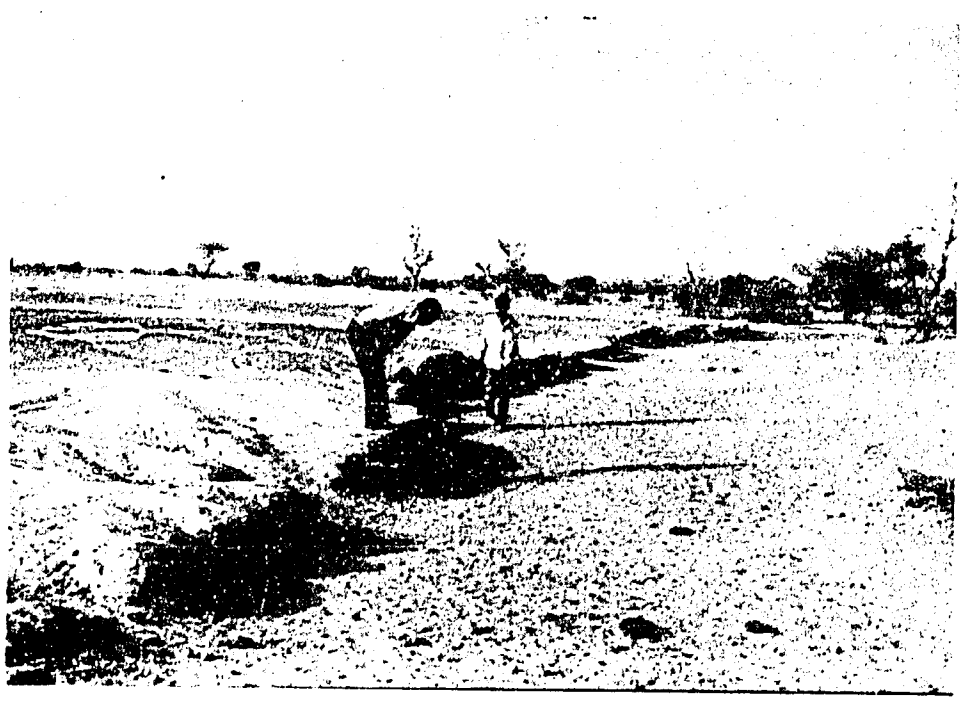
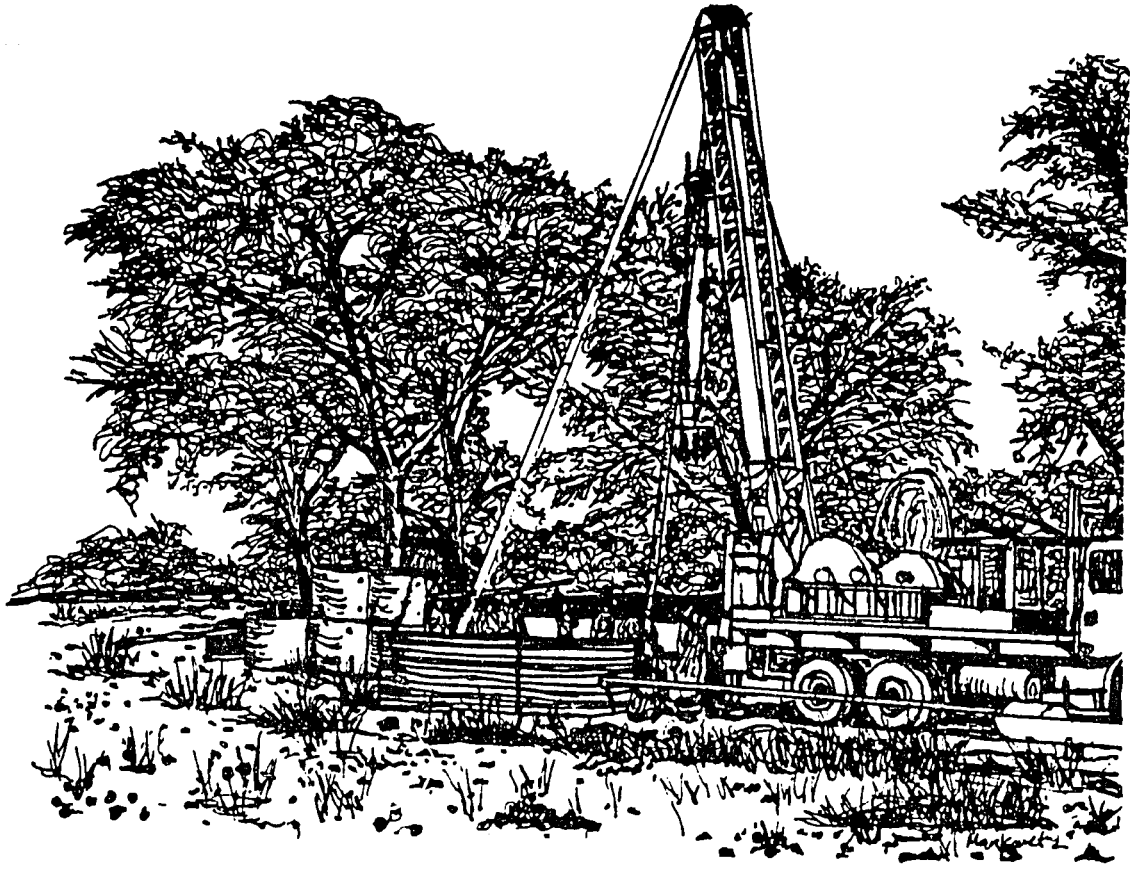


Fig. 3.21. Shallow gully erosion in the Ferlo south of Mboune. This type of erosion increases southward as one moves into the Gambia River drainage basin. April 1984.



D. Conclusions Concerning Surficial Water

It is difficult to establish a water budget for Senegal because of the complex relationships between rainfall, evaporation, transpiration, humidity, temperature, brush fires and even the effects of cultivation and other more complex but minor factors. It is estimated that evapotranspiration returns 60% of the rain of Senegal to the atmosphere during years of excessive rain, but can reach as much as 100% during years of deficit rainfall. In years when normal rainfall is exceeded, the remainder of the water either enters the underground recharge system of the aquifers or runs off the surface into streams. Thus we can conclude that in an area receiving 750 mm average rainfall only a maximum 350 mm, or 40%, enters the aquifers of the region. However, during years of rainfall deficit, no water enters the aquifers and no recharge can be expected. We can also assume that during the dry period suffered during the last 15 years little or no water has been

added to Senegal's subsurface aquifers in those areas receiving less than 750 mm rainfall.

3.10.4.2 Underground Water

There exist in Senegal a number of subsurface levels at which water occurs. In each case, the conditions under which the water collects and moves and the quality and quantity of water are different. These water sources can be classified into two types (deep and shallow) on the basis of the depth of the occurrence. In many cases, these water tables tend to influence each other where they are in contact; however, little is known about these relationships which are controlled by the permeability of the contact between formations and the structural relationships of the units.

A. Deep Aquifers

The deep aquifers of Senegal are all sedimentary formations of Cretaceous to Tertiary age. The deepest is known as the nappe profonde du Maestrichtien. Two shallower and less continuous aquifers occur in the Paleocene and Eocene.

1. The Maestrichtian Aquifer

The name "Maestrichtian" refers to the relative age (Upper Cretaceous) of this formation which underlies much of the Senegalese Sedimentary Basin. The following information relative to this formation and its water bearing potential has been gathered from various sources:

Age:	Upper Cretaceous, Maestrichtian
Lithology:	Mostly continental sands and coarse sands with occasional intercalations of shaley and calcareous materials; toward the west the lithology becomes more argillaceous.
Thickness:	Along the eastern edge of the basin the thickness of this formation is approximately 80 m and is variable as one moves west. The thickness depends on basement features in the basin. Generally it thickens to about 300 m in the center of the basin (Diourbel) and then thickens to 1000 m offshore of Senegal. The average thickness is 200 m.
Area:	+130,000 km^2
Total Water Contained:	$2.6 \times 10_{12} m^3$

Depth to Aquifer:	Variable--at surface in the Horst de Ndiass, 20 m west of Dagana, to 600 m west of Oussouye in the Casamance and +500 m in a small basin north of Tambacounda.
Water Quality:	500 mg/l residue
Present Use:	Between 10 and 20 million m^3/yr.
Recharge:	Possibly along the Senegal River between Matam and Diaba-Dekle on the Senegal River. Probable east of Dagana. Minor but certain in the Horst de Ndiass. Other sources unlikely.
Contamination:	Possible saline incursion from west at contact with saline water of Atlantic. Probable saline incursion from saline bearing water of underlying older formations in a region west of 14°30'.
Water Loss:	Possible loss of water to overlying Paleocene and Eocene sequences.
Potential per well/day:	3500 m^3
Water Origin:	Fossil (Cretaceous, Paleocene)
Porosity:	Good, 10% or more
Permeability:	Generally good. Drawdown tests at Kaolack indicate that permeability is high between wells in that area.
Other:	Water occasionally artesian in the Saloum Valley. Often rises to 40 m of the surface, permitting deep well to shallow well exchange (puits/forage).

2. The Paleocene Aquifer

The Paleocene aquifer consists mainly of limestones and calcareous shales and sands. This aquifer supplies water to a large section of western Senegal, particularly south of Thiès and in the Cap Vert Peninsula where solution channels in the Paleocene limestones are recharged by the underlying Maestrichtian sands. Two major sources of water for the Cap Vert (Dakar) draw water from this reservoir at Sébikhotane and Pout. The following information summarizes the characteristics of the Paleocene aquifer:

Age:	Lower Paleocene
Lithology:	Mostly limestones, marly limestones and marls, with sandy and shale sand horizons (Figs. 3.22 and 3.23).
Thickness:	The maximum thickness was found in drill holes at Rufisque (300 m). In the remainder of the basin, the thickness varies from 40 to 120 m (see Hydrologic map).
Area:	$\pm$120,000 km^2
Total Water Contained:	Unknown
Depth to Aquifer:	Variable, at or near surface in the Falaise de Thiès and south of Thiès to Fadiout.
Water Quality:	Variable, 400 mg/l at Pout.
Present Use:	15 to 20 million m^3/yr (mostly by Dakar from 7 wells at Pout and Sebikhotane).
Recharge:	Probably continuous from underlying Maestrichtian aquifer. In the eastern part of the Senegalese Sedimentary Basin, Paleocene and Maestrichtian sediments consist of continuous sandy facies and permit groundwater transmission from the Maestrichtian to the Paleocene.
Contamination:	Paleocene sediments outcropping along the Petite Côte permit the influx of saline oceanic waters into the karst solution channels of the Paleocene (Fig. 3.24). In the Upper Paleocene, certain marine and chemically deposited facies have a high content of dissolved salts. Their location is difficult to establish as they may have a very localized extension.
Water Loss:	The Paleocene probably loses water to the Atlantic along the Petite Côte.
Potential per well/day:	Variable, but $\pm$7500 km^3/day at Sébikhotane.

Water Origin:	Variable, partially connate and partially infiltrated from underlying Maestrichtian aquifer.
Porosity:	Generally poor except where karstification has occurred or in sandy facies.
Permeability:	Generally poor except in sandy facies.

Fig. 3.22. Well at Ndiaganiao Catholic Mission. The well was being dug in marls and fossiliferous limestones of probable Paleocene age. At 8 m the well was still dry. The well in the background was dug to 13 m and had only a trace of water.

Fig. 3.23. Group of approximately 20 trainees with instructors during a field trip carried out at the end of 1984. This group included resource specialists from the D.A.T., the University of Dakar and the ENEA and was one of 5 seminars held by the project. Location: quarry in Paleocene limestones east of Pout.

Fig. 3.24. Karst features in Paleocene limestone east of Tasset at Keur Ndiogou Ndiaye. September 1984.

3. Eocene Aquifer(s)

The lithologic composition of the 3 levels of the Eocene sediments is extremely variable laterally and vertically. Only certain levels in the mid-Eocene (Upper Lutetian) limestones have proved to be useful aquifers. They are generally located in the northwestern part of Senegal. Many village wells in west central Senegal tap these aquifers. The potential of the Eocene aquifers is difficult to determine and will require additional research. The following information summarizes the characteristics of the middle and lower Eocene aquifer:

Age:	Ypresian and Lutetian
Lithology:	Highly variable vertically and horizontally; composed mostly of marls and limestones of variable composition and origin. Lateral changes in lithology constitute a major constraint in the search for water.
Thickness:	The Ypresian varies from 40 to 120 m; it reaches its maximum thickness of 200 m south of the Senegal Delta; its base is an impermeable attapulgite. The Lutetian varies in depth across the Senegalese Sedimentary Basin from 100 to 140 m; near St. Louis the formations of the middle Eocene increase to more than 200 m.
Area:	$\pm$120,000 km^2
Total Water Contained:	Unknown
Depth to Aquifer:	Variable; it outcrops in parts of western Senegal and along the Senegal River or is covered by as much as 180 m of younger sediments in the Casamance. In western and west central Senegal where this sequence provides many wells, it occurs between 20 and 60 m of the surface.
Water Quality:	Variable, often highly alkaline and sometimes saline.
Present Use:	Unknown; probably about 1500 wells draw $\pm$5m^3/day each or a total of 7500 m^3/day

Recharge:	Where these formations are in contact with overlying permeable formations, recharge may occur through percolaton of atmospheric waters.
Contamination:	Is probable from the Sine Saloum estuary and contact of these formations with oceanic waters in the Cap Vert and along the Cayor coast.
Water Loss:	Most of the water bearing horizons consist of lenses rather than continuous layers and so probably do not lose much water to underlying or overlying formations.
Potential per well/day:	Unknown, although 2 wells east of Louga drilled by project SERPA probably tap the lower Eocene (at depths of 61 and 63 m), and yield 163 m^3/hr. and 180 m^3/hr., respectively.
Water Origin:	Probably infiltrated from overlying aquifers during a period of higher rainfall.
Porosity:	Good in certain areas (in lenses).
Permeability:	Good locally but generally poor.

B. "Shallow" Aquifers

The shallow aquifers of Senegal constitute the major source of water for most villages. These aquifers include superficial formations of Tertiary, Quaternary and Recent age. They include the uppermost Eocene and Mio-Pliocene sediments of the Casamance trough, the ubiquitous "Continental Terminal" deposits of the eastern basin, the dune and interdune sediments of the Niayes region, the subvolcanic (infrabasaltic) sands of the Cap Vert Peninsula, the alluvial sediments of the Senegal and Gambia rivers and other streams, and the fossil alluvial deposits of the Ferlo, Saloum and western Senegal.

1. The Uppermost Eocene

The formations comprising this series are only found in the Casamance trough, and due to their argillaceous nature make very poor aquifers.

2. The Mio-Pliocene Sediments of the Casamance

These sediments are generally argillaceous, but near the coast at Cap Skirring (Fig. 3.14) and on the coast of the Gambia River there occur coarse ferruginous sands which in Basse Casamance serve as the main aquifer for small villages, such as Essaout, Kabrousse, and the resort area of Cap Skirring. Water is found from 3 to 8 m below the surface in coarse cross-bedded sands. The quality of the water is good. The potential of this aquifer cannot be measured. It is also probable that because of its interface with saline waters it will be easily permeated by salt water if heavy demands are made of it. Recent droughts have caused a lowering of the water table in the Basse Casamance, but changes are difficult to measure because of the highly faulted nature of this area and differential compaction of the sediments due to drawdown on the aquifer.

3. The "Continental Terminal" (Mio-Pliocene of the Internal Part of the Sedimentary Basin)

Much of the eastern and southern part of the Senegal Sedimentary Basin is covered by continental deposits referred to as the Continental Terminal. Recent work has indicated that these sediments are of Mio-Pliocene Age and that they may be at least in part of marine origin. These sediments tend to be sandy or shaley sands and reach a maximum thickness of 150 m north of Tambacounda. Because of their porosity and permeability, they are the captors for much of the rain that falls in the eastern part of the Senegalese Sedimentary Basin. They are therefore one of the main shallow aquifers of the Ferlo, Ferlo Boundou, Ferlo Djolof, Ouli, and parts of the Niari, Pakao and Rip (see map 2.3, Geohydrology map and Fig. 3.25). The Continental Terminal is often capped by laterites which act as relatively impermeable barriers to the passage of water and tend to provide for runoff toward the areas where the laterites have been dissected and eroded. Runoff concentrates in these valleys and enters into the Continental Terminal along preferential directions which usually correspond to fractures or faults.

The Continental Terminal probably covers over 80,000 km^2 and has an average thickness of 40 m. The water from this aquifer is of good quality, and dissolved solids are not excessive. The water bearing potential of this aquifer is difficult to estimate, but it does presently constitute a prime source of water in Senegal due to its role as the primary collector of rain water.

4. The Aquifer of the Niayes Region

The coastal dunes which stretch from Dakar north to St. Louis are a major water reservoir (Fig. 3.17). Most of the water which accumulates in them originates from rainfall. The high porosity (30 to 35%) of these sands and their extreme permeability provide for rapid

Fig. 3.25. Well being dug in "Continental Terminal" near Koutia Bã in the Ferlo. This well had reached 40 m without tapping any aquifers.

concentration and accumulation of atmospheric water. Unfortunately, during periods of drought these reservoirs are quickly depleted. This resource should not be considered as having a potential but for the Niayes themselves (Fig. 3.26), because any pumping of this aquifer would result in the replacement of fresh water by salt water (Arnaud, 1952). Nevertheless, this aquifer has been heavily exploited at Thiaroye where the dune sands exceed 50 m. Generally these sands average 15 to 25 m in thickness. J. Dépagne and H. Mousseau (1967) consider this aquifer (from Dakar to Kayar) as having a potential production of 100,000 m^3/day. They add that this source of water is underused in the Niayes where it supplies water for horticultural purposes. In 1967, production from this aquifer was 12,000 m^3/day.

Fig. 3.26. The figure above shows a saline delta in Lake Retba. During high tides induced by storms, sea water enter Lake Retba and forms this delta, raising the saline water level and permeating the surrounding dunes. The rectangular dark patches are reforested beach sands.

5. The Subvolcanic (nappe infrabasaltique) Aquifer of Cap Vert

Similar to those sands described in 4, these dune sands dip beneath the extruded volcanic rocks of Quaternary age. Until 1952 these sands supplied the entire needs of Dakar from 14 wells which tap a 50 m sand aquifer. In 1967, these wells provided from 16,000 to 18,000 m^3/day of high quality water. Their potential is unknown.

6. The Alluvial Deposits of the Senegal and Other Rivers

During the rainy season, the valley sediments of all the streams in Senegal accumulate large volumes of water which in most cases migrate to the underlying water tables. In the case of the Senegal River, the annual high waters submerge most of the valley and refill the underlying aquifer, as well as supplying water laterally to such

other aquifers as the Eocene, Paleocene, and possibly even the Maestrichtian. Other streams that possess broad valleys in which large amounts of water accumulate in superficial aquifers and from which water is also probably distributed laterally into adjacent aquifers include, the Gambia, Casamance, Falémé Niokolo Koba, Niéri Ko, Koulountou, Kambaya, Sanone, Sandougou, Gandamaka. To a lesser extent, the Saloum, Sine Tarare, and the entire Ferlo system also act as collectors of rain water that accumulates in perched or deeper aquifers.

The total volume of water in these aquifers is immeasurable and only significant in terms of development where other sources are not available. Once the Diama and Manantali dams are built, the Senegal River Basin should have a stable water table which will only vary depending on the rainfall in the flood plain itself. When these alluvial aquifers occur near the ocean, any decision for major use of their water must be based on the effects of possible saline incursion into the aquifers.

7. The Fossil Valleys of Senegal

The fossil valleys of Senegal are outlined on available maps where they can be seen as clear topographic features. Thus the Sine, Saloum, Ferlo, and Tarare are clearly delineated. These streams were active during the Quaternary and earlier during the Tertiary. The significance of these fossil alluvial deposits as aquifers gains in importance when we realize that the streambeds contain as much as 50 m of highly permeable and porous alluvial sediments which filled these valleys since the time of Quaternary glacial low sea levels. During low sea levels and periods of higher rainfall, the streams were active and cut their beds to base levels far below their present levels. As sea level returned to its present state, the deeply incised river valleys began to fill with sediment (and water) and now constitute a considerable source of fresh water. In fact, we have found that many villages in the Ferlo are located on these fossil rivers and draw water from these relatively "shallow" aquifers. Water pressure in some of these wells is very strong and supplies large volumes to satisfy village needs for both people and livestock.

Interpretation of Landsat imagery has identified a large number of such fossil streams (Fig. 3.16), and we propose that these valleys be used to augment the water supply of many communities in the Groundnut Basin and the Ferlo. We proposed earlier in this report, that the entire Sedimentary Basin was drained by such streams, which formed an east-west system. Many of the streams flowed into a major river which emptied into the ocean via the Kayar Canyon. It is probable that the Gambia River and its tributaries also flowed northwest toward this river, whereas the Ferlo-Gorgol rivers drained into the Atlantic south of St. Louis. If this hypothesis is correct, then there exist many water bearing fossil stream beds in the Groundnut Basin and eastward in the Ferlo.

8. Other Aquifers in Crystalline Rocks

In Senegal Oriental the water table is related to the crystalline, metamorphic, and metasedimentary rocks of the region. None of the Paleozoic or Birrimian series provide widespread homogeneous aquifers accessible to the local population. Notwithstanding the problems of accessibility, Senegal Oriental offers a large source of subsurface water but one that must be tapped by means which are locally considered unconventional. Such wells must be drilled and equipped with small hand pumps. Most of the water now used by the local population is drawn from shallow wells or temporary excavations called céanes (Fig. 3.27).

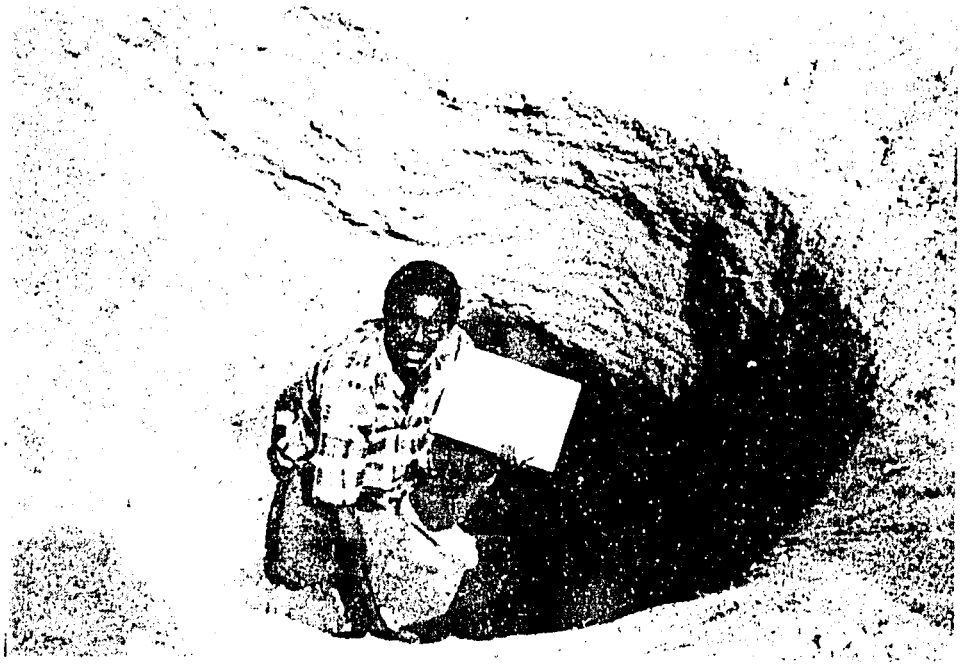


Fig. 3.27. A typical céane in Senegal Oriental. Water is "ladled" out in buckets.

Unquestionably structural and stratigraphic factors affect the location of water in this region. In the Bakel Series in particular, water should be sought in the broad downfolded schist sections which occur between the quartzitic ridges. Wells should be located whenever possible in highly fractured areas and where two major faults intersect. This method applies to all the Paleozoic and Precambrian soils of Senegal Oriental.

3.10.4.3 Structural Controls of Aquifers

Major structures affect the location, static level, quantity and quality of all but a few of the aquifers in Senegal. This effect is particularly notable in the more continuous aquifers, such as the Maestrichtian, Paleocene, Eocene and Continental Terminal. A glance at the Hydrologic and the Tectonic maps of Senegal shows that the Maestrichtian aquifer clearly rises to within 20 m of the surface near Dagana in what is known as the Dahra anticline. This occurrence brings the Maestrichtian water table to within a few meters of the surface in a large area of northern Senegal. Conversely, in the region of Tambacounda the Maestrichtian is found in a large depression. This depression, though more difficult to exploit than shallower zones, probably contains a much thicker sequence of Maetrichtian rocks and therefore a larger reserve of fresh water.

It is quite obvious that any overuse of the Maestrichtian aquifer will first affect the upwarped sequence of Maestrichtian sediments and that such areas will be the first reservoirs to be depleted. A careful analysis of the gravity map of Senegal and the available drill cores should provide further information on the basinal and domal structures of the Maestrichtian, their thickness and water potential.

Faults related to major tectonic movements and their associated fracture systems act as major conduits for water by controlling drainage patterns and infiltration routes (Fig. 3.10). This type of faulting is prevalent throughout the Ferlo and western Senegal. The intersections of such fault systems as a Fete Bowal, Diobène and at numerous other locations are the probable sites of deep and surface water accumulations. These faults act as conduits for downward migrating surface water, as well as for the upward transmission of water from deep aquifers.

3.10.4.4 Landsat Interpretation of Hydrologic Features and Verification

Two geologic features related to hydrologic potential were interpreted from Landsat imagery. The first comprises the structural trends or lineaments which are visible on the imagery and which directly relate to faults, fractures or joint systems controlling subsurface water flow and the relative position of water bearing formations. The second feature visible on Landsat comprises the fossil channels which crisscross the Senegalese Sedimentary Basin. Both of

these features are shown on the Geohydrologic and the Hydrologic maps.

The project tried to verify a certain number of these features on the ground but found that the surface expression of many of these features is not visible or is too muted to be considered valid verification. During some of the overflights, the general trend of the features established on Landsat was more often verifiable. Verification of faults was best accomplished by comparing our interpretation to drill hole results and the isopach maps derived from core logs. (Monciardini, 1966 and Le Priol, 1984). We have indicated relative movement along such faults by comparing the isopach maps to the gravity map and deducing displacement.

Aside from indicating faults, lineaments and relative movement, the isopach lines plotted on our hydrology map show the relative position of the top of the Maestrichtian, Paleocene and Lutetian aquifers. The map also shows alluvial channels and fossil streams as interpreted from Landsat imagery. Finally, the map shows the locations of wells measured by project personnel. These measurements and their significance will be discussed in the next section.

3.10.4.5 Well Measurements Made by the Project

The project measured over 530 conventional* and deep drilled wells to establish if the drought had any measurable effect on the water supply of Senegal. The tables in Appendix A (III-2) show the locations of these wells and describe certain such characteristics as well and water depth, water quality, stratigraphic relationships, etc. Our aim was to establish whether or not the water tables of the Sine Saloum and Groundnut Basin were dropping.

Our measurements were made with a plumb line and metered rope which were lowered into the well until the plumb bob, a 2-inch plumbing "L" connection, touched the water; this distance was measured and then the plumb bob was dropped to the bottom of the well and a second measurement made. Measurements of deep wells (forages) were based on data available at the pumping stations either inscribed on plaques or available through discussion with the operators.

The data from these wells has been noted on the Hydrologic maps at 1:500,000 scale. These data were collected approximately every 10 km in order not to overcrowd the maps.

*We define a conventional well as any hand dug well, lined or unlined, with or without a perforated casing, and with or without an above ground structure.

The analysis of these measurements has yielded a considerable amount of information. We found that of the 532 wells measured, 99 were dry (18.6%), 51 (9.6%) were saline or alkaline, and 170 (31.9%) had 50 cm of water or more at the time of measurement.

In addition, we found that there has been no significant shift or lowering of the water table eastward from the Cayor coast or northward from the Saloum River. We did find, however, that dry or nearly dry wells tended to concentrate in the region between Mekhe, Ndande and Lompoul. We also found a large number of dry or nearly dry wells along the highway form Mbour to Kaolack, and in a small area just southeast of Thiès as far as Tiénaba. Generally, we found good water and large quantities of water in wells south of the Saloum River and north of the Gambia River with static levels .50 cm to as much as 5 m above the well bottoms. As might be expected, the most polluted, saline or alkaline, water was found in wells along the north side of the Sine Saloum estuary as far as Kaolack.

We also attempted to compare data collected by our project with previously collected information, which was sometimes difficult as villages move, names change and the same wells may not be found. Tables 3.3, 3.4 and 3.5 show these comparisons and indicate quite clearly that wells are allowed to fill with sand (thus decreasing their depth), a number of wells have been deepened and a small but measureable decrease in the water table can be defined by the results.

Table 3.3

Name of Town	Project No.	1984 Well Depth	1984 Water Depth	DEGALLIER 1962 Well Depth	DEGALLIER 1962 Water Depth	Difference Well	Difference Water
Nauiri	328	59.0	0.80	58.27	0.75	+ 0.73	+ 0.05
Boula Taly	109	55.0	0.50	40.0	-	+15.0	-
Thilogne	118	12.5	0.05	10.0	1.0	+ 2.5	- 0.95
Lour Ouolof	124	66.0	3.0	57.43	0.85	+ 8.57	+ 2.15
Yonoféré	103	52.0	0	55.20	0.60	- 2.80	- 0.60
Kanel	336	16.0	0.50	12.0	1.0	+ 4.0	- 0.50
Ogo	333	21.0	4.50	-	0.80	-	+ 3.70
BAIAI	331	51.0	0.06	53.28	0.60	- 2.28	- 0.55
Fété Fawrou	327	54.0	0.25	50.77	-	+ 4.0	-
Mboule	104	59.0	0.35	57.78	0.70	+ 1.22	- 0.35
Dentiadi	112	23.0	0.10	8.78	0.60	+14.22	- 0.50

Comparison of wells and water depth in Senegal--1962. From "Hydrogéologie du Ferlo septentrional (Sénégal)". Mém. du bureau de recherch. géo, no. 19, by R. Dégallier, 1962.

Table 3.4

Name of Town	Project No.	1984 Well Depth	1984 Water Depth	1966 Well Depth	1966 Water Depth	Difference Well	Difference Water
Koutia Bâ	283	56.0	0.40	58.80	0.28	- 2.8	+ 0.12
Koussanar	302	24.0	0.40	22.95	0.52	+ 2.0	- 0.12
Maleme Niani	299	55.0	0.10	45.50	0.33	+10.0	- 0.23
Mayel Dibi	311	28.0	0.10	26.89	2.14	+ 1.11	- 2.04
Koutia Gaidi	293	53.5	0.30	49.85	0.24	+ 3.65	- 0.06
Palaguê	288	66.0	0.30	68.70	0.30	- 2.70	
Boki Sada	279	90.0	0.80	75.56	3.06	+14.44	- 2.26
Touba Fall	309	23.0	0.10	17.40	2.30	+ 5.60	- 2.20
Diarel Assane	318	55.0	0.15	52.47	0.35	+ 2.53	- 0.20
Nhar	323	63.0	0.40	60.30	0.40	+ 2.70	
Sintiou Amar Ali	315	40.0	0.20	34.57	1.72	+ 5.43	- 1.52
Malème Bâ	290	76.0	0.30	66.25	0.62	+ 9.75	- 0.32
Lycounda	307	25.0	0.10	20.64	0.84	+ 4.36	- 0.74
Saré Sikouna	295	60.0	0.25	60.55	0.11	- 0.55	+ 0.14
Fete Fowrou	327	54.0	0.25	54.20	0.45	- 0.20	- 0.20
Sintiou Bocar Ali	317	46.0	0.05	46.07	0.17	- 0.07	- 0.12
Sintiou S. Toubou	312	28.0	0.15	29.20	0.29	- 1.20	- 0.14
Koussanar	304	23.0	sec	22.30	0.50	+ 0.70	- 0.50
Lycounda	308	24.0	0.10	17.88	1.26	+ 6.12	- 1.16
Olougueì	281	52.0	3.50	49.97	0.17	+ 2.03	+ 2.08

Comparison table of wells and water depth in Senegal--1966 data from Etude hydrogéologique pastorale de la zone sud-ouest du Ferlo, 67, A-13, par E. Dagassan, Dakar.

Table 3.5

Name of Town	Project No.	1984 Well Depth	1984 Water Depth	1981 Well Depth	1981 Water Depth	Difference Well	Difference Water
Koutia Gaidi	293	53.5	0.30	51.35	0.35	+ 2.15	- 0.05
Saré Sikouna	295	60.0	0.25	60.40	0.25	- 0.40	
* Lofé	297	40.0	0.30	64.80	0.20	-24.80	+ 0.10
Malème Bâ	290	65.0	0.40	66.15	0.95	- 1.15	- 0.50
Palaguê	288	66.0	0.30	68.30	0.15	- 2.30	+ 0.15
Fâs Gounas	286	45.0	0.60	46.25	0.56	- 1.25	+ 0.04
* Koutia Bâ	283	56.0	0.40	65.60	0.30	- 8.60	+ 0.10
Boki Sada	279	90.0	0.80	74.40	0.35	+15.60	+ 0.45
Guente Olougel	281	52.0	3.50	57.35	5.50	- 4.65	- 2.0
* Panal	282	54.0	0.70	65.50	1.15	-11.50	- 0.45
Koutia Bâ Ouolof	284	77.0	0	58.90	1.60	+18.10	- 1.60
Sintiou Bocar Ali	317	46.0	0.05	46.25	1.35	- 0.25	- 1.30
Diarel Assane	318	55.0	0.10	55.10	0.15	- 0.10	
Sintiou Barinabé	316	39.0	0.25	36.65	0.05	+ 2.35	+ 0.20
Sintiou Amar Ali	315	40.0	0.20	39.25	0.30	+ 0.75	- 0.10
Toubéré Bafal	321	61.0	0.20	60.87	0.17	+ 0.13	+ 0.03
Nhar	323	63.0	0.40	61.0	0.75	+ 2.0	- 0.35
MbaTladji	367	20.0	sec	21.90	0.35	- 1.90	- 0.35
* Sintiou M. Boubou	369	17.0	0.12	25.45	0.25	- 7.55	- 0.13
Ouro Kaba	365	30.0	0.15	28.30	0.05	+ 1.70	+ 0.10
Sintiou Tapsirou	364	34.0	0.35	27.0	0.25	+ 7.0	+ 0.10
Baniou	358	43.5	0.15	42.80	0.40	+ 1.70	- 0.25
Sohol	361	36.5	0.35	35.95	0.25	+ 1.60	+ 0.10
Ndia	356	34.0	0.35	34.90	0.60	- 0.90	- 0.25
Sarré	371	19.5	0.50	19.85	0.55	- 0.35	- 0.05
Gabou	377	5.0	sec	9.00	0.10	- 4.0	- 0.10
Tourimé	348	14.5	0.05	17.00	1.20	- 2.50	- 1.15
Katob	485	28.0	2.0	26.90	1.67	+ 1.10	+ 0.33
Maka	476	24.0	0.30	24.57	1.37	- 0.57	- 1.07
Hamdallaï	388	12.5	0.20	12.20	0.15	+ 0.30	+ 0.05
Koumaré	486	60.0	2.50	58.50	0.20	+ 1.50	+ 2.30
Borsafé	473	43.0	2.0	34.55	1.35	+ 8.45	+ 0.65
Koromadji	385	13.5	0.75	12.55	2.60	+ 0.95	- 1.85
Kotiari	382	30.0	0.50	27.50	0.30	+ 2.50	+ 0.20
Diankoro Mandingue	387	28.0	0.25	23.90	0.02	+ 4.10	+ 0.23
Ardoulaye	390	37.5	0.15	37.0	0.50	+ 0.50	- 0.35
* Wassadou Dépôt	392	9.0	0.40	13.90	0.35	- 4.90	+ 0.05
Ségou	403	8.0	0.30	5.95	1.12	+ 2.05	- 0.82

Comparison of wells and water depth in Senegal Oriental--1981. From Cataloque des points d'eau du Sénégal Oriental, SODEFITEX, 1981.

* Measurements are probably not from the same wells.

In comparing our work to the most recent such survey, we found that the SODEFITEX project and our field work had made 89 common measurements for wells in Senegal Oriental. Our well measurements followed the SODEFITEX survey by 4 to 9 years. In these areas of Senegal Oriental, part of the SODEFITEX survey was conducted at the end of the rainy seasons which casts doubts on the usefulness of their data. Where such measurements were made after the rainy season, SODEFITEX found high levels of water in shallow wells, whereas the project found that during the dry seasons these wells were often dry or nearly dry.

In most cases, we found that the wells measured by both projects had similar depths. At a few locations, the wells had been deepened, but generally they had decreased in depth by 30 to 100 cm and were simply filling with sand or rubble. Water levels were somewhat different but it is believed that this variation is due to the fact that measurements were taken at different times of day and different seasons. An efficient survey would require that wells be measured 5 times a year, at the end and beginning of the rainy season and 3 times during the dry season. Wells should also be measured at dawn and at sunset to establish highest and lowest levels of water in the wells.

Deep wells (forages) were visited in a number of places, especially in the Ferlo. Most of these wells are drilled to the Maestrichtian. No indications of decreased flow from the aquifer were evident. The only obvious problem at most of these deep well sites was the lack of fuel, batteries and spare parts. In almost every case, maintenance was more than adequate despite the low wages paid to the operator who was typically not the man originally assigned to the job but a relative or friend.

3.10.5 Conclusions on the Hydrology of Senegal

The project's work in Senegal indicates the following:

1. Landsat analysis made evident the existence of large numbers of linear trends and fractures which indicate the existence of faults. These faults may be assumed to be good targets for water for they act as conduits for surface and subsurface waters. Water can be expected at the intersections of such faults.

2. Landsat analysis also indicated the presence of numerous fossil channels that may provide additional supplies of drinking water.

3. Well measurements indicate that during the last decade a large number of wells have been deepened and that others have dried up, thus providing evidence for a noticeable if not general lowering of the superficial water table. This decrease is true for a crescent-shaped area from Loumpol on the coast south through Thiès and Tiadiaye to Kaolack.

4. Well measurements and comparisons with previous data indicate that numerous wells are poorly maintained and should be cleaned.

5. Well measurements also indicate that in certain regions water levels are high and supplies adequate.

6. Deep well (forage) measurements indicate that drawdown on deep wells is not affecting the water table.

7. Deep wells could produce much higher volumes of water if the necessary spare parts, equipment and fuel were available.

8. Landsat analysis indicates that deep well sites tend to attract large herds which have adverse environmental effects on the biomass in those areas. This degradation may become irreversible if a solution is not found.

9. Analysis of deep well data suggests that the Maestrichtian aquifer may be capable of sustaining many more wells throughout the Ferlo. These wells could provide water to more cattle, but more importantly they would allow for the dispersal of the present herds, thus creating a better environmental balance.

10. Analysis of available data suggests that during the last 10 years almost no atmospheric water reached the superficial water table(s) of Senegal and that most rainfall was lost to evapotranspiration.

11. Hydrogeologic analysis shows that the Senegalese Sedimentary Basin is structurally more complex than indicated by authors who have treated the hydrologic potential of the region. This complexity would imply that the potential of the prime aquifers, Maestrichtian, etc., must be reanalyzed and viewed not as continuous aquifers but as aquifers composed of separate block faulted and folded segments.

3.10.6 Senegal's Water Potential

The project's water and mineral resources map of Senegal is at a scale of 1:1,000,000. Therefore, by its nature it can only represent a generalized view of the water potential. Any further requirements relating to the specific location of water would demand a more in-depth analysis and a mapping effort at a minimum scale of 1:200,000.

The map provided shows the extent of the two main deep aquifers of Senegal--the Maestrichtian and the early Tertiary (Paleocene/Eocene). The map also indicates other major sources of water in alluvial deposits of present and fossil streams. It is quite apparent from scanning this map that the important water bearing sediments of the Continental Terminal series are not shown. It goes without saying that these sediments represent an important source of water. The existence of the Continental Terminal aquifer is well known, and it presently

provides much of eastern and east central and northern Senegal with its water. Although this source is well known, it does not constitute a major resource for the future, nor is it likely to provide much more production to villages presently tapping it. It remains a marginal source and is not considered as potentially important as the Maestrichtian.

The water resources of the basement and Paleozoic region of Senegal Oriental have not been noted on our map for essentially the same reasons. Although these rocks are undoubtedly prolific reservoirs, their development depends on the modification of the way of life and economy of eastern Senegal. Such a development is unlikely in the near future; therefore, these rock units are not considered as viable producers with important potential. Nevertheless, their development should not be ruled out and will follow rapidly and automatically if mineral development comes to this region.

The development of the water resources of Senegal must now focus on two requirements, those of the major urban centers (Dakar in particular) and those of the rural sector, including agriculture and animal husbandry. Another essential point to remember is that the area south of The Gambia and including nearly all of the Casamance is not directly affected in any such analysis because of its climatic location and relatively abundant rain.

What then are the options for the development of this sector and what should be the priorities?

If we assume that the Manantali and Diama dams will resolve the problems of supplying an adequate and continuous water supply to Dakar and other major centers, including St. Louis, Louga, Kébémer, Thiès, Rufisque, and the phosphate industry at Taïba and Lam-Lam, and in addition provide for the agricultural development of the Senegal River Valley, we must then consider a vast area of land including the Ferlo and most of the Groundnut Basin that will continue to suffer a water deficiency. Since most of the rural population of Senegal occupies this latter region, it is obvious that this problem must be addressed and solved. If a solution is not found (i.e., adequate supplies of water are not provided for the growing rural population in this area and for the increasing herds that will be required to feed the burgeoning populations of existing cities), then we can expect major migrations to the cities, particularly Dakar, and the resultant critical overcrowding and water shortages.

The solution considered here is to provide water to the Groundnut Basin from the deep Maestrichtian aquifer, as well of course as from the overlying aquifers. In view of the minimal use of water made by rural populations, 20 l/day/person versus that by residents of Dakar 175 l/day/person, it is imperative that the use of this nonrenewable resource be restricted to rural use and the burden of the needs of cities and those of irrigable lands be placed on the renewable supplies

of the Senegal River. Although the cost of supplying Dakar with water from the Senegal River will be high and certainly exceed the cost of tapping the coastal dune or Maestrichtian aquifers, the long term costs and grave ecological consequences of such a choice will be much higher.

Another important question arises relating to the development of the hydrologic resources of Senegal. Should the Maestrichtian aquifer be used to irrigate? Based on all available work, the Maestrichtian aquifer has enormous potential. If further necessary studies confirm this potential, it would seem that limited use of this aquifer for specialized irrigation within the land area described above could have enormous beneficial effects on the economic development of the rural population. Thus, it would seem beneficial to irrigate small parcels of land for villages exceeding, for example, 3000 people. These waters would be used to irrigate orchards or vegetable gardens but not basic grain cash crops. Thus, every village of 3000 people would be able to irrigate 3 to 5 ha of land in order to produce dietary supplements presently not available. It follows then that every village with a population exceeding 3000 would have to have a deep well. The cost of such a well could be supported by the village once cropping of vegetables and fruit becomes commonplace.

It is an established fact that after the Diama and Manantali dams are built and the flow fo the Senegal is controlled, approximately 30% of the water of the river will still reach the Atlantic. Using at least part of this water for irrigation and the improvement of the environment would seem appropriate. In this regard, we have previously proposed (earlier project reports, 1984) and again suggest that a portion of this water be diverted into the headwaters of the Ferlo system. We suggest that such a diversion would use approximately 3% of the total flow of the Senegal and would create a green belt traversing the Ferlo which would provide year-round water for cattle and horticultural development the entire length of the Ferlo system. The most appropriate location for this diversion would be 8 km east of Kanel on the main stream of the Senegal River. The total distance the waters would have to be pumped would be ±20 km to the headwaters of the Tiangol Venndou Gaoudi. The difference in elevation between those two points is 79 m. Although this proposal seems somewhat farfetched, a similar idea was seriously considered some years ago. However, in the previous case it would have been necessary to build a large dam at Bakel, and water flow would not have been continuous. We believe that water in the Ferlo Valley and the green belt that would result would vastly improve the environment in this belt and obviate the need for numerous additional deep wells required by livestock in the Ferlo. The cost of pumps and fuel will decrease because fewer wells will be needed. The cost of the required pumps and fuel to provide water to the green belt will be less onerous because rather than being spread out along bad roads across the Ferlo, the equipment will be located along a 20 km axis with east access to the Bakel-St. Louis highway.

In summary, this suggestion may have the following benefits:

1. Create a greenbelt 220 km in length from Kanel to the Lac de Guiers.

2. Provide a year-round source of water for people and cattle.

3. Provide adequate supplies of water for limited horticultural use.

4. Limit the ecological damage cattle are now causing at deep well sites.

5. Decrease the amount of water taken from the Maestrichtian aquifer by decreasing the number of wells and their use.

6. Decrease the amount of fuel and equipment used to acquire water from the Maestrichtian aquifer.

7. Make better use of the Senegal River.

3.11 APPENDIX A: HYDROGEOLOGY

Table III-1

Characteristics of Landsat Imagery

Previous Page Blank

Region of Landsat Scene	Date	Path Row Scene or Subscene	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Dakar	05/05/73	221 50	Enhanced	MSS Digitized Color Comp.	1:250,000	EROS/RSI	Excellent	Base-Image enhanced for detailed interpretation
Dakar	17/12/78	221 50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for dry season analysis lithology & faults, hazy
Dakar	06/12/80	221 50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for dry season analysis lithology & faults, hazy
Dakar	05/05/73	221 50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for end of dry season interpretation
Dakar	04/04/79	S.S. B,C,D	Bulk	RBV Black & White	1:250,000	EROS	Average	Good for additional detail in certain areas
St. Louis	06/11/77	220 49	Enhanced	MSS Digitized Color Comp.	1:250,000	EROS/RSI	Excellent	Base image enhanced for detailed interpretation
St. Louis	16/04/73	220 49	Bulk	Color Comp.	1:250,000	EROS	Good	Good for faults & lithology groundwater assessment
St. Louis	06/11/77	220 49	Bulk	Color Comp.	1:250,000	EROS	Good	Good for lithology, (dunes)
St. Louis	30/09/79	220 49	Bulk	Color Comp.	1:250,000	EROS	Good	Not particularly good for geohydrology because vegetation masks lithology good for dune V/S interdune areas
St. Louis	18/10/79	220 49	Bulk	Color Comp.	1:250,000	EROS	Average	Good for drainage, hazy
St. Louis	14/08/81	220 49	Bulk	Color Comp.	1:250,000	EROS	Good	Same as above, but good for comparison with 1978 image but only 1/2 image

Table III-1 Characteristics of Landsat Imagery

Region of Landsat Scene	Date	Path Row Scene or Subscene	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
St. Louis	30/09/79	S.S. B,D	Bulk	RBV Black & White	1:250,000	EROS	Average	Good for detailed analysis of dune area
St. Louis	05/11/79	S.S. C	Bulk	Black & White	1:250,000	EROS	Average	Good for detailed analysis of dune area
St. Louis	23/11/79	S.S. A,B,C,D	Bulk	Black & White	1:250,000	EROS	Average	Cloudy, but good for detailed analysis of dune areas
St. Louis	06/11/77	220 49	Bulk	MSS Black & White Channels:	1:250,000	EROS		
				4			Good	Water features
				5			Good	Terrain features
				6			Good	Vegetation
				7			Good	Vegetation
St. Louis	30/09/72	220 49	Bulk	Black & White Channels:	1:250,000	EROS		
				4			Good	Water features
				5			Good	Terrain features
				6			Good	Vegetation
				7			Good	Vegetation
St. Louis	30/09/79	220 49	Bulk	Black & White Channels:	1:250,000	EROS		
				4			Good	Water features
				5			Good	Terrain features
				6			Good	Vegetation
				7			Good	Vegetation

Region of Landsat Scene	Date	Path Row Scene or Subscene	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Diourbel	23/11/79	220 50	Enhanced	MSS Digitized Color Comp.	1:250,000	EROS/RSI	Good	Base image enhanced for detailed interpretation good for geologic interpretation
Diourbel	21/02/73	220 50	Bulk	Color Comp.	1:250,000	EROS	Average	Poor resolution, good for faults & hydrology
Diourbel	16/04/73	220 50	Bulk	Color Comp.	1:250,000	EROS	Average	Average resolution, very good for faults & good for lithology
Diourbel	23/11/79	220 50	Bulk	Color Comp.	1:250,000	EROS	Average	Average resolution good for faults & lithology
Diourbel	24/09/80	220 50	Bulk	Color Comp.	1:250,000	EROS	Average	Malfunction in satellite, provides only half image
Diourbel	07/10/81	220 50	Bulk	Color Comp.	1:250,000	EROS	Average	Provides one half image, somewhat hazy, too much vegetation
Diourbel	23/11/79	S.S. A,B,D	Bulk	RBV Black & White	1:250,000	EROS	Average	Good , higher resolution for land use
Diourbel	23/11/79	220 50	Bulk	MSS Black & White Channels: 4 5 6 7	1:250,000	EROS	Good	Water features, salinity Terrain features Vegetation Vegetation

Region of Landsat Scene	Date	Path Scene or Subscene	Row	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Diourbel	21/02/73	220	50	Bulk	MSS Black & White Channels: 5 7	1:250,000	EROS	Good	 Terrain features Vegetation features
Ziguinchor	21/02/73	220	51	Enhanced	MSS Color Comp.	1:250,000	EROS/RSI	Excellent	Base image enhanced for detailed interpretation, good for geologic features
Ziguinchor	05/11/72	220	51	Bulk	Color Comp.	1:250,000	EROS	Good	Good for comparison of wet & dry season imagery, good for laterites and stream capture areas
Ziguinchor	21/02/73	220	51	Bulk	Color Comp	1:250,000	EROS	Good	Good for dry season, same as enhanced imagery above, good for salinity, structure, lithology, etc.
Ziguinchor	26/02/79	220	51	Bulk	Color Comp.	1:250,000	EROS	Good	Good for interpreting change since 1972/73
Ziguinchor	05/11/72	220	51	Bulk	Black & White Channels: 4 5 6 7	1:250,000	EROS	 Good Good Good Good	 Good for water features Good for terrain features Good for vegetation Good for vegetation
Ziguinchor	26/02/79	220	51	Bulk	Black & White Channels: 4 5 6 7	1:250,000	EROS	 Good Good Good Good	 Good for water features Good for terrain features Good for vegetation Good for vegetation

Region of Landsat Scene	Date	Path Scene or Subscene	Row	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
					MSS				
Podor	29/12/77	219	49	Enhanced	Color Comp.	1:250,000	EROS/RSI	Excellent	Base image - enhanced for detailed interpretation, good for laterites
Podor	10/03/73	219	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good for dunes (recent)
Podor	18/06/78	219	49	Bulk	Color Comp.	1:250,o00	EROS	Good	Good for sand dunes, too blue
Podor	29/12/77	219	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good for everything
Podor	02/01/79	219	49	Bulk	Color Comp.	1:250,000	EROS	Average	Too yellow resolution poor Good for lakes and rivers
Podor	02/04/79	219	49	Bulk	Color Comp.	1:250,000	EROS	Good	Excellent for geo. and hydro. interp.
Podor	11/11/80	219	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good (partial image)
Podor	13/08/81	219	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good (partly cloudy, partial image)
Podor	06/08/81	219	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good (partial image)
Podor	10/03/73	219	49	Culk	Black & White Channels: 5 7	1:250,000	EROS	 Good Good	 Good for fossil rivers Good for vegetation
					RBV				
Podor	02/01/79	S.S. A		Bulk	Black & White	1:250,000	EROS	Average	Good detail due to better resolution
Podor	08/05/79	S.S. A,B,C,D		Bulk	Black & White	1:250,000	EROS	Average	Good detail due to better resolution
Podor	22/11/79	S.S. A,B,C,D		Bulk	Black & White	1:250,000	EROS	Average	Good detail due to better resolution

Region of Landsat Scene	Date	Path Scene or Subscene	Row	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
					MSS				
Tiel	02/01/79	219	50	Enhanced	Digitized Color Comp.	1:250,000	EROS/RSI	Excellent	Base image enhanced for detailed interpretation, good for lithologic and structural interpretation
Tiel	10/03/73	219	50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for structure and geology
Tiel	04/11/72	219	50	Bulk	Color Comp.	1:250,000	EROS	Good	Somewhat hazy, not very good for geology
Tiel	02/01/79	219	50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for geology
Tiel	22/11/79	219	50	Bulk	Color Comp.	1:250,000	EROS	Good	Hazy, too vegetated, partial image
Tiel	23/09/80	219	50	Bulk	Color Comp.	1:250,000	EROS	Good	Cloudy, very vegetated, partial image
Tiel	13/08/81	219	50	Bulk	Color Comp.	1:250,000	EROS	Good	A little cloudy, highly vegetated, partial image
Tiel	15/09/81	219	50	Bulk	Color Comp.	1:250,000	EROS	Good	Cloudy, overly vegetated, partial image
Tiel	10/03/79	219	50	Bulk	Black & White Channels:	1:250,000	EROS		
					5			Good	Good for lithology
					7			Good	Good for vegetation
					RBV				
Tiel	22/11/79	S.S.	A,B,C,D	Bulk	Black & White	1:250,000	EROS	Average	Good due to improved resolution
Tiel	08/05/79	S.S.	A,B,C,D	Bulk	Black & White	1:250,000	EROS	Average	Good due to improved resolution

Region of Landsat Scene	Date	Path Scene or Subscene	Row	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
					MSS				
Kolda	03/02/78	219	51	Enhanced	Digitized Color Comp.	1:250,000	EROS/RSI	Excellent	Base image enhanced for detailed interpretation, good for lithologic and structural interpretation
Kolda	03/02/78	219	51	Enhanced	Digitized Black & White				
					Ratio 7/5	1:250,000	EROS/RSI	Excellent	Good for soils/vegetation
					Ratio 5/7			Excellent	Good for soils/vegetation
					Ratio 6/5			Excellent	Good for soils/vegetation
Kolda	10/03/73	219	51	Bulk	Color Comp.	1:250,000	EROS	Good	Good for lithologic & fault interpretation, but dark
Kolda	04/11/72	219	51	Bulk	Color Comp.	1:250,000	EROS	Good	Too much vegetation
Kolda	03/02/78	219	51	Bulk	Color Comp.	1:250,000	EROS	Good	Used in located stream, piracy, drainage, good structure, good lithology
Kolda	22/11/79	219	51	Bulk	Color Comp.	1:250,000	EROS	Good	Used as base for streams, bottom lands, saline areas, and some laterites, faults
Kolda	27/04/81	219	51	Bulk	Color Comp.	1:250,000	EROS	Poor	Partial image only, good
Kolda	02/06/81	219	51	Bulk	Color Comp.	1:250,000	EROS	Poor	Partial image only, cloudy
Kolda	10/03/73	219	51	Bulk	Black & White Channels:	1:250,000	EROS		
					4			Good	Good for water features
					5			Good	Good for location of faults
					6			Good	Good for vegetation & as base for topo.
					7			Good	Good for vegetation

Region of Landsat Scene	Date	Path Row Scene or Subscene		Type	Product	Scale	Source	Quality	Purpose (Usefulness)
					MSS				
Kolda	22/11/79	219	51	Bulk	Black & White Channels	1:250,000	EROS		
					4			Good	Good for water features
					5			Good	Good for terrain, lithologic analysis
					6			Good	Good for vegetation analysis
					7			Good	Good for vegetation analysis
					RBV				
Kolda	22/11/79	Subscene A,B,C,D		Bulk	Black & White	1:250,000	EROS	Good	Improved resolution, good for soils, vegetation and particularly land use
Kolda	02/04/79	Subscene A,B,C,D		Bulk	Black & White	1:250,000	EROS	Good	Improved resolution, good for soils, vegetation and particularly land use
					MSS				
Matam	21/11/79	218	49	Enhanced	Digitized Color Comp.	1:250,000	EROS	Excellent	Base image enhanced for detailed interpretation, good for lithologic and structural interpretation
Matam	02/05/73	218	49	Bulk	Color Comp.	1:250,000	EROS	Good	Hazy, not very good, greenish
Matam	09/03/73	218	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good quality for geology
Matam	10/12/77	218	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good for comparison with similar season in 1979, hazy, good for faults
Matam	17/06/78	218	49	Bulk	Color Comp.	1:250,000	EROS	Good	Good for structure/lithology, somewhat too green, hazy
Matam	08/09/78	218	49	Bulk	Color Comp.	1:250,000	EROS	Good	Average
Matam	10/01/79	218	49	Bulk	Color Comp.	1:250,000	EROS	Good	Poor scale, good for faults, cloudy

Region of Landsat Scene	Date	Path Scene or Subscene	Row	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Matam	21/11/79	218	49	Bulk	Color Comp.	1:250,000	EROS	Average	Part of image
Matam	10/10/80	218	49	Bulk	Color Comp.	1:250,000	EROS	Poor	Part of image missing, cloudy
Matam	06/10/81	218	49	Bulk	Color Comp.	1:250,000	EROS	Poor	Part of image
Matam	09/03/73	218	49	Bulk	MSS Black & White Channels 5 7	1:250,000	EROS	Good	Good for lithology, terrain, structure Good for vegetation
Matam	21/11/79	Subscene A,C,D		Bulk	RBV Black & White	1:250,000	EROS	Good	Good for detailed work on lithology due to better resolution
Mboune	10/12/77	218	50	Enhanced	MSS Color Comp. Digitized	1:250,000	EROS/RSI	Good	Hazy quality, not very good for geology or hydrology, too vegetated
Mboune	09/03/73	218	50	Bulk	Color Comp.	1:250,000	EROS	Good	Generally good for geology and structure, good for drainage
Mboune	10/12/77	218	50	Bulk	Color Comp.	1:250,000	EROS	Good	Hazy quality (see above) burned areas not good for geology
Mboune	02/02/78	218	50	Bulk	Color Comp.	1:250,000	EROS	Average	Good for structure & lithology some clouds
Mboune	21/11/79	218	50	Bulk	Color Comp.	1:250,000	EROS	Good	Good, but too much vegetation, good for drainage, too much burned area

Region of Landsat Scene	Date	Path Row Scene or Subscene	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Mboune	09/03/73	218 50	Bulk	Black & White Channels: 5 7	1:250,000	EROS	Good	Good for lithology/streams Good for vegetation/water
Mboune	01/04/79	Subscene A,B,C,D	Bulk	RBV Black & White	1:250,000	EROS	Good	Good due to improved resolution
Mboune	21/11/79	Subscene A,B,C,D	Bulk	Black & White	1:250,000	EROS	Good	Good due to improved resolution good for Paleozoic/PreCambrian lithology
Vélingara	10/12/77	218 51	Enhanced	MSS Color comp.	1:250,000	EROS/RSI	Good	Used as base image but somewhat too vegetated due to seasonal rains, hazy, some clouds
Vélingara	10/12/77	218 51	Enhanced	Black & White 7/5 Ratio	1:250,000	EROS/RSI	Good	Poor for lithology, good for structure for vegetation/land use, some clouds
Vélingara	18/02/75	218 51	Bulk	Color Comp.	1:250,000	EROS	Good	Good for lithology and structure due to dry season effects
Vélingara	26/03/75	218 51	Bulk	Color Comp.	1:250,000	EROS	Good	Excellent for everything
Vélingara	02/02/78	218 51	Bulk	Color Comp.	1:250,000	EROS	Average	Some clouds, good for sedimentary areas
Vélingara	18/02/75	218 51	Bulk	Black & White Channels: 5 7	1:250,000	EROS	Good	Good for lithology and structure Good for structures, terrain features

Region of Landsat Scene	Date	Path Row Scene or Subscene	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Vélingara	01/04/79	Subscene A,B,C,D	Bulk	RBV Black & White	1:250,000	EROS	Good	Good due to detail but poor contrast in some areas
Bakel	21/02/73	217 50	Enhanced	MSS Color Comp. Digitized	1:250,000	EROS/RSI	Excellent	Base image enhanced for detailed interpretation, excellent for lithology, structures and tectonic interpretation
Bakel	08/01/74	217 50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for structures and lithology
Bakel	21/11/77	217 50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for structures and lithology
Bakel	27/12/77	217 50	Bulk	Color Comp.	1:250,000	EROS	Good	Good for structures and lithology
Bakel	04/03/79	217 50	Bulk	Color Comp.	1:250,000	EROS	Good	Excellent for structures & lithology
Bakel	27/10/80	217 50	Bulk	Color Comp.	1:250,000	EROS	Poor/Average	Too much vegetation, 1/2 image shows only a small part of Senegal
Bakel	02/12/80	217 50	Bulk	Color Comp.	1:250,000	EROS	Average	Shows only small part of Senegal
Bakel	08/01/74	217 50	Bulk	Black & White Channels: 5 7	1:250,000	EROS	Good	Very good for lithology & structure Good for vegetation
Bakel	20/11/79	Subscene A,C	Bulk	RBV Black & White	1:250,000	EROS	Good	Good for detailed structures & geology especially folding

Region of Landsat Scene	Date	Path Scene or Subscene	Row	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Kédougou	27/12/77	217	51	Enhanced	MSS Digitized Color Comp.	1:250,000	EROS/RSI	Good	Too much vegetation for effective geologic interpretation, but used as base for mapping
Kédougou	72/12/77	217	51	Enhanced	Black & White 7/5 Ratio	1:250,000	EROS/RSI	Good	Good for vegetation
Kédougou	08/08/73	217	51	Bulk	Color Comp.	1:250,000	EROS	Average	Hazy, but good for some structures
Kédougou	26/01/74	217	51	Bulk	Color Comp.	1:250,000	EROS	Good	Very good for lithology & structure
Kédougou	07/03/75	217	51	Bulk	Color Comp.	1:250,000	EROS	Good	Good for lithology and structure
Kédougou	25/03/75	217	51	Bulk	Color Comp.	1:250,000	EROS	Good	Very good for structure
Kédougou	27/12/77	217	51	Bulk	Color Comp.	1:250,000	EROS	Good	Good for geology & structure
Kédougou	08/03/30	217	51	Bulk	Color Comp.	1:250,000	EROS	Poor	Partial image only
Kédougou	21/09/80	217	51	Bulk	Color Comp.	1:250,00	EROS	Poor	Partial image, cloudy
Kédougou	26/01/74	217	51	Bulk	Black & White Channels:	1:250,000	EROS	Good	
					4				Good for water features/wetness
					5				Good for lithology/structure
					6				Good for structure
					7				Good for structure
Kédougou	21/09/80	217	51	Bulk	Black & White Channels:	1:250,000	EROS	Good	
					4				Good for water features/wetness
					5				Good for lithology/structure
					6				Good for structure
					7				Good for structure

Region of Landsat Scene	Date	Path Row Scene or Subscene	Type	Product	Scale	Source	Quality	Purpose (Usefulness)
Kédougou	20/11/79	Subscenes A,B,C,D	Bulk	RBV Black & White	1:250,000	EROS	Good	Good for detailed work but too heavily vegetated
Kénieba	20/11/77	216 51	Enhanced	MSS Digitized Color Comp.	1:250,000	EROS/RSI	Excellent	Base image enhanced for detailed interpretation, but too vegetated
Kénieba	20/11/77	216 51	Enhanced	Black & White 7/5 Ratio	1:250,000	EROS/RSI	Excellent	Good for vegetation/land use
Kénieba	30/04/73	216 51	Bulk	Color Comp.	1:250,000	EROS/RSI	Good	Very good for lithology
Kénieba	20/11/77	216 51	Bulk	Color Comp.	1:250,000	EROS/RSI	Good	Too vegetated, burned areas
Kénieba	03/03/79	216 51	Bulk	Color Comp.	1:250,000	EROS/RSI	Good	Good for lithology, average for structure
Kénieba	02/11/77	216 51	Bulk	Color Comp.	1:250,000	EROS/RSI	Good	Hazy, too vegetated
Kénieba	07/03/73	216 51	Bulk	Black & White Channels: 5 7	1:250,000	EROS/RSI	Good	Good for lithology & structure Good for lithology & structure
Kénieba	17/04/79	Subscene A,C	Bulk	RBV Black & White	1:250,000	EROS/RSI	Good	Good due to higher resolution, good due to dry season
Kénieba	26/10/80	Subscene A,C,	Bulk	Black & White	1:250,000	EROS/RSI	Good	Somewhat overvegetated so of limited use

APPENDIX A

Table III-2

Catalog of Wells and Well Measurements of 532 Wells in Senegal 1983-1985

PROJET TELEDETECTION ET CARTOGRAPHIE DES RESSOURCES NATURELLES
PLAN NATIONAL D'AMENAGEMENT DU TERRITOIRE

Fiche Hydrologique

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond(m)	Qualite eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
1	5/3/84	Cap Vert	Bargny	Yène Mer		*voir no. 146				cf		
2	"	Cap Vert	Bargny	Yène Mer		*voir no. 147	Pollution					
3	"	Cap Vert	Bargny	Yène Mer		*voir no. 148						
4	"	Cap Vert	Bargny	Yène Mer		*voir no. 149						
5	"	Cap Vert	Bargny	Yène Mer								
6	"	Sine Saloum	Fimela	Mar Lodj								Traces d'huile dans l'eau
7	"	Sine Saloum	Fimela	Mar Lodj		Sec						
8	6/3/84	Sine Saloum	Fimela	Mar Lodj								
9	"	Thiès	Thiadiaye	Ndiaganio (CER)								
10	"	Thiès	Thiadiaye	Ndiaganio				100	100			
11	"	Thiès	Thiadiaye	Ndiaganio M. catholique		*voir no. 166	--			Calcaire + fossiles, arg.		
12	"	Thiès	Fissel	Soussoum Sanda	0.05	39.0	ED			3 m de calcaire		
13	"	Thiès	Fissel	Keur Ouali (Soussoum)	0	40.0	--			Calcaire		
14	"	Thiès	Fissel	Dieleng Keur Assane Helle		*voir no. 168						

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS Profondeur eau (m)	PUITS Profondeur fond(m)	Qualite eau	FORAGES Fond (m)	FORAGES m3/h	OBSERVATIONS Stratigra-phiques	OBSERVATIONS Structu-relles	AUTRES OBSERVATIONS
15	"	Thiès	Notto	Tassèt		*voir no. 159		80	750	cf		
16	"	Thiès	Tiénaba	Diack		*voir no. 177	F.D.				entre 2 in-trusion dolé	
17	"	Thiès	Tiénaba	N'Goudiane		*voir no. 176	E.D.					
18	"	Thiès	Tiénaba	Mbambara		15-18	E.D.					
19	"	Thiès	Tiénaba	Khombole		*voir no. 178						Vérification de failles
20	7/3/84	Thiès	Pambal	Baligue		*voir no. 252	E.D.					Puits approfondi il y a 70 ans; il y a pas eu baisse d'eau
21	"	Thiès	Pambal	Ndiassane		*voir no. 253	-					
22	"	Thiès	Pambal	Keur Mambaye Khari	Sec	20	-					
23	"	Thiès	Pambal	Keur Ndiobo		*voir no. 254	E.D.					
24	"	Thiès	Méquane	Mdomor		*voir no. 255	E.D.					Equipé d'une pompe à main
25	"	Thiès	Méouane	Mboro		*voir no. 256	E.D.					
26	"	Thiès	Médina Dakhar	Médina Dakhar	0.50	35	E.D.					
27	"	Thiès	Médina Dakhar	Mbodiène Nguéséré	T.E.	36	E.D.					
28	"	Thiès	Niakhène	Ndiné Amar		*voir no. 189	E.D.					
29	7/3/84	Thiès	Niakhène	Wadia Dieng	T.E.	36	E.D.			Niveau phosphaté		

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS Profondeur eau (m)	PUITS Profondeur fond (m)	PUITS Qualite eau	FORAGES Fond (m)	FORAGES m3/h	OBSERVATIONS Stratigra-phiques	OBSERVATIONS Structu-relles	AUTRES OBSERVATIONS
30	7/3/84	Thiès	Ndini	Kalom n°2	T.E.	36	E.D.			Niveau phosphaté		
31	"	Diourbel	Baba Garage	Sam Sam Teuge	T.E.	36	?					
32	"	Diourbel	Baba Garage	Thieppe Peul	T.E.	36	?					
33	"	Diourbel	Lambaye	Marène Couré		36	?			Calcaire et quartz		
34	"	Diourbel	Ngoye	Dara Mango	T.E.	36	E.D.			Calcaire si-lifié avec fossiles		
35	8/3/84	Diourbel	Ndoulo	Sambé	T.E.	30	E.D.	30		Calcaire à "Ostria"		
36	8/3/84	Diourbel	Ndoulo	Ndoulo	2	20	E.D.	48		Calcaire avec fossiles		
37	"	Diourbel	Ngoye	Darou Khafor	T.E.	48		48				Equipé d'une éoliene
38	"	Diourbel	Ndame	Ngabou	T.E.	35	E.D.					
39	"	Diourbel	Ndame	Keur Mbaye		*voir no. 205				Calcaire avec fossiles		
40	"	Diourbel	Ndame	Keur Ndoa		*voir no. 206						
41	"	Sine Saloum	Kolobane	Tjissi	Adduction venant des 2 châteaux de Baïla (*voir no. 208)							
42	"	Sine Saloum	Kolobane	Taïf		*voir no. 209						
43	"	Sine Saloum	Kolobane	Sadatou		*voir no. 210						

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
44	8/3/84	Sine Saloum	Kolobane	Ngaraf		*voir no. 211						
45	"	Sine Saloum	Kolobane	Gayna Tamsire		*voir no. 212	sale E.D.					
46	"	Sine Saloum	Birkelane	Diam Weli		*voir no. 215						
47	"	Sine Saloum	Malème Hodar	Thione	0	79.0		6	79			
48	"	Sine Saloum	Birkelane	Navel		*voir no. 217						
49	"	Sine Saloum	Birkelane	Birkelane	T.E.	± 25						
50	9/3/84	Sine Saloum	Birkelane	Nguer	0	10	salée					
51	"	Sine Saloum	Kahone	B'Gatye	T.E.	± 10	salée					
52	"	Sine Saloum	Kahone	Farabougou	T.E.	6	salée					
53	"	Sine Saloum	Kahone	Kahone	0	5-6	-					
54	"	Sine Saloum	Kahone	Touba Ndini	T.E.	± 10	E.D.					
55	"	Sine Saloum	Kahone	Thiolongane	T.E.	28	un peu salée					
56	"	Sine Saloum	Kahone	Nguékokh			E.D.					
57	"	Sine Saloum	Kahone	Likémé	T.E.	37						
58	"	Sine Saloum	Kahone	Har Diakhal	T.E.	26	E.D					
59	"	Sine Saloum	Kahone	Dagga Sambané	T.E.	30	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
60	9/3/84	Sine Saloum	Kolobane	Kolobane	1,00	37	END					
61	"	Sine Saloum	Gandiaye	Sagne Bambara	T.E.	6	Un peu salée					
62	"	Sine Saloum	Gandiaye	Keur Alfa	T.E.	8						
63	"	Thiès	Fissel	Ndioudiouf	0,50	8	E.D					
64	"	Thiès	Nguékokh	Keur Balla	T.E.	6						
65	"	Thiès	Nguékokh	Diamaguène		9,5	Un peu salée					
66	"	Thiès	Nguékokh	Sindia		*voir no. 153						Puits éoliens
67	13/3/84	Louga		Thille Peul	Sec	32,5	-					
68	"	Louga		Santhie Thilla		34,0	E.D					
69	"	Thiès		Santhie Bouna		34,0	E.D					
70	"	Thiès		Khadiawane		32,0	E.D					
71	"	Louga		Médina Beye	Sec	20,0				Sable jaune + sable blanc		
72	"	Louga		Médina Beye	0,30	25,0	E.D					
73	"	Louga		Tawa Fall	T.E.	17,5	E.D					
74	"	Thiès		Lompoul (verger)		*voir no. 194						
75	"	Thiès		Lompoul	T.E.	4,0	E.D					
76	"	Louga		Diokoul	0,90	37,5	E.D					
77	"	Louga		Baghadje Samba	0,60	29,0	E.D			Sable blanc		

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES	OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond m3/h (m)	Stratigra-phiques	Structu-relles	
78	13/3/84	Louga		Médina Thialao	0,80	29,0	E.D		Sable blanc-jaune sable rouge		
79	"	Louga	Sakal	Léonia Ndiaye	0,20	25,0	E.D				
80	"	Louga	Sakal	Potou	0,10	7,0	E.D				
81	"	Louga		Kanadji	2,5	23,5	E.D				
82	"	Louga	Sakal	Massar Diop I	0,60	19,5	E.D				
83	"	Sakal	Sakal	Sakal (prefecture)	0,05	22,5	E.D				
84	"	Fleuve	Rao	Mpal	0,15	13,5	E.D				
85	"	Fleuve	Rao	Rao	0,20	8,5	E.D				
86	14/3/84	Fleuve	Rao	Rao	0,15	5,20	E.S				
87	"	Fleuve	Rao	Croisement Rao (Maraîcher)		6,0	E.D				
88	"	Louga	Mbédiène	Keur Siny Dieng	0,10	30,5	E.D		Sable blanc + niveau phosphaté		
89	"	Louga	Koki	Ouarack	0,08	21,5	E.D				
90	"	Louga	Koki	Koki	0,05	20,5	E.S				
91	"	Louga	Koki	Koki	0,08	22,0	E.S				
92	"	Louga	Koki	Djiadiordé	Sec	20,0					
93	"	Louga	Koki	Gueli	a) Sec b) 0,50	23,0 82,0					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
94	14/3/84	Louga	Koki	Moukh Moukh	a) T.E.	43,0	E.D	b) 100	50			
95	"	Louga	Dahr	Niandoul	6,0	21,5	E.D					
96	"	Louga	Darou Moust	Bélél Gueloki	6,0	72,0	E.D					
97	"	Louga	Yang Yang	Yang Yang	2,0	33,0	E.D					
98	"	Louga	Yang Yang	N'Gouye Dieri	1,0	47,0	E.N.D					
99	"	Louga		N'Diakhate	4,0	47,5	E.D					
100	"	Louga	Dodji	Doundodji	4,5	12,0	E.D					
101	"	Louga		Mboundiel	11,0	44,0	E.D					
102	15/3/84	Louga		Loumbél Lana	0,50	55,0	E.D					
103	"	Fleuve	Ouro Sogui	Yonoféré	Sec	52,0						
104	"	Fleuve		Mboule	0,35	59,0	E.D					
105	"	Fleuve		Guentou Bhoki	0,30	71,0	E.D			Craie?		
106	"	Fleuve	Ouro Sogui	Darou Nema	0,25	62,0	E.D			Craie?		
107	"	Fleuve	Ouro Sogui	Darou Nema	0,50	62,0	E.D					
108	"	Fleuve	Ouro Sogui	Fourdou				289	50			
109	"	Fleuve	Ouro Sogui	Boula Taly	0,50	55,0	E.D					
110	"	Fleuve	Ouro Sogui	Ranérou				280	50			
111	"	Fleuve	Ouro Sogui	Dendoudi				236	75			

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
112	15/3/84	Fleuve	Ouro Sogui	Dentiadi	0,10	23,0	E.D					
113	"	Fleuve	Ouro Sogui	Modv Macka	5,0	24,0	E.D					
114	"	Fleuve	Ouro Sogui	Thiambe	0,25	15,0	E.D			Sable jaune		
115	"	Fleuve	Ouro Sogui	Sintiou Mago	2,50	15,50	E.D					
116	"	Fleuve	Ouro Sogui	Doumga Ouro Alpha	0,30	14,80	E.D					
117	16/3/84	Fleuve	Thilogne	Diaba	0,50	14,0	E.D					
118	"	Fleuve	Thilogne	Badène	0,05	12,5	E.D					
119	"	Fleuve	Thilogne	Agnam Civol	0,30	13,5	E.D					
120	"	Fleuve		Diaba Deklé	0,05	18,0	E.D					
121	"	Fleuve	Saldé	Galoya	4,0	25,0	E.D					
122	"	Fleuve	Saldé	Boqué Diégué	0,30	46,0	E.D					
123	"	Fleuve	Saldé	Bonué Dialouhe	2,0	20,0	E.D					
124	"	Fleuve	Saldé	Lour Ouoloff	3,0	66,0	E.D					
125	16/3/84	Louga	Koki	7 km à l'est Moukh Moukh	1,0	65,0	E.D.					
126	"	Fleuve	Saldé	Lour Ouoloff	Sec	49,0	E.D.			Calcaire gleucone		
127	"	Fleuve	Saldé	Bogué Diégué	3,0	14,5	E.D.					
128	"	Fleuve	Kaskas	Mbouda	0,10	17	E.D.					
129	"	Fleuve		Ouro Hawa Bandou Ba	7,0	23,0	E.S.			Calcaire		

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES	OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond m3/h (m)	Stratigra-phiques	Structu-relles	
130	16/3/84	Fleuve		Diaga Lao	0,05	19,0	E.D		Sable blanc		
131	"	Fleuve		Gourel Dieri	0,05	21,0	E.D		Sable blanc		
132	"	Fleuve	Ndioum	Diomandou	0,10	21,0	E.D				
133	"	Fleuve		Ouro Mangaye	0,04	34,0	E.D				
134	"	Fleuve	Ndioum	Ndioum	0,10	17,5	E.D				
135	"	Fleuve		Medina Freslé	0,20	22,5	E.D				
136	17/3/84	Fleuve	Ndioum	Taredji	0,10	17,0	E.D				
137	"	Fleuve	Thille Boubacar	Fanaye Diéri	0,40	16,0	E.D				
138	"	Fleuve		Gouniela	0,10	18,0	E.D				
139	"	Fleuve	Dagana	Talle Bakhlé	0,30	9,0	E.D				
140	"	Louga	Keur Momar Sar	Keur Momar Sar	Sec	7,0					
141	"	Louga	Mbédiène	Niomré Lo	1,80	29,0	E.D				
142	"	Louga	Ndandé	Tiey Tiey	0,70	36,0	E.D				
143	"	Louga	Ndandé	Ndandé	Sec	35,0					
144	"	Fleuve	Thillé Boubacar	Tivaouane II	5,5	19,0	E.D				
145	"	Fleuve		Kadhiogne	0,10	16,0	E.D				

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
146	3/4/84	Cap Vert	Bargny	Yène-sur-Mer	4,5	9,0	E.ALC	250				
147	"	Cap Vert	Bargny	Yène-sur-Mer	2,5	10,0	E.ALC					
148	"	Cap Vert	Bargny	Yène-sur-Mer (entrée)	2,0	12,5	E.D					
149	"	Cap Vert	Bargny	Yène-sur-Mer (entrée)	3,0	13,0	E.D					Creusé il y a 60 ans
150	"	Cap Vert	Bargny	Doukoura Ouolof	1,5	21,5	E.D					Tous les arbres arrosées par l'eau de ces puits ont dépérri
151	"	Thiès	Nguékokh	Diass	Sec	Sec						Pierres, saleté
152	"	Thiès	Nguékokh	Loumbou	1,5	24	E.D					
153	"	Thiès	Nguékokh	Sindia	1,0	22,0	E.D					
154	"	Thiès	Nguékokh	Sindia	1,0	21,0		310	10			
155	"	Thiès	Nguékokh	Nguékokh	1,0	9,0	E.D			Cuirasse sable jaune		
156	"	Thiès	Nguékokh	Nguékokh	0,30	9,0	E.D	197	20			
157	"	Thiès	Nguékokh	Nguékokh	0,20	7,0	E.D			Cuirasse		
158	"	Thiès	Nguékokh	Keur Balla	0,15	9,0	E.ALC			Calcaires + fossiles		
159	"	Thiès	Thiadiaye	Keur Balla	0,75	8,5	E.L	140	70			
160	"	Thiès	Thiadiaye	Garage Diakhère	1,5	16,5	E.D			Calcaire		

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
161	3/4/84	Thiès	Thiadiaye	Thiadiaye (prefecture)	0,05	10,0	E.D	500	26,7	Sable quaternaire		
162	"	Thiès	Thiadiaye	Ndiadiène	Sec	9,0	–					
163	"	Thiès	Fissel	Fissel	Sec	5,0	–	253	46			
164	"	Thiès	Fissel	Ndiadiène Keur Couly	0,30	11,0	E.D					
165	"	Thiès	Thiadiaye	Sandiara Ouolof	Sec	10,0	–	58	12,3			
166	"	Thiès	Thiadiaye	Ndiaganiao Mission C.	Sec	8,0		100	100			
167	"	Thiès	Fissel	Soussoum Mbefetjié	3,0	30,0	E.D					
168	"	Thiès	Fissel	Dieleng Keur Assane Wellé	1,5	50,0	E.D					
169	"	Thiès	Noto	Tassèt	2,0	40,0	E.D	750	80			
170	"	Thiès	Noto	Pout Diack	2,0	28,0	E.ALC					
171	"	Thiès	Noto	Noto(préfecture)	0,02	12,0	E.D	100	10			
172	"	Thiès	Noto	Silmang	0,01	17,0	E.D					
173	4/4/84	Thiès	Tiénaba	Keur Madaro	0,05	10,5	E.D					
174	"	Thiès	Tiénaba	Tiénaba	Sec	10,0						
175	"	Thiès	Tienaba	Croisement Ngoudiane	0,80	14,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
176	4/4/84	Thiès	Tiénaba	Ngoudiane	0,40	19,0	E.D	350	40			
177	"	Thiès	Tiénaba	Diack (carrière)	1,0	30,0	E.D					Le puits est situé entre 2 intrusions dolériques
178	"	Thiès	Tiénaba	Sortie de Khombole	Presque à sec	13,0	-					
179	"	Thiès	Tiénaba	Ndiongué	0,40	18,0	E.D					
180	"	Diourbel	Ngoye	Ndangalma	1,60	20	-					Puits éolien
181	"	Diourbel	Ngoye	Ndangalma	0,15	18,0	E.ALC					
182	"	Diourbel	Lambave	Toubédièye	2,0	19	-					Puits éolien
183	"	Diourbel	Lambaye	Silane	3,0	25,0	E.D			Calcaire		
184	"	Diourbel	Lambaye	Darou Mbow	1,0	39,0	E.D					Creusé en 1927
185	"	Diourbel	Lambaye	Ndiagne Sitor	0,80	34,0	E.D					
186	"	Diourbel	Baba Garage	Mbadiagol	0,50	27,0	E.D					
187	"	Diourbel	Ndini	Keur Ngane		*voir no. 167	E.D					
188	"	Thiès	Niankhène	Ndialba[2]	0,10	32,0	E.D					
189	"	Thiès	Niankhène	Ndiné Amar	0,50	30,0	E.D					
190	"	Thiès	Médina Dakhar	Ngueye Ngueye	1,0	29,0	E.D			Calcaire avec fossiles		
191	"	Thiès	Ndandé	Teug Diass (Dawakh)	0,60	32,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
192	4/4/84	Louga	Méaoune	Thille Peul	Sec	32,0	-					
193	"	Thiès	Méouane	Lompoul	0,10	5,50	E.D					
194	"	Thiès	Méouane	A 3km de Lompoul dans un verger		*voir no. 74	E.D					
195	5/4/84	Louga	Sagata	Gade Afé	0,15	37,0	E.D					
196	"	Louga	Sagata	Ndiatar Fall	0,40	34,0	E.D					
197	"	Louga	Sagata	Namène	0,20	36,0	E.D					
198	"	Louga	Sagata	Kalsane	0,50	35,0	E.D					
199	"	Louga	Sagata	Bargué	Sec	15,0	-					
200	"	Louga	Sagata	Bargué	2,0	53,0	E.D					
201	"	Louga	Darou Mousti	Sarr Sara								L'eau est recherchée au forage de Darou Mousty et de Taysire
202	"	Louga	Darou Mousti	Darou Mousti				285	50			Un réservoir de 1.000m³ assure le revitaillement du bétail
203	"	Diourbel	Ndamé	Mbayène Missira	0,20	70,0						
204	"	Diourbel	Ndamé	Ndindi Abdou	Sec	40,0	-					L'eau est recherchée au forage de Touba Mbacké
205	"	Diourbel	Ndamé	Keur Mbaye	Sec	35,0	-					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
206	5/4/84	Diourbel	Ndamé	Keur Ndao	3,5	46,0	E.D	280	140			
207	"	Diourbel		Ouro Diofo	Sec	84,0	-			Calcaire grêseux		L'eau est recherchée au château de Baïla
208	"	Sine Saloum	Kolobane	Tjissi	0,60	81,0	E.D					Il existe aussi une adduction d'eau vennant de Baïla
209	"	Sine Saloum	Kolobane	Taïf	7,50	60,0	E.D					
210	"	Sine Saloum	Kolobane	Sadatou	4,0	58,0	E.D					
211	"	Sine Saloum	Kolobane	Ngaraf	0,15	35,0	E.D					
212	"	Sine Saloum	Kolobane	Gayna Tamsire	T.E	39,0	E.D					
213	"	Sine Saloum	Kolobane	Bané	0,01	32,0	E.D					
214	"	Sine Saloum	Kolobane	Bountou Mbar	Sec	45,0	-					Les villages s'approvisionnent au forage de M'bar
215	"	Sine Saloum	Birkelane	Diamwéli	14,0	80,0	E.D					
216	"	Sine Saloum	Birkelane	Dagavn'der	0,30	25,0	E.D					
217	"	Sine Saloum	Birkelane	Navel	0,10	20,0	E.D			Sable blanc & jaune. Niveau phosphaté		
218	"	Sine Saloum	Birkelane	Ngaye Keur Magaye	0,50	22,0	E.S					
219	"	Sine Saloum	Birkelane	Bossalèle Peul	0,10	24,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
220	6/4/84	Sine Saloum	Birkelane	Mbos	3,0	44,0	E.D	289	60			Abduction venant du forage
221	"	Sine Saloum	Kahone	Darou Djadji	0,02	63,0	E.S			Calcaires + fossiles		
222	"	Sine Saloum	Kahone	Guinguinéo				237	151			Robinets
223	"	Sine Saloum	Kahone	Ségnagne Oualo	0,5	34,0	E.D					
224	"	Sine Saloum	Darou Bak									Puits éolien
225	"	Sine Saloum	Ouadiour	Mbos	2,5	32	E.D					Puits éolien
226	"	Sine Saloum	Ouadiour	Ndiébel	0,10	24,0	E.D					
227	"	Diourbel	Ndoulo	Nébé Teugue	0,60	33,0	E.D					Adduction venant de Ndiarème (Diourbel)
228	"	Diourbel	Ndoulo	Touré Mbonde	0,20	24,0	E.D					Puits éolien
229	"	Diourbel	Ndindi	Loumène	0,20	33,0	E.D					Recreusé en mars 84
230	"	Diourbel	Ngoye	Ndiatta	0,50	29	E.D					Puits éolien
231	"	Diourbel	Ngoye	Ngoye	0,5	30,0	E.D					
232	"	Sine Saloum	Niakhar	Diadiakh	0,10	13,0	E.S					Château d'eau dans le village
233	"	Sine Saloum	Niakhar	Mbafaye	0,002	13,0	E.D					
234	7/4/84	Sine Saloum	Kahone	Parassel	0,01	10,0	E.S					
235	"	Sine Saloum	Kahone	Ngtaye Naoudé	0,10	13,0	E.S					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
236	7/4/84	Sine Saloum	Gandiaye	Keur Massaer	0,30	9,50	E.S					
237	"	Sine Saloum	Gandiaye	Gamboul	Sec	15,0	-					
238	"	Sine Saloum	Gandiaye	Gamboul		13,0	-					
239	"	Sine Saloum	Gandiaye	Ndolongui	Sec	13,0	-					
240	"	Sine Saloum	Gandiaye	Ndolongui	Sec	10,0	-					
241	"	Sine Saloum	Tataguine	Ndionar	0,10	8,0	E.S					
242	"	Sine Saloum	Tataguine	Diouroup	Sec	12,0	-	40,5	-			
243	"	Sine Saloum	Tataguine	Garage Mbambara	Traces	8,0	E.S					
244	"	Sine Saloum	Tataguine	Mbouguel	0,10	7,0	E.D					
245	"	Sine Saloum	Fimela	Loul Séssène	Traces	5,0	E.S	290,6	45			
246	"	Sine Saloum	Fimela	Djilas	Traces	5,0	E.S					
247	"	Sine Saloum	Fimela	Diofior	Traces	7,0	E.S					
248	"	Sine Saloum	Tiadiaye	Samba Dia (verger)	0,40	7,0	E.D	150 (privé)	34			
249	"	Sine Saloum	Tiadiaye	Ndiarogne	1,10	9,0	E.D					
250	"	Thiès	Tiadiaye	Mbodiène	21,0	38,0	E.D					
251	"	Thiès	Tiadiaye	Nianing	0,1	7,0	E.D					
252	"	Thiès	Tiadiaye	Baling	15,0	65,0	E.D					Puits appronfondi il a 70 ans. Depuis, il n'y a pas eu de baisse d'eau.

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
253	7/4/84	Thiès	Pambal	Entrée Ndiassane	12,5	23,5	E.D					
254	"	Thiès	Pambal	Keur Ndiobo	0,40	22,0	E.D					
255	"	Thiès	Méouane	Ndomor	1,80	25,0	E.D					
256	"	Thiès	Méouane	Mboro (village)	0,20	19,0	E.D	26,7	15			
257	"	Thiès	Méouane	Mboro (verger)	0,50	4,0	E.D					
258	12/4/84	Sine Saloum	Malème-Hodar	Pété (village)	0,05	65,0	E.D					
259	"	Sine Saloum	Malème-Hodar	Baba Touré	0,05	70,0	E.D					
260	"	Sine Saloum	"	Mbelbouk	0,40	61,0	E.S					Creusé en 1931
261	"	Sine Saloum	"	Mbeuli	0,40	45,0	E.D					
262	"	Sine Saloum	"	Mandakhe	0,35	35,0	E.ALC					
263	"	Sine Saloum	"	Mborokounda	0,50	22,5	E.ALC					
264	"	Sine Saloum	"	Maleme-Hodar	0,90	61,0	E.ALC					
265	"	Sine Saloum	"	Diam Diam	1,10	58,5	E.D			Niveau phosphaté		
266	"	Sine Saloum	"	Delbi	0,20	40,0	E.D					
267	"	Sine Saloum	"	Ndiote Seyane	0,60	46,0	E.D					
268	"	Sine Saloum	"	Khour Loumbé	0,90	54,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
269	12/4/84	Sine Saloum	Malème-Hodar	Nierguel	0,40	85,0	E.D					
270	"	Sine Saloum	Malème-Hodar	Darou Miname				317,5	41,9			
271	"	Sine Saloum	Barkédji	Diaga Keur Bamba Mbaye	0,20	90,0	E.D					
272	"	Louga	Barkédji	Sibaul	0,20	76,0	E.D					
273	"	Louga	Barkédji	Tiel				273	50			
274	13/4/84	Louga	Barkédji	Vendouilo	0,30	76,0	E.D					
275	"	Louga	Barkédji	Vélingara				304	50			
276	"	Louga	Barkédji	Sessoum	0,15	50,0	E.D					
277	"	Louga	Barkédji	Bélél Touflé	0,40	25,0	E.D	330	32			Eau très chaude
278	"	Louga	Barkédji	Mboundou Mbaba	0,30	51,0	E.D					Bcp d'eau grâce à un robinet situé dans le puits
279	"	Sénégal Oriental	Koumpentoum	Bokhi Sada	0,80	90,0	E.D					
280	"	"	Koumpentoum	Payar	4,30	23,0	E.D					
281	"	"	Koumpentoum	Diouguel	3,5	52,0	E.D					
282	"	"	Koumpentoum	Panal	0,70	54,0	E.D					
283	"	"	Koumpentoum	Koutia Bâ Peul	0,40	56,0	E.D					
284	"	"	Koumpentoum	Koutia Bâ Ouolof	T.E	77,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES	OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond m3/h (m)	Stratigra-phiques	Structu-relles	
285	13/4/84	Sénégal Oriental	Koumpentoum	Sintiou Dhoki	T.E	58,0	E.D				
286	"	"	Koumpentoum	Fass Gounasse	0,60	45,0	E.D				
287	14/4/84	"	Koumpentoum	Palagué Hamari	-	44,0					Puits en cours de creusement initié par le Projet Bamba
288	"	"	Koumpentoum	Palagué Hamari	0,30	66,0	E.D				Dont un puit qui n'est pas encore achevé
289	"	"	Koumpentoum	Palagué Manding	0,50	66,0	E.D				
290	"	"	Koumpentoum	Malèm Bâ	0,40	65,0	E.D				
291	"	"	Koumpentoum	Malèm Bâ	0,30	76,0	E.D				
292	"	"	Koumpentoum	Vélingara Sintiou	0,35	59,0	E.D				
293	"	"	Koumpentoum	Koutia Gaïda	0,30	53,5	E.D				
294	"	"	Koumpentoum	Saré Bamaul Diallo	0,50	54,5	E.D				
295	"	"	Koumpentoum	Saré Sikouna	0,25	60,0	E.D				
296	"	"	Koumpentoum	Saré Sikouna	1,0	60,0	E.D				
297	"	"	Koumpentoum	Lofé	0,30	40,0	E.ALC				Eau très chaude

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
298	14/4/84	Sénégal Oriental	Koumpentoum	Touba Thiamène	0,35	37,0	E.D	117	50			
299	"	"	Koumpentoum	Malème Niani	0,10	55,0	E.D	131,06	50			
300	"	"	Koumpentoum	Malème Niani (Sodefitex)								
301	"	"	Koumpentoum	Haltou Fass	0,40	55,0	E.D					
302	"	"	Koussanar	Koussanar	0,40	24,0	E.D	127,01	50			
303	"	"	Koussanar	Koussanar Escale	T.E.	15,0	E.D	128,35	70			
304	"	"	Koussanar	"	Sec	23,0	-					
305	"	"	Koussanar	Vélingara Samba	0,15	30,0	E.D					
306	"	"	Koussanar	Sintiou Malème	0,10	23,0	E.D					
307	"	"	Koussanar	Lycounda	0,10	25,0	E.D					
308	"	"	Koussanar	Lycounda	0,10	24,0	E.D					
309	"	"	Koussanar	Touba Fali	0,10	23,0	E.D					
310	"	"	Koussanar	Dialacoro-bougou	0,50	23,5	E.D					
311	16/4/84	"	Koussanar	Mayel Djiby	0,10	28,0	E.D			Grès rouge		
312	"	"	Goudiri	Sintiou Samba Boubou	0,15	28,0	E.D			Niveau phosphate		

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
313	16/4/84	Sénégal Oriental	Goudiri	Madina Toua	0,15	34,0	E.D					
314	"	"	Goudiri	Bala Bané	0,80	30,0	E.D					Flux d'eau. Autre puits au fond du puits datant X temps. A sec depuis 20 ans au moins.
315	"	"	Goudiri	Sintiou Amar Ali	0,20	40,0	E.D					
316	"	"	Goudiri	Sintiou Barinabé	0,25	39,0	E.D					
317	"	"	Goudiri	Sintiou Bocar Ali	0,05	46,0	E.D					
318	"	"	Goudiri	Diarel Assane	0,15	55,0	E.D					Flux d'eau au fond du puits couleur de l'eau - rouge
319	"	"	Goudiri	Toulde Thiekoyi	Sec	60,0	-					
320	"	"	Goudiri	Toudlé Thiekoyi	2,00	65,0	E.D					Flux d'eau au fond du puits
321	"	"	Koussanar	Toubéré Bafal	0,20	61,0	E.D					
322	"	"	Koussanar	Toubéré Diaobhé	0,70	63,0	E.D					Flux d'eau dans le puits
323	"	Fleuve	Koussanar	Nghar	0,40	63,0	E.D					
324	"	Fleuve	Kanel	Mboune	0,15	54,0	E.D					
325	"	Fleuve	Kanel	Fété Bowé	1,80	59,0	E.D					
326	"	Fleuve	Kanel	Fété Bowé	0,50	39,0	E.D					Eau chaude
327	"	Fleuve	Kanel	Fété Fowrou	0,25	54,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
328	16/4/84	Fleuve	Kanel	Namâri	0,80	59,0	E.D	320	40,2			
329	"	Fleuve	Kanel	Namâri	5,0	21,0	E.D					Eau chaude
330	"	Fleuve	Ouro Sogui	Houndaleï	0,65	52,0	E.D					
331	"	Fleuve	Ouro Sogui	Bélél	0,06	51,0	E.D	a) 278 b) 34,4	41 4			
332	"	Fleuve	Ouro Sogui	Loumbol				304	50			
333	17/4/84	Fleuve	Ouro Sogui	Ogo	4,50	21,0	E.D	78	12			
334	"	Fleuve	Ouro Sogui	Sintiou Garba	1,0	27,0	E.D	80	44			Puits éolien
335	"	Fleuve	Ouro Sogui	Sintiane	0,10	18,0	E.ALC					
336	"	Fleuve	Kanel	Kanel	0,50	16,0	E.ALC	a) 37 b) 25	31 30			
337	"	Fleuve	Kanel	Ouro-Sidy	0,65	27,0	E.ALC					
338	"	Fleuve	Kanel	Sintiou Bamambé	0,15	28,0	E.D	141	40			
339	"	Fleuve	Kanel	Hamadi Hounaré	0,50	14,0	E.ALC					
340	"	Fleuve	Semmé	Orkadiéré	0,50	16,0	E.D					
341	"	Fleuve	Semmé	Semmé	Sec	7,0	-	137	46,5			
342	"	Fleuve	Semmé	Semmé (préfecture)	0,50	26,0	E.D					
343	"	Fleuve	Semmé	Diamounguél	traces	12,0	E.D					
344	"	Fleuve	Semmé	Diamounguél	traces	12,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES	OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond m3/h (m)	Stratigra-phiques	Structu-relles	
345	17/4/84	Fleuve	Semmé	Fadiar	0,10	17,50	E.D				
346	"	Fleuve	Semmé	Bokeladji	11,0	30,0	E.D				
347	"	Sénégal Oriental	Diawara	Bondji	Traces	12,0	E.D				Petits puits creusés par les villageois
348	"	"	Diawara	Tourime	0,05	14,5	E.D				
349	18/4/84	"	Diawara	Ololdou	3,0	13,5	E.D				
350	"	"	Diawara	Ololdou	0,05	6,0	E.D				
351	"	"	Diawara	Ololdou		4,0					Séanes
352	"	"	Diawara	Madina Abdou	0,80	13,5	E.S				
353	"	"	Diawara	Madina Abdou	0,03	4,0	E.D				Séanes
354	"	"	Goudiri	Toulékédi	0,20	48,0	E.D				
355	"	"	Goudiri	Boulél	0,50	41,0	E.D				
356	"	"	Goudiri	Ndia	0,35	34,0	E.D				
357	"	"	Goudiri	Nida-maisons familiales rurales	0,30	40,0	E.D				
358	"	"	Goudiri	Baniou	0,15	43,5	E.D				
359	"	"	Goudiri	Baniou	0,15	48,0	E.ALC				
360	"	"	Goudiri	Baniou-puits projet élevage	1,30	55,50	E.D				
361	"	"	Goudiri	Sohol	0,35	36,5	E.D				

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
362	18/4/84	Sénégal Oriental	Goudiri	Siwabé	0,10	33.5	E.D					
363	"	"	Goudiri	Guina	2,0	34,5	E.D					
364	"	"	Goudiri	Sintiou Tapsirou	0,35	34,0	E.D					
365	"	"	Goudiri	Ouro Kaba	0,15	30,0	E.D					
366	"	"	Goudiri	Sintiou M. Boubou	0,20	26,0	E.D					
367	"	"	Goudiri	M'Baïladji	Sec	20,0	-					
368	"	"	Goudiri	M'Baïladji	0,40	23,5	E.D				Grès noyés au fond du puits	
369	"	"	Goudiri	Sintiou M. Boubou	0,12	17,0	E.ALC					
370	"	"	Diawara	Béllé	0,10	28,5	E.D					
371	"	"	Diawara	Saré Fadoumé	0,50	19,5	E.D					
372	19/4/84	"	Diawara	Bema	0,20	3,5	E.D	78	2,3			
373	"	"	Diawara	Bema	0,10	8,0	E.D					
374	"	"	Diawara	Bema	Sec	9,0	-					
375	"	"	Diawara	Marsa	0,10	14,0	E.D	70	17,6			
376	"	"	Diawara	Gourel Mandji	0,15	15,0	E.D					2 sources opposées

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
377	19/4/84	Sénégal Oriental	Diawara	Gabou	Traces	5,0	E.D					
378	"	"	Goudiri	Sintiou Doubhé	0,05	19,0	E.D					
379	20/4/84	"	Goudiri	Boïnguel Mbamba	Sec	28,0	-					
380	"	"	Bala	Bala	Sec	25,0	-					Tous les puits sont à sec, puits hydraulique
381	"	"	Bala	Bala Foulbe	Sec	47,0	-	187	?			
382	"	"	Bala	Kotiari	0,50	30,0	E.D					
383	"	"	Bala	Ina Diné	0,10	24,0	E.D			Sables jaunes au fond du puits		
384	"	"	Koussanar	Kerwané	0,20	16,0	E.D					
385	"	"	Koussanar	Koromadji	0,75	13,50	E.D					
386	"	"	Koussanar	Botou	0,80	31,0	E.D					
387	17/5/84	"	Missira	Dienkor Manfin	0,25	28,0	E.D			Niveau phosphaté		
388	"	"	Missira	Hamdalaye Pont	0,20	12,5	E.D					Puits traditionnel
389	"	"	Missira	Sodefitex Missira	0,30	15,0	E.D					
390	"	"	Missira	Ardoulaye	0,15	37,5	E.D			Grès rouge		

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
391	17/5/84	Sénégal Oriental	Missira	Gourel Yobha	0,40	25,0	E.D			Marnes		Puits traditionnel
392	"	"	Missira	Wassadou Dépôt	0,48	9,0	E.D			Grès alluvionaires		
393	"	"	Missira	Dar Salam	0,05	16,0	E.D					
394	"	"	Missira	Diénoum Oiala	1,50	11,5	E.D			Sable hétérogène		
395	"	"	Missira	Niokolo Koba	0,10	13,0	E.D					
396	"	"	Bandafassi	Niéménéki	Traces	14,0	E.D					
397	18/5/84	"	Bandafassi	Fadiga	0,05	11,0	E.D					
398	"	"	Bandafassi	Bandafassi	0,40	14,60	E.D					
399	"	"	Bandafassi	Ibel	0,10	9,50	E.D					
400	"	"	Bandafassi	Ndébou	0	8,0	-					Puits traditionnel
401	"	"	Bandafassi	Landiène	Traces	17,0	E.D			Argiles		
402	"	"	Bandafassi	Thiakoum Malal	0,05	8,0	E.D			Gravier fluviatile très grossier		
403	"	"	Bandafassi	Ségou	0,3	8,0	E.D					
404	19/5/84	"	Saraya	Diakhaba	0,05	15,0	E.D			Granite		
405	"	"	Saraya	Diakhaba	0,05	17,0	E.D			Schiste, granite, talc		
405	"	"	Saraya	Sabou ssiré (Fondala)	0,03	6,5	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
406	19/5/84	Sénégal Oriental	Saraya	Saboussiré (Fondala)	0,03	6,5	E.D					
407	"	"	Saraya	Bembou	0,03	7,5	E.D			Granite		
408	"	"	Saraya	Diakha Medina	0,03	14,5	E.D					
409	"	"	Saraya	Saraya	traces	16,5	E.D					
410	20/5/84	"	Saraya	Diobi	traces	10,5	E.D					
411	"	"	Saraya	Kondokbou	0,05	16	E.D					
412	"	"	Saraya	Balakonko	0,03	19,5	E.D			Schistes phyllitiques		
413	"	"	Saraya	Daloto	0,10	25,4	E.D					
414	"	"	Saraya	Daloto	0,03	25,5	E.D					
415	"	"	Saraya	Medina								Pas de puits au village; eau prov. de la rivière ± à 12 km
416	"	"	Saraya	Sambara Bougou	-	14,0	-					
417	"	"	Saraya	Kossanto	-	6,0	-					
418	"	"	Saraya	Kossanto	3,0	10,5	sale					
419	21/5/84	"	Bandafassi	Kaneméré	-	7,0	-					Harigot
420	"	"	Bandafassi	Kaneméré	-	13,5						
421	"	"	Goudiri	Feteniébé	0,45	26,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
422	15/6/84	Sine Saloum	Ndiedieng	Touba Sanokho	3,0	13,0	E.D					
423	"	Sine Saloum	Ndiedieng	Keur Waly Ndiaye	0,30	10,30	E.D					
424	"	Sine Saloum	Djilor	Keur Bakary	0,60	9,0	E.D					
425	"	Sine Saloum	Toubakouta	Sokone	0,20	9,0	E.D					
426	"	Sine Saloum	Toubakouta	Sandikoli	0,20	9,30	E.D					
427	"	Sine Saloum	Toubakouta	Dagga Babou	0,20	7,50	E.D					
428	"	Sine Saloum	Toubakouta	Saroudia	-	15,0	sec					
429	"	Sine Saloum	Toubakouta	Saroudia	-	12,0	sec					
430	"	Sine Saloum	Toubakouta	Saroudia	0,25	17,50	E.D					
431	"	Sine Saloum	Toubakouta	Karang	0,10	15,50	E.D					
432	"	Sine Saloum	Toubakouta	Keur Samba Guèye	-	22,0	Sec					
433	"	Sine Saloum	Toubakouta	Keur Samba Guèye	0,30	19,5	E.D					4 puits sont à sec
434	"	Sine Saloum	Toubakouta	Bombadala Thiakho	1,0	16,0	E.D					
435	"	Sine Saloum	Toubakouta	Keur Aly Kane	0,30	10,50	E.D					
436	"	Sine Saloum	Toubakouta	Ndiaye-Ndiaye	1,20	13,0	E.D					
437	"	Sine Saloum	Toubakouta	Ndramé Escale	1,0	15,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
438	15/6/84	Sine Saloum	Toubakouta	Koular	1,20	12,5	E.D					
439	"	Sine Saloum	Wak Ngouna	Koutango	0,10	14,0	E.D					
440	"	Sine Saloum	Wak Ngouna	Wak Ngouna	0,10	27,0	E.D					
441	"	Sine Saloum	Wak Ngouna	Keur Madiabel	0,15	20,0	E.D	92 92	72 5,6			
442	"	Sine Saloum	Ndiedieng	Tiarène	1,10	27,0	E.D					
443	"	Sine Saloum	Ndiedieng	Ndiobène Rokhi	0,60	21,0	E.D					
444	"	Sine Saloum	Ndoffane	Kavil	traces	18,0	E.D					
445	16/6/84	Sine Saloum	Ndoffane	Keur Ya Habi	0,05	13,5	E.D					
446	"	Sine Saloum	Ndoffane	Sintiou Keur Mboutou	-	13,5	sec					
447	"	Sine Saloum	Paoskoto	Keur Samba Malick	5,0	34,0	E.D					
448	"	Sine Saloum	Paoskoto	Keur Kaba	2,5	29,0	E.D					
449	"	Sine Saloum	Paoskoto	Nioro du Rip	1,20	24,0	E.D	42 56,35	18 100			
450	"	Sine Saloum	Paoskoto	Firgui	0,60	14,0	E.D					
451	"	Sine Saloum	Paoskoto	Dabali	0,25	18,5	E.D					
452	"	Sine Saloum	Medina Sabakh	Kaymor	3,0	21,5	E.D					
453	"	Sine Saloum	Medina Sabakh	Sonkoron	0,80	21,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
454	16/6/84	Sine Saloum	Medina Sabakh	Diama Passy	2,0	40,50	E.D					
455	"	Sine Saloum	Nganda	Nganda(élevage)	-	35,0	Sec					
456	17/6/84	Sine Saloum	Birkelane	Ségré Sékko	0,80	34,0	E.D					
457	"	Sine Saloum	Birkelane	Ndillé	2,50	37,0	E.D					
458	"	Sine Saloum	Ndoffane	Darou Keur Balla	1,70	30,0	E.D					
459	"	Sine Saloum	Paoskoto	Touba Saloum	0,30	40,0	E.D					
460	"	Sine Saloum	Birkelane	Sine-Madiamel	3,0	39,0	E.D					
461	"	Sine Saloum	Birkelane	Daga Balla	2,30	53,0	E.D					
462	"	Sine Saloum	Birkelane	Mbene Mamour	0,80	49,0	E.D					
463	"	Sine Saloum	Malème-Hodar	Medina Mbadiane	1,0	61,0	E.D					
464	"	Sine Saloum	Malème-Hodar	Touba Saloum Baye Niass	1,50	59,0	E.D					
465	"	Sine Saloum	Malème-Hodar	Darou Salam II	2,0	54,0	E.D					
466	"	Sine Saloum	Malème-Hodar	Missira	0,80	52,0	E.D					
467	"	Sine Saloum	Kougheul	Yamong	0,40	42,5	E.D					
468	"	Sine Saloum	Koungheul	Koungheul	0,20	17,0	E.D	103,4	50			
469	18/6/84	Sine Saloum	Koungheul	Keur Omar Boune	0,15	54,0	E.D					
470	"	Sénégal Oriental	Maka	Kanta	0,20	54,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
471	18/6/84	Sénégal Oriental	Koumpentoum	Village Onze (Terres Neuves)	2,0	54,0	E.D					
472	"	"	Koumpentoum	Medina Bissi	0,60	54,0	E.D					
473	"	"	Koumpentoum	Borsafa	2,0	43,0	E.D					
474	"	"	Maka	Touba Bélél (Village 9)	4,0	54,0	E.D					
475	"	"	Maka	Mapagne	2,0	53,0	E.D					
476	"	"	Maka	Maka	0,30	24,0	E.D					
477	"	"	Maka	Fadiya Counda	0,40	14,5	E.D					
478	"	"	Maka	Madina Kayadia	0,20	17,0	E.D					
479	"	"	Koussanar	Ndoga Babacar	0,10	22	E.D					
480	"	"	Maka	Sintiou Bouna	0,30	45,0	E.D					Puits traditionnel
481	19/6/84	"	Missira	Diounkore Peul	2,0	18,5	E.D					Puits traditionnel à sec
482	"	"	Missira	Gouloumbou (chez A.Diop)	0,40	21,5	E.D					Puits traditionnel
483	"	"	Missira	Coumba Koutou	0,90	11,5	E.D					
484	"	"	Missira	Nétéboulou	T.E	13,50	E.D					
485	"	"	Maka	Katob	2,0	28,0	E.D					
486	"	"	Koumpentoum	Koumaré	2,50	60,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS Profondeur eau (m)	PUITS Profondeur fond (m)	PUITS Qualité eau	FORAGES Fond (m)	FORAGES m3/h	OBSERVATIONS Stratigraphiques	OBSERVATIONS Structurelles	AUTRES OBSERVATIONS
487	20/6/84	Sénégal Oriental	Koungheul	Ndiaya	1,0	11,0	E.D					
488	"	"	Koungheul	Pakala	0,60	22,0	E.D					
489	"	"	Nganda	Ngotou Malik	2,50	60,0	E.D					
490	"	"	Nganda	Lagué	0,20	23,0	E.D					
491	28/6/84	Casamance	Vélingara	Picadouze	0,60	42,0	E.D					Puits traditionnel
492	"	Casamance	Vélingara	Medina Touat	1,20	25,0	E.D					
493	"	Casamance	Medina Yoro Foula	Médina Gounas	0,15	23,5	E.D	170	2,5			
494	"	Casamance	"	Rabat	0,15	11,5	E.D					
495	"	Casamance	"	Teyel	0,20	10,0	E.D					
496	29/6/84	Casamance	Kolda	Kolda, Mission catholique	2,00	4,0	E.D	46,80 300	5 200			
497	"	Casamance	Dioula Colon	Hamdallaï Kamako	0,60	5,60	E.D					
498	30/6/84	Casamance	Diattacounda	Goudomp	0,50	19,0	E.D					Puits éolien
499	"	Casamance	Niaguis	Koundioundou	TE	10,0	E.D					
500	"	Casamance	Niaguis	Niaguis	TE	17,0	E.D					Puits éolien
501	1/7/84	Casamance	Nyassia	a) Brin	0,15	17,5	E.D	b) 154,34	42,8			
502	"	Casamance	Nyassia	Nyassia (sous-préfec.)	0,20	8,0	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
503	1/7/84	Casamance	Loudia Ouoloff	Mlomp	0,90	15,60	E.D					
504	"	Casamance	Loudia Ouoloff	Cagnout	0,25	8,40	E.D					
505	"	Casamance	Loudia Ouoloff	Loudia Ouoloff	0,35	6,20	E.D					
506	"	Casamance	Oussouye	Oussouye				35,4 52	13,8 33,9			
507	"	Casamance	Loudia Ouoloff	Boukitingo	0,25	7,0	E.D	119	43	Sable		
508	"	Casamance	Kabrousse	Kabrousse	0,50	8,50	E.D	32,8	20			
509	2/7/84	Casamance	Tanghory	Tobor	1,20	2,70	E.D					
510	"	Casamance	Tanghory	Tabi	a) Sec b) 0,05	14,50 12,50	- E.D					
511	"	Casamance	Tanghory	Koutenghor	1,22	6,20	E.D			Sable, latérite		Puits traditionnel
512	"	Casamance	Sindian	Kaparan	0,20	18,5	E.D					
513	"	Casamance	Diouloulou	Bélaye	2,0	10	E.D					
514	"	Casamance	O.ouloulou	Djinaki	0,20	10,20	E.D					
515	"	Casamance	Diouloulou	Diouloulou	0,03	4,50	E.D	157				
516	"	Casamance	Sindian	Kassaïte	2,0	8,5	E.D					
517	"	Casamance	Diouloulou	Kaware	0,50	8,50	E.S					
518	19/9/84	Cap Vert		Croisement Keur Massar	0,30	10,20	E.D					

N° D'OBS	DATE	REGION	ARRONDISSEMENT	LOCALITE	PUITS			FORAGES		OBSERVATIONS		AUTRES OBSERVATIONS
					Profondeur eau (m)	Profondeur fond (m)	Qualité eau	Fond (m)	m3/h	Stratigra-phiques	Structu-relles	
519	19/9/84	C. Vert		Niakoul Rap	Sec	10,50	-					
520	"	C. Vert		Niakoul Rap	0,50	7	E.D					
521	"	C. Vert		Ndiakhirate	0,80	6	E.D					
522	"	C. Vert		Bambilor	Sec	8	-					
523	"	C. Vert		Bambilor	0,15	6	E.D					
524	"	C. Vert		Bérré	0,05	12	E.D					
525	"	C. Vert		Keur Abdou Ndoye	0,15	6	E.D					
526	"	Thiès		Kayar	0,30	2	E.D					
527	"	Thiès	Pambal	Ndiare	0,30	9,50	E.D					
528	"	Thiès	Pambal	Keur Mbire	0,40	6	E.D					
529	"	Thiès	Pambal	Keur Modou Maï (Sao)	0,05	5	E.D					
530	"	Thiès	Pambal	Mont Rolland	0,05	9,75	E.D					
531	2/8/84	Cas.	Kabrousse	Essaout	2,0	8,50	E.D.					
532	5/4/84	Sine Saloum		Kolobane	0,37	100,0	END					

ERRATA SHEET FOR TABLE III-2

# 63	-	City and well data not on map (see table)
# 64	-	City and well data not on map (see table)
# 78	-	City and well data not on map (see table)
#102	-	Well data omitted (see table)
#192	-	Well data omitted (see table)
#286	-	City and well data not on map (see table)
#151	-	Wrong information (see table)
#181	-	E.ALC, <u>not</u> E.D.
#232	-	E.D., <u>not</u> E.S.
#271	-	Well data on wrong city (see table)
#289	-	Well data on wrong city (see table)

APPENDIX A

Table III-3

Rock Sample Identification

TABLE III-3

PROJET TELEDETECTION ET CARTOGRAPHIE DES RESSOURCES NATURELLES
PLAN NATIONAL D'AMENAGEMENT DU TERRITOIRE

Catalogue des
échantillons géologiques

N° D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
Néant	6/3/84	Thiès	Nguékokh	Popenguine (Cap de Naze)	I-1	Marnes, calcaires	
10	6/3/84	Thiès	Thiadiaye	Ndiaganiao	I-2-I	Calcaire avec fossiles	Eocène inférieur
12	6/3/84	Thiès	Fissel	Soussoumesanda	I-3	Calcaire	
14	6/3/84	Thies	Fissel	Keur Ouali (Soussoume)	I-4	Calcaire	
21	7/3/84	Thiès	Pambal	Ndiassane	I-5	Calcaire	
26	7/3/84	Thiès	Médina Dakhar	Médina Dakhar	I-6	Calcaire à nummulites	Eocène supérieur
27	7/3/84	Thiès	Médina Dakhar	Mbodiene Nguessere	I-7	Calcaire à nummulites	Eocène supérieur
29	7/3/84	Thiès	Niakhène	Wadia Dieng	I-8	Niveau phosphate	
30	7/3/84	Diourbel	Ndindi	Kalom N° 2	I-9	Niveau phosphate	
31	7/3/84	Diourbel	Lambaye	Marène Couré	I-10	Calcaire et quartz	
34	7/3/84	Diourbel	Ngoye	Dara Mango	I-11	Calcaire silicifié avec fossiles	
35	7/3/84	Diourbel	Ndoulo	Sambé	I-12	Calcaire à "Ostrea"	
36	8/3/84	Diourbel	Ndoulo	Ndoulo	I-13	Calcaire avec fossiles	

N°D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
39	8/3/84	Diourbel	Ndame	Keur Mbaye	I-14	Calcaire avec fossiles	?
48	8/3/84	Sine Saloum	Birkelane	Navel	I-15	Sables hétérogenes	?
54	9/3/84	Sine Saloum	Kahone	Touba Ndindi	I-16	Sables hétérogènes	?
61	9/3/84	Sine Saloum	Gandiaye	Sagne Bambara	I-17	Sables héterogènes	?
63	9/3/84	Thiès	Fissel	N'Dioudiouf	I-18	Niveau phosphaté	?
88	14/3/84	Louga	Niomré	Keur Sini Dieng	II-1	Calcaire à Nummulites	Eocène Moyen
99	14/3/84	Louga	Koki	Gueli	II-2	Calcaire	?
113	15/3/84	Fleuve	Ouro Sogui	Modi Macka	II-3	Sables hétérogènes	Continental Terminal
103	15/3/84	Fleuve	Ouro Sogui	Guento Bhoki	II-4	Niveau ferrugineux	?
	15/3/84	Fleuve	Semmé	Tienkolel	II-5	Calcaire avec fossiles	?
122	16/3/84	Fleuve	Saldé	Bogué Diégué	II-6	Grès argileux	Continental Terminal
	16/3/84	Fleuve	Semmé	Doumengale	II-7	Calcaire silicifié	Eocène
	20/3/84	Sénégal Oriental	Goudiri	Boinguel Mbaba	II-8	Sables hétérogènes	?
		Thiès	Djilor	Loumène	II-9	Sable jaune?	?
150	3/4/84	Cap Vert		Ndoukoura	III-1	argiles, marnes	?
158	3/4/84	Thiès	Nguékokh	Keur Balla	III-2	Calcaires avec fossiles	Paléocène
161	3/4/84	Thiès	Thiadiaye	Thiadiaye	III-3	Sable rouge	Quaternaire
183	4/4/84	Diourbel	Lambaye	Silane	III-5	Calcaire	Eocène Moyen

N° D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
100	4/4/84	Thiès	Médina Dakhar	Ngueye Ngueye	III-6	Calcaire	Eocène Moyen
201	5/4/84	Diourbel	Ndame	Ouro Dioffo n°1	III-7	Calcaire	Eocène Moyen
217	6/5/84	Sine Saloum	Birkelane	Navel	III-8	Calcaire	?
221	6/4/84	Sine Saloum	Kahone	Darou Diadji	III-9	Calcaire avec fossiles	Paléocène
265	12/4/84	Sine Saloum	Malème-Hodar	Diame Diame	IV-1	Niveau phosphate	Puits
Néant	12/4/84	Louga	Barkedji	Ras Touré	IV-2	Calcaire a nummulites	Eocène supérieur
272	12/4/84	Louga	Barkedji	Sibaul	IV-3	Calcaire a nummulites	Eocène supérieur
276	13/4/84	Louga	Sessoum	Sessoum	IV-4	Grès argileux	Continental Terminal
287	13/4/84	Sénégal Oriental	Koumpentoum	Palagué Hamari	IV-5	Sable rouge	Puits en cours de creusement (projet Bamba)
307	14/4/84	Sénégal Oriental	Koussanar	Lycounda	IV-6	Argile, laterite, alumine	Quaternaire
311	16/4/84	Sénégal Oriental	Koussanar	Mayel Djiby	IV-7	Grès rouge (niveau ferrugineux)	Quaternaire
312	16/4/84	Sénégal Oriental	Goudiri	Sinthiou Samba Boubou	IV-8	Niveau ferrugineux	Quaternaire
328	16/4/84	Fleuve	Kanel	Namâri	IV-9	Niveau ferrugineux	Quaternaire
333	17/4/84	Fleuve	Ouro Sogui	Ogo	IV-10	Calcaire	Eocène Moyen
342	17/4/84	Fleuve	Semmé	Semmé	IV-11	Laterite, argile	Eocène Moyen

N° D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
334	17/4/84	Fleuve	Semmé	Diamoungél	IV-12	Calcaire	?
357	18/4/84	Sénégal Oriental	Goudiri	Ndia	IV-13	Grès grossiers, argiles	Continental Terminal
371	18/4/84	Sénégal Oriental	Diawara	Saré Fadoumé	IV-14	Schistes chloritiques et quartzites	Infra Cambrien - Cambrien
375	19/4/84	Sénégal Oriental	Diawara	Marsa	IV-15	Gneiss, tillites	Infra Cambrien - Cambrien
376	19/4/84	Sénégal Oriental	Diawara	Gourel Mandji	IV-16	Meta-andesites et metabasites	?
384	20/4/84	Sénégal Oriental	Koussanar	Kerwané	IV-17	Grès rouge	Quaternaire
387	17/5/84	Sénégal Oriental	Missira	Dienkore Manfin	V-1	Niveau phosphate	Puits
390	17/5/84	Sénégal Oriental	Missira	Ardoulaye	V-2	Grès rouge	Puits
391	17/5/84	Sénégal Oriental	Missira	Gourel Yobha	V-3	Marnes	Puits traditionnel
393	17/5/84	Sénégal Oriental	Missira	Dar Salam	V-4	Schistes phyllitiques	Puits, trace huile
394	17/5/84	Sénégal Oriental	Missira	Diénoum Diala	V-5	Sable hétérogène	Puit-probable-alluvion fluviatile
395	17/5/84	Sénégal Oriental	Missira	Parc Niokolo Koba	V-6	Gabbro	28 km nord ouest de Niololo Koba
Néant	17/5/84	Sénégal Oriental	Missira	Parc Niokolo Koba	V-7	Gabbro	±24 km nord ouest de Niokola Koba
Néant	17/5/84	Sénégal Oriental	Missira	Parc Niokolo Koba	V-8	Dolerite/Gabbro	Niemeneki

N° D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
396	17/5/84	Sénégal Oriental	Bandafassi	Niéménéki	V-9	Dolérite	Matériel provenant du fonds du puits
Néant	17/5/84	Sénégal Oriental	Bandafassi	Mako	V-10	Cipolin	Gravier du fleuve Gambie
Néant	17/5/84	Sénégal Oriental	Bandafassi	Tomboronkoto	V-11	Amphibolite	Roche verte volcanique
398	18/5/84	Sénégal Oriental	Bandafassi	Bandafassi (village)	V-12	Diorite	Molybdène/graphite
Néant	18/5/84	Sénégal Oriental	Bandafassi	Bandafassi	V-13	Granite "atectonique"	
Néant	20/5/84	Sénégal Oriental	Bandafassi	Koulountou	V-14	Pyroxénite	
Néant	18/5/84	Sénégal Oriental	Bandafassi	Bandafassi	V-15	Dolérite	
Néant	18/5/84	Sénégal Oriental	Bandafassi	A l'ouest d'Ibel	V-16	Cipolin	Birrimien
Néant	18/5/84	Sénégal Oriental	Bandafassi	A l'ouest d'Ibel	V-17	Marbre Cipolin	Birrimien
Néant	18/5/84	Sénégal Oriental	Bandafassi	Bandafassi	V-18	Cipolin	Birrimien
404	19/5/84	Sénégal Oriental	Saraya	Diakhaba	V-19	Granite, schiste, talc	Puit du marabout qui a donné son nom à ce village
Néant	19/5/84	Sénégal Oriental	Saraya	Rive Ouest du fleuve Diaguiri, Rte de Kédougo-Saraya	V-20 V-20-I	Sable aurifère Saprolite de schiste chloritique	Couche: 4m de la surface Bedrock

N° D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
Néant	19/5/84	Sénégal	Bélé	Laminia	V-22	Couche aurifère dans le fleuve Gambie	Conglomerat, ferruqineux
Néant	20/5/84	Sénégal Oriental	Saraya	Sambarabougou	V-23	Gabbro	
117	20/5/84	Sénégal Oriental	Saraya	Kossanto	V-24	Schistes sericiteux	Bed-Rock sur lequel se trouve l'or
Néant	20/5/84	Sénégal Oriental Sénégal Oriental	Bandafassi	8 km à l'est de Mako	V-25-I V-25-II	Agglomerat	Birrimien
Néant	20/5/84	Sénégal Oriental	Bandafassi	2 km au nord de Tomboronkoto	V-26-I	Amphibolite	Roches volcaniques vertes
Néant	20/5/84	Sénégal Oriental	Bandafassi	A 1 km de Mako sur la Rte de Sabodala	V-27	Gabbro? Diabase?	Roches "volcaniques" vertes
Néant	20/5/84	Sénégal Oriental	Saraya	A 1 km au nord de Saraya Rte Missira	V-28	Sable/marigot sur granite	Près du sondage Cogema n°386
Néant	20/5/84	Sénégal Oriental	Saraya	7 km avant Kossanto	V-29	Phyllite	Birrimien
Néant	20/5/84	Sénégal Oriental	Saraya	A 7 km à l'est de Kossanto	V-29-I	Roche intrusive Basique	Analyse = Au
Néant	21/5/84	Sénégal Oriental	Bandafassi	Koulountou	V-30	Pyroxénite-Peridotite	Analyse Cr, Au, Pt

N° D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
Néant	22/5/84	Sénégal Oriental	Missira	Niokolo Koba	V-31	Grès blanc	Ordovicien
Néant	27/5/84	Sénégal Oriental	Diawara	Sours le petit pont juste avant Gabou en allant vers le nord Gabou	V-33 V-33B	Serpentine Jaspe rouge Pyroxénite	Analyse = Cr
Néant	27/5/84	Sénégal Oriental Sénégal Oriental	Diawara	7 km au nord de Gabou	V-34 V-34-I	Williamsite Serpentinite	Analyse = Cr
Néant	21/5/84	Sénégal Oriental	Bandafassi	Bandafassi	V-35-I	Cipolin	Birrimien
Néant	21/5/84	Sénégal Oriental		Koulountou	V-36	Pyroxènite	Birrimien
Néant	21/5/84	Sénégal Oriental	Bandafassi	Bandafassi	V-37 I-V	Cipolin avec chalco-pyrite, pyrite	Analyse Pb, Zn, Ag
				Période du 13 juin au 20 juin 1984			
423	15/6/84	Sine Saloum	Ndiedieng	Keur Ouali Ndiaye	VI-1	Sable jaune	Quaternaire
424	15/6/84	Sine Saloum	Djilor	Keur Bakari	VI-2	Sables hétèrogènes	Quaternaire
427	15/6/84	Sine Saloum	Toubakouta	Dagga Babou	VI-3	Sable, cuirasse ferrugineuse	Continental Terminal + Quaternaire
444	15/6/84	Sine Saloum	Ndoffane	Kavil	VI-4	Cuirasse ferrugineuse	Continental Terminal

N° D'OBS.*	DATE	REGION	ARRONDISSEMENT	LOCALITE	N° ECHANTILLON	IDENTIFICATION	PROVENANCE, REMARQUES
446	16/6/84	Sine Saloum	Ndoffane	Keur Mboutou	VI-5	Cuirasse ferrugineuse	Continental Terminal
450	16/6/84	Sine Saloum	Paoskoto	Firgui	VI-6	Niveau phosphate Cuirasse ferrugineuse	Continental Terminal
475	18/6/84	Sénégal Oriental	Mak	Mapagne	VI-7	Sable jaune	Quaternaire
478	18/6/84	Sénégal Oriental	Mak	Madina Kayadia	VI-8	Sables hétèrogènes (rouge et jaune)	Quaternaire
			Période du 27/6 au 27/7/84				
Néant	28/6/84	Casamance		Cap Skirring	VII-1	Grès ferrugineux	Oligo-Miocène
Néant		Sénégal Oriental		Koulountou	V-21-I V-21-II	Gabbro	Birrimien
Néant		Sénégal Oriental		Koulountou, 2 km à l'est de	V-21-III	Spillite	Birrimien

APPENDIX A

Table III-4

Sample Analysis

The following tables show the analyses made by mass soectrometer of a number of rock samples collected by the project. These samples were analysed by the laboratories of the Direction des Mines et Géologie at Dakar, Senegal. The locations of the samples can be crossreferenced by consluting the sample/site locations in Appendix A, Table III-3.

Previous Page Blank

TABLE III-4
SAMPLE ANALYSIS

GROUPE LABORATOIRES DE LA DIRECTION DES MINES ET DE LA GEOLOGIE
B.P. 260 - Tél. 22.52.78
DAKAR

Demande d'Analyse no.....
de M ANDREW STANCIOFF

Territoire Sénégal **Mission**.....

Echantillons envoyés le 7 Juin 1984

Bulletin d'Analyse no. 4.102 à 4.107

- Projet USAID RSI/DAT -

N° de travail.....

Echantillons reçus au laboratoire
Le 7 Juin 1984 **N°** 154

Offset I.S.P.

N°	Situation		Nature de l'échantillon	Titrages demandés								
				Pt ppm	Ti ppm	Cr ppm	W ppm	Sn ppm	Zn ppm	Pb ppm	Au ppm	Ag ppm
V	24'						< 2	< 5				
	26	Toubor-okoto							3	130	< 0,1	< 0,1
	30	Koulou-ntou		< 0,1		2 600					< 0,1	0,3
	33	Serpen-tine			< 250	100					< 0,1	< 0,1
	34	Diagal Serpen-tine		< 0,1		2 250					< 0,1	< 0,1
	35	Banda							11	105	< 0,1	1,2

Méthode d'analyse – **1°) Attaque** ..... **2°) Dosage** .....

A DAKAR, le 7 Juin 1984
Le Demandeur,

M. Andrew Stancioff.-

Le Chimiste,

A DAKAR, le 25 Juin 1984
Le Chef de laboratoire,

G. Sall

GROUPE LABORATOIRES
DE LA
DIRECTION DES MINES
ET DE LA GEOLOGIE
B.P. 268 - Tél. 22.52.78
DAKAR

Demande d'Analyse no.....

de M. Andrew STANCIOFF

Territoire Sénégal Mission Projet US - AID

Echantillons envoyés le 5.07.84

Bulletin d'Analyse no. 888 à 892

N° de travail.....

Echantillons reçus au laboratoire

Le 5.07.84 N° 3

Offset I.S.P.

N°	Situation		Nature de l'échantillon	Titrages demandés								
				Mo ppm	Cr ppm	Ni ppm	Pb ppm	Zn ppm	Cu ppm	Pt ppm	Au ppm	Ag ppm
V-37 II		Banda					< 10	28				1,5
37 III		Banda					< 10	47				1,2
37 IV		Banda					< 10	62				1,7
37 V		Banda					< 10	54				1,5
37		Banda-fassi					< 10	46				1,5

Méthode d'analyse — 1°) Attaque ..... 2°) Dosage .....

A DAKAR, le 5.07.84

Le Demandeur,

A. Stancioff.-

Le Chimiste,

A DAKAR, le 4 Août 1984

Le Chef de laboratoire, d'A.A.

M. Ndoye.-

GROUPE LABORATOIRES
DE LA
DIRECTION DES MINES
ET DE LA GEOLOGIE
B.P. 268 - Tél. 22.52.78
DAKAR

Demande d'Analyse no.....

de M. Andrew STANCIOFF

Projet

Territoire Sénégal Mission US-AID

Echantillons envoyés le 5 Juillet 1984

Bulletin d'Analyse no. 878 à 887

N° de travail.....

Echantillons reçus au laboratoire

Le 5 Juillet 84 N° 3

Offset I.S.P.

N°	Situation		Nature de l'échantillon	Titrages demandés								
				Mo ppm	Cr ppm	Ni ppm	Pb ppm	Zn ppm	Cu ppm	Pt ppm	Au ppm	Ag ppm
V-14		Koulou-ntou		< 2	182				74		< 0,1	0,7
21 I	8km est de Mako	Koulou-ntou			74	61					< 0,1	< 0,1
22 à	2 km ouest	Koulou-ntou		< 2							< 0,1	0,5
32											< 0,1	< 0,1
13		Banda-fassi		< 2								< 0,1
33-B		Gabou			195	262				< 0,1	< 0,1	0,2
21 II	8km est de Mako	Koulou-ntou									< 0,1	< 0,1
38											< 0,1	
36		Koulou-ntou			14 000	156			6	< 0,1	< 0,1	< 0,1
37 I		Banda-fassi					< 10					1,2

Méthode d'analyse – 1°) Attaque ..... 2°) Dosage .....

A DAKAR, le 5 Juillet 1984

Le Demandeur,

A. Stancioff.-

Le Chimiste,

A DAKAR, le 4 Août 1984

Le Chef de laboratoire, d'A.A.

M. Ndoye.-

APPENDIX A

Tables III-5a and III-5b

Field Activities

APPENDIX A

TABLES III-5a and III-5b
FIELD ACTIVITIES

FIELD REPORT

Mapping and Remote Sensing of Natural Resources for the PNAT

USAID/RSI Project n° 685-0233

FIELD REPORT OR AERIAL OVERFLIGHT: Hydrogeologic Team n° 1

SUBJECT: Verification of the interpretation of the Dakar and Diourbel scenes

PERIOD: March 5-9, total km 1224
Departure: 46,098 Arrival: 47,32[illegible]

AREA: Cap Vert, Thiès, Diourbel and Sine Saloum

PARTICIPANTS/AGENCY: A. Stancioff, Geologist, Hydrologist, RSI/SDSU
A. Sow, Geologist, Direction des Mines et da la Géologie
S. Niang, Land Planner, DAT

MATERIAL: Project vehicle, geological hammer, mesure cord, magnifier, compass, maps (scale 1/250,000), Landsat images MSS and RBV (scale 1/250,000), geological maps and hydrogeological maps (scale 1/500,000), spada, sample bags.

OBSERVATIONS: For Cap Vert and Petite Côte, we

1) familiarized ourselves with the geology of the region.
2) verified certain geologic structures seen on the Landsat imagery (faults), and other structures that can be seen on the geological map (volcanic intrusions of Ndiass, of Cap de Naze, etc.).

For Thiès, Diourbel and Sine Saloum, we

1) verified the hydrogeologic interpretations made from Landsat imagery (determined the existence of fossil rivers).
2) mesured the depth of wells following well-defined criteria in order to understand the nature and characteristics of existing aquifers. Those mesurements were usually accompanied by samples of rock material taken from the wells. It was used to determine the existing relationships between the hydrology and the stratigraphy of each region (seven samples).

FIELD REPORT

Mapping and Remote Sensing of Natural Resources for the PNAT

USAID/RSI Project n° 685-0233

FIELD REPORT OR AERIAL OVERFLIGHT: Hydrogeologic Team n° 4

SUBJECT: Verification of the interpretation of the Tiel, Mboune and Bakel Landsat scenes

PERIOD: April 10-20, 1984; km traveled ± 2259

AREA: Sine Saloum, Ferlo, Fleuve, Senegal Oriental

PARTICIPANTS/AGENCY: A. Stancioff, Geologist, RSI/SDSU
A. Sow, Geologist, Direction des Mines et de la Géologie
S. Niang, Land Use Planner, DAT

MATERIAL: Geological map, road maps, hammer, sample bags, tents, beds, bedding, nylon rope, etc.

REMARKS: 1) The team continued to verify the geohydrologic and geologic interpretation made for these Landsat-image areas.

2) The team continued to make well mesurements in villages and towns along the route.

CONCLUSIONS: 1) A number of fossil channels were verified in the Ferlo region.

2) Significant erosion was found to exist in the portion of the Ferlo region where the Gambia River streams have this source.

3) Very hot waters were noted in a number of relatively shallow wells (60m) in the Ferlo region.

4) There appears to be no real lack of water in this region, with the exception of the areas between Bakel and Sintiou Fissa along the Senegal and Falémé rivers.

5) Possible sources of water in the Precambrian schistose of eastern Senegal might be found in the cores of synclinal folds.

6) Over 110 wells were logged and 15 geologic samples collected.

APPENDIX A

Tables III-6a and III-6b

Overflights

APPENDIX A

TABLES III-6a and III-6b
OVERFLIGHTS

FIELD REPORT

Mapping and Remote Sensing of Natural Resources for the PNAT

USAID/RSI Project n° 685-0233

AERIAL OVERFLIGHT REPORT: n° 36

SUBJECT: Aerial reconnaissance flight serving to provide oblique aerial photographs of vegetation; soils, land use and geologic units previously interpreted from Landsat imagery

PERIOD: August 8, 1984; duration: 4 hours

REGION: Flew along the following route: Dakar-Bambey-Touba-Linguère-Yonoférè-Ndioum-Podor-Gnit-Louga-Kayar-Dakar

PARTICIPANTS/AGENCY: M. Staljanssens, Soil Scientist, USAID/RSI
G. Tappan, Ecologist, USAID/RSI
A. Bodian, Botanist, Eaux et Forêts
M. Sall, Geographer, Dept de Géographie
B. Diouf, Trainee, USAID/RSI

MATERIAL: A piper twin-engine aircraft; IGN map of Senegal at 1:1,000,000; IGN map of Senegal at 1:500,000; Landsat scenes at 1:1,000,000 of Diourbel, Tiel, Podor, and St. Louis

REMARKS: The flight was a success overall given that the visibility was good over most areas. Four rolls of slides were taken. These have been processed and annotated as to their location. They serve as an excellent photographic record of the major map units observed from an altitude of 2500 feet. The only problem was a dust storm encountered in the Ndioum area, which reduced visibility to one mile or so. Navigation became a problem, requiring a change of course in order to facilitate it. We were not able to fly over a series of linear dunes in the Tatki area due to the change in course. The new course took us west to Lac de Guier, then south to Louga.

FIELD REPORT

Mapping and Remote Sensing of Natural Resources for the PNAT

USAID/RSI Project n° 685-0233

AERIAL OVERFLIGHT REPORT: n° 36

SUBJECT: Aerial reconnaissance flight to obtain aerial photographs of vegetation, soils, land use and geology

PERIOD: September 17, 1984; duration: 4.5 hours

REGION: Flew along the following route: Dakar-Foundiougne-Mioro-Farafenni-Kolda-Sédhiou-Ziguinchor-Elinkine-Banjul-Toubakouta-Mbour-Dakar

PARTICIPANTS/AGENCY: M. Staljanssens, Soil Scientist, USAID/RSI
G. Tappan, Ecologist, USAID/RSI
B. Diouf, Trainee, USAID/RSI
S. Diop, Geographer, Dépt de Géographie

MATERIAL: An Africair Piper twin-engine aircraft; IGN map of Senegal at 1:000,000; Landsat scenes of Dakar, Diourbel, Kolda and Ziguinchor at 1:500,000 and 1:000,000; three 35mm cameras using Ektachrome (64 films).

REMARKS: The flight was the most successful to date given the excellent visibility. Eight rolls of slides were exposed. The geographic location of each photograph was recorded at the time of exposure. These recordings will be used to annotate each photograph. The flight was made at an altitude of 1500 to 1800 feet. A brief rest stop at Ziguinchor was included.

APPENDIX A

Table III-7

Aerial Photography

The project used aerial photographs at a scale of 1:40 000 to verify the interpretations made from Landsat. The following aerial photograph interpretations were made in an effort to establish the veracity of our Landsat interpretation.

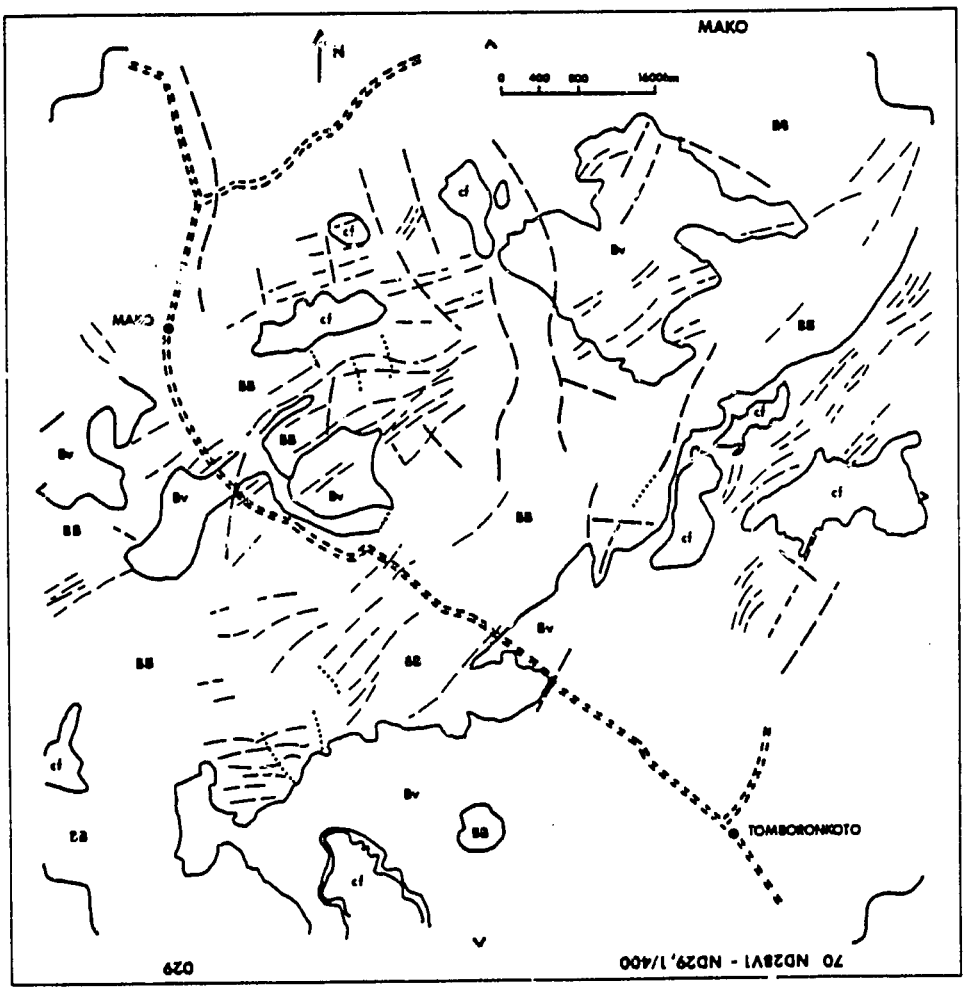
An interpretation is made by viewing with a stereoscope two consecutive pictures from a flightline. The drawings that follow were usually made by interpreting at least two and sometimes as many as four photographs.

Since these interpretations are only working documents, we have not gone beyond simple annotation and some comments. Had our objective been in-depth interpretation of aerial photographs, the work presented would have been much more detailed and more information would be given on the altitude of the aircraft, camera, etc. Our aim here is to simply show some results from the work done in support of the Landsat interpretation.

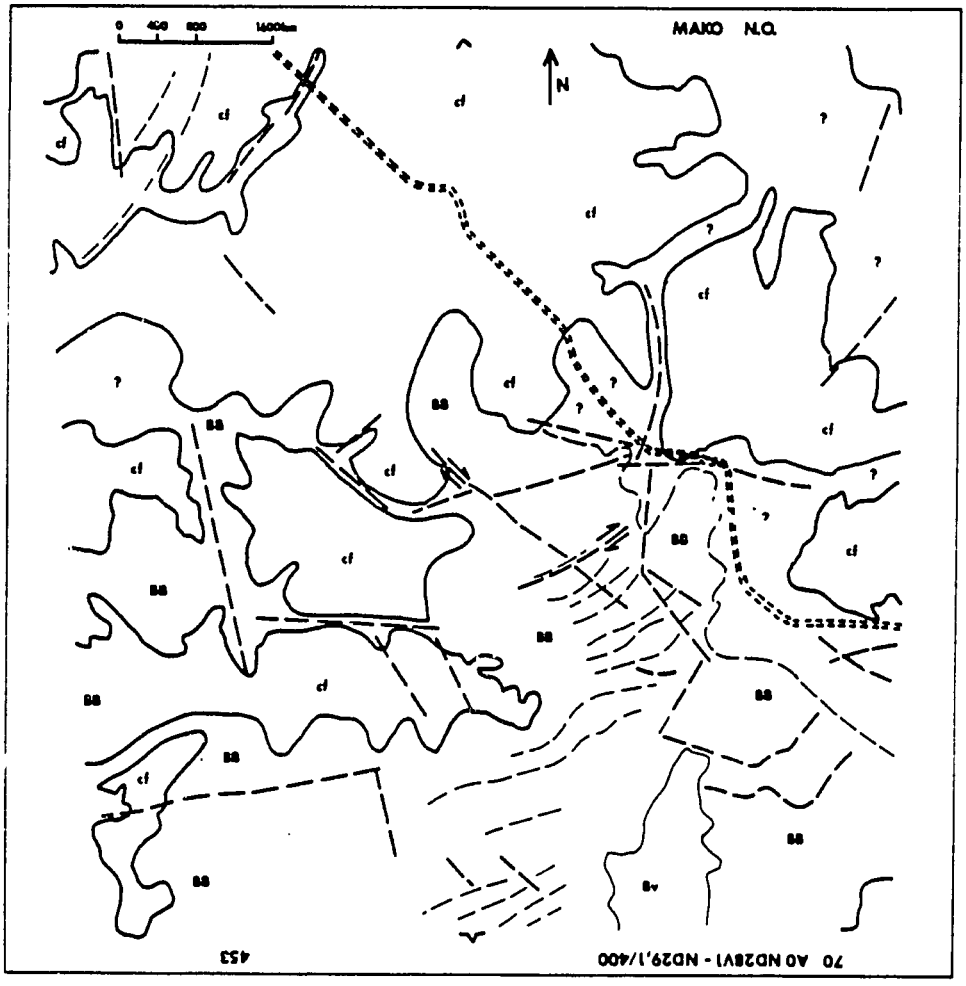
1. Aerial Photoanalysis: Mako--70 ND28V1-ND29, 1/400, #029
Mako N.O.--70 ND28V1-ND29, 1/400, #453

A set of six photographs was viewed stereoscopically and anlayzed in an attempt to discern lithology, faults, folds and other geologic characteristics. Broad, massive dark units with "minor" internal structure were interpreted as Birrimian ultrabasic rocks, BB. Finer, less dense, lighter toned units were interpreted as Birrimian volcano-sedimentary rocks, BV. Flat topped, light colored mesas with sharp or angular topographic edges were mapped as cf (cuirasse ferrugineuse), laterite cap. The fine, curvilinear, parallel lines represnet NE/SW trends in the country rock. The broader lines and dotted lines represent faults or fractures. The arrows indicate relative movement along possible faults.

Mako



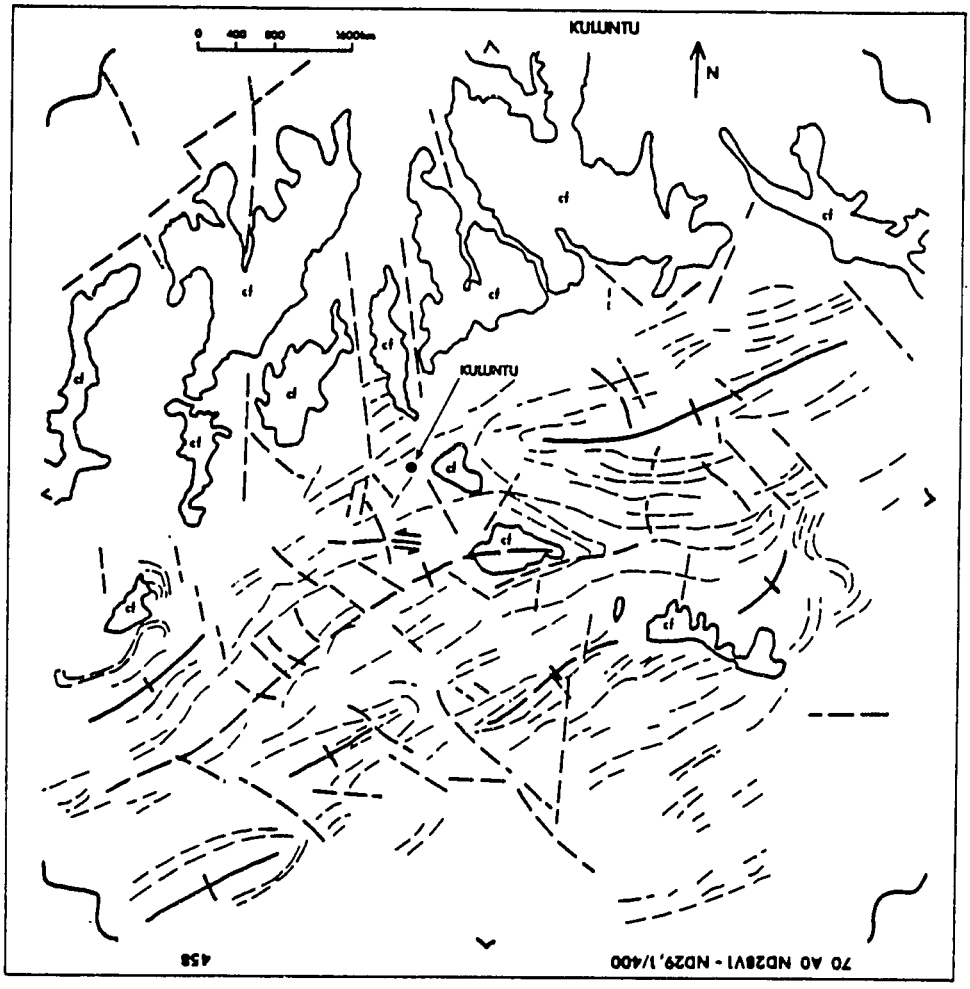
Mako N.O.



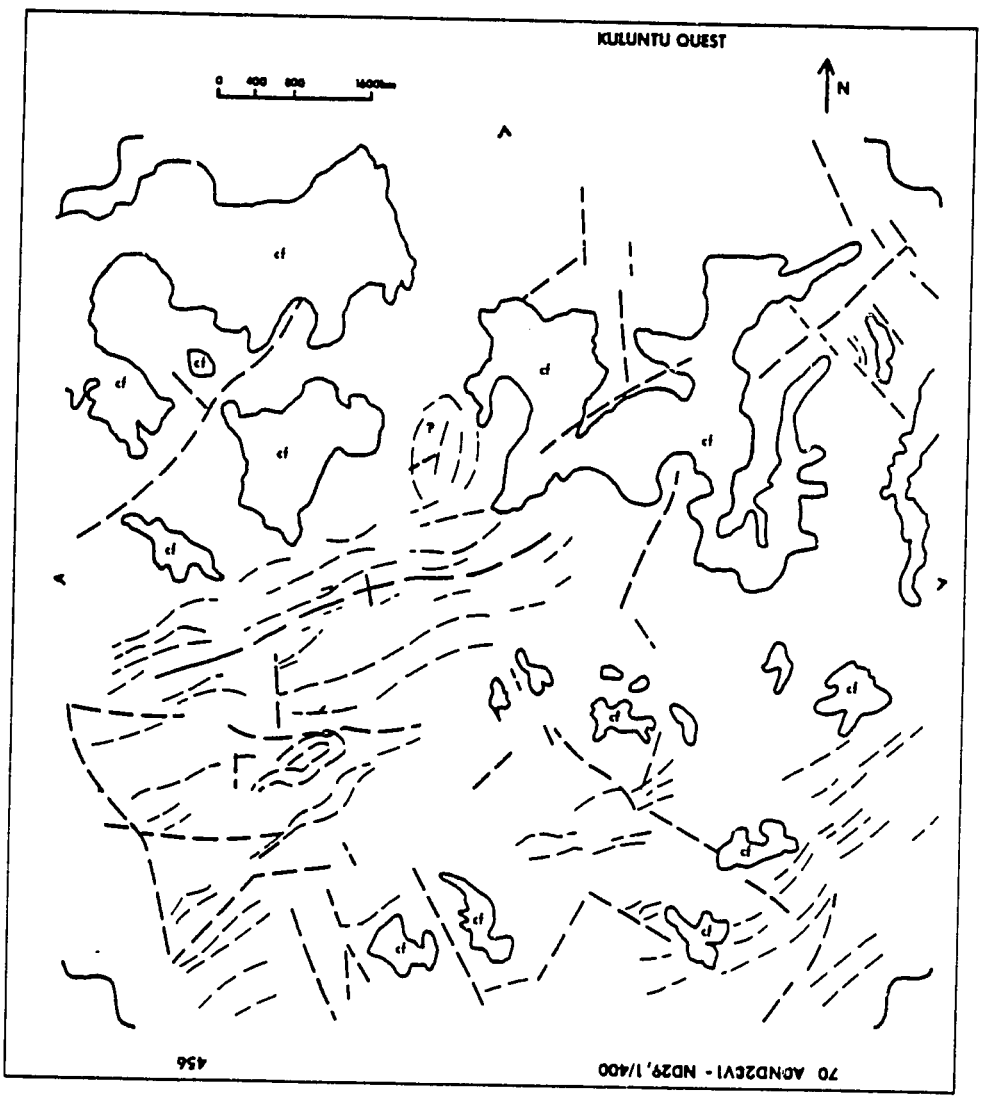
2. Aerial Photoanalysis: Kuluntu--70 AO ND28V1-ND29, 1/400, #459
Kuluntu Ouest--70 AO ND28VI-ND29, 1/400, #456

On these photographs we note two major terrain features: a broken, north-sloping laterite cap (cf) drained by numerous streams and a NE/SW trending sequence of complexly folded and faulted rocks of the Mako Series. The fine lines represent contacts and the general strike of the formations; they also indicate the tightness of the folds. The folds are indicated by thick, continuous lines trending northeast, with one short perpendicular line indicating the dips of the strata. The short dashed, heavy lines are faults or fractures, which typically trend NW/SE or NS. The arrows indicate the possible relative movement interpreted along an E/W fault. The majority of the rock units here are Birrimian ultrabasics and volcano-sedimentary rocks of the Mako and Dialé series.

Kuluntu



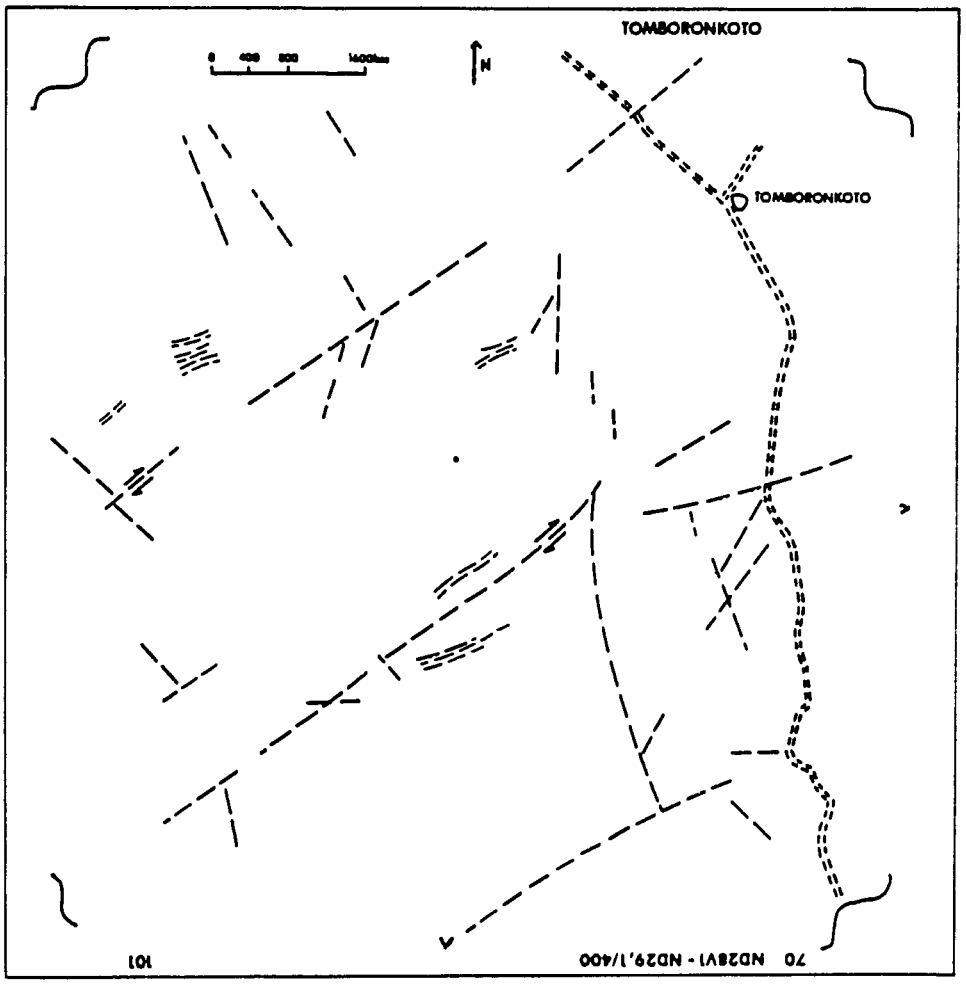
Kuluntu Ouest



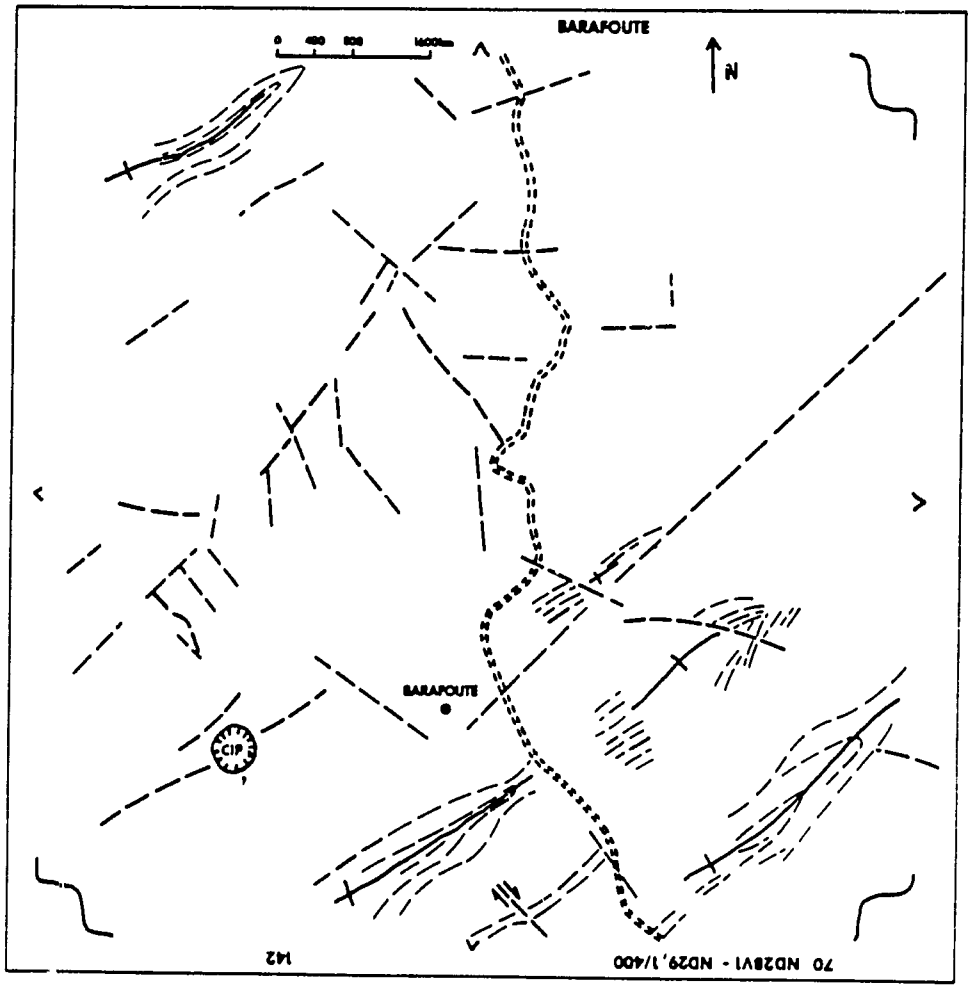
3. Aerial Photoanalysis: Tomboronkoto--70 ND28V1-ND29, 1/400, #101
Barafoute--70 ND28V1-ND29, 1/400, #142

The interpretation of these photographs of two areas along the road between Mako and Kédougou shows little except a very broken terrain with many small patches of lateritic cap and the typical NE/SW trends of the Birrimian Dialé Series. Some tight folds are also interpreted from these photographs. An interesting feature occurs 2 km west of Barafoute. In this area, it appears that a 400 m wide depression occurs which may represent a karstified outcrop of Birrimian calcareous rocks (cipolins).

Tomboronkoto



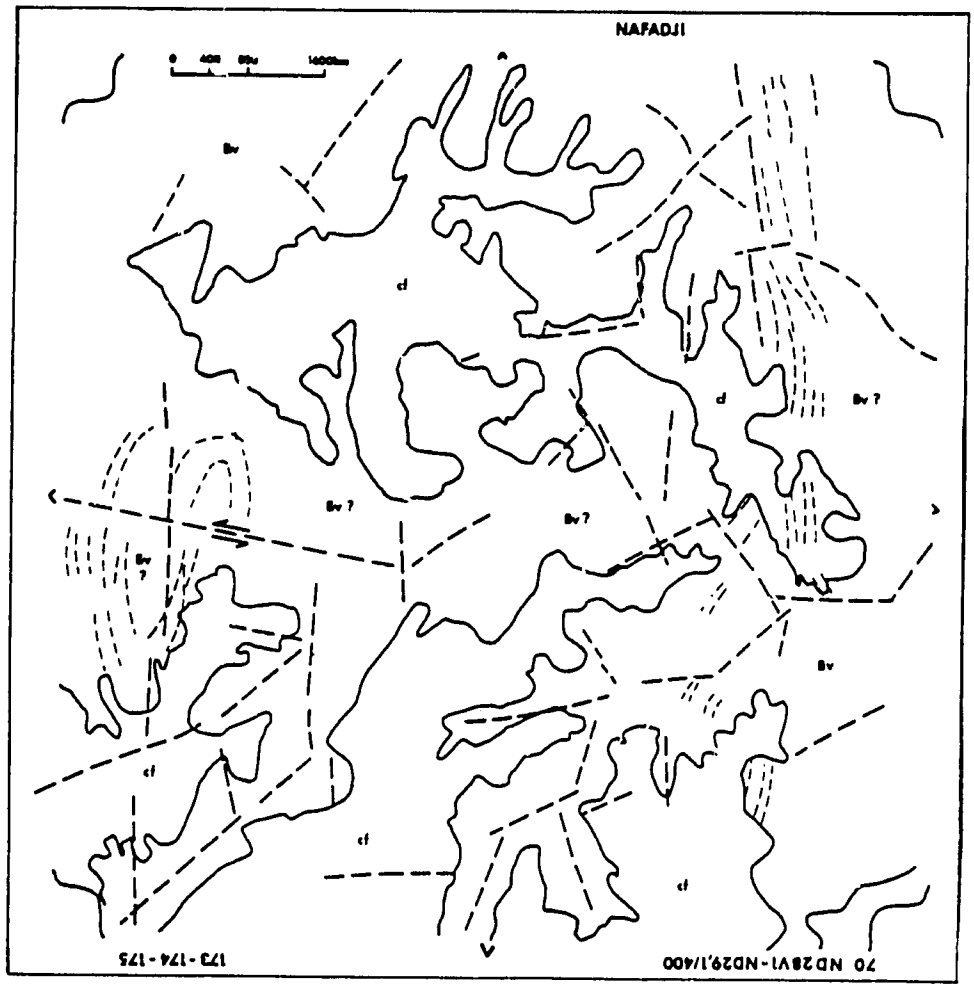
Barafoute


70 ND28V1 - ND29, 1/400
142
CIP
BARAFOUTE
BARAFOUTE
N
0 400 800 1600m

4. Aerial Photoanalysis: Nafadji--70 ND28V1-ND29, 1/400, #173-175

This is the area where the Boboti granites or granodiorites are said to occur. Our interpretation was not able to locate them. North/south trending contacts suggest thin bedded volcano-sedimentary rocks of the Daléma Series. Laterite capping is ubiquitous and tends to mark much of the bedrock. In the bottom center of the photograph, multi-directional faults and fractures suggest a crystalline bedrock, which could represent a granitic mass. Displacement is assumed where shown by the arrows.

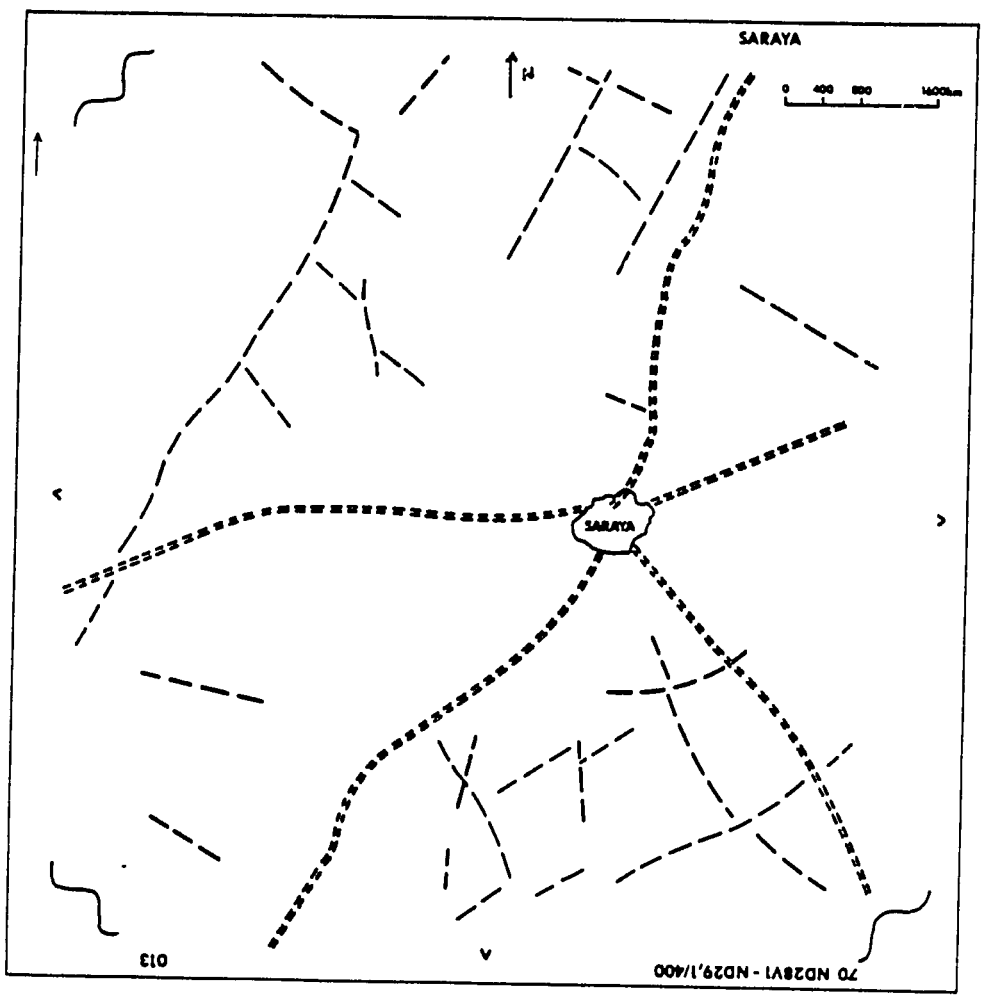
Nafadji



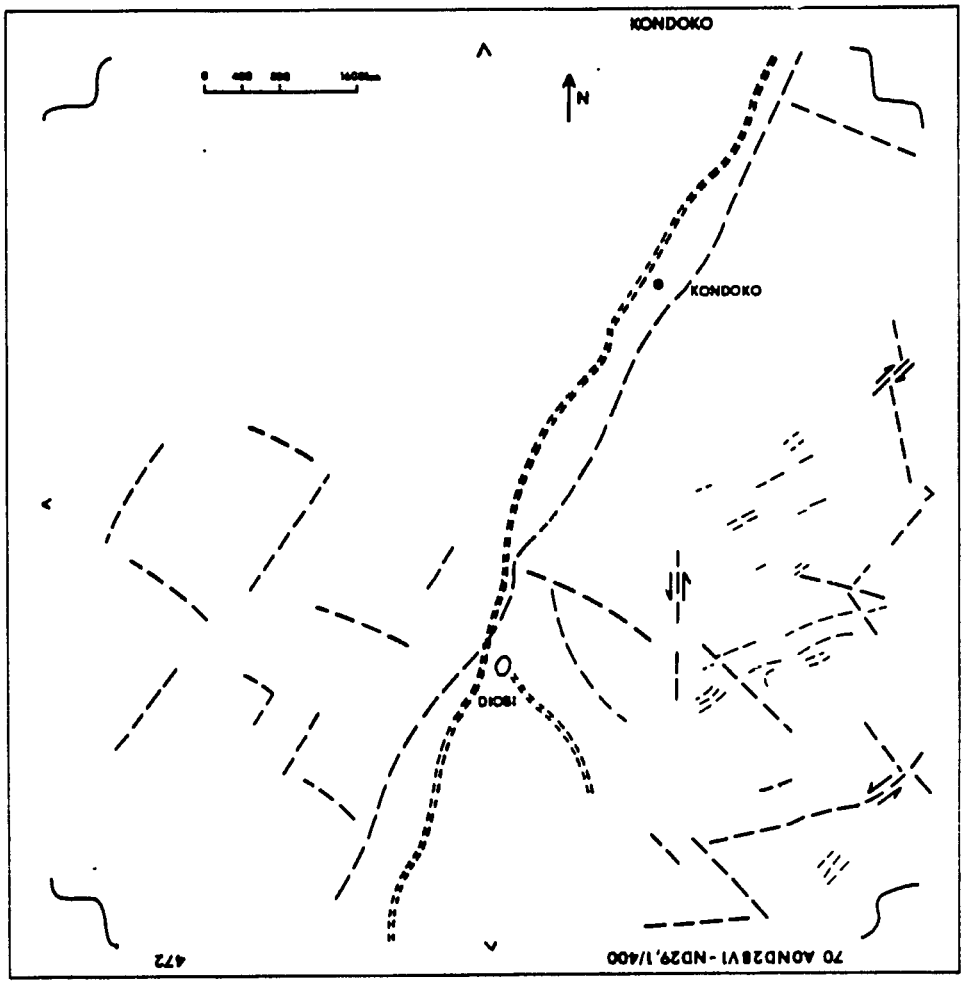
5. Aerial Photoanalysis: Saraya--70 ND28V1-ND29, 1/400, #013
Kondoko--70 ND28V1-ND29, 1/400, #472

These two photographic interpretations cover a large area over the Saraya granite. In both interpretations, we note orthogonal sets of points or faults typical of granitic terrain. In the eastern section of the Kondoko interpretation, fine NE trending lines suggest lithologic contacts, which would indicate a possible migmatic origin for this granite and not a plutonic one as has been suggested by previous authors.

Saraya



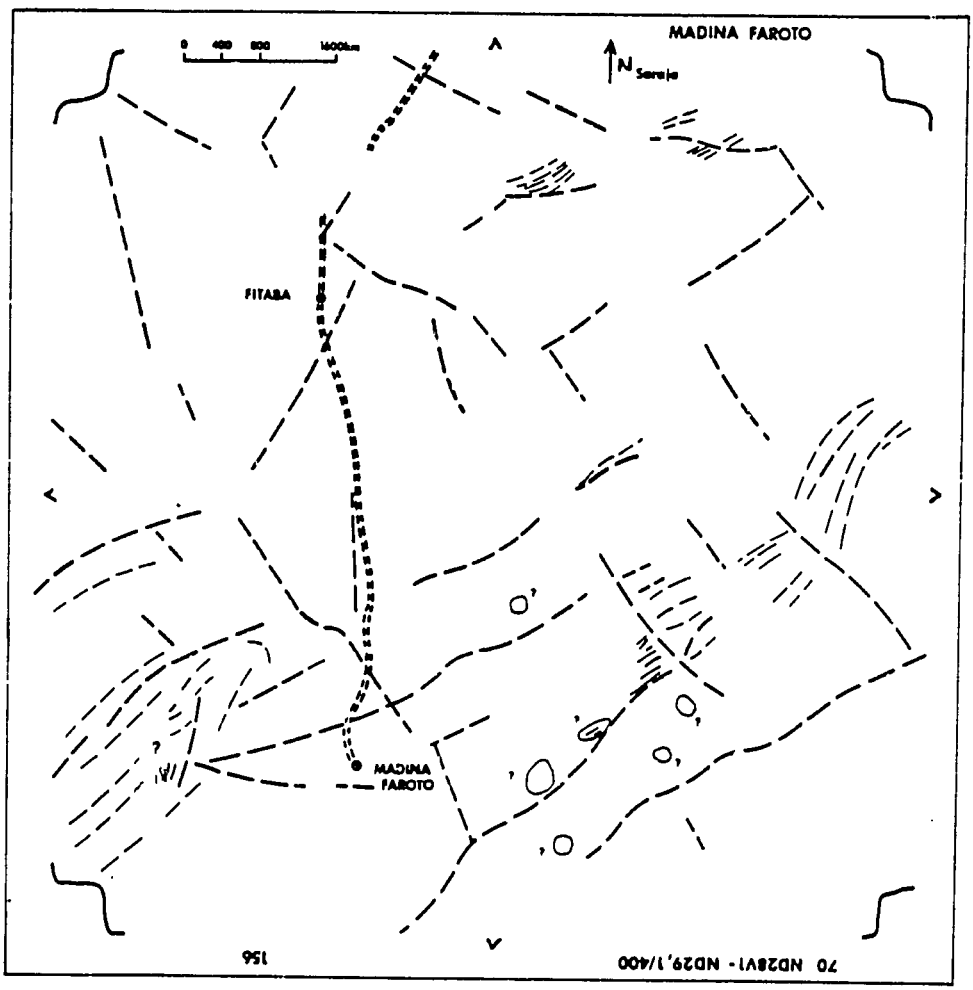
Kondoko



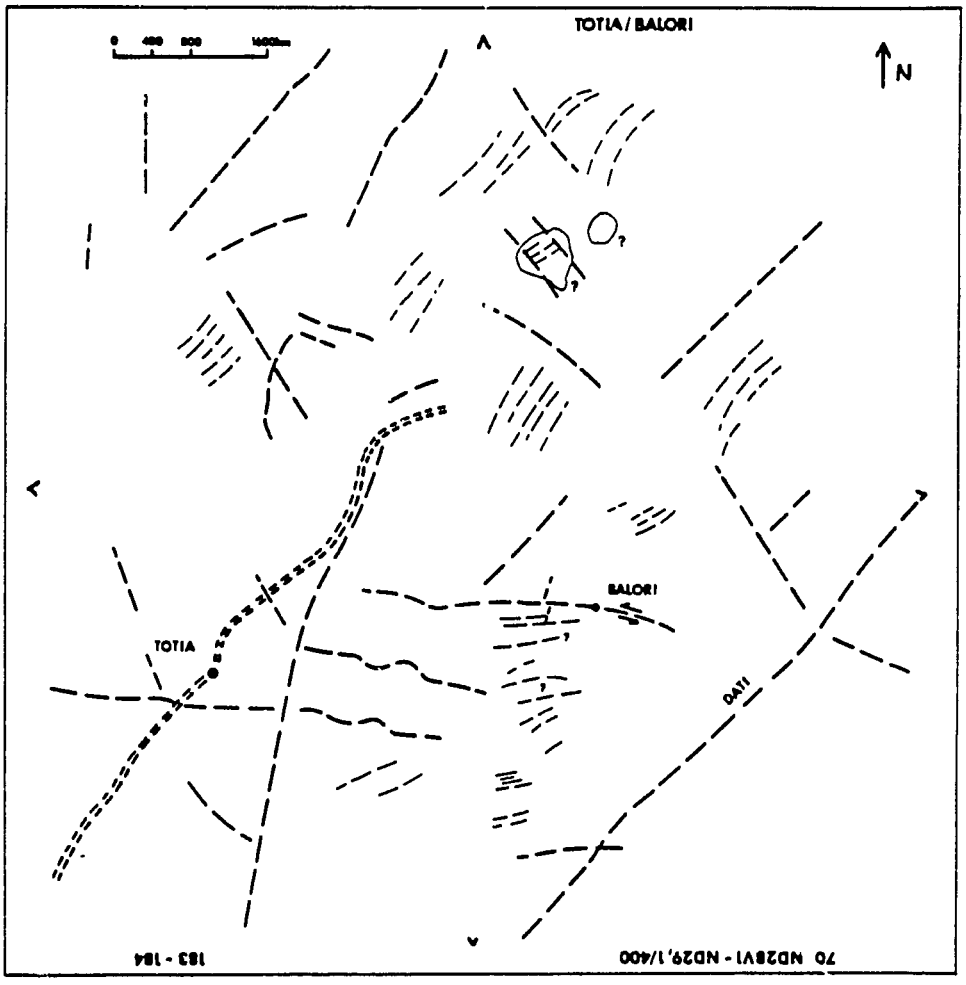
6. Aerial Photoanalysis: Madina Foroto--70 ND28V1-ND29, 1/400, #156
Totia/Balori--70 ND28V1-ND29, 1/400, #183-184

These two interpretations cover areas south of Saraya in the Saraya granite. Here we see numerous, rather clear NE and EW trends, which suggest a metasedimentary terrain (gneissic). Numerous small hills (circles) dot the area and also provide evidence of a gneissic terrain. Some of them have tonal characteristics akin to gossan zones and should be investigated for their uranium and tin-tungsten potential.

Madina Foroto



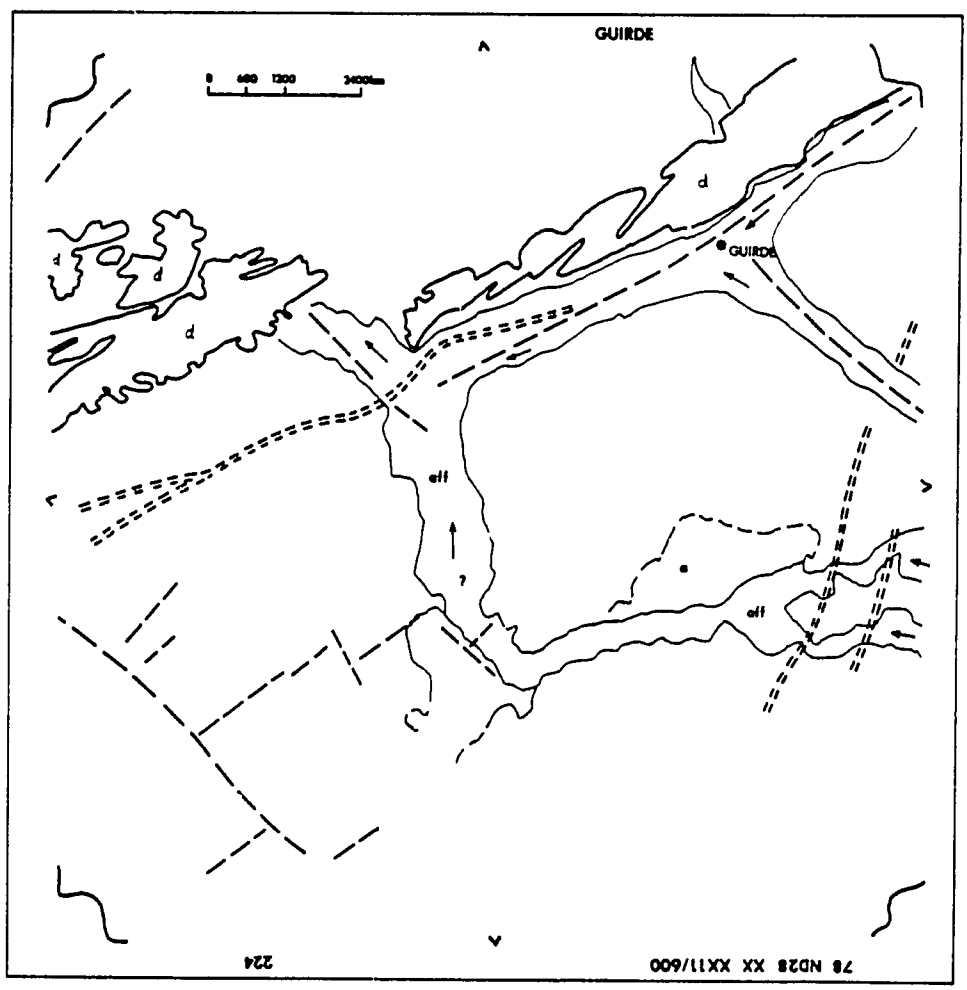
Totia/Balori



7. Aerial Photoanalysis: Guirde--78 ND28 XX XX11/600, #224

This area is situated south of Revane and shows recent dunes (d) filling a fossil valley (aff). The arrows indicate the direction of flow of the fossil rivers before the dunes filled the channels. The dashed lines are interpreted as faults, and the two trends shown here fully support the interpretation made from Landsat imagery. It should be noted that the streams and later the dunes follow the same trend(s) as the interpreted faults. The area to the north of the dunes is elevated and overlies a large positive gravity anomaly which trends NE. It is assumed that the NE trending fault passing through Guirde is the southern limit of this anomaly, and the area south of the fault is downfaulted.

Guirde



3.12 BIBLIOGRAPHY

Ahmed, Z. (1984) Stratigraphic and textural variations in the chromite composition of the ophiolitic Sakhakot-Quila complex, Pakistan. Bull. Soc. of Econ. Geo. 79(6):1334-359.

Alabaster, T. and Pearce, J. (1985) The interrelationships between magmatic and ore-forming hydrothermal processes in the Oman ophiolite. Bull. Soc. of Econ. Geo. 80(1):1-16.

Arnaud, G. (1952) Note sur l'hydrologie de la région de Dakar. Bull. de la Dir. des Min. 10:61-74. (H)

Aubouin, J. trans. (1978) Comptes-rendus des séance de l'Académie des Sciences. T. 286, Sér. D, No. 25.

Audibert, M. (1966) Etude hydrogéologique de la nappe profonde du Sénégal: Nappe maestrichtienne. Mém. du BRGM. No. 41. 102 p. (H)

_____. (1970) Etude hydro-agricole du bassin du fleuve Sénégal. Rapport de Mission. Tomes I et II. PNUD. (H)

Bardet, M. (1974) Géologie du diamant: Deuxième partie; gisements de diamant d'Afrique. No. 83. Mém. du BRGM. 223 p.

Bassot, J.P. (1966) Etude géologique du Sénégal Oriental et des ses confins guinéo-maliens. No. 1. Dir. des Min. et de la Géo. BRGM. 321 p.

Bellion, Y et Guiraud, R. (1984)

Bessoles, B. (1977) Géologie de l'Afrique: Le craton ouest african. Mém. du BRGM. No. 88. 403 p.

Bliss, C. (1981) Republic of Senegal prospective technical assistance in conventional energy, lignite and imported coal. Office of Energy, USAID.

Blot, C., et al. (1962) Mesures gravimetriques et magnetiques en Afrique occidentale de 1956 à 1958. ORSTOM.

BRGM (1962) Carte géologique du Sénégal: 1/500 000e. 36 p.

_____. (1963) Notice explicative de la feuille "Bakel"; une carte à 1/200 000e. 8 p.

_____. (1963) Notice explicative de la feuille "Dalafi"; une carte à 1/200 000e. 8 p.

_____. (1963) Notice explicative de la feuille "Kédougou"; une carte à 1/200 000e. 8 p.

_____. (1963) Notice explicatie de la feuille "Kéniéba"; une carte à 1/200 000e. 8 p.

_____. (1963) Notice explicative de la feuille "Kossanto"; une carte à 1/200 000e. 8 p.

_____. (1963) Notice explicative de la carte géologique "Tambacounda"; une carte à 1/200 000e. 17 p.

_____. (1963) Notice explicative de la feuille "Youkounkoun"; une carte à 1/200 000e. 6 p.

_____. (1967) Notice explicative de la carte géologique "Kaedi"; une carte à 1/200 000e. 44 p.

_____. (1967) Notice explicative de la carte géologique "Louga"; une carte à 1/200 000e. 30 p.

_____. (1967) Notice explicative de la carte géologique "Matam"; une carte à 1/200 000e. 41 p.

_____. (1967) Notice explicative de la carte géologique "Podor"; une carte à 1/200 000e. 34 p.

_____. (1967) Notice explicative de la carte géologique "Selibabi"; une carte à 1/200 000e. 44 p.

_____. (1984) Rapport sur le gisement d'ordre Sabodala.

Campredon, R, et al. (1982) Essai de cartographie géologique automatisée dans un secteur sahélien; influence des facteurs pédologiques et phytosociologiques. Bull. Soc. Géo. 24(1):9-12.

Chamard, P. et Barbey, C. (1970) Contribution à l'étude de la côte occidental de la presqu'île de Cap Vert: Indices morphométriques et morphoscopiques des galets de plage. Bull. de l'IFAN: Sér. A. 32(4): 850-68.

Cisse, A. (1984) "The use of remote sensing and a geographic information system for natural resources management in Senegal." Proceedings of the Eighteenth International Symposium on Remote Sensing of Environment, Paris, Oct. 1-5. pp. 1197-1206.

Clifford, T. and Gass I., eds. (1970) African magmatism and tectonics. Hafner Pub. Co. 461 p.

Colwell, R., ed. (1983) Manual of remote sensing, 2nd ed. Vols. I and II. Amer. Soc. Photo. Sheridan Press.

Comte, J., ed. (1982) Etude d'hydraulique villageoise: Nord Sénégal. BRGM. 166 p. (H)

Cornet, A. (1964) Notice explicative de la carte géotechnique au 1/500 000e. BRGM. 37 p.

Cuney, M. (1978) "Geologic environment, mineralogy, and fluid inclusions of the Bois Noir-Limouzin uranium vien, Forez, France." Econ. Geo. 73:1567-610.

Curetti, P. (1984) Evaluation des possibilités hydrauliques. Projet d'élevage de Bakel. USAID/DSPA. SEN/81/-003. 5 p. (H)

Curtin, P. (1975) Economic change in precolonial Africa: Senegambia in the era of the slave trade. Madison: Univ. of Wisconsin Press. 363 p.

Dagassan, E. (1967) Etude hydrogéologique pastorale de la zone sud-ouest du Ferlo. Rép. du Sénégal Min. de l'Econ. Rurale. 80. p. (H)

Dalstead, K., ed. (1982) Resource inventory of southwestern Mauritania USAID/RSI project. SDSU-RSI-82-03. Contract No. AID/afr-C-1619. 334 p. (H)

Dana, J. (1959) Dana's manual of mineralogy, 17th ed. Revised by C.S. Hurbut, Jr. New York: John Wiley and Sons. 609 p.

Dégallier, R. (1962) Hydrogéologie du Ferlo septentrional (Sénégal). Mém. de BRGM. No. 19. (H)

Depagne, J. et Moussu, H. (1969) Notice explicative de la carte hydrogéologique du Sénégal au 1/500 000e et la carte hydrochimique au 1/1 000 000e. BRGM. 35 p. (H)

Domain, F. (1977) Carte sédomentologique du plateau continental sénégambien: Extension a une partie du plateau continental de la Mauritanie et de la Guinée-Bisseau. ORSTOM. 17 p. (H)

Dorbath, C., et al. (1984) Seismotectonics of the Guinean earthquake of December 22, 1983. Geophysical Research Letters 2(10):971-74.

Dunlap, L. and Spinazola, A. (1983) Interpolating water table altitudes in west-central Kansas using kriging techniques. USGS Water Supply Paper 2238. 19 p. (H)

Elouard, P. (1962) Etude épologique et hydrologique des formations sédimentaires du Guebla Mauritanien et de la Vallée du Sénégal. Mém. de BRGM. No. 7. 274 p. (H)

Filho, R. (1984) Multiseasonal and geobotanical approach in remote detection of albitized-greisenized areas in the Serra da Pedra Branca granitic massif, Goîas State, Brazil. Bull. Soc. of Econ. Geo. 79(8):1914-920.

Gorodski, A., et al. (1952) Etudes géologiques et hydrologiques de la presqu'île de Cap Vert. BRGM. No. 10. 133 p. (H)

Gutentag, E., et al. (1984) Geohydrology of the high plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming. USGS Prof. Paper 1400-8. 63 p. (H)

Haggerty, S. (1984) Final technical report. The mineralogy of global magnetic anomalies. Project MAGSAT, Goddard Spce Flight Center. Contract No. NAS5-16414. 156 p.

Hjelmfelt, A. Jr., et al. (1975) Hydrology for engineers and planners. Ames: Iowa State Univ. Press. 210 p. (H)

Hutchinson, C. (1983) Economic deposits and their tectonic setting. New York: John Wiley and Sons. 365 p.

Johannsen, C. and Sanders, J., eds. (1982) Remote sensing for resource management. SCSA. 665 p.

King, L. (1967) The morphology of the earth: A study and synthesis of world scenery. London: Oliver and Boyd. 726 p.

Labovitz, M., et al. (1985) A "blind" test of a methodology for the detection of mineralization through the remote sensing of vegetation. Bull. Soc. of Econ. Geo. 80(3):560-74.

L'Appartient, J.R. (1983) Le Continental Terminal du Sénégal: Une formation marine néogène continental. Proc. Second Workshop. Cont. Project No. 127, IVGS-IGCP. Revision of the Concept of the Continental Terminal in Africa Vol. I. Ahmadu Bello Univ. Dept. Geo. Oceans Pub. No. 7.

Laurent, J., et. al. (1979) Etudes parues dans la chronique de la recherche minière en 1978. Chron. de la Recherch. Min., 1979. No. 447. 67 p.

Le Blanc, M. and Violette, J. (1983) Distribution of aluminum-rich and chromium-rich chromite pods in in ophiolite peridotites. Bull. Soc. of Econ. Geo. 78(2):293-301.

Le Page, A. et Campredon, R. (1981) Contribution des données des images Landsat à l'étude structurale d'un secteur des Mauritanides en Mauritanie du sud et Sénégal Oriental. Rev. de l'Inst. Fr. du Pét. 36(1):17-34.

_____. (1982) Le traitement d'une image Landsat par la technique des gradients horizontaux: Application à l'analyse structurale d'un secteur du Sénégal Oriental. Bull. Soc. Géo. Fr. 1:131-37.

Linsley, R. Jr, et al. (1982) Hydrology for engineers, 3rd ed. New York: McGraw-Hill Book Co. 506. (H)

Malanjin, M. (1968) Rapport sur la méthode du traitement des échantillons de gravier au cours de la prospectin pour l'or et diamant effectuée par le Fonds Spécial des Nations Unies au Sénégal Oriental. Recherch. Min. Sénégal Oriental. 16 p.

Mangis, P. (1955) Comptes-rendus des études de préreconnaissance pétrolière en Afrique occidentale française. BRGM. 134 p.

Meyer, C. (1985) Ore metals through geologic history. Science. 227(4693):1421-434.

Michel, P. et Pascal, M. (1967) Notice explicative de la carte géologique au 1/200 000e: St. Louis. BRGM. 33 p.

Michel, P. (1973) Les Bassins des fleuves Sénégal et Gambie: Etude géomorphologique. Tomes I à III. ORSTOM. 365 p. (H)

Ministère de l'Hydraulique (1983) Projet d'étude hydrogéologique de la bordure meridonale du Ferlo entre Kaffrine et Tambacounda. Dir. des Etudes Hyd. 24 p. (H)

Monciardini, C. (1966) La sédimentation éocène au Sénégal. Mém. de BRGM. No. 43. (H)

Monod, T. et Pourquie, A. (n.d.) Le Cratère d'Aouvelloul (Adrar, Sahara occidental). Bull. de l'IFAN. 13:294-304.

Morin, S. (1973) Le plateau de Bargny (Sénégal Oriental). Bull. de l'IFAN. Sér. A. 35(4):764-811.

_____. (1974) Glacis et cuirasses de la falaise de Thiès (Sénégal Occidental). Bull. de l'IFAN. Sér. A. 36(4):75-88.

Nahon, D. (1971) "Genèse et évolution des cuirasses ferrigineuses quaterniares sur grès: Exemple du massif de Ndiass (Sénégal occidental)." Bull. du Ser. de la Carte Géo. d'Alsace et Lorraine. 24(4):219-42.

Page, N., et al. (1984) Distribution of platinum-group elements in the Bati Kef chromite deposit, Guleman-Elazig area, Eastern Turkey. Bull. Soc. of Econ. Geo. 79(1):172-76

Paris-Teynac, E. (1962) Contribution à la connaissance du fleuve Sénégal. Bull. de l'IFAN. Sér. A. 24(1):54-68. (H)

Paul, C. and Mascarenhas, A. (1981) Remote sensing in development. Science 214(4517):139-45.

Pélissier, P. (n.d.) Notes et documents: La géologie de l'ouest sénégalais d'après F. Tessier. pp. 894-97.

Peters, W. (1978) Exploration and mining geology. New York: John Wiley and Sons. 695 p.

Petkovic. H. (1971) Rapport sur la recherche du cuivre à Gabon, Department de Baké. 42 p.

Pough, F. (1953) A field guide to rocks and minerals, 4th ed. Boston: Houghton-Mifflin Co. 317 p.

Ray, R. (1960) Aerial photographs in geologic interpretation and mapping. USGS Prof. Paper 373. 230 p.

Renaud, L. (1961) Le Précambrien du sud-ouest de la Mauritanie et du Sénégal Oriental. Mem. de BRGM. No. 5. 134 p.

Richardson, B. Jr., ed. (1982) Proc. Pecora VII Symposium: Remote sensing--an input to geographic information systems in the 1980's. Sioux Falls, South Dakota, Oct. 18-21. 619 p.

Robertson, A.H.F. (1984) Mesozoic deep water and Tertiary volcaniclastic deposition of Maia, Cape Verde Islands: Implication for Atlantic paleoenvironments and ocean island volcanism. Geo. Soc. Am. Bull. 95:433-53.

Robineau, B. (1984) Esquisse tectonique de l'Afrique occidentale. Unpublished report.

Rochette, C. (1974) Le Bassin du fleuve Sénégal. Mono. Hydro. ORSTOM. 325 p. (H)

Rodier, J. (1972) Estimation des débits de crues décennales pour les bassins versants de superficie inférieure à 200 km^2 en Afrique occidentale. ORSTOM. 30 p. (H)

_____. (1975) Evaluation de l'écoulement annuel dans le Sahel tropical africain. Trav. et Doc. de l'ORSTOM. No. 46. 121 p. (H)

Rosso. J. (1975) Contribution à l'étude paléontologique du Quaternaire sénégalo-mauritanien: Mollusques du Nouakchottien de St. Louis (Sénégal). Bull. de l'IFAN. Sér. A. 36(4):789-841.

Secretariat of the United Nations Conference on Desertification, Nairobi. (1977) Desertification: Its causes and consequences. Oxford: Pergamon Press. 447 p. (H)

Selly, R. (1978) Ancient sedimentary environments, 2nd ed. New York: Conrnell Univ. Press. 287 p.

Siegal, B. and Gillespie, A. eds. (1980) Remote sensing in geology. New York: John Wiley and Sons. 702 p.

Simon, B. (1981) Confrontation de la télédétection (analyse numérique et analogique téléinterprétation à petite échelle) avec la cartographie géologique classique et les données gravimétriques du Mali sud occidental. Bull. de la Soc. Géo. de Fr. pp. 13-24.

Sims, P. and James, H. (1984) Banded iron formations of late Proterozoic age in the Central Eastern Desert, Egypt: Geology and tectonic setting. Bull. Soc. of Econ. Geo. 79(8):1777-784.

Skinner, B., ed. (1981) Economic geology: Seventy-fifth anniversary volume, 1905-1980. Econ. Geo. Pub. Co. 963 p.

Slansky, M., et Lallemand, A. et Millot, G. (1964) La Sédimentation et l'alternation latérique des formations phosphatées du gisement de Taïba du Sénégal). T. 17. Fas. 4. pp. 311-24.

Smith, C.H. (1958) Bay of Islands igneous complex, western Newfoundland. Mem. Geo. Sur. Can. 290:132-46. (H)

A special issue devoted to the Bushveld complex. (1985) Bull Soc. of Econ. Geo. 80(4):803-1225.

Spengler, A. de, et al. (1984)

Stancioff, A. (1972) Report on the geology and economic potential of the diamond and gold deposits of Guinea, Africa. CIFAC. Internal report. 55 p.

_____. (1978) Remote sensing analysis for uranium in southwestern Nova Scotia. Lacana Mining Co.

_____, et al. (1981) Report on the accomplishments of ERTS in Zaire in North Shaba, 1980-1981. Vol. I. ERTS-Zaire. 77 p.

Sustrac, G., et. al. (1985) Plan minéral de la Republique du Sénégal. T. I et II. BRGM.

Trenous, J.Y. et Michel, P. (1971) Etudes de la structure du dôme de Guiers (Sénégal nord-occidental). Bull. Soc. Geo. Fr. Sér. 7. 13(1-2)

Tricart, J. (1961) Notice explicative de la carte géomorphologique du delta du Sénégal. Mém de BRGM. 137 p.

Van Sleen, L., ed. (1980) Comptes-rendus du séminaire de télédétection. Vols. I and II. SDUS-RSI-VISP-80-04.

Viessman, W., et al. (1972) Introdution to hydrology, 2nd ed. T. Crowell ed. New York: Harper and Row. 704 p. (H)

Vielleneuve, M. (1984) Etude géologique sur la bordure sud-ouest du craton ouest-african. Th., Fac. des Sci. et Tech. de St. Jérome. 476 p.

Witschard, F. (1965) Contribution à l'étude géologique pétrographique et métallogénique des massifs granitiques de Sénégal Oriental. Mém. de BRGM. No. 44. 169 p.

_____. (1984) Large-magnitude ring structures on the Baltic shield: Metallogenic significance. Bull. Soc. of Econ. Geo. 79(6):1400-405.

CHAPTER IV

SOILS AND LAND CAPABILITY

CHAPTER IV: SOILS AND LAND CAPABILITY

4.1 Introduction..... 279
4.2 Mapping Procedure..... 279
4.2.1 Introduction..... 279
4.2.2 Acquisition of Remotely Sensed Data..... 280
4.2.3 Literature Review..... 280
4.2.4 Interpretation..... 280
4.2.5 Fieldwork..... 281
4.2.6 Finalization..... 285
4.2.7 Other Means of Verification..... 285
4.3 Map Production (Morphopedology)..... 285
4.3.1 Introduction..... 285
4.3.2 Legend..... 285
4.3.3 Mapping Unit Description..... 290
4.3.3.1 Formations sur terrains quaternaires ou a volcanisme recent..... 290
A. Formations littorales et deltaïques, L... 290
Dunes littorales, La
Cordons littoraux, Lb
Vasières, Lc
Terrasses sableuses, Ld
Complexe côtier, Le
Levées, Lf
Cuvettes de décantation, Lg
Dépôts lagunaires, Lh
B. Formations sur dépôts alluviaux et colluvions, A..... 305
Terrasses colluvio-alluviales, vallons functionnels, Aa
Vallées mortes, Ab
Vallées sèches, (anastomosées), Ac
Vallées (semi-) permanentes, Ad
C. Formations éoliennes, E..... 315
Ergs anciens, E1
Surfaces pénéplanées et sables de couverture, E1a
Comblement sableux, E1b
Vallées, E1c
Basses terres, E1d
Ergs recents, E2
Dunes de l'intérieur, E2a
Dunes de la région du fleuve, E2b
Dunes de la côte, E2c
Vallées interdunaires et niayes, E2d
Interdunes inondables, E2e
D. Formations volcaniques récentes, V..... 328

4.3.3.2 Formations sur terrains secondaires et tertiares..... 329
A. Formations sur grès plus ou moins argileux du "Continental Terminal" Oligo-Mio-Pliocène, O..... 329
Plateaux et buttes résiduels, Oa
Dépressions de plateaux, Ob
Zones d'envahissement dunaire, Oc
Versants, pentes et glacis d'épandage, Od
Basses plaines et cuvettes, Oe
Bordures de plateau, Of
B. Formations sur roches marno-calcaires (Paléocène-Eocène), P..... 350
Bas plateau d'élévation supérieure à 50 m, P1
Plateau, P1a
Falaise, P1b
Piedmont, P1c
Bas plateaux d'élévation inférieure à 50 m, P2
Plateaux, P2a
Dépressions ensablées, P2b
Bords de plateaux et pentes, P2c
Basse plaine alluviale, P3
Bas glacis collinaire, P4
Massifs collinaires, P4a
Glacis de raccordement, P4b
Vallées d'érosion, P4c
C. Formations sur grès maestrichtiens (Crétacique), C..... 358
Plateaux, Ca
Vallons, Cb
4.3.3.3 Formations sur roche primaire ou roches volcano-sédimentaires anciennes..... 359
A. Formations sur roche d'origine essentiellement sédimentaire, S..... 359
Collines et glacis cuirassés sur schistes durs, faciès paléovolcanique, S1
Collines, S1a
Glacis cuirassé, S1b
Vallons d'érosion, S1c
Collines et glacis sur grès tendres argileux et quartzites, S2
Collines, S2a
Piedmonts, S2b
Glacis, S2c
Glacis étagés et plaines sur grès argileux et pelites, S3
Interfluves, glacis étagés, S3a
Vallons, basses pentes, S3b

Basses plaines, S3c
Basses plaines et vallées sur pelites, faciès paléovolcanique, S4
Basses plaines, S4a
Vallées, S4b
Basses plaines et vallées sur schistes metamorphisés, S5
Plaines, S5a
Vallées, S5b
Roches subhorizontales
Côte schisteuse, S6
Côte, S6a
Piedmont, S6b
Côte gréseuse, S7a
Piedmont, S7b
B. Formations sur roches essentiellement métamorphiques (Birrimien), M..... 380
Sols sur roches basiques diverses et matériau argileux gonflant d'altération, M1
Collines, M1a
Pentes, M1b
Vallons, M1c
Glacis, M1d
Plaines, M1e
Sols sur roches acides, migmatitiques, M2
Collines, M2a
Glacis étagé, M2b
Basses plaines ondulées, M2c
Sols sur matériau résiduel gravillonnaire, cuirassé, M3
Glacis étagé, M3a
Basses plaines ondulées, M3b
C. Formations sur roches de type granitique (granite d'anatexie), G..... 388
Buttes et interfluves, Ga
Plaines collinaires, Gb
Vallons et bas de pentes, Gc
Basses plaines, Gd
D. Formations sur roches ignées micro-grenues, I..... 392
Granites post tectoniques, I1
Diorites et metabasites, I2
Carrière, Cr
4.3.3.4 Miscellaneous Land/Soil Types..... 394
4.3.3.5 Soil Classification..... 394
I. Classe des sols minéraux bruts (Immature Soils)..... 394
II. Classe des sols peu évolués (Weakly Developed Soils)..... 395
III. Classe des vertisols (Vertisols)..... 396

IV. Classe des andosols (Andosols)..... 396
V. Classe des sols calcimagnésiques (Calcimagnesian Soils)..... 396
VI. Classe des sols isohumiques (Isohumic Soils)..... 397
VII. Classe des sols brunifiés (Brunified Soils)..... 397
VIII. Classe des sols podzolises (Podzols)..... 397
IX. Classe des sols à sesquioxydes (Sesquioxides Soils)..... 397
X. Classe des sols ferralitiques (Ferallitic Soils)..... 398
XI. Classe des sols hydromorphes (Hydromorphic Soils)..... 398
XII. Classe des sols sodiques (Sodic Soils)... 399
4.4 Production of Derived Maps..... 399
4.4.1 Introduction..... 399
4.4.2 Land Capability Map..... 400
4.4.2.1 Criteria..... 400
A. Introduction..... 400
B. First Order Parameters..... 401
Definition
1. Slope
2. Useful Soil Depth
3. Texture
4. Stoniness
5. Rockiness
6. Coarse Fragments
7. Drainage
8. pH
9. Salinity
10. Sodicity
11. Actual Erosion
C. Second Order Parameters..... 409
Definition
1. Water Holding Capacity
2. Permeability
3. Potential Irrigability
4. Workability
5. Seeding Establishment
6. Potential Mechanization
7. Wind Erosion Susceptibility
8. Water Erosion Susceptibility
9. Erosion Hazard
10. Chemical Fertility
D. Soil Climate Zones..... 416
4.4.2.2 Ratings..... 418
A. Introduction..... 418
B. Capability Classes for Cultivation..... 418
C. Capability Classes for Grazing..... 421
D. Capability Classes for Forestry..... 422

4.4.3 Soil Degradation Map..... 422
4.4.3.1 Introduction..... 422
4.4.3.2 Degradaton Types..... 423
4.5 Appendix B: Soils and Land Capability..... 425
4.6 Bibliography..... 472

4.1 INTRODUCTION

Given its major impact on agricultural development, the soil survey is one of the most important aspects of the natural resources inventory for land management at the regional or national level. This section accounts for the work done in this field by The Mapping and Remote Sensing Project for the National Plan for Land Use and Development (PNAT). However, one should bear in mind that this text was based on the results of several experts, consultants and trainees who successively worked on the project and who, due to various reasons, had no or very little contact with each other. It has thus been attempted here to make the best use of available data.

The mapping procedure relies extensively on the interpretation of Landsat imagery. The content of each delineated mapping unit is defined by correlating them with available documents, maps and reports or with data gathered during field survey or low altitude overflights. The soil classification system employed is that used by the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), centre de Dakar-Hann. Reference to the American and international classifications (Soil Taxonomy System, STS and Food and Agriculture Organization of the United Nations, FAO) is also made. The criteria employed for the design of the derived maps (land capability map, soils degradation map) have been developed by RSI through many years of international experience and largely follow the United States Department of Agriculture Soil Survey Manual and the recommendations of the Food and Agriculture Organization of the United Nations.

Hence, one original and two derived maps have been prepared:

-morphopedology of Senegal, at 1:500,000, 4 sheets and one legend sheet, full color

-land capability map of Senegal, at 1:500,000, 4 sheets, black and white

-soils degradation map of Senegal, at 1:1,000,000, 1 sheet, black and white

Technical aspects of soil survey and mapping are described in section 4.3.2. Section 4.3.3.3 briefly describes the mapping units (morphopedology). Procedures and criteria applied to the production of derived maps are detailed in section 4.3.4 and their mapping units are described in sections 4.4.2.2 and 4.4.3.2.

4.2 MAPPING PROCEDURE

4.2.1 Introduction

Changes in personnel and contractual constraints strongly interfered with the procedure described hereunder. The successive

phases of a typical 1:500,000 scale soil survey are mentioned, but the purely cartographic aspects, e.g., printing and reproduction, are not considered here.

4.2.2 Acquisition of Remotely Sensed Data

The quality and limitations of the available imagery have already been discussed earlier in this report (2.5). Hence, only a few remarks on the use of the imagery for soil mapping are given here.

Generally, the imagery best suited for soils interpretation was that recorded during March, since at this time of the year the physiography appears to be the most discernible on the false color composites. During this period, the hardpan does not only appear outstandingly well on the plateaus, but also at the break in slope along the edges of the plateaus. Some imagery recorded early in the dry season is useful in identifying the exact position of the talwegs. Because vegetation wilts later in the drainageways, the talwegs show a stronger response in the infrared. In this regard, however, areas with higher rainfall pose a problem. The number of available imagery dates was limited and quality of the imagery was often poor. In most cases, vegetation masked the physiography, giving the false color composites a general reddish hue. Therefore, the interpretation of the Casamance area is less detailed, although soil maps at 1:200,000 or 1:100,000 scale are available.

The scale variations of the products furnished by the EROS Data Center presented a problem experienced equally by the other project resource scientists.

4.2.3 Literature Consulted

Existing maps, reports and documents should be collected prior to interpretation. The study of available data can help in identifying problems, delineating well-known areas, and determining those areas which have never been studied in detail. This process provides the surveyor with a general view of the country, its natural regions and geological provinces, and its physiography; it also provides a good understanding of the soil types present and their distribution. At the same time, and together with exploratory field trips, a small scale (1:1,000,000) pre-interpretation is normally conducted, and a first approximation of the legend is also prepared.

Most of this work actually had to be done toward the end of the project, since the results of earlier exploratory field trips were lost because of changes in personnel.

4.2.4 Interpretation

The imagery interpretations are then realized at working scale (1:250,000) for the whole country, and the first structured legend is

designed. This interpretation aids in planning efficient field work and soil sampling. In actuality, the field work had to be done after the partial interpretation in order to meet the deadlines for the shipment of the soil samples to laboratories.

4.2.5 Field Work

Field trips are then organized to check the validity of the imagery interpretations through field work. The technique chosen toward the end of the project was meant to save time by reducing the amount of field work to a minimum. The method employs numerous transects systematically run across the mapping units (see Appendix IV-1, Soil Survey Routes, 1982-84). Soil observations consist of augerings, mini-pits or profile pits, and all along the transect, and at each observation point, notes are also made on physiography, vegetation status, rock outcrops, erosional features, etc.

An augering (Fig. 4.1) is realized using a soils auger--a tool which enables the surveyor to take a sample of approximately 7 cm in diameter up to a depth of 125 cm. Augerings allow for a rather quick and easy check on texture, color, pH, coarse fragments, drainage and, when applicable, the depth of the water table, the hard pan or the gravelly layer.

A mini-pit (Fig. 4.2 and 4.3) is dug with a pick and shovel. It has a small, often rectangular shape (76 x 50 x 50 cm), and an augering is made at the bottom of the pit. Mini-pits are semi-detailed observations. The 50 upper centimeters may be studied on site and more characteristics can be observed, such as structure, porosity, consistence, etc.

A profile pit (Fig. 4.4) is deeper and larger (125 x 75 x 150 cm). The description of all horizons can be completed and soil samples are taken for laboratory analyses. Since this technique is slow and expensive, it is infrequently used, but profiles were dug to characterize the dominant, representative soils identified within the mapping units.

Due to the conditions particular to the project, all survey operations had to be conducted more or less simultaneously within a period of time which was too short.

Fig. 4.1. Augering.

Fig. 4.2. The mini-pit.

Fig. 4.3. Another view of a mini-pit.

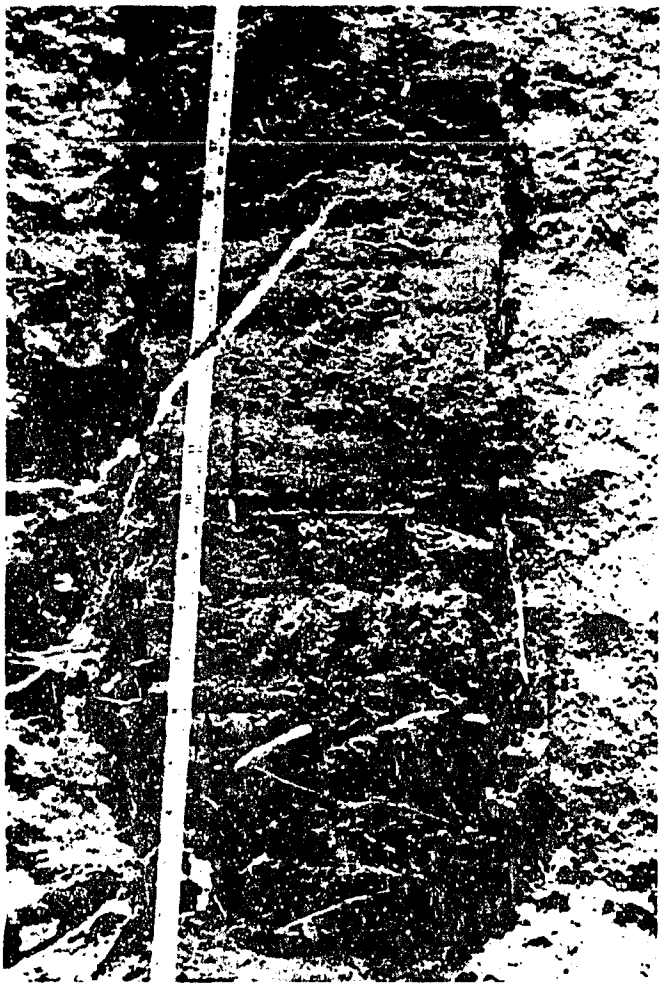


Fig. 4.4. The profile pit.

4.2.6 Finalization

The final map unit boundaries which based on field work results and on data gathered from literature is then prepared, and the legend is given its final structure. At this point, mistakes in the imagery interpretation should be corrected and uncertainties clarified.

In this study, emphasis was put on correlating the mapping units obtained by imagery interpretation with information from the available documents. This process was necessary to properly characterize the nature of the soilscape units despite insufficient field work.

4.2.7 Other Means of Verification

Where available, other means of verifying the interpretation of satellite imagery can also be used during the final interpretation/delineation. More field trips may still be organized, but they can be advantageously combined with low altitude overflights and systematic photographic coverage. In spite of rather bad climatic conditions, the project had some success in completing such overflights. Their interest for soil survey lies in the fact that they offer an intermediate level of observation, one whose scale is between that of the field observation and that of satellite imagery. The study of slides taken during overflights or traditional aerial photographs provides useful additional information.

4.3 MAP PRODUCTION (MORPHOPEDOLOGY)

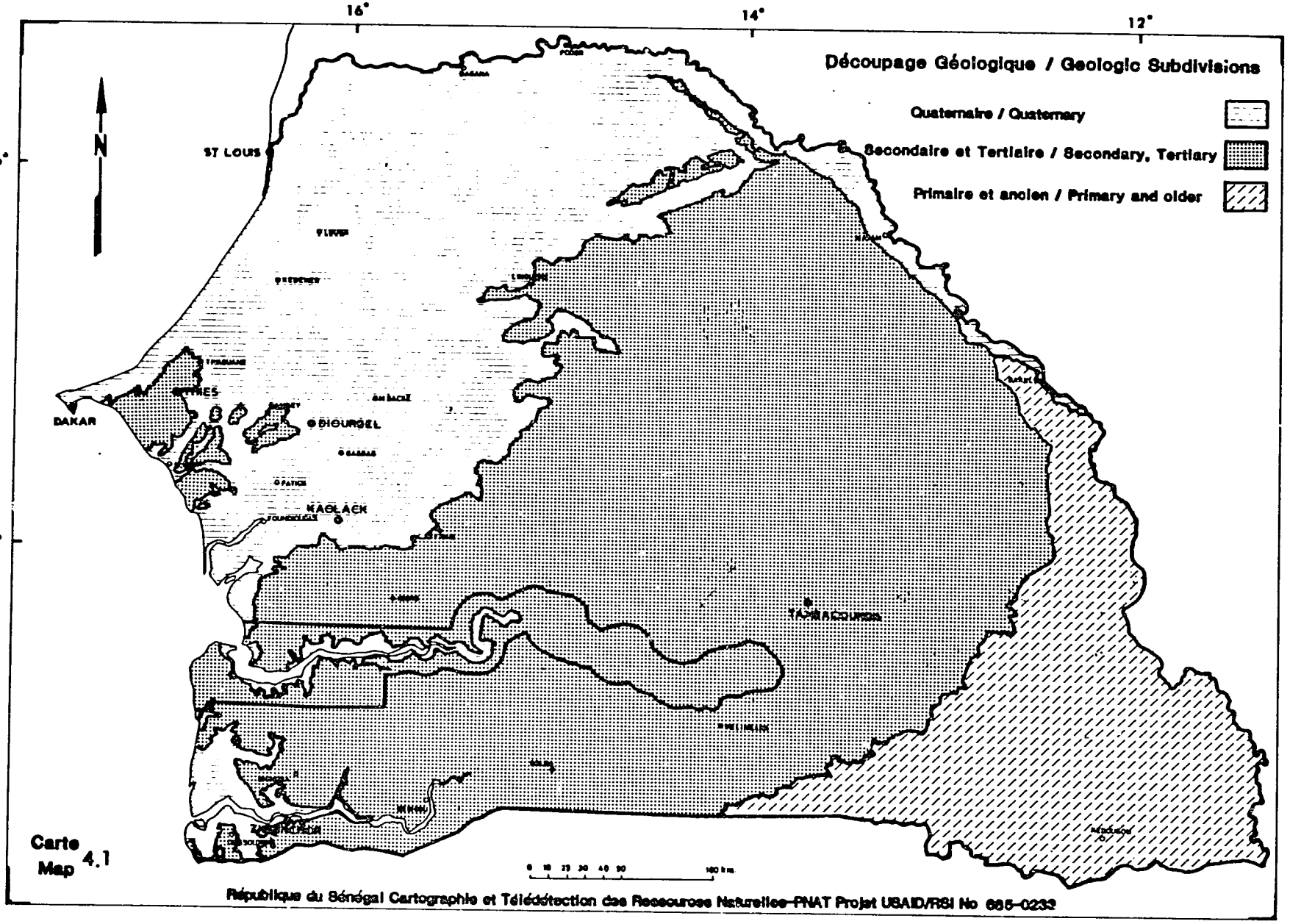
4.3.1 Introduction

Time and scale constraints, as well as the fact that the map is to be used for the Plan National d'Aménagement du Territoire, PNAT, justify the publication of a soilscape map (morphopedology) with a physiographic legend rather than with the purely taxonomic legend of the traditional soils map. In this section, the structure of the legend will be explained, the mapping units described, and some comments on soil classification made.

4.3.2 Legend

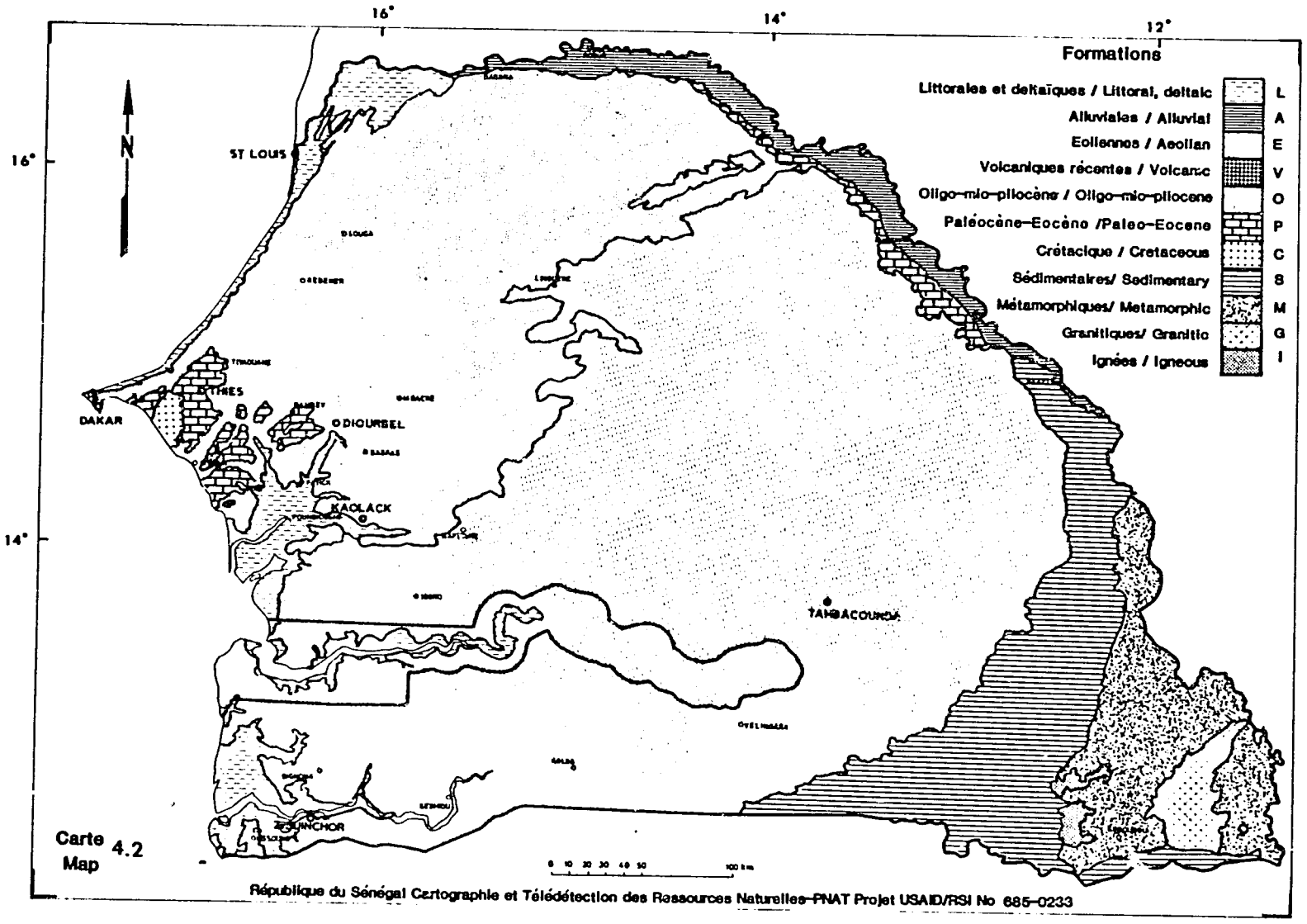
The legend gets its structure from geologic subdivisions and is further subdivided according to physiography.

Three blocks corresponding to different geological eras (Map 4.1) are divided into eleven formation types (Map 4.2). Each formation type is symbolized by a capital letter, which also becomes the first symbol element of the corresponding mapping unit. Map 4.2 shows the distribution of the formation types throughout the country.



Carte 4.1
Map

République du Sénégal Cartographie et Télédétection des Ressources Naturelles-PNAT Projet USAID/RSI No 685-0232


16°
14°
12°
16°
14°
N
Formations
Littorales et deltaïques / Littoral, deltaic
Alluviales / Alluvial
Eoliennes / Aeolian
Volcaniques récentes / Volcanic
Oligo-mio-pliocène / Oligo-mio-pliocene
Paléocène-Eocène /Paleo-Eocene
Crétacique / Cretaceous
Sédimentaires/ Sedimentary
Métamorphiques/ Metamorphic
Granitiques/ Granitic
Ignées / Igneous
L
A
E
V
O
P
C
S
M
G
I
ST LOUIS
DAKAR
THIES
DIOURBEL
KAOLACK
TAMBACOUNDA
ZIGUINCHOR
Carte 4.2
Map
République du Sénégal Cartographie et Télédétection des Ressources Naturelles-PNAT Projet USAID/RSI No 685-0233

Formations

In the Quaternary, four formation types are recognized according to the dominant depositional process which has led to the existence of those formations.

Littoral and deltaic formations (L) are formations resulting from fluvio-marine or coastal sedimentation.

Colluvio-alluvial formations (A) include the Senegal River Valley along with most of the country's drainageways. Only the Senegal River Valley is shown in Map 4.2, but Map 4.3 shows the complete colluvio-alluvial formations, and one can see that the shape of the hydrographic system is strongly correlated to climate and to the nature of the geologic substratum. For a better comprehension, deltas have also been shown in Map 4.3.

Eolian formations (E) correspond to sandy deposits that make up the large Quaternary ergs in the northern and western parts of the country.

The recent volcanic formations (V) are those formations in the Cap Vert peninsula.

Three formation types were recognized based on their age and petrography for the period covering the Secondary and Tertiary eras. Formations of the "Continental Terminal" on more or less clayey sandstone (O) are inprecisely related to the Oligo-Mio-Pliocene. Formations on marno-calcareous rocks (P), dated from the Paleo-Eocene, constitute the Matam strip and the lower plateaus of Thies and Bargny.

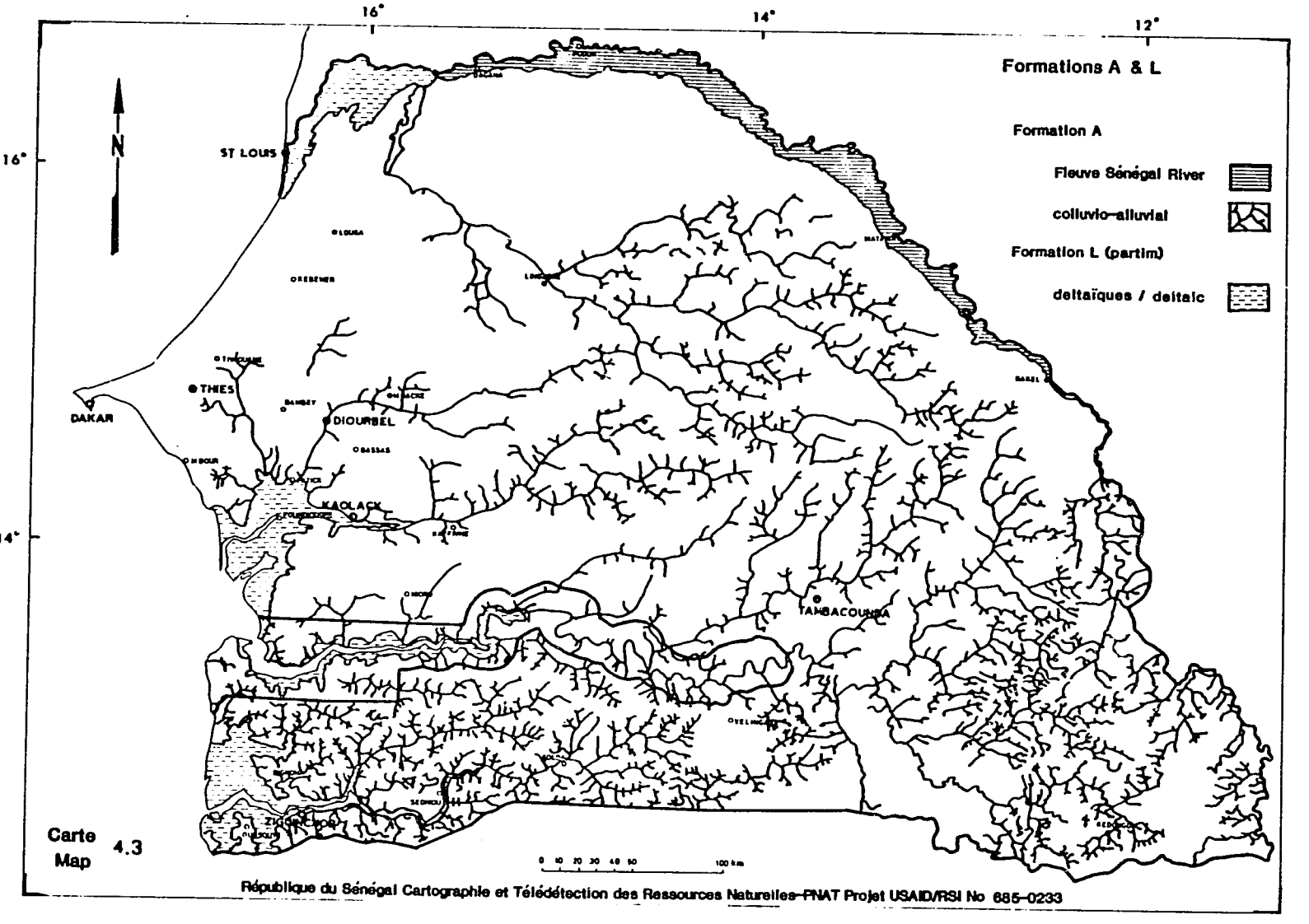
Formations on sandstones (C), dated from the Cretaceous (Maestrichtian), correspond to the Ndiass Massif.

Four kinds of formations are recognized in Senegal Oriental on primary or ancient bedrocks. Distinctions are based on photography. To the west, formations correspond to bedrocks with an essentially sedimentary origin (S).

To the east, formations are essentially on metamorphic bedrocks (M) dated from the Birrimian.

The Saraya Massif formations (G) are on granitic bedrock (anatexic).

Formations around the Gambia River loop near Mako and of the Bandafássi Massif are on micrograined igneous bedrock (I).



Formations A & L (partim)

The first cartographic symbol element is thus one of the following capital letters: L, A, E, V, O, P, C, S, M, G, I.

The second element is a number from 1 to 7 with no other specific significance other than showing the change in age or parent material within a given type of formation. No number is mentioned if this kind of distinction is not applicable; hence, the only cases are: E1 and 2; P1, 2, 3 and 4; S1 to 7; M1, 2 and 3; I1 and 2.

The third symbol element is a lower case letter (a, b, c...h) which designates a change in physiography (plateau, piedmont slope, mud flat, etc.).

The fourth element is another lower case letter (x, y and z) which shows, when applicable, physiographic subdivisions of the preceding level. The fourth element is rarely necessary.

The fifth element is a number from 1 to 15 and is given to the various soil associations represented within the same physiographic unit or subunit. No number is mentioned if only one association is shown on the map; hence, any mapping unit will be identified by a symbol counting a maximum of five elements, e.g., E2ay3.

4.3.3 Mapping Units Description

4.3.3.1 Formations sur terrains quaternaires ou a volcanisme recent

A. Formations littorales et deltaiques, L

Grouped under this heading are all formations proceeding from coastal or fluvio-marine sedimentation. They are coastal dunes, coastal ridges, various types of tidal flats and mangroves and marine terrasses, as well as levees, splays and basins of the Senegal River Delta, and other smaller complex coastal units.

DUNES LITTORALES, La

The coastal dunes are shown as four mapping units; the first one represents the "white dunes" (dunes blanches), also including beaches, while the three others represent the "yellow" dunes (dunes jaunes) in relation to their wind erosion susceptibility which is shown by the extent of their fixation through vegetation (Fig. 4.5). All these dunes are rather low in elevation.

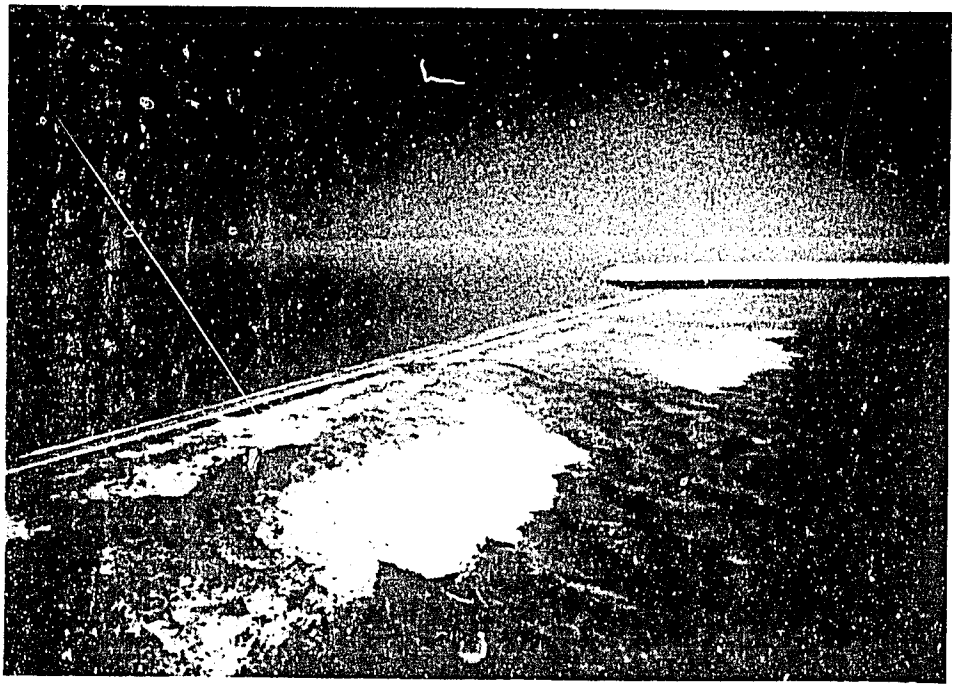


Fig. 4.5. Low oblique aerial photograph of units La1, La3 and La4. It also shows a fringe of unit E2cx2 near Fâs Boye.

Symbols: La1, La2, La3, La4

Description

La1: Dunes littorales vives et plages marines, sols minéraux bruts d'apport

The beaches of the Grande Côte are usually sandy. The sand is made up of a mixture of quartz grains and calcareous tests. The beaches of the "Petite Côte" are narrower with often clayey, more developed sodic or hydromorphic soils that are closely related to those of the adjacent formations in which they were therefore included. The beaches of the Sine Saloum and of the Casamance rivers are also included in adjacent formations, such as coastal ridges. The beaches of the "Grande Côte" are shown in a common unit with the "white dunes" (mobile). In between Yopp and Lake Retba, "white" and "yellow" dunes were put together in a single unit which is slightly wider in actuality because the actual dimensions are incompatible with the publishing scale. The "white dunes" are continuously reworked by winds, and they support almost no vegetation, except at the reforestation perimeters

where some interesting results are noticeable. The Eaux et Forêts afforestation policy should certainly be encouraged.

La2: Dunes littorales semi-fixées, sols minéraux bruts d'apport

These "yellow" dunes (dunes jaunes) are colonized by vegetation to some extent, but large areas still remain open to wind action. They extend in a continuous strip less than 3 km wide from St. Louis to half way between Sag and Toundé Maléyé. Their stabilization remains a priority.

La3: Dunes littorales fixées, sols peu évolués et sols minéraux bruts, d'apport

These relatively vegetated "yellow" dunes (dunes jaunes) extend in an irregular and discontinuous strip (which may reach up to 3 km in width) from the northern edge of Lake Retba to mapping unit La2, about half way between Toundé Maléyé and Sag. Soils may locally show the beginnings of development but their fixation remains precarious, and the reactivation of wind erosion remains a great hazard. The pH is acid.

La4: Dunes littorales ravivées, sables vifs, sols minéraux bruts d'apport et d'érosion

This mapping unit delineates areas from the preceding unit which are affected by a strong remobilization of sand due to the regression of the vegetation. Such areas need urgent protective and erosion-control measures; therefore, it was felt that they should be mapped individually.

CORDONS LITTORAUX, Lb

Coastal ridges are shown by two mapping units that correspond to different periods of deposition. The first ones are more recent and soils have not yet developed; the second division includes older depositions which show some soil development.

Symbols: Lb1, Lb2

Description

Lb1: Cordons littoraux récents et subrécents, sols minéraux bruts ou sols peu évolués d'apport

Recently deposited coastal ridges are found along the coast in front of each delta or included in them. They lie in more or less parallel rows in the Saloum Islands and are more irregularly aligned in Basse Casamance. Adjacent beaches are included in this mapping unit.

Either raw mineral deposited soils (sols minéraux bruts d'apport) or weakly developed deposited soils, sometimes hydromorphic, (sols peu évolués d'apport, parfois hydromorphes) are found. These soils are always extremely sandy (over 90% sand), unstructured (quick) and show little color. Most often they contain no or little organic matter, although some such matter may give the topsoil a slight color on some of the subrecent ridges. An aliotic or even crusted layer can be found supporting a freshwater table. The pH varies greatly and these soils are in general chemically poor. Some parts of sandy terraces may be included in the unit, and small mudflats are often found behind the recent ridges, such as the Langue de Barbarie. These mudflats constitute the minor inclusions whose soils are mostly sodic.

Altogether these soils would be of no agricultural value if it were not for the palm groves on subrecent ridges. These soils are extremely susceptible to wind erosion.

Lb2: Cordons littoraux anciens, sols brun-rouge subarides

Only the Senegal River Delta shows coastal ridges which are old enough that soils may have undergone some kind of profile development. The mapping unit extends west of Rao and abuts the Senegal River near Maka. The most eroded part lies north of Djeuss; in the south, the unit consists of minor inclusions constituting bare, grassy mudflats with slightly acid saline soils and basins with strongly acid saline soils. Various sodic soils are found along the transition to the neighboring mapping units. The major soils (up to 80%) are red-brown subaridic isohumic soils (isohumiques, brun-rouge subarides). They are truly sandy to loamy sand over sand, and they have a thick humic horizon which has a low organic matter content. They are noncohesive and have single grain structure. The colors are rather pale: the topsoil is brown, the soil below yellowish-red with occassional hydromorphic mottles. The pH is neutral, the salinity negligible.

These soils support an open tree savanna, where *Acacia raddiana* grows. These grazing lands are of good quality during the rainy season and at the beginning of the dry season. Although locally cultivated, these soils do not have great agricultural value. They also are extremely susceptible to wind erosion.

VASIERES, Lc

Deltaic flats were subdivided into eight mapping units. First a complex unit combines recent tidal flats and coastal ridges. Two other units cover recent functional or partially denuded mangroves, and five others correspond to four stages in the evolutive sequence of an old mangrove: functional, partially denuded, denuded and grassy, as well as a reworked facies in the Senegal River Delta.

Symbols: Lcx, Lcy1, Lcy2, Lcz1, Lcz2, Lcz3, Lcz4, Lcz5

Description

Lcx: Complexe de vasières et de cordons littoraux récents, sols minéraux bruts ou sols peu évolués d'apport hydromorphes

This complex includes soils of mapping units Lb1 and Lcy1. Hence, it does not offer important agricultural possibilities, but proper management of palm groves may be considered for the coastal ridges.

Lcy1: Vasières récentes fonctionnelles, sols peu évolués d'apport hydromorphes avec sols halomorphes

These mangroves are located immediately behind coastal ridges. In Basse Casamance, they arch from Kafountine to Elinkine and Essaoul and cover the western half of the Goelette Island. In the Sine Saloum, they also arch from Barra to Niodior and Mar Lodj.

Most soils (up to 80%) are hydromorphic, weakly developed deposited soils (sols peu évolués d'apport hydromorphes) on low organic and low pyritic muds in Basse Casamance or on more or less sandier sulphidic muds in the Sine Saloum. Various types of sodic soils, usually acidified saline soils characteristic of barren mudflats (tannes vifs) or saline gley soils characteristic of sandflats (tannes sableux), belong to the minor component. Behind the coastal ridge of Joal, soils are richer in organic matter and somewhat peaty. Some fragments of coastal ridges or sandy terraces, and even ferralitic soils on islands of the Casamance plateau enclosed in the mangrove may also be present as minor inclusions. These soils are thus typically, recent *Avicennia nitida* mangrove soils. Profile characteristics vary: the color is usually gray and the profile is spongy and fibrous with a high organic matter content (which does not exceed 10% except perhaps in the Sine Saloum). Shell layers are sometimes found and the pH then becomes quite alkaline. The pH is otherwise neutral, but after oxidation, the sulphides present may lead to strongly acid values (but still above 4).

One may consider management practices to improve salinity, drainage and potential acidity. However, it would seem wiser, for obvious ecoclimatological reasons, to protect the mangroves since they are degraded their regression shows remarkedly on the imagery.

Lcy2: Vasières récents partiellement dénudées, sols halomorphes avec sols peu évolués d'apport hydromorphes

These mudflats are clearly discernible on the imagery east of Boukot Ouolof. Although the area is located in the middle of recent mudflats where mangroves have a similar spectral signature, the grassy mudflats there are also discernible. This suggests either a quick evolution or the rejuvenation of an ancient system. Acidified saline

soils, or acid sulphated soils sols halomorphes, salins acidifiés on clays or on sands are characteristic of the mudflats (over 50% of the soils), and hydromorphic, weakly developed deposited soils (sols peu évolués d'apport hydromorphes) are characteristic of the recent mangroves that are confined to the channels (less than 40%).

These soils vary in texture. The thin topsoil is light brown to beige, and its organic matter content is low. When the topsoil loses organic matter, this results in the settling of the horizon and a relative increase in the bulk density. Deeper horizons have a similar aspect and organic matter content as those of mangrove soils but with bright yellow jarosite streaks along root lines. The pH is strongly acid, the salinity is very high, and small salt crystals are visible in the topsoil. Some halophytic Cyperaceae are sometimes evident on these barren mudflats.

Crop cultivation requires obligatory desalinization and pH correction. An important investment is thus required, and results may not be positive, or cost-effective. A well-adapted reforestation scheme may be the most appropriate solution.

Lcz1: Vasières anciennes fonctionnelles, sols hydromorphes organiques plus ou moins tourbeux avec sols halomorphes

These mangroves are located between the recent mangroves and the continental zone or along the major rivers. In the Sine Saloum, they only reach Soum to the north, but they may also be found in small areas along the Gambia River as far as Bambali. In Basse Casamance, they colonize most of the delta reaching into Guinea-Bissau to the south, beyond Ziguinchor to the east and Tiobon to the north.

Soils are hydromorphic or weakly developed, deposited, hydromorphic soils (sols hydromorphes--ou sols peu évolués d'apport hydromorphes). They are more or less organic, more or less peaty soils on clayey and usually highly pyritic muds. Small sandy terraces with weakly developed soils and surrounded by various sodic soils may be present as inclusions, especially in the Sine Saloum. They are thus soils of well developed mangroves that support *Rhizophora mangle* and *Avicennia nitida*. As in the case of recent mangrove soils, profile characteristics are variable. The profile is still gray-colored, spongy and fibrous. Sometimes shell layers also exist, but the organic matter content is higher and may greatly exceed 10%. The sulphide content is also higher and the pH, which is neutral in situ, can drop to values far below 4 after oxidation, as in the case of an air dried sample. These soils are also quite saline to strongly saline, and again, it seems that the mangroves should be protected. One may also remember that the *Rhizophora* can be used for firewood and that several edible animal species survive in and around the mangrove (crabs, shellfish, etc.).

Lcz2: Vasières anciennes partiellement dénudées, sols halomorphes salins acidifiés et sols hydromorphes organiques

These partially denuded mangroves extend beside the functional mangroves near the main channels which are hence separated from the barren mudflats. In the Sine Saloum they are found north of Djirnda and Fetan, while in Basse Casamance they are located in the lower reaches of the Bignona and the Soungrougrou streams (marigots). They are also found along the Gambia River up to its confluence with the Nianija Bolon. An alluvial phase, identified by the "a" on the map, shows the transition from the fluvio-marine deposits to the true alluvium. At the surface, these soils are slightly saline, slightly acid and sodic. They mainly belong to the Salikene Series of the Gambian Soil Classification.

These tidal flats are at an intermediate stage of evolution, between the functional mangrove and barren mudflats. They are largely bare, partially under tidal influence and often inundated. The mangrove only grows along the tidal channels.

The soils of the two neighboring units Lcz1 and Lcz3 are found in variable proportions. The extent of the peaty soils is more significant near the sea, while the extent of the acidified saline soils is greater upstream. They may also have fewer extreme characteristics, with a lower organic matter content or a less acid pH. The texture is usually fine, the structure massive, the consistence sticky, and the color gray. Because fresh water leaches the upper horizons during the rainy season, cultivation is possible following the ebb tide. Mangroves should still be protected to assure their natural evolution and prevent any accelerated degradation.

Lcz3: Vasières anciennes dénudées, sols hydromorphes à gley salé et sols halomorphes salins hydromorphes

From a morphological point of view, this mapping unit actually comprises sandy or clayey barren mudflats (tannes vifs) and lower, more often clayey than sandy, terraces. These formations have in common the fact that they are no longer regularly invaded by the tide. They are best represented in the Sine Saloum where they cover most of the northern part of the delta. They are limited to rather small areas in Basse Casamance, the largest being in front of Tionk Essil.

Soils vary between sodic and saline hydromorphic. They are nonorganic saline gley soils--hydromorphic soils (sols hydromorphes, minéraux à gley salé) on sands or on clayey terraces in Basse Casamance and hydromorphic, usually strongly saline soils with salt efflorescences at the surface--sodic soils (sols halomorphes, fortement salés hydromorphes à efflorescences salines en surface)--on sands or clays in the Sine Saloum. More or less peaty hydromorphic soils can be present as inclusions in both cases. Thus, soils of this mapping unit have rather variable characteristics. Texture varies from one profile

to the other and often also within the same profile. Sandy soils are usually less differentiated.

The color is generally light gray, more or less mottled with rusty patches, which often begin at the surface, and yellow jarosite streaks, which do usually appear at medium depth. The topsoil is often beige, especially in saline soils, and is partially reoxidized and somewhat fine blocky angular structure, if clayey. The deep horizons are massive and plastic (clay) or fluid (sand).

The clayey terraces of Basse Casamance are cultivated for rice. Management practices controlling fresh water supply from precipitations can provide sufficient leaching for desalinization of the soil surface for cultivation. The Sine Saloum climate is markedly drier and thus these soils of this area are less favorable to agricultural improvement.

Lcz4: Vasières anciennes enherbées, sols halomorphes salins hydromorphes moyennement salés

This mapping unit is represented in the northern part of the Sine Saloum delta by small areas included within the preceeding unit. It actually combines grassy mudflats and small terraces or continental formations that are undifferentiable at the publishing scale. The inclusions are composed of hydromorphic soils with gley at depth or of leached ferruginous tropical soils, which have less restrictive limitations than those of the sodic main component. The areas too small to map were included in mapping unit Lcz3.

The soils of the grassy mudflats are sodic, hydromorphic moderately saline soils (sols halomorphes, salins hydromorphes moyennement salés). The topsoil is thus sufficiently desalinized for vegetation of halophytic Cyperaceae to grow. During their development, these soils actually lost water and organic matter, which resulted in their settling. Since wind easily mobilizes strongly saline clays, the soil surface was then shaped into a basin by deflation. Subsequent rain water accumulations assured the desalinization of the soil surface. These soils are thus similar to those of the preceeding unit, but they are less saline at the surface and more acid with depth. They are typical acid-sulphate soils (sols sulfatés acides typiques).

The texture is fine; the color is light brown to beige for the few upper centimeters and then quickly becomes gray with rusty (hydromorphic) then yellow (jarosite) streaks at depth. The salinity and acidity of these soils may be improved but the investment may not be returned. A well-adapted reforestation scheme may thus be preferred. The soils mentioned as inclusions are more favorable for agriculture.

Lcz5: Vasières anciennes remaniées, sols halomorphes salins acidifiés

These ancient mudflats are located in the lower delta of the Senegal River at its confluence with some of its major tributaries such as the Lampsar and the Djeuss rivers. This area, which extends from Rao to Maka between the dunes and coastal ridges, has a morphology which is influenced by the meandering rivers that are reworking the fluvio-marine deposits. Formations are mixed: mudflats, basins, small subrecent levees, fragments of dunes or terraces. However, the majority of the soils are sodic, saline and more or less acidified (sols halomorphes, salins acidifiés). Some hydromorphic weakly developed soils and hydromorphic isohumic soils are present as inclusions.

The acidified soils have an acid to strongly acid pH, fine texture at the surface, and medium texture at depth. They have weak structure, coarse prismatic at the surface, massive at depth. The color is gray with typical brightly colored mottles.

Rice cultivation may be attempted upon successful control of submersion and salinity. The soils present as inclusions are somewhat more favorable. The natural rangeland is of good quality during the dry season.

TERRASSES SABLEUSES, Ld

Marine sandy terraces of various sizes and of elevations ranging from 1 to 8 m are found in all deltas. They were grouped in only one mapping unit, but they are also present as minor inclusions in mapping units Lcz1 and Lcy1, especially in the Sine Saloum.

Symbol: Ld

Description

Ld: Terrasses sableuses, sols peu évolués d'apport

These terraces are characterized by the presence of weakly developed, deposited soils (sols peu évolués d'apport). Facies variations are frequent and related to the age and relative position of the terraces. The middle terraces of the Basse Casamance show a depleted facies (Elinkine), while the high terraces show a ferruginous facies (Diakène Ouolof, Mlomp, Hillol). The smaller terraces scattered on the Saloum Islands have a hydromorphic facies in the northern Gandoul Island where they are lower in elevation and lead to soils which are more acid, more hydromorphic and with higher organic matter and nutrient content (but also slightly saline). These soils give good results for rice cultivation during the rainy season. The terrace shown in the Senegal River Delta has a hydromorphic facies with a relatively finer texture. The soil surface is micro-undulated and

rather frequently reworked by wind action. The elevation may in such a case exceed 12 m.

The texture is most often sandy with a single-grain structure. The topsoil is gray or brown; slightly organic, the lower horizons are light colored, often beige. The pH is most often acid, sometimes strongly acid and less often neutral. Hydromorphic signs appear at variable depths depending on the facies. These soils are generally poor chemically and not recommended for irrigation because of their very coarse texture. Palm trees grow well naturally there. The higher terraced areas of Basse Casamance where the water table is not too deep can be cultivated with some success.

COMPLEXE COTIER, Le

This complex unit was identified on the Petite Cote between Rufisque and Popenguine. It combines beach elements and exundated sand bars, partially sand-covered, ancient mangroves, and river alluvium. These formations are too small to be mapped individually, and their spectral signatures also do not allow proper separation.

Symbol: Le

Description

Le: Complexe côtier, sols halomorphes sur matériau plutôt argileux, sols hydromorphes sur matériau argileux, sols peu évolués d'apport sur sables exondés

The sodic soils are mainly clayey and saline and have a powdery structure during the dry season. At depth they become organic and rich in sulphides. The profile shows them as black with yellow streaks. These soils are best represented near Yenne (over 50%), but they are always present (up to about 40%). They have no agricultural value.

Hydromorphic soils (about 30%) are mainly represented near Bargny and Popenguine. Their hydromorphic character is evident from the surface. Their color is dark brown; they are clayey, massive in the upper horizon, strongly humic and often characterized by calcareous accumulations at depth. They support a thorny shrub vegetation and can be grazed or cultivated (sorghum) and give good results in forestry.

The weakly developed soils (about 25%) are sandy with a hydromorphic or sodic tendency and have no agricultural suitability. Overall, this mapping unit is best suited to forestry.

LEVEES, Lf

Regarding the levees which are present in the Senegal River Delta, a distinction was made between subrecent point bar complexes and two types of levees and splays that are differentiated on the basis of their salinity or hydromorphic character.

Symbols: Lfx, Lfy1, Lfy2

Description

Lfx: Faisceaux de levées subactuelles, soils hydromorphes, sols halomorphes et sols peu évolués

Subrecent point bar complexes are found along the meanders of the Senegal and the Gorom rivers. Although easily identified on the imagery, they were not always represented on the map because of their small size. Due to the sedimentation process, the unit is a complex of hydromorphic soils: completely gleyed from the surface, with saline gley and pseudogley with streaks and concretions; generally fine textured over medium textured sodic soils (acidified saline, and along the Gorom saline alkaline soils on medium textured material). On parts of higher levees hydromorphic, weakly developed deposited soils are present as inclusions. Many of these soils have such strong limitations that they cannot be immediately cultivated. The typical microtopography of this type of sedimentation may also be a handicap. These formations usually support good rangeland (Sporobolus ssp.) during the dry season.

Lfy1: Levées et deltas de rupture, sols halomorphes salins acidifiés, avec sols hydromorphes à gley

This system of levees and splays extends upstream along the Senegal River from Richard Toll to Débi, as well as to the east and south of the Lampsar to Ndiol. The soils are mainly (up to 70%) undifferentiated acidified saline soils (sols halomorphes, salins acidifiés indifférenciés) with some hydromorphic weakly developed deposited soils on the higher parts. Small basins constitute the minor component of the association (less than 20%) with gley or pseudogley (hydromorphic) soils.

The undifferentiated acidified saline soils are less often inundated, and salinity is often concentrated at the surface. They have a gray color with typical red, then yellow, streaks at depth and also signs of hydromorphic processes. The texture is most often medium, loam over silt loam; it may also be coarser in the higher reaches (since the increase in the sand fraction basically replaces the clay fraction) and finer in the lower reaches, with clay at the surface and loamy clay or clay loam over silt loam at depth. The structure is generally massive with a coarse angular blocky tendency. The organic matter content is low, the pH slightly acid, and the salinity variable

(but soils are often more saline at the surface).

Chemical fertility is fair, but desalinization remains a delicate problem for these weakly structured soils. Vegetation varies with salinity; it is generally a savanna with Acacia nilotica that offers medium quality grazing lands during the rainy season and in the beginning of the dry season. Rangeland is of somewhat better quality in the basins.

Lfy2: Levées et deltas de rupture, sols halomorphes salins acidifiés, avec sols salins très acides

This system of levees and splays extends downstream, west of the Lampsar and north of the Djeuss. As in the preceding mapping unit, about 70% of the soils are undifferentiated acidified saline soils (sols halomorphes, salins acidifiés indifférenciés). The difference between this unit and the preceding one lies in the fact that the soils of the small basins that constitute the minor component of the association (about 20%) are also sodic soils. They are strongly acidified saline soils toward Lampsar and, slightly acidified soils elsewhere.

The characteristics of this mapping unit are generally similar to those of the preceding unit. The texture may be finer than average; the salinity is higher and the pH lower. Cultivation of such soils presents the same difficulties. The quality of the grazing land is equivalent on the levees, but pastures in the small basins are unevenly scattered and can only be used during the dry season.

CUVETTES DE DECANTATION, Lg

The basins located in the deltaic area of the Senegal River have been grouped in five soil associations. Various elements which cannot be represented at the scale of the map, such as levees, terraces and mudflats, are included as minor inclusions within these mapping units.

Symbols: Lg1, Lg2, Lg3, Lg4, Lg5

Description

Lg1: Cuvettes de décantation, sols hydromorphes

This mapping unit covers the basins and some of the levees located between the Lac de Guiers and the Senegal River immediately downstream of Richard Toll and where the Richard Toll cultivation scheme is installed. The morphology of the terrain has been profoundly modified, and the soils have undergone a particular evolution due to the modern cultivation methods adopted there. The natural vegetation has practically disappeared.

They are mainly hydromorphic soils that are completely gleyified from the surface, with rare inclusions of coarse-textured pseudogley soils on the levees and splays of the Tawé toward the eastern part of the unit. On certain levees and terraces, some undifferentiated, acidified saline soils are still found. In the basins, soils normally have a clayey texture; they are very dark near the surface and mottled or completely gleyified at depth. The pH varies but it is, on the average, neutral to very slightly acid. These soils have rather good fertility, but significant investments are required for their cultivation.

Lg2: Cuvettes de décantation, sols hydromorphes, sols à gley salé

These basins extend along the Senegal River from Richard Toll to Ross Bethio. They show completely gleyified and saline gley soils (sols hydromorphes, à hydromorphie d'ensemble et à gley salé) as well as minor inclusions of pseudogley soils or undifferentiated, acidified saline soils on fluvio-marine deposits.

The texture is normally fine, though saline gley soils are generally very fine. The color of the topsoil is very dark; the lower horizons are bleached and mottled. The structure is most often platy or massive, with weakly developed shrinkage cracks. The pH remains slightly acid to neutral. Salinity is still very low for the saline gley soils, which allows them to be classified as nonsaline soils.

Although these soils are rather fertile, their cultivation requires investments. Rice may be cultivated. The natural vegetation is a grassland with *Oryza barthii*, which is good rangeland during the dry season.

Lg3: Cuvettes de décantation, sols hydromorphes, sols halomorphes salins acidifiés peu acides

These basins extend south of Diaouar. Hydromorphic soils with surface gley or completely gleyified (sols hydromorphes à gley de surface et d'ensemble) dominate the association (about 45%), but slightly acidified saline soils (sols halomorphes, salins acidifiés peu acides) are an important fraction (up to 35%). Some undifferentiated, acidified saline soils on fluvio-deltaic deposits constitute minor inclusions.

Although lighter textured, the hydromorphic soils are similar to those of the preceeding mapping unit. The slightly acidified saline soils have a pH higher than or equal to 5. They are slightly saline and at the surface have fine textures (clay); then they become medium textured (clay loam) at depth. These soils most often have a weak, coarse prismatic structure near the surface, and are massive, firm and sticky at depth. They are gray with bright yellow or red streaks which become entirely yellow at depth. The organic matter content and the chemical fertility are medium. These soils can be cultivated (sorghum,

cowpeas, rice) if salinity and submersion are controlled. They support good quality grazing land with Oryza barthii during the dry season.

Lg4: Cuvettes de décantation, sols halomorphes salins acidifiés peu acides à très acides

These basins are found in the northwestern part of the delta, west of Diaouar, along and north of the Gorom River. The soils are generally slightly acidified, saline soils (sols sodiques, salins acidifiés peu acides) (up to 60%) with to a lesser extent, strongly acidified, saline soils (sols halomorphes, salins acidifiés très acides) (about 30%). Like the preceding mapping unit, the slightly acid soils have a pH higher than or equal to 5, clay over clay loam texture and prismatic structure. They are extremely hard when dry in the upper horizon and massive and firm at depth. The strongly acid soils have a pH lower than 5. They are typical of the following mapping unit, brighter colored, more variable in texture, richer in organic matter. Peaty layers are sometimes present.

These soils may support good Oryza barthii or Sporobolus ssp. rangeland during the dry season.

Lg5: Cuvettes de décantation, sols halomorphes salins acidifiés très acides

This mapping unit corresponds to Ndiael. It is mainly composed of strongly acidified, saline soils in basins (sols halomorphes, salins acidifiés très acides).

These soils have a pH that is lower than 5 in at least part of the profile, which is otherwise very similar to the profile of slightly acid soils. Peaty horizons can be present together with sulphidic products. These soils are also quite saline. They have a gray color, which remains dark at depth, and typical red and yellow mottles. The texture is quite variable, from sandy loam to very fine loam, but often it is clayey. Fine sandy eolian accumulations are discernible at the soil surface. The structure is coarse angular blocky or prismatic (depending on whether the topsoil texture is medium or fine), massive and more or less plastic at depth. The organic matter content is higher than that of the slightly acid soils.

These soils present acute drainage and desalinization problems. They support scattered Sporobolus ssp. vegetation during the dry season which provides good rangeland.

DEPOTS LAGUNAIRES, Lh

Grouped under this heading are the soils of the alluvial formations that were formed by the depression lakes that are located behind the coastal dunes. The mapping units, which are recognized distinguish between hydromorphic and sodic soils.

Symbols: Lh1, Lh2

Description

Lh1: Dépôts lagunaires, sols hydromorphes

This unit extends in a narrow strip around the saline area of Lake Tanma. The topography is level. Soils are sometimes very similar to those found in the Niayes (E2d).

These are moderately organic, hydromorphic soils with gleyification at depth. They are thus poorly drained. The upper horizon can be relatively rich in undecomposed organic matter. The organic matter content generally reaches 2% and may greatly exceed 3%. Dark at the surface, these soils quickly become pale gray with depth in the waterlogged area. Hydromorphic signs are generally discernible from the surface, and the water table may be present at within one meter of the surface. The texture varies from sandy clay loam to sand with a poorly developed structure that shows a crumbly tendency near the surface. The structure is most often of single grain type at depth. If there is still enough of the fine fraction present in the profile, a vertic tendency results; this is particularly the case for clayey alluvium near the southern tip of Lake Tanma. A wide range of pH values can be found: acid to strongly acid in the sands, slightly alkaline in the shell layers.

The vegetation which is normally a dense grass cover, may be grazed. However, the soils are rather fertile, and following ebb tides, irrigated vegetables can be grown. A pH correction is advisable.

Lh2: Dépôts lagunaires, sols halomorphes

This unit surrounds the lakes of the Grande Côte. The development of sodic soils is related to the presence of a saline water table (Retba), marine incursions or the presence of saline deposits or recent marine sediments (Tanma).

Most of the soils (solonchaks) present show whitish, salt efflorescence. The soil surface is composed of a bleached, poorly decomposed, organic layer, finely incrusted with salt crystals. The profile is not differentiated: it is sandy, light beige and colored with gray and rusty mottles. The pH is alkaline but remains less than 8. The saline water table is generally very close to the surface.

These soils support typical halophytic grassy vegetation and are useless without a major investment for irrigation and drainage. The results of such an investment are tenuous, and these soils will certainly have an extremely high wind erosion susceptibility when cultivated.

B. Formations sur dépôts alluviaux et colluvions, A

These formations cover most valley bottoms: valleys that are functional during the rainy season and terraces on colluvio-alluvial material in Senegal Oriental and Casamance; fossil valleys in Ferlo; large, dry, braided river floodplains; and current (semi-)permanent valleys and alluvial systems.

These valley systems are composed of soil associations and complexes which cannot be represented at the publishing scale. The formations' characterizations are thus based on very broad physiographic and soil criteria, and the mapping unit descriptions also remain very general.

TERRASSES COLLUVIO-ALLUVIALES, VALLONS FONCTIONNELS, Aa

Mentioned under this heading are most valleys of the Casamance, southern Ferlo and Senegal Oriental which usually function during the rainy season but are not permanent streams. Four mapping units were recognized on the basis of major soil differences. Hydromorphic soils are grouped according to their parent material, e.g., colluvial, gravelly or alluvial. Ferruginous tropical soils are mapped as a separate unit.

Symbols: Aa1, Aa2, Aa3, Aa4

Description

Aa1: Terrasses colluvio-alluviales, vallons fonctionnels, sols peu évolués d'apport et sols hydromorphes sur matériau colluvial

This mapping unit covers most of the valleys developed on essentially colluvial material of Casamance. In the Basse Casamance this includes fragments of terraces.

The heads of these valleys and the areas along the streambeds usually consist of weakly developed deposited soils which sometimes show a tendency toward ferruginization (sols peu évolués d'apport, à tendance ferrugineuse). These soils have a rather uniform grayish color and a quite homogeneous and friable profile. A faint pseudogley can be found at a medium to very shallow depth. The texture varies from sand to sandy loam, with sandy clay loam at depth. The pH is neutral to slightly acid, the organic matter content medium, and the chemical fertility medium to low. These soils are normally rather dry and cultivation is strongly dependent on periods of flooding.

The valley bottoms (Fig. 4.6) are occupied by slightly organic hydromorphic soils, with gleying present at depth or near the surface (sols hydromorphes peu humifiés, à gley de profondeur ou de surface). Typically shaped termite mounds are often found (Fig. 4.7). These soils have quite variable hydromorphic characteristics. The texture usually varies between sandy clay loam, sometimes sandy loam, and clay loam at the surface, but at depth it may be clayey, clay loam, or clay. These soils remain friable to a great depth, and, although they do have a medium to low chemical fertility, their physical characteristics are often very satisfactory. These soils are thus suitable for cultivation as long as organic matter and fertilizers are applied to maintain the structure and balance the nutrient content.

Fig. 4.6. Functional valley bottom in the Haute Casamance; unit Aa1.

Fig. 4.7. Mushroom-shaped termite mound on hydromorphic soil; unit Aa1.

Aa2: Terrasses colluvio-alluviales, vallons fonctionnels, sols peu évolués d'apport hydromorphes ou sols hydromorphes, sur matériau gravillonnaire

This mapping unit covers the drainageways on the upstream areas of the Gambia River.

The major component is a hydromorphic, weakly developed deposited soil on gravelly material with a crust at shallow depth (sols peu évolués d'apport hydromorphe sur matériau gravillonnaire avec carapace à faible profondeur). The hydromorphic soils (sols hydromorphes) are

found in the lower reaches. The color and texture vary from a light beige gray, moderately gravelly, sandy clay loam, near the surface to a slightly mottled, pale yellow, quite gravelly clay loam at depth. The structure is massive, the fine earth is moderately to strongly cohesive. The physical characteristics are in general not very favorable. The organic matter content is medium to rather low, the chemical fertility medium to low, and the pH slightly acid to strongly acid.

The hydromorphic soils have suitabilities that are a little more favorable than those of the gravelly soils of the plateaus. Groundnuts or sorghum can be grown in the better-drained zones and rice in the depressions. Organic matter and fertilizer applications are still indispensable. The quality of the natural rangeland is fair to good.

Aa3: Terrasses colluvio-alluviales, vallons fonctionnels, sols hydromorphes sur matériau alluvial

This mapping unit covers all the valleys on essentially alluvial material of Casamance and the small valleys of Senegal Oriental.

The soils are usually hydromorphic with surface gley or completely gleyified on various types of alluvial material that is most often clayey, clay loam or clay, (sols hydromorphes à gley de surface et d'ensemble sur matériau alluvial). These soils are rather dark colored near the surface with a moderately well developed fine angular blocky structure in the first few centimeters. They are gray or light brown at depth with various streaks and mottles according to the degree of moisture saturation. The organic matter content is medium, but chemical fertility varies greatly. The values for potassium and phosphorus remain low and the pH is neutral to slightly acid.

These soils are best suited to rice. Organic matter and mineral fertilizers are needed but above all, the periodicity of the floods and the duration of submersion must first be controlled to assure a regulated water supply.

Aa4: Terrasses colluvio-alluviales, vallons fonctionnels, sols ferrugineux tropicaux lessivés à concrétions et à taches

This unit covers many valley bottoms of Senegal Oriental and Ferlo. The streambeds are occupied by hydromorphic soils, but the map scale does not allow for their individual representation. They therefore constitute a minor inclusion. The major component is a depleted ferruginous tropical soil, with streaks and concretions, developed on colluvio-alluvial material (sols ferrugineux tropicaux lessivés, à taches et à concrétions, sur matériau colluvio-alluvial). They are most often dry soils. The texture varies from loamy sand or sandy loam at the surface to sandy clay loam or sandy clay at depth. The topsoil is gray or brown, humic, weakly structured, most often massive and strongly cohesive, with vertical shrinkage cracks. The

color becomes paler in the next horizon, then ochre and light ochre in the lower horizons. The structure most often remains massive, but it is sometimes angular blocky, rather weakly developed in the lower horizon which may also be gravelly. These soils are well or moderately well drained and usually show signs of pseudogley at depth. In the lower horizon, there is also often a sharp discontinuity at the crust or cuirasse layer. These soils actually have poor structure; rather low, although sometimes medium, organic matter content; low chemical fertility (very low potassium, strongly deficient in phosphorus); and neutral to slightly acid, or even a strongly acid, pH at depth.

These soils are, nevertheless, suitable for cultivation if fertilizers are used to compensate for the phosphorus deficiency and if organic matter is applied to improve the surface structure. The organic matter supports the cation exchange capacity of the soil. Tillage combined with the application of organic matter may improve rain water infiltration and thus lower the erosion hazard while improving the soil's water holding capacity. The quality of the natural grazing lands is fair to good during the dry season.

VALLEES MORTES, Ab

Grouped under this heading are the valleys of the eastern Ferlo and the Sine Saloum regions most of which seldom or never function as such. Four units are recognized, each based on a major soil characteristic: hydromorphic soils on gravelly, clayey, sandy or very humic material.

Symbols: Ab1, Ab2, Ab3, Ab4

Description

Ab1: Vallées mortes, sols hydromorphes sur matériau gravillonnaire

The unit covers most of the valleys of the northern Ferlo. The soils are mostly hydromorphic, often on gravelly material at shallow depth (sols hydromorphes, sur matériau gravillonnaire à faible profondeur). Most often the texture varies from sandy clay loam to clay loam over clay. Signs of long periods of moisture saturation appear at shallow depth. The gravelly layer is quite often found at the surface, which seems to indicate a continuing degradation process that disfavors cultivation. Since sand deposition is noticeable in other sections of these valleys, it was thought that representing their locations by the spot symbol "s" could be useful.

The natural vegetation, including *Acacia seyal* and *Schoenefeldia gracilis*, provides good grazing during the rainy season and fair during the dry season.

Ab2: Vallées mortes, sols hydromorphes sur matériau argileux

This unit is mainly composed of the depressional clayey areas enclosed by sandy ridges within Ferlo valleys. A temporary water hole is often found at their center and soils are very often greatly influenced by long periods of moisture saturation. They are gray at the surface, brown to light beige at depth. At medium depth distinct hydromorphic mottles are evident as well as incipient concretions and some ferruginous gravel. Upon wetting, these soils are very cohesive, but the structure remains often quite well developed (angular blocky). These depressions are characterized by an endoreic drainage type, but since they depend almost exclusively on rainfall, the water supply is very irregular (Fig. 4.8) Hence, the control of submersion through lost-cost structures seems difficult at best. The area is partially drying out due to climatic evolution and sand deposition. An "s" represents sand invasion on the map.

The vegetation is very often remarkably dense, and grazing lands, with Acacia seyal and Andropogon Pinguipes good during the rainy season but poor during the dry season.

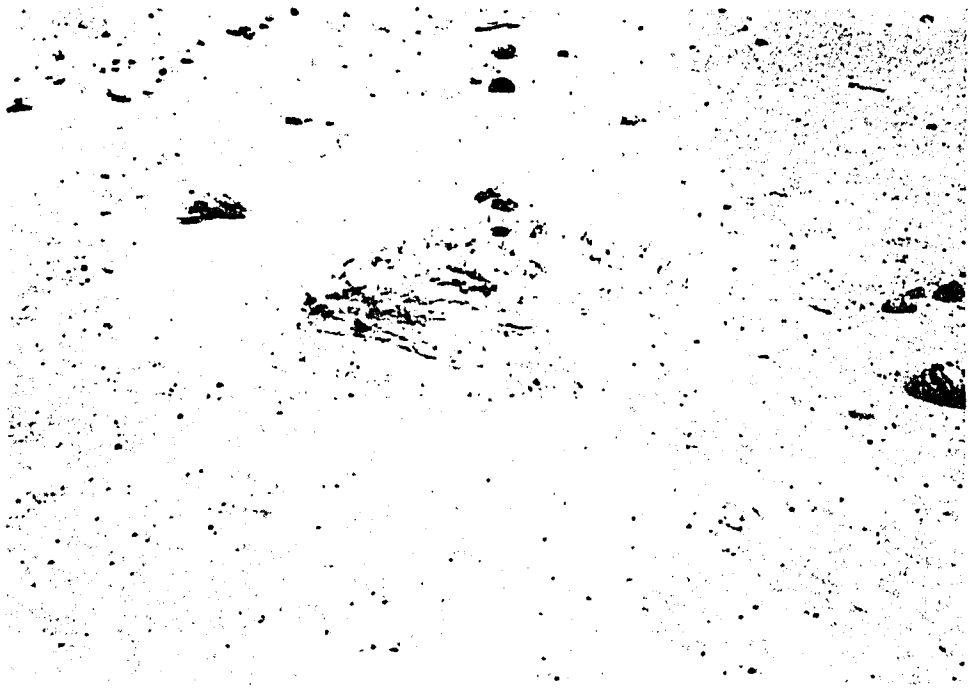


Fig. 4.8. The glazed surface and residual microrelief left by sheet erosion; unit Ab2.

Ab3: Vallées mortes, sols hydromorphes sur matériau sableux

This mapping unit groups the sand-filled valleys of the Sine Saloum. Valley bottoms are occupied by the very humic hydromorphic soils characteristic of unit Ab4, but most of the soils are hydromorphic soils with surface pseudogley. These soils are rather dark colored at the surface. The texture is often quite rich in fine sand with a low to medium clay content (sand or loamy sand). Rusty hydromorphic mottles appear near the surface; the organic matter content and chemical fertility are medium; and the pH is neutral.

These soils are suitable for cultivation of vegetables if conservation practices are employed and maintained and organic matter and fertilizers are applied.

Ab4: Vallées mortes, sols hydromorphes sur matériau très humifère

This unit covers the valleys to the east of the Thies plateau. These soils are rather organic hydromorphic soils, sometimes quite similar to the soils of the Niayes. Most of these soils show the characteristics of long periods of moisture saturation. They are most often sandy, very dark colored for the first few tens of centimeters, then white, mottled with rusty streaks at depth. They practically have no structure but very friable. The organic matter content is high and the chemical fertility is medium.

These soils are suited to vegetable cultivation, though conservation practices and improvements are still indispensable.

VALLEES SECHES, (anastomosées), Ac

Two braided-valley systems are grouped under this heading: first the Lower Ferlo and its tributaries, second the lower parts of the valleys reaching the Sine Saloum Delta.

Symbols: Ac1, Ac2

Description

Ac1: Terrasses et bourrelets alluviaux (Ferlo), sols hydromorphes et sols ferrugineux tropicaux peu évolués

This mapping unit includes most of the Ferlo valley, as well as some of the major tributaries that show the same braided morphology. Three components define this soil association.

The lower reaches that correspond to the streambed are still more or less regularly flooded, which happens more frequently downstream and near the Lac de Guiers. These gley soils (sols hydromorphes à gley) are greenish gray with rusty mottles at shallow depth and possible signs of salinity at depth under the form of pseudo-mycelium. The

rather homogeneous texture is loam to clay loam, with a tendency towards sandy loam at depth. The structure is platy in the first few centimeters and quickly becomes massive or sometimes prismatic with depth. The organic matter content is medium to rather high.

The higher reaches which correspond to the major streambed and abandoned channels are occupied by hydromorphic soils with a complete pseudogley (sols hydromorphes à pseudogley d'ensemble). The color and texture are variable--often very dark sandy loam to sandy clay loam at the surface, over pale gray sand at depth. Hydromorphic signs begin at the surface; the structure is platy in the first few centimeters and massive and extremely compact below. The organic matter content is medium.

Occurring as islands of flattened dunes along the streams, the eolian sandfills contain depleted ferruginous tropical soils (sols ferrugineux tropicaux lessivés). These weakly differentiated, well-drained soils are developed on very heterogeneous, often extremely sandy (fine sand), yellowish alluvial material which is reworked by wind action.

Grazing lands are usually of fair to good quality, but near the Lac de Guiers they are usable only during the dry season.

Ac2: Terrasses et bourrelets alluviaux (Sine Saloum), sols peu évolués d'apport

This unit corresponds to the valleys in the Sine Saloum area that are partially filled with sandy alluvium and reworked by wind action.

Soils are very sandy, weakly developed deposited soils (sols peu évolués d'apport). They are weakly differentiated and may show signs of salinity, usually near the streambed, or incipient ferruginization in the higher reaches.

These soils are extremely susceptible to erosion and are severely degraded; their agricultural potential is thus rather low.

VALLEES (SEMI-)PERMANENTES, Ad

These valleys constitute the core of the currently active alluvial system. They are the large (semi-)permanent streams and the formations of the Senegal River for which three mapping units have been recognized, i.e., the point bars, the levees and splays, the basins, and eventually the contact zones between certain rivers and the fluvio-deltaic plains.

Symbols: Adx, Ady1, Ady2, Ady3, Adz

Description

Adx: Complexe alluvial indifférencié, sols peu évolués d'apport, sols hydromorphes

Most of the major streams are included in this mapping unit. In their meandering valleys are found typical yet complex alluvial features: terraces, cut-off meanders, basins, point bars, etc. The landscape position occupied by each facies varies from valley to valley. Though certain soils characterize the various features, a wide range of variation nevertheless exists.

The Haute and Moyenne Gambie, the Koulountou and the Kayanga rivers have many associated basins and partially silted up cut-off meanders. Weakly developed soils with a brown eutrophic tendency with quite interesting agricultural possibilities are found downstream along the Falémé River. The soils of the Sandougou are generally hydromorphic with surface pseudogley.

Although their textures are extremely variable and they are usually deficient in phosphorus and often potassium, many of these soils may possess favorable chemical characteristics. In order to cultivate these soils, their submersion frequency must be controlled.

Ady1: Faisceaux de levées subactuelles, sols peu évolués d'apport hydromorphes, sols hydromorphes et vertigues

In this unit point bars constitute a complex of soils whose nature is strongly correlated to its microtopograhy. Medium-textured hydromorphic, weakly developed deposited soils are found on the higher levees; medium-to fine-textured hydromorphic, pseudogley soils are mainly found on the lower parts of the levees; and fine textured vertic soils are found in the basins. In terms of soils, this mapping unit is also a complex of the soils of the following two units (Ady2 and Ady3). These soils are of quite good quality, but microtopography is a handicap. Rangeland can be good during the dry season.

Ady2: Levées et deltas de rupture, sols peu évolvés d'apport hydromorphes et sols hydromorphes

The levee and splay system of the Senegal River is mainly characterized by hydromorphic soils. They are hydromorphic weakly developed deposited soils on the higher levees (sols peu évolués d'apport, hydromorphes), hydromorphic soils with pseudogley on the lower levees (sols hydromorphes à pseudogley), and hydromorphic soils with surface gley in the lower reaches (sols hydromorphes à gley de surface et d'ensemble), where fine textured vertic, weakly developed deposited soils (sols peu évolués d'apport vertiques) may also be found. Small basins with fine-textured vertic soils are present as

minor inclusions, since the map scale does not allow for their individual representation.

The hydromorphic, weakly developed deposited soils and the hydromorphic soils with pseudogley have a common texture: sandy clay loam, becomes medium to fine in the lower reaches, although pseudogley soils show a tendency toward finer textures. On the higher landscape positions, the topsoil may be a sandy loam. These soils show an often weakly developed structure with a subangular blocky tendency near the surface. They are massive with a prismatic tendency at depth and more often massive in the case of the pseudogley soils. Somewhat variable in color, they are most often a rather light brown, and the weakly developed soils are yet a lighter brown. Mottles begin from the surface in the pseudogley soils. Pseudogley soils also have a slightly acid pH, while hydromorphic, weakly developed soils have a neutral pH at the surface which can, however, be strongly acid or alkaline at depth without significantly influencing cultivation. These soils are also somewhat variable in terms of salinity but remain within acceptable limits. Minor saline soils with friable upper horizons near Dagana and undifferentiated, acidified saline soils near Golère occur but are not shown on the map.

These soils have quite good chemical fertility and can be irrigated for various crops. The natural vegetation is an Acacia seyal or Acacia nilotica savanna, which offers good quality rangeland during the dry season.

Ady3: Cuvettes de décantation, sols vertiques avec sols hydromorphes

The depressions within the Senegal River floodplain are mainly characterized by nongrumosolic topomorphic vertic soils (sols vertiques topomorphes non grumosoliques). Small levees with hydromorphic soils, pseudogley with streaks and concretions or vertic, weakly developed deposited soils may be present as inclusions. The basins are quite clearly visible on the imagery, but with the scale limiting the possibilities of representation, only the largest basins and areas with a high density of smaller ones were delineated.

The vertic soils are usually dark colored and fine textured. These soils do not always demonstrate the typical microrelief (gilgai) or the cracks and pressure faces of vertisols, but since they are located in basins, they are almost always hydromorphic soils. The typical soil profile is relatively uniform: most often it is brown with a few fine mottles; the texture is clayey with very often over 50% clay. The structure is coarse angular (blocky) for the first few centimeters, prismatic up to 20 or 50 cm in depth, and usually massive below that level. The pH is slightly acid to neutral. The organic matter content is low, the chemical fertility rather high. There is no salinity prob-

lem except for rare cases of undifferentiated acidified saline soils along small levees near Dagana, which are mentioned as inclusions.

Cultivation following the ebb is possible (sorghum, cowpeas), but because of the very low permeability of these soils, rice might be the best-suited crop. The natural grazing lands are accessible during the dry season.

Adz: Contact alluvial-fluvio-marin, soils hydromorphes à gley salé

This unit covers the downstream stretch of rivers where salt water incursions from the tides or the presence of saline sediment from ancient transgressions have lead to saline soils. These soils sometimes show localized salt efflorescences, have a low humic content, and are very moist most of the year. Bleached, with a somewhat crumbly, weakly developed, angular blocky structure at the surface, they often show a dark horizon at a very shallow depth; the structure here becomes coarse prismatic and the soil is quite strongly cohesive. They also usually have bright yellow or red streaks. The texture is often clayey but sandy layers may be found at depth along with fragments of decomposed cuirasse.

These soils can be cultivated (rice paddies) if the salinity problem is solved and the frequency of submersion is controlled.

C. Formations éoliennes, E

These sandy formations correspond to certain depositional periods in the Quaternary which were characterized by an arid climate favorable to the development of ergs. The formations generally located east of the Ferlo Valley are at least 35,000 years old. The formations extending mainly between the Grande Côte, the Sine Saloum and the Ferlo Valley belong to a more recent period and are 15,000 to 20,000 years old. These two formations were identified and respectively designated by the terms "ancient erg" (ergs anciens) and "recent erg" (ergs recents), but this separation is not absolute.

ERGS ANCIENS, E1

The dunes of the ancient erg are longitudinal dunes with very attenuated shapes. They are often over 10 km long and are about 800 m wide. The undulating relief is evident by the shape and direction of some mapping units; i.e., elongated along an azimuth varying from 65° in the west to 70° in the center of the Ferlo. This topography shows two levels of peneplanation and small variations in elevation. The actual dunes were grouped by the Project under the name "peneplanation surfaces and cover sands" (surfaces pénéplanées et sables de couverture). A sandy threshold supposedly corresponding to an ancient streambed of the Gorgol River, fossil valleys and erosional valleys, as well as a lower sandy erosional slope constitute the other formations

represented on the map as part of the ancient erg.

SURFACES PENEPLANEES ET SABLES DE COUVERTURE, E1a

Two peneplains interpenetrate in the middle of the northern Ferlo. The lower peneplain extends north and east toward the Senegal River Valley and the higher peneplain extends south and west towards the Ferlo Valley. Other units border these two main units, but their physiography is not clearly apparent on the imagery. The third mapping unit, made up of oblong areas, extends directly north of the Ferlo Valley; the two levels of peneplanation are present but not discernible on the imagery. The next three mapping units are located, from north to south, east of the Lac de Guiers. The topography is no longer discernible because the sand cover has been reworked and the relief eroded away. Differences in physiognomy do, however, correspond to variations in vegetal cover and soil associations.

Symbols: E1a1, E1a2, E1a3, E1a4, E1a5, E1a6

Description

E1a1: Surfaces pénéplanées et sables de couverture, sols ferrugineux tropicaux peu lessivés, sur matériau sableux, A1a1

This mapping corresponds, to a great extent, to the higher peneplain. A majority of the slopes are undulating.

Soils are weakly leached ferruginous tropical soils (sols ferrugineux tropicaux peu lessivés). They show no illuvial horizon but, at the most, a slightly more cohesive horizon. Their color is gray at the surface and rather yellow at depth. Soil texture is sandy though on the lower slopes, they are loamy sands. The structure is usually massive and very firm. The organic matter content is low and the pH slightly acid on the higher sites but rather neutral elsewhere.

The vegetation is an open shrub steppe (seldom a tree steppe), with Sclerocarya birrea and Balanites aegyptiaca offering rangeland which is usually fair during the dry season and often very good during the rainy season. These soils are extremely susceptible to eolian erosion, and wind ripples are very often seen on the surface. They also have a rather low fertility and their conservation constitutes a priority.

E1a2: Surfaces pénéplanées et sables de couverture, sols brun-rouge subarides dégradés et sols ferrugineux tropicaux peu lessivés, sur sables limoneux

This unit corresponds to the lower peneplain. It has an almost level topography that is characterized by the presence of numerous small irregular ponds which quickly dry out after the rainy season (hivernage). This unit has more variable soil composition. In the

central Ferlo, it interpenetrates the preceding unit and shows large, elongated, interdunal depressions similar in dimension to the dunes. The soils are somewhat enriched in the fine earth fractions, and a gravelly horizon that belongs to the substratum may locally appear at the surface. Hence, soils vary from weakly leached ferruginous tropical soils (sols ferrugineux tropicaux peu lessivés) to red brown subaridic soils (sols brun-rouge subarides). In the most northwestern part, the gravelly horizon is often closer to the soil surface, and sand cover becomes thicker in the east toward the Senegal River Valley. The soils are more or less degraded and truncated red brown subaridic soils, but to the west, the relief has been smoothed, and the soils are rather weakly leached, ferruginous, tropical soils.

All these soils are commonly gray or brownish gray at the surface and rather red at depth. The texture is loamy sand; the structure is most often massive, sometimes platy at the surface. The organic matter content is low, and the pH is slightly acid to neutral.

While the typical vegetation of the shrub steppes are Balanites aegyptiaca and Schoenefeldia gracilis, a tree steppe with extensive areas of barren crusted areas exists in the south (Fig. 4.9). These areas have been extremely degraded by cultivation and grazing; the soils are extremely susceptible to eolian erosion. Grazing of rangelands is almost satisfactory during the dry season and usually fair to rather good in the west during the rainy season.

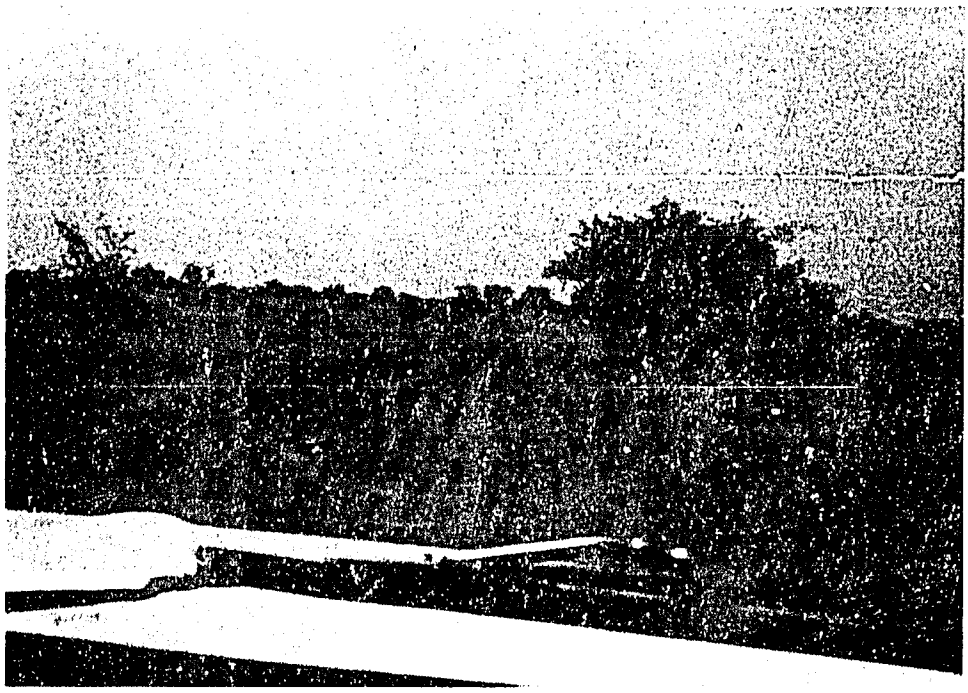


Fig. 4.9. A firebreak in the sandy Ferlo; unit Ela2.

E1a3: Surfaces pénéplanées et sables de couverture, sols ferrugineux tropicaux peu lessivés et sols brun-rouge subarides

This mapping unit combines parts of the higher and lower peneplain, e.g., leached ferruginous tropical soils (sols ferrugineux tropicaux peu lessivés) and compacted red brown subaridic soils (sols brun rouge subarides). Their characteristics have already been described in the two preceding units. They have a sand or loamy sand texture; they are massive and have low chemical fertility and low organic matter content. They have a neutral pH, which becomes acid at depth.

The vegetation consists of a shrub steppe on the higher parts and a tree steppe in the lower parts. The rangeland quality is fair during the dry season and quite often very good during the rainy season. The previously mentioned agricultural limitations apply.

E1a4: Surfaces pénéplanées et sables de couverture, sols ferrugineux tropicaux peu lessivés et sols bruns intergrades

This unit covers reworked or eroded areas to the east of the Lac de Guiers and, to the north, forms a very slightly undulating plateau. The soils are weakly leached ferruginous tropical soils (sols ferrugineux tropicaux lessivés) (up to 60%) with minor various brown intergrade soils (sols bruns intergrades) to the north (about 20% or more).

These soils have usually developed some structure near the surface; the remainder of the profile has a massive structure. They have a higher clay content: the loamy sand becomes sandy loam or even sandy clay loam at depth. The material contains finer sands in the north of the unit. The color also varies from brownish gray to reddish yellow.

These soils are arable when the fallow period is sufficiently long; the vegetation is a shrub steppe, sometimes a tree steppe, with *Balanites aegyptiaca* and *Schoenefeldia gracilis*. While the quality of grazing lands is only fair during the dry season, it is rather good during the rainy season.

E1a5: Surfaces pénéplanées et sables de couverture, sols brun-rouge subarides peu évolués dégradés, E1a5

Extending north of the preceding unit, this unit has comparatively thicker cover of sands.

The soils are weakly developed and degraded red brown subaridic soils (sols brun-rouge subarides, peu évolués et dégradés). Their characteristics are thus not very favorable and their fertility is rather low. The soil structure is massive except for a thin platy layer at the surface; the texture varies from loamy sand to sandy loam.

The vegetation still consists of a shrub steppe that has been degraded by cultivation and overgrazing. Grazing is rather poor during the dry season and fair during the rainy season.

E1a6: Surfaces pénéplanées et sables de couverture, sols ferrugineux tropicaux peu lessivés et sols intergrades sur matériau gravillonnaire

This unit also has a rather level topography. It is located east of the Lac de Guiers, in the loop formed by the Ferlo Valley. The immediate surroundings of the Ferlo Valley are characterized by the presence of the hard pan which is evidenced as boulders on the soil surface and as a gravelly horizon in intergrade soils (about 20%).

Elsewhere soils are weakly depleted ferruginous tropical soils (sols ferrugineux tropicaux peu lessivés) for up to 20% of the unit. They have a sandy topsoil, with a crust over a moderately developed structure in the upper horizon. They are massive at depth and the soil colors are reddish yellow.

These soils support fair pastures during the dry season and very good ones during the rainy season.

COMBLEMENT SABLEUX, E1b

A zone corresponding to a former sand infill area extends from the vicinity of Dek Do to Boké Namadi and Lour Ouolof. Its morphology is the same as that of the peneplains.

Symbol: E1b

Description

E1b: Complement sableux, sols ferrugineux tropicaux peu lessivés et à tendance hydromorphie

Weakly depleted ferruginous tropical soils constitute the major component of this mapping unit (sols ferrugineux tropicaux peu lessivés). They show a hydromorphic tendency in the lower reaches in the northern part of the unit, starting at Gonkol.

These soils have a sandy texture that becomes loamy sand at depth; they are very low in organic matter, massive, firm, rather yellow and extremely susceptible to wind erosion. The pH is neutral to slightly acid. The vegetation consists of an open shrub steppe which may provide fair grazing lands during the dry season and good to very good grazing lands during the rainy season.

VALLEES, E1c

Two types of valleys were represented on the map, e.g. fossil valleys that correspond in the field to slightly depressed areas and erosional valleys that border plateaus.

Symbols: E1c1, E1c2

Description

E1c1: Vallée fossile, sols brun-rouge subarides intergrades ferrugineux

On the soil map only one fossil valley system is shown in the triangle formed by Dagana, Fanayé Diéri and Tatki. A second system was identified in the neighborhood of Sangame, but, being located within the sidelap of two adjacent Landsat scenes, its boundaries could not completely be defined because of spectral differences between the two dates of the available imagery. It was therefore not shown on the map.

The texture is sand over loamy sand; the soils are red brown subaridic intergrades (sols brun-rouge subarides, intergrades) similar to those described earlier in unit E1a5 and in the northern part of unit E1a2.

E1c2: Vallées d'érosion, régosols sur matériau gravillonnaire

These valleys include the intensively eroded slopes at plateau edges and along the drainageways. One is shown near Boke Namadi, another near Ouarkokh. Soils are weakly developed, eroded and deposited soils (starting from the surface), frequently with gravelly material (sols peu évolués d'érosion et d'apport, sur matériau gravillonnaire). Stones and boulders from dismantled hard pan are common on the soil surface. The texture is sand over loamy sand, the structure is platy at the surface beneath a crust that has developed over large areas. The physical properties of these soils and their high susceptibility to erosion are major limitations. While the quality of the rangeland may be locally good during the rainy season, they are poor to very poor in quality during the dry season, and trampling is a severe problem.

BASSES TERRES, E1d

The lower reaches of the glacis sableux gravillonnaire, as defined by P. Michel (1973), are the land areas currently exposed to the influence of the Senegal River delta or of the Lac de Guiers. Three mapping units were represented as follows: first the erosional terrain with its channels running to the lake or delta; second, the lands closer to the delta where the slopes merge with fluvio-deltaic deposits and basins; third, the lower reaches around the lake that receive flooding.

Symbols: E1dx1, E1dx2, E1dy

Description

E1dx1: Basses terres, sols peu évolués d'apport hydromorphe

This unit covers the lower part of the glacis sableux gravillonnaire that extends north of Yamane between the lake and the delta. It is relatively level; the sand cover is much thicker in the south, while areas showing gravelly material at the surface are more often found in the north, where they alternate with crusted areas. There are minor inclusions of hydromorphic or sodic soils. Small, sandy mounds constitute a microrelief.

The soil texture is variable but usually coarse; the structure is massive and the consistency is friable; the color varies but is usually light. The organic matter content is rather low. The pH remains near neutral. The gravelly layer is never very deep; these soils are poorly drained.

These soils support fair rangeland during the rainy season; the grazing becomes poor to very poor during the dry season. The soils are very susceptible to erosion.

E1dx2: Basses terres, peu évolués d'apport hydromorphe , sols hydromorphes et halomorphes

This unit combines the flood-susceptible lower slopes. The former component comprises hydromorphic, weakly developed soils (sols peu évolués hydromorphes) with indifferentiated acidified saline soils (sols halomorphes, salins acidifiés non différenciés), while the latter soils are on the fluvio-deltaic deposits and the hydromorphic soils in the basins (sols hydromorphes, à gley de surface et d'ensemble).

The hydromorphic, weakly developed soils correspond to those of the preceding unit. The sodic soils have a medium texture and a massive structure, which shows a tendency to break into subangular blocky subunits. They are poorly drained and have a low organic matter content. The pH is slightly acid. The hydromorphic soils are similar to those of the following unit.

Overall these soils are unsuited to cultivation; though the saline soils could perhaps be improved. Grazing is generally only possible during the dry season.

Eldy: Basses terres, sols hydromorphes

The flood-susceptible lower reaches around the Lac de Guiers constitute most of this unit.

The soils are hydromorphic with surface gley (sols hydromorphes, à gley de surface et d'ensemble). They are very poorly drained. Their color, which varies greatly, is usually very dark near the surface and becomes lighter at depth. The texture is usually fine or very fine, and the structure is generally platy at the surface and massive at depth. The pH is just slightly acid and the organic matter content is medium.

The shrub vegetation is characterized by, among others, the Acacia nilotica. Though grazing land is of fair quality during the rainy season, it is poor to very poor during the dry season, except in the lower reaches, which are inundated for a longer time and where rather good pastures are only accessible during the dry season.

ERGS RECENTS, E2

The recent ergs have first been divided into three zones. The inland dunes extend east of the Thies plateau, from the Saloum Valley in the south to the Ferlo Valley near Linguère and Barkédji in the north. The dunes of the Senegal River extend along the valley from Thilé Boubacar almost to Horé Fôndé and at several places penetrate the northern Ferlo.

The coastal hinterland dunes extend from the Cap Vert Peninsula in an approximately 15 km wide strip west of the road from Thies to Louga, where the unit widens to meet the Ferlo Valley and constitutes a series of contorted areas along the valley within the inland dunes. Some areas are more or less included in the Senegal River Delta. The Niayes and the interdunes are considered as separate formations.

Within these zones, the dunes were next characterized by their morphology and finally by the soil types. This hierarchical approach results in a total of twelve mapping units.

DUNES DE L'INTERIEUR, E2a

The inland dunes usually are smoothly shaped. Two undulating units are represented on the map: one corresponds to the higher terrain, the other to the depressions. Three units with a flattened physiography were distinguished by their physiognomy on the imagery; one is slightly differentiated, one shows the alignments of ponds, another shows unaligned ponds.

Symbols: E2ax1, E2ax2, E2ay1, E2ay2, E2ay3

Description

E2ax1: Dunes de l'intérieur à modélé ondulé, crêtes, sols ferrugineux tropicaux non ou peu lessivés, bien drainés et sols brun-rouge subarides intergrades ferrugineux tropicaux

This unit has an average elevation of about 40 m and the topography is undulating. It is represented by the elongated areas around Louga.

These soils are very sandy diors (ferruginous tropical soils), which are quite fine and slightly cohesive. Their color varies. The pH becomes slightly acid at depth and the organic matter content is low. They are accompanied by ferruginous intergrades of red brown subaridic soils with intermediate characteristics, which differ from the "diors" mainly by their brown color, slightly higher organic matter content of the topsoil and better fertility.

These soils are rather low in fertility; they are very susceptible to wind erosion and are very much depleted by cultivation.

E2ax2: Dunes de l'intérieur à modélé ondulé, dépressions, sols ferrugineux tropicaux non on peu lessivés moins bien drainés

This unit covers the depressions between the ridges of the preceding unit. The topography is almost level.

Surface soil texture is fine and becomes sandy with sometimes a loamy sand layer at moderate depth. The clay content may be much higher than that of the soils of the preceding unit, especially for the upper horizons. They are more compact, have a brown color and show a tendency to a coarse angular blocky structure with cementation at depth. The pH is slightly acid.

These soils have a low fertility, but they are better than the soils of the previous unit. They have a rather good forestry potential.

E2ay1: Dunes de l'interiéur, modélé attenué peu différencié, sols ferrugineux tropicaux non ou peu lessivés, plus ou moins bien drainés

The composition of this unit is not very clearly defined. Its topography is usually almost level or very slightly undulating. It extends from the Senegal River Delta down to Fâs and Keur Momar Sarr and from the Ferlo Valley to Touba Merina and Afé. While well-drained ferruginous tropical soils are found on the summits (about 55%), less well-drained soils are found in the lower reaches (about 45%). The inclusions are mainly red brown subaridic intergrades.

These soils have as common characteristics (see E2ax1 and E2ax2) a sandy texture, low organic matter content, slightly acid pH and high wind erosion susceptibility.

They have thus a rather low fertility, and offer fair pastures during the dry season and good ones during the rainy season.

E2ay2: Dunes de l'intérieur, modélé attenué avec alignement de mares, sols ferrugineux tropicaux non ou peu lessivés

This unit has a rather level or slightly undulating topography and extends as a series of discontinuous areas, which are also included in unit E2ay3 (described below) south of the preceding unit down to the Saloum Valley. It can be distinguished from unit E2ay3 by the characteristic alignment of of its ponds. Its northern boundary is very irregular, passing near Touba Merina, Afé and Khogue Tobène.

The soils are sandy, extremely susceptible to erosion and strongly depleted. The pH is neutral at the surface and acid at depth; the organic matter content is extremely low. The color varies considerably.

E2ay3: Dunes de l'intérieur, modélé attenué avec mares non alignées, sols ferrugineux tropicaux non ou peu lessivés

The topography is level to slightly undulating. The unit covers a great part of the Baol region. It corresponds to ferruginous tropical soils, commonly called diors (sols ferrugineux tropicaux non ou peu lessivés) and extends east of the Thiès plateau, from the Saloum Valley in the south to Darou Mousti and Déali in the north.

These soils are sandy in most of the profile, and the sand becomes loamy sand at depth. Their color varies among gray, beige or red. They have a weakly developed structure, a low humic content and a slightly acid pH. No streaks or concretions are evident.

The very sparse tree vegetation includes *Faidherbia albida*, and the grasses provide little ground cover. The soil is very much degraded by cultivation and extremely susceptible to wind erosion. These soils are arable (groundnuts), but very efficient conservation practices are required.

DUNES DE LA REGION DU FLEUVE, E2b

The dunes of the Senegal River are made up of recent accumulations of sand from Mauritania. Only one delineation of this mapping unit is represented on the map.

Symbol: E2b

Description

E2b: Dunes de la région du fleuve, sables vifs, sols peu évolués ferrugineux tropicaux sur matériau sableux éolien

These dunes are only partially stabilized; they have sloping to steep slopes. The soils are weakly differentiated, formed in fine orange sand, single grain and very slightly cohesive, extremely susceptible to eolian erosion and slightly acid with a low organic matter content.

The vegetation is a degraded tree steppe which provides only poor to very poor rangelands during the dry season.

DUNES DE LA COTE, E2c

The coastal hinterland dunes are relatively stabilized, red dunes. Three mapping units are differentiated according to the steepness of the relief and the soil types. These units may contain niayes in the areas closer to the coast or to the delta.

Symbols: E2cx1, E2cx2, E2cy

Description

E2cx1: Dunes de la côte, très fortement marquées, sols brun-rouge subarides intergrades ferrugineux

This unit extends in the north from Maka Touré to the Senegal River Delta and in discontinuous areas along the Ferlo Valley, areas that are perpendicular to the axis of the valley itself. The relief is rolling and niayes are present in the areas adjacent to the delta.

Soils are red brown subarid soils (sols brun-rouge subarides) on the summits, ferruginous intergrades (intergrades ferrugineux) on the side slopes and hydromorphic ferruginous tropical (sols ferrugineux tropicaux hydromorphes) in the depressions and interdunal valleys. The soil color does relate to the position of these various soil types: the dunes are orange while the interdunes are a rather pale gray.

These soils have common characteristics, e.g., a sandy texture, a clay content slightly increasing with depth (especially in the soils of the depressions), a slightly acid pH (close to neutral at the surface), a very low organic matter content (the soils become a little richer further in the series, but only in the upper horizons), a very low chemical fertility and a weakly developed structure.

These soils are very susceptible to eolian erosion. Interdunal depressions are arable, but fertilizers and soil conservation practices

are indispensable. During the dry season these soils usually support poor grazing lands that become fair during the rainy season.

E2cx2: Dunes de la côte très fortement marquées, sols ferrugineux tropicaux faiblement lessivés

This unit extends beyond the coastal dunes from Mboro to Rao. It varies in width from 2 km in the south to 8 km in the north and only exceptionally exceeds 12 km. These "red dunes" (dunes rouges) are among the steepest. They are generally stabilized, but a quite marked tendency toward wind-induced remobilization is noticeable. The soils are red diors, ferruginous tropical soils (sols ferrugineux tropicaux). They are fine sandy soils with a weakly developed structure, and have a low organic matter content and a low nutrient content. While the pH is neutral at the surface, it becomes slightly acid at depth.

These soils have a rather low fertility and are greatly degraded when cultivated. Moreover, they are extremely susceptible to erosion. This unit, however, includes a rather high proportion of niayes, the soils of which are much more feasible targets for exploitation and are almost the only soils in this mapping unit that should be cultivated.

E2cy: Dunes de la côte moins fortement marquées, sols ferrugineux tropicaux faiblement lessivés

These are the older stabilized dunes that constitute most of the sandy soils of the Presqu'île du Cap Vert from Dakar and along the Grande Côte up to near Pal Mbaouar. The general topography is rolling.

These dunes are formed in siliceous sands that are orange with a weakly developed structure. Sands have a marked tendency to settle. The organic matter content is low, the pH slightly acid.

The vegetation is episodically grazed, and groundnut cultivation has strongly depleted the soils. They are extremely susceptible to eolian erosion and their cultivation requires major applications of organic matter and longer fallow periods. It might be wiser to choose shrub or tree crops over groundnuts.

E2d: Vallées interdunaires, niayes, sols hydromorphes

These are the interdunal depressions that are susceptible to flooding for at least a short period during the rainy season and remain moist near the surface throughout most of the year. Some are crossed by fossil valleys that are most often blocked in the north by the coastal dunes.

Symbol: E2d

Description

E2d: Vallées interdunaires, niayes, sols hydromorphes

This unit includes a series of small discontinuous areas inland from the coastal dunes of the Grande Côte, from Yoff to Lompoul. The large area shown near Sangalkam is actually a dune area of the type belonging to the E2cy unit but with a very high concentration of niayes (almost 40%). The topography is undulating.

The soils are sandy and characterized by an accumulation of organic matter that causes the soil profile to be dark colored for more than one meter in depth. Their structure is weakly developed. Signs (gley) of long periods of moisture saturation appear very near the surface; the watertable is often found within one meter of the surface. At the surface, the pH is neutral mainly due to agricultural practices, but it may become strongly acid at depth.

These soils are particularly suited to growing vegetables when the waters have receded at the end of the rainy season and when irrigation is practiced in dry season. Intensive cultivation will, however, require fertilization. Palm trees could be grown under better control to prevent their regression. If the gardens are well protected, the erosion hazard will remain moderate, though these sandy soils are greatly susceptible to eolian erosion.

INTERDUNES INONDABLES, E2e

Certain interdunal depressions are influenced by the proximity of the delta. The evacuation of water is slower and salt water incursions are possible. Two types of interdunes are thus shown on the map--those with or without sodic soils.

Symbols: E2e1, E2e2

Description

E2e1: Interdunes inondables, sols brun-rouge subarides et sols peu évolués hydromorphes

These interdunes only show a few basins that constitute minor inclusions of hydromorphic soils (gley soils) and seldom include sodic soils.

The most common soils are of the same type as those of the surrounding dunes of the E2cx1 unit: red brown, subaridic soils (sols brun-rouge subarides). Their organic matter content is low and their color a rather pale brown with hydromorphic mottles at depth. The texture is sandy and the pH is rather neutral throughout the profile,

which has a single grain structure. These soils support an open tree savanna which may be grazed; while the quality of this rangeland is generally fair during the dry season, it is good in rainy season.

E2e2: Interdunes inondables, sols halomorphes salins acidifiés, avec sols peu évolués hydromorphes, E2e2

These interdunes are the most exposed to salt water incursions. Basins enclosed by marine terraces exist. Some hydromorphic, weakly developed soils (sols peu évolués hydromorphes) are usually formed on the terraces or on coarse textured sandfills (less than 25%).

The major soils (about 65%) are various kinds of sodic soils: more or less acidified saline soils in the basins and soils with a friable topsoil or with a salt crest on the marine terraces. They vary greatly. Their texture is most often fine at the surface; they may become peaty at depth, as in the case of the strongly acidified soils of the basins, or medium to coarse textured, as in the case of the less acid soils.

Although their salinity is a major limitation, some of these sodic soils might be cultivated (rice) but at an often high cost (embankment construction, irrigation) and with much uncertainty as to the results.

D. Formations volcaniques récentes, V

The only soil formations corresponding to Quaternary volcanic activity shown on the map are those of the Presqu'ile du Cap Vert. The only mapping unit thus recognized includes the soils that have developed on the weathered material of these basaltic flows. It extends along the Corniche from the neighborhood of Fann to the Pointe des Almadies.

Other volcanic outcrops can be recognized on the imagery but they were not mapped because of their small size. Their influence on soil formations may also be considered negligible.

Symbol: V

Description

V: Epanchements basaltiques du Cap Vert, sols ferrugineux tropicaux faiblement lessivés sur matériau complexe

Except for the Mamelles and the erosional features affecting the Corniche, the unit has a rather flat topography. The soil depth depends on whether or not the profile is truncated (intense water erosion removing the upper layers) or buried under colluvium. The textural gradient observed is not related to the translation of the fine fraction but to the enrichment of the upper horizon with wind-deposited sandy materials. The texture ranges from loamy sand to

sandy loam at the surface; the dry horizons are made up of sandy clay loam or sandy clay from the weathering zone. The coarse fragment content varies from ferruginous concretions quite evenly distributed throughout the profile to calcareous nodules of various shapes and sizes that appear at various levels and show the heterogeneity of the parent rock. The structure is generally weakly developed. The color varies and mottles are evident in the lower horizons.

Although the chemical fertility of these soils is quite satisfactory, the urban use of the area becomes a sociological limitation to its agricultural use. The natural limitations are the low organic matter content and the risk of compaction, especially when the deeper horizons are exposed due to erosion.

The natural vegetation is very much degraded: a grassland dominated by Schoenefeldia gracilis is generally all that remains.

4.3.3.2 Formations sur Terrains Secondaires et Tertiaires

A. Formations sur grès plus ou moins argileux du "Continental Terminal" (Oligo-Mio-Pliocene), O

These formations cover most of the country. They are grouped in three physiographic units: residual plateaus and buttes, erosional and depositional slopes, lower plains and basins. The depressions on the plateaus, the areas of sand accumulation and the pediment slopes at the edge of the Ferlo plateaus constitute three other minor physiographic groupings.

PLATEAUX ET BUTTES RESIDUELS, Oa

Grouped under this heading are the relatively level surfaces usually located in the higher parts of the topography. The compilation of the available documents allowed the completion of the interpretation and fifteen soils associations to be delineated.

Symbols: Oa1, Oa2, Oa3, Oa4, Oa5, Oa6, Oa7, Oa8, Oa9, Oa10, Oa11, Oa12, Oa13, Oa14, Oa15

Description

Oa1: Plateaux et buttes résiduels, lithosols sur cuirasse

This unit covers the interfluves of northern Ferlo Boundou. Its hard pan is subhorizontal, not very thick, pisolitic in its upper part (the soils appear most often covered with ferruginous gravel) and massive at depth (Fig. 4.10). It does not seem, however, to be present as a continuous pavement.

Fig. 4.10. A firebreak in the Ferlo Boundou; the soil is gravelly beginning at the surface; unit Oa1.

These soils are the final result of a long erosional process. They are not suitable for cultivation and the shrub steppe provides grazing only during the rainy season.

Oa2: Plateaus et buttes résiduels, lithosols sur cuirasse, régosols ou sols peu évolués d'apport hydromorphes, sur matériau gravillonnaire

This unit is largely represented in the east of the country on both sides of the "Route nationale 1", Dakar-Tambacounda-Kidira. It forms an association with three components most frequently found.

The regosols and the hydromorphic weakly developed, deposited soils on gravelly material (régosols et sols peu évolués d'apport hydromorphes) (up to 60%) are found on the plateaus. The lithosols on hard pan (about 30%) are mainly represented at the nickpoints at the edge of the plateaus where the hard pan outcrops as a ledge, or locally on the plateaus as a hard pan pavement, or as areas covered with ferruginous stones and boulders.

The weakly developed soils are arable, but require mineral and organic improvements to maintain their structure and their fertility. The regosols are the most fertile, and, although they become very quickly degraded, they can be used for growing millet and groundnuts. The hydromorphic, weakly developed soils are the least fertile and, if cultivated, a ridge tillage system should be employed. Sorghum and groundnuts could then be grown. Grazing lands are rather poor during the dry season.

Oa3: Plateaux et buttes résiduels, lithosols sur cuirasse, régosols ou sols peu évolués d'apport hydromorphes, sur matériau gravillonnaire, sols ferrugineux tropicaux peu profonds tronqués

This unit covers plateaus and interfluves of the central part of the formations on "Continental Terminal". The topography is rather level and the elevation does not exceed 80 m.

The soil association includes one more element than that of the preceding unit (Oa2); truncated and indurated depleted ferruginous tropical soils (sols ferrugineux tropicaux lessivés, tronqués et indurés) make up about 20% of this unit (Fig. 4.11). These soils are characterized by the presence of an indurated layer at medium depth. They are a pink gray color at the surface and pink with red ferruginous streaks or concretions at depth. The texture varies from loam at the surface to clay at depth with a clay accumulation in a horizon characteristic of translocation. The structure is massive to medium subangular blocky near the surface but is nearly always massive below the thin humiferous horizon. The organic matter content is generally low, the pH acid, and the chemical fertility low to medium (but with a phosphorus deficiency). Thus, these soils have limitations similar to those of the other components of this soil association: lithosols (about 30%) and regosols or weakly developed soils (about 50%). They are suitable for the cultivation of millet, sorghum or groundnuts.

Although this unit offers agricultural and pastoral potential largely equivalent to that of the preceding unit, a larger proportion of soils are perhaps suited to millet cultivation.

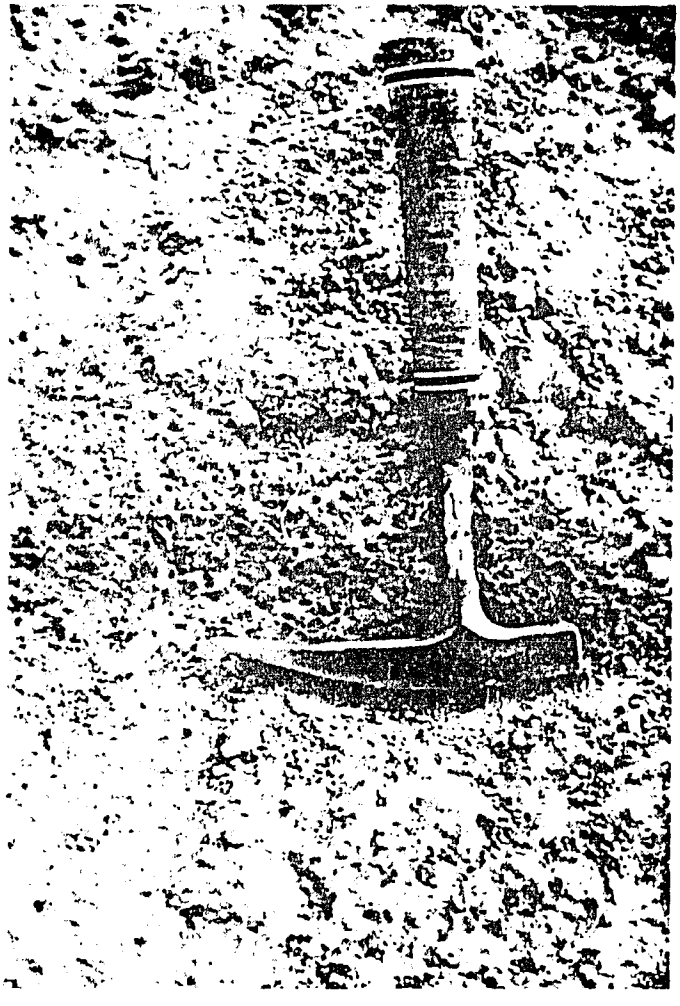


Fig. 4.11. Indurated ferruginous (plinthite) exposed to the air by erosion.

Oa4: Plateaux et buttes résiduels, sols peu évolués d'apport hydromorphes ou regosols, sur matériau gravillonnaire, sols ferrugineux tropicaux lessivés sur matériau de colmatage, lithosols sur cuirasse

This unit covers many of the nearly level plateaus and interfluves below 80 m elevation in the central part of the formations on the "Continental Terminal". This unit adds one more element to the soil association that constitutes unit Oa2. The soils in this unit, however, are better differentiated than those of the preceding unit (Oa3).

These leached ferruginous tropical soils (sols ferrugineux tropicaux lessivés, sur matériau de colmatage) (about 30%) have formed in the infertile material found on the plateaus have a texture which is richer in the silt fraction (clay loam over clay). The hard pan can be found at about one meter in depth but soil may also have a crust or a gravelly layer. The structure is coarse prismatic near the surface, but becomes angular blocky at depth. Many streaks and concretions appear at about 50 cm in depth. The pH is acid and the chemical fertility is rather low.

While these soils may not be very favorable for the cultivation of cotton or groundnuts, they are suitable for sorghum when ridge tillage is employed. The lithosols are uncultivable, but constitute only a minor component (about 20%). The major component (up to 50%) combines regosols and hydromorphic weakly developed, deposited soils, both on gravelly material (régosols et sols peu évolués d'apport, hydromorphes) The former have a higher fertility level but are quickly depleted; they are suitable for millet and groundnuts. The latter are less fertile, but give quite good results when ridge tillage is used to sorghum or groundnuts. According to available information, two phases, based on the occurrence of gravel (g) and hard pan (c), are shown on the map thus suggesting which material predominates; yet, the distinction is only tentative and the phases were not considered in construction of the land capability map. Rangeland is of rather fair quality during the dry season.

Oa5: Plateaux et buttes résiduels, lithosols sur cuirasse, sols peu évolués d'apport hydromorphes sur matériau gravillonnaire

This unit is quite well differentiated on the imagery: it extends between Nhar and Mboune and has a very flat topography with elevations ranging from 40 to 80 m.

The soils typical of units Oa5 and Oa6 are grouped as part of this soil association. The cuirasse is very often present as a pavement alternating with shallow and strongly hydromorphic gravelly soils. In this case, the hydromorphic character and shallow depth seem to constitute too much of a limitation for this unit to have any significant agricultural value. The rangeland is also poor. Shallow hydromorphic ferruginous tropical soils on cuirasse may locally be present as inclusions.

Oa6: Plateaux et buttes résiduels, sols peu évolués d'apport hydromorphes sur matériau gravillonnaire, Oa6

This unit is represented in the southern Ferlo Boundou where it extends over almost flat areas.

The major component is a hydromorphic, weakly developed, deposited soil on gravelly material (sols peu évolués d'apport hydromorphes, sur matériau gravillonnaire). The fine earth fraction of these gravelly

soils actually has a rather fine texture (clay loam to silty clay); colors are light gray. They overlie a strongly indurated hard pan at shallow depth. The structure is usually massive and the soil is rather strongly cohesive. The organic matter content and the chemical fertility are rather low. The pH is slightly acid and the physical properties are unfavorable.

These soils can, to some extent, be cultivated on ridges for sorghum or groundnuts. They support fair grazing lands during the rainy season.

Oa7: Plateaux et buttes résiduels, régosols sur matériau gravillonnaire et lithosols sur cuirasse

This unit corresponds to the gravelly plateaus of the Ferlo, north of the road going from Linguère to Matam.

The soils are shallow to a dismantled hard pan or to gravel. Numerous ponds of variable sizes are found in this unit and the largest ones have been mapped separately (Ob1). An "s", which tentatively represents areas subject to sand encroachment, is shown on the map near the Ferlo Valley.

The rangeland is very good during the rainy season, poor to very poor in the dry season. The vegetation is a shrub savanna (sangaré).

Oa8: Plateaux et buttes résiduels, sols ferrugineux tropicaux sur matériau gravillonnaire, sols brun-rouge subarides tronqués, lithosols sur cuirasse

This unit corresponds to the gravelly plateaus located in the contact zone between the formations on the "Continental Terminal" and the eolian formations. Most soils are ferruginous tropical soils (about 70%). They are deep, brown, and sandy in the upper horizons and become yellow and heavier with depth and massive with a tendency toward an angular blocky structure (sols ferrugineux tropicaux). Truncated, red brown subaridic soils (sols brun-rouge subarides, tronqués) are characteristic of the following mapping unit (about 20%), and lithosols on hard pan may exist in certain areas.

While the rangeland is very good during the rainy season, it is poor to very poor during the dry season.

Oa9: Plateaux et buttes résiduels, sols brun-rouge subarides tronqués et sols ferrugineux tropicaux sur matériau gravillonnaire

This unit corresponds to the preceding unit, but the components' proportions are reversed. The truncated red brown subaridic soils (sols brun-rouge subarides tronqués) form the majority (at least 50%), and the ferruginous tropical soils (sols ferrugineux tropicaux) form the minor component (about 30%).

The gravelly horizon often exposed at the surface and the soils are at best moderately deep. They are loamy sands with a platy structure at the surface and massive at depth. Their color is red brown with signs of long periods of moisture saturation at depth. The pH is very slightly acid, and the chemical characteristics (fertility) are generally not very favorable.

These soils support poor to very poor pastures during the dry season; they are fair during the rainy season.

Oa10: Plateaux et buttes résiduels, sols ferrugineux tropicaux faiblement lessivés, bien drainés

This unit extends over a large area in the western part of the formations on the "Continental Terminal", from Mboune to Bem Bem north of the Mboune Valley, from Paraouol to Mboundou Mbaba between the Mboune Valley and the Saloum Valley, and eventually from Patakour to Ndioum Guent along the valley. The topography is almost level and the elevation ranges from 40 m in the west to 60 m in the east.

The soils are generally well drained, weakly leached, ferruginous tropical soils (sols ferrugineux tropicaux faiblement lessivés). They are slightly differentiated, deep, sandy and brown to red in color. They have very weakly developed structure and are slightly cohesive, and their organic matter content and chemical fertility are very low. The pH is slightly acid.

The natural rangeland is fair to good.

Oa11: Plateaux et buttes résiduels, sols ferrugineux tropicaux faiblement lessivés, moins bien drainés

This unit extends in a discontinuous fashion from Linguère in the Ferlo Valley and follows the Mboune Valley to Bem Bem in the north, Loumbol in the south and Mbabane in the west. The elevation ranges from 40 to 50 m and slopes are very gently sloping.

Although the soils are weakly leached ferruginous tropical soils (sols ferrugineux tropicaux faiblement lessivés), they are generally not as well drained as those of the preceding unit (Oa10). They are deep but slightly richer in clay for a more variable texture--loamy sand to sandy loam at the surface and sandy clay loam to sandy clay at depth. There is a tendency toward a fine angular blocky structure at depth, and hydromorphic mottles and concretions frequently appear. The pH is slightly acid, the organic matter content very low, and the chemical fertility remains very low, though it is slightly higher than that of unit Oa10.

Rangeland is fair to good.

Oa12: Plateaux et buttes résiduels, sol ferrugineux tropicaux lessivés

This unit extends along the Saloum Valley from Lofé to Ndioum Guent. The topography is almost flat and the elevation ranges from 40 to 50 m. The soils are leached ferruginous tropical soils (sols ferrugineux tropicaux lessivés). They are deep and texture is sandy at the surface and at the limit between loamy sand and sandy loam at depth. The color varies with the drainage conditions: rusty with reduced streaks in a massive structure or reddish brown with a weakly developed medium blocky structure. The organic matter content is very low as is the chemical fertility. The pH ranges from neutral near the surface to very slightly acid at depth.

The rangeland is of rather good quality.

Oa13: Plateaux et buttes résiduels, sols ferrugineux tropicaux faiblement lessivés sur cuirasse

This unit extends along the Mboune Valley from Sivi Abé to join unit Od8. The topography is extremely gently sloping and seldom reaches 60 m elevation; the most frequent elevation is 50 m.

The soils are weakly leached ferruginous tropical soils (sols ferrugineux tropicaux faiblement lessivés) with hard pan at shallow depth. They usually show hydromorphic signs and some areas may be gravelly. The texture is most often coarse or medium. These soils are susceptible to water erosion because of their low infiltration capacity. They have low organic matter and nutrient contents.

Rangeland is poor to very poor.

Oa14: Plateaux et buttes résiduels, sols ferrugineux tropicaux divers, peu ou non lessivés, lessivés, hydromorphes, et lithosols sur cuirasse où régosols sur matériau gravillonnaire

The plateaus and interfluves of most of the Haute Casamance and parts of the Moyenne and Basse Casamance, as well as some small areas east of the Kouloutou River, are included in this mapping unit. The elevation seldom exceeds 100 m and often remains below 50 m in the north. The unit surrounds the Anambé depression: its western boundary passes near Tiara and Fafakourou and then follows the Gambia in the Moyenne Casamance to Saré Samba Cissé where the unit widens to the south toward Sillabounda to eventually close near Badimbour in the Basse Casamance. Small occurences around Hamdallaï Amadou and Saré Bodio in the Moyenne Casamance are also included. The slopes are generally very gentle, but some steeper slopes exist along the Kayanga River.

These soils are among the most leached ferruginous tropical soils in Senegal. The illuviated clay horizon forms a layer restrictive to the movement of soil moisture as evidenced by the hydromorphic

characteristics of numerous soils, especially in the center part of the plateaus. Different amounts of concretions occur at variable depths over a hard pan. The hard pan can be present as a pavement, and outcrops are most common along the valleys. Elsewhere, the most common soils (about 70%) are leached ferruginous tropical soils with concretions (sols ferrugineux tropicaux lessivés, à concrétions). Their texture is most often coarse at the surface (sand or loamy sand), and it then becomes sandy loam, sandy clay loam or, rarely, sandy clay at depth. The clay content increases suddenly at a medium depth along with concurrent signs of prolonged moisture saturation. The organic matter content and the chemical fertility are medium. Furthermore, fertility is strongly imbalanced (unfavorable quantities of potassium and phosphorus). The pH varies greatly from neutral toward slightly acid, to acid or strongly acid with depth.

The combination of rather high rainfall and the usually limited infiltration capacity of the numerous soils having hard pan at a shallow depth intensifies water erosion. Along The Gambia and in the Moyenne and the Basse Casamance soils are on the average very shallow, viz., shallow ferruginous tropical soils over hard pan, or very gravelly regosols. Termite mounds are evident throughout this unit (Fig. 4.12). Termite mounds are quite large (Fig. 4.12).

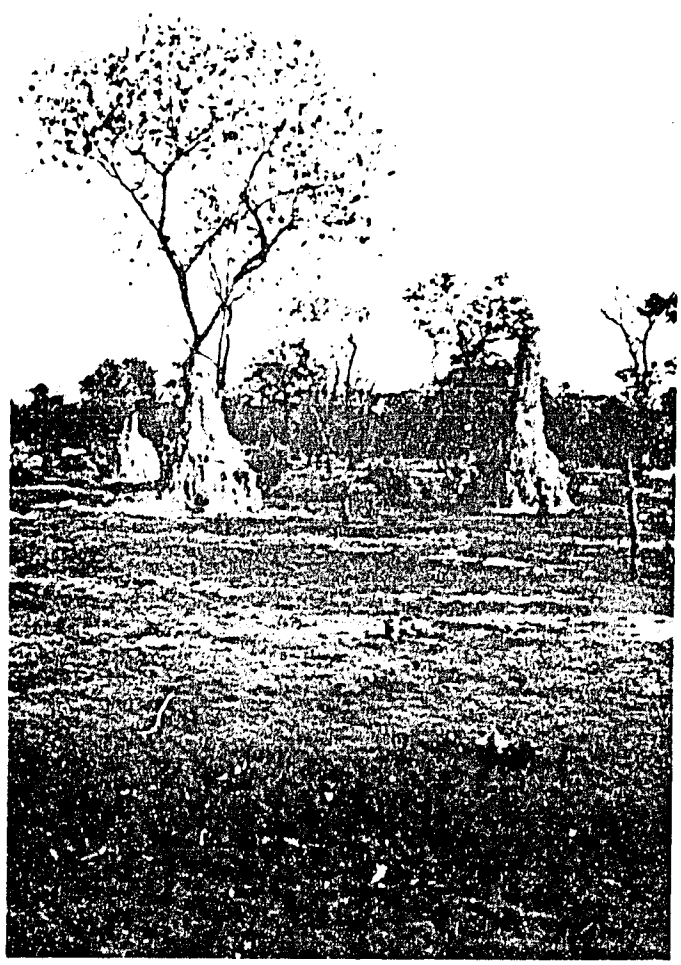


Fig. 4.12. Termite mounds on deep, ferruginous tropical soils; unit Oa14

Best suited for forestry are the indurated soils or those over cuirass. The ferruginous tropical soils with streaks (lamellae) and concretions form the major component of the soils association and are arable when the organic and mineral contents are improved. Groundnuts would then grow quite well.

Oa15: Plateaux et buttes résiduels, sols faiblement ferralitiques, sols ferrugineux tropicaux lessivés, sols peu évolués

The lower plateaus of the Casamance constitute most of this unit, which seldom reaches 50 m elevation and extends from the coast to Bounkiling, Sillakounda, Diaba Senegal and Fafakourou to the north and Kaudiator, Tiara and the Kayanga Valley to the east. This unit also follows the Gambia River as a series of small irregular areas and covers most of the lower Gambia. Slopes are very gently sloping but some steeply sloping areas exist along the Kayanga River. The soils are most often (about 70%) weakly ferralitic soils (sols faiblement ferralitiques). They are usually extremely deep and well drained and colors are often bright red or yellow. Along the Gambia River they are, however, often shallow to over hard pan. The texture is coarse at the surface (loamy sand) and, though finer with depth (sandy clay), the soil remains highly permeable. The structure is medium to fine crumb, or granular, and is rather well developed near the surface, becoming less well developed with a blocky tendency, at depth. The pH ranges from neutral at the surface to slightly acid at depth. The chemical fertility is low, sometimes medium. The organic matter content is medium to low.

These soils are of interest because of their exceptional useful depth and the beneficial physical properties. They are always found in well-drained sites. The inner zones of the most extended plateaus comprise ferruginous tropical soils that evidence streaks and concretions. Hard pan outcrops may be evident at nickpoints, and the lower slopes are then occupied by weakly developed soils on products of dismantled hard pan. If hard pan is not present, weakly differentiated, leached, ferriginous tropical soils are usually present.

The vegetation is a moderately dense forest that contains *Pterocarpus erinaceus*.

DEPRESSIONS DE PLATEAUX, Ob

Some ponds of the northern Ferlo and larger depressions, such as the Anambe which is subdivided into two distinct mapping units, were grouped under this heading because of their particular morphology or agricultural importance.

Symbols: Ob1, Ob2, Ob3

Description

Ob1: Dépressions de plateaux, sols hydromorphes, sols ferrugineux tropicaux hydromorphes

This unit corresponds to ponds which form in places where a clayey layer is closer to the surface, e.g., in depressions on the plateaus or over collapsed hard pan. It is represented as small ovoid-shaped or circular areas within the dune plateau or the hard pan outcrops (Fig. 4.13). Only the largest areas have been shown on the map. The soils are hydromorphic or hydromorphic ferruginous tropical soils (sols hydromorphes, sols ferrugineux tropicaux hydromorphes) and are quite deep. They contain a gravelly have a horizon which seldom occurs at the surface. They usually rather well developed structure (angular blocky), with strongly cohesive sandy clay loams over massive, compact clay. The upper soil horizon most often has a platy structure. The pH is neutral, and the fertility low.

The vegetation is a shrub steppe which offers good rangeland during the rainy season, but is rather poor during the dry season.

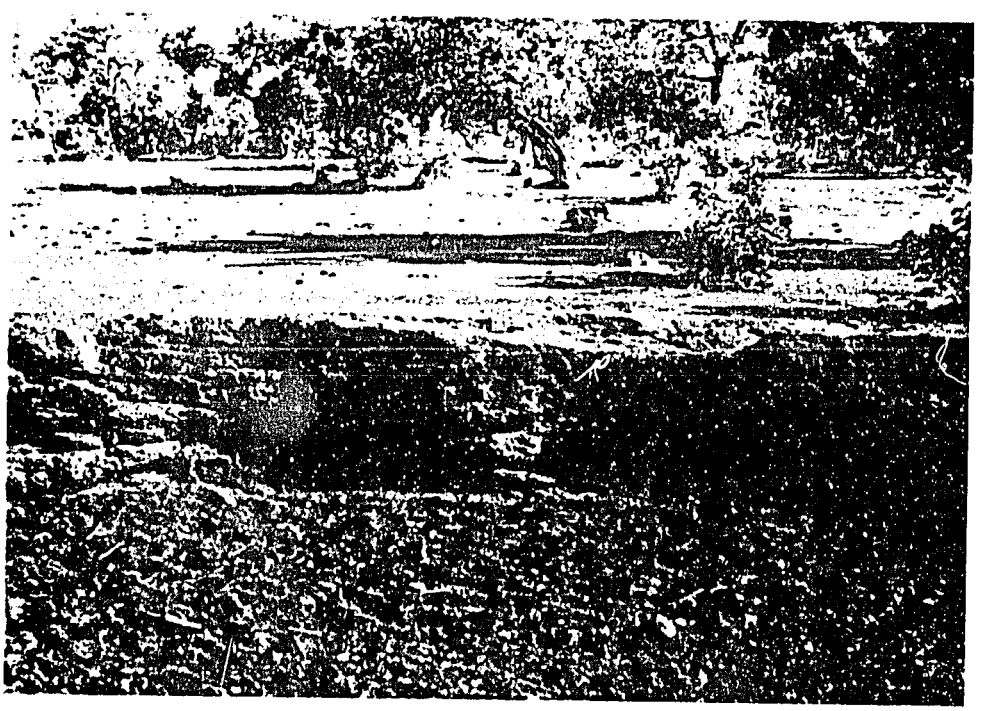


Fig. 4.13. Cuirasse pavement. In the foreground (naturally or artifically) dismantled cuirasse provides an area where a small accumulation pond can develop.

Ob2: Dépressions de plateaux, sols hydromorphes

This unit covers the external zone of the Anambé depression as well as a few areas around the Gambia River upstream of its confluence with the Koulountou River. The soils are hydromorphic soils to varying degrees.

In the case of the Anambé depression, the soil characteristics depend on the soil position relative to the center of the depression. Yet all these soils are regularly flooded. They are sandy clay loams with a heavier subsurface horizon that becomes thicker toward the center of the depression where the whole profile may have a clayey texture. The structure can be platy or silted up for the first few centimeters; it is, however, usually angular blocky, especially in the upper horizons when dry. The lower horizons have a less well developed structure which tends toward prismatic. They are gray at the surface and a mottled beige at depth. The occurence and abundance of mottles and concretions varies greatly. Hydromorphic signs are always noticeable and begin from the surface mainly as rusty streaks along the root channels. Away from the center of the depression, the concretions usually appear very deep, while they are moderately deep toward the center of the depression. The pH is generally acid, organic matter content medium--which is high for the area--and chemical fertility satisfactory, though in addition to the usual potassium deficiency, the low calcium content and the relatively high magnesium content are indicative of chemical imbalance. Mineral additives are thus recommended to correct this imbalance. The drainage problem is largely a matter of controlling the periodicity of the floods and thus of improving waterways to control flood levels.

The soils near the Gambia River are somewhat different. Their structure is less well developed; they are more cohesive, often paler in color and have concretions at medium depth. They have a lower organic matter content and a lower fertility, but they are still arable if fertilizers are applied and if the drainage conditions are taken into account in deciding upon the agricultural practices to be used.

Ob3: Dépressions de plateaux, sols vertiques

The central part of the Anambé depression is inundated for quite a while, not only during the rainy season, but also for some time during the dry season. The soil surface shows a typical microrelief (gilgai) of small basin-like depressions and small buttes covered with concretions and calcareous nodules.

These soils have strong vertic features; all transitional types between the typic vertisols and the various kinds of hydromorphic soils of the preceding unit can be found. They have developed on sandy clay over loamy sand at about one meter in depth. The structure is fine angular blocky, especially near the surface, while the remaining substratum has an overall prismatic structure. The vertic

characteristics, e.g., cracks, pressure faces, etc., are more or less well developed. Signs of long periods of moisture saturation are present, along with, quite often, numerous concretions and various nodule types near the surface. The pH ranges from slightly acid at the surface to strongly alkaline at depth; locally, the upper part of the profile reacts to acid. Although the organic matter content is quite low and the chemical fertility is satisfactory, these soils are difficult to cultivate because of their limiting physical properties. Flood control remains a major problem.

A tree savanna with Terminalia macroptera and Andropogon gayanus is typical of this type of formation.

ZONES D'ENVAHISSEMENT, Oc

The dunes and sand cover that encumber some of the inactive valleys and plateaus of the northern Ferlo bear signs of still active eolian transportation, which justifies the creation of this special unit.

Symbol: Oc

Description

Oc: Zones d'envahissement dunaire, sols ferrugineux tropicaux et sols brun-rouge intergrades

The soils vary between the leached ferrugineous tropical soils (sols ferrugineux tropicaux lessivés) and the modal red brown subaridic soils (sols brun-rouge subaride modal). They are, in any case, very deep, slightly cohesive and sandy with a slight relative increase in the clay content at depth. They are excessively well drained and have an acid pH. Their structure is weakly developed blocky or is massive. The color is always rather pale. It varies between red and yellow, except for the first 20 or 40 cm, which are generally dark brown. These soils have a low content of organic matter and nutrients.

The vegetation is a savanna or even a shrub steppe with Combretum glutinosum. Its suitability for grazing is moderate during the dry season and very good during the rainy season. These soils are quite frequently cultivated, but they are very susceptible to eolian erosion.

VERSANTS, PENTES ET GLACIS D'EPANDAGE, Od

Valley slopes and erosional or depositional slopes that extend between the plateaus and valley bottoms are grouped under this heading. The data of the available documents allowed the completion of the interpretation, and eleven soils associations were established.

Od1: Versants, pentes et glacis d'épandage, lithosols sur cuirasse et régosols sur matériau gravillonnaire

This unit includes the southeastern part of the formations on the "Continental Terminal"; these soils constitute the transition between units Oa1 and Od6.

The soils on the upper slopes are lithosols that contain stones and boulders from dismantled hard pan (greater than 30%). The soils on the lower slopes (about 60%) are weakly developed, eroded and deposited soils on gravelly material (sols peu évolués d'érosion et d'apport sur matériau gravillonnaire). The general characteristics of these soils are quite similar to those described for unit Od6: weakly developed, erosional soils on gravelly material. Their limitations are due to the presence of lithosols on hard pan.

Od2: Versants, pentes et glacis d'épandage, lithosols sur cuirasse et sols peu évolués d'apport hydromorphes sur matériau gravillonnaire

This unit is almost level and has elevations generally lower than 100 m It is as a transition between units Oa1 and Od6 in the southeastern Ferlo Boundou and is made up of a soil association quite similar to that of the preceding unit Od6. Here the weakly developed soils of the lower slopes (about 60%) are of the hydromorphic type on gravelly material already described for unit Oa6. They can thus possibly be cultivated--sorghum or groundnuts using ridge tillage--although their chemical fertility is rather low and their physical properties are less favorable than those of the regosols. Two phases, gravelly "g" and hard pan "c", are shown on the map to account for a possible variation in the proportions between the components, but since these differences were unverified, they were not kept in the land capability map.

The rangeland is of fair quality during the rainy season. The lithosols on the hard pan (about 30%) of the upper slopes have high runoff. Thus, limiting this area's agricultural potential.

Od3: Versants, pentes et glacis d'épandage, lithosols sur cuirasse, régosols ou sols peu évolués d'apport hydromorphes, sur matériau gravillonnaire, sols ferrugineux tropicaux lessivés sur matériau colluvio-alluvial

This unit only covers a few areas east of the Niéri Ko. These formations are almost level or very gently sloping: they do sometimes exceed 80 m elevation.

This unit combines the associations of the two preceding units Od1 and Od2, adding a ferruginous tropical element. Lithosols on dismantled hard pan (about 30%) that are without agricultural interest occur on the upper slopes and plateau edges. Most slopes are divided

between 30 to 40% regosols and hydromorphic, weakly developed deposited soils (sols peu évolués d'apport hydromorphes). Though both soil types are on gravelly material, the regosols have a greater gravel content. Leached ferruginous tropical soils on colluvio-alluvial material (sols ferrugineux tropicaux lessivés sur matériau colluvio-alluvial) of the same type as those described for unit Aa4 are found on the lower slopes (about 30%). While these soils are deep, they have low fertility and a serious phosphorus deficiency. They are also very susceptible to erosion.

Groundnuts can be grown on all these soils, but additions of fertilizers and organic matter are necessary to improve and conserve the structure and to prevent the loss of the nutrients. The Ridge tillage could be attempted on the hydromorphic weakly developed, deposited soils. Sorghum cultivation could also be attempted on these soils, as well as on the ferruginous soils. Grazing lands are fair to good during the dry season.

Od4: Versants, pentes et glacis d'épandage, lithosols sur cuirasse, regosols sur matériau gravillonnaire, sols ferrugineux tropicaux lessivés sur matériau colluvio-alluvial

This unit occurs on most slopes of the valleys of the Ferlo west of the Niéri Ko and is found as far south as the Gambia River. Slopes are very gentle and the average elevation is 50 m.

This unit is made up of the same soil association as unit Od1 to which is added a ferruginous tropical component. The major component (30 to 40%) is constituted of rather deep, though gravelly to very gravelly, regosols of the same kind as those that characterize unit Od6. On the upper slopes, the minor component (less than 30%) is made up of lithosols on dismantled hard pan material. The secondary component (over 30%) is found on the lower slopes, i.e., leached ferruginous tropical soils on colluvio-alluvial material (sols ferrugineux tropicaux lessivés sur matériau alluvio-colluvial). This secondary component corresponds to the soils of unit Aa4, which are deep, but have low fertility, and are severely deficient in phosphorus. They also have poorly developed structure and are very susceptible to erosion. The regosols have a relatively higher fertility than the lithosols and ferruginous tropical soils and become very easily degraded by cultivation. Therefore, organic matter and fertilizers are needed to improve and maintain the structure and to prevent the loss of the nutrients added by fertilization. In this unit, millet and groundnuts are suited to the regosols and groundnuts and sorghum to the ferruginous soils. The grazing lands are of generally fair to rather good quality on the ferruginous soils.

Od5: Versants, regosols sur matériau gravillonnaire, sols ferrugineux tropicaux sur matériau gravillonnaire ou colluvio-alluvial

On the imagery, this unit is differentiated by numerous major parallel erosional channels that are often as close to each other as 200 m.

The soils are deep regosols (60%) and ferruginous tropical (30%) soils on gravelly material, which may locally appear at the surface. They are sandy, most often massive at the surface, and relatively rich in clay; they demonstrate a rather well developed, angular blocky structure at depth. The color is variable and shows signs of prolonged moisture saturation with depth. The chemical characteristics are somewhat favorable, but the erosion susceptibility is a major limitation. The vegetation, a shrub savanna, provides good grazing during the rainy season.

Od6: Versants, pentes et glacis d'épandage, régosols sur matériau gravillonnaire

This unit mainly represents the valley slopes in the southeastern part of the formations on the "Continental Terminal".

The major component is made up of weakly developed, erosional soils on gravelly material (sols peu évolués d'érosion sur matériau gravillonnaire). This material is generally colluvio-alluvial in origin. Although deep, these soils are gravelly to very gravelly. They have a medium organic matter content and well-developed fine, angular blocky structure at the surface. On the average, the texture of the fine earth is loam varying from sandy loam at the surface to clay loam at depth. The pH is neutral to very slightly arid and the chemical fertility which is related to the organic matter content, is quite satisfactory.

These soils are suitable for millet and groundnut cultivation, but become very quickly degraded by the associated mineralization of the organic matter. They require organic matter to maintain their structure and fertility.

Od7: Versants, pentes et glacis d'épandage, sols rubéfiés polyphasés ou sols polyphasés ou sols ferrugineux tropicaux tronqués, remaniés

This unit extends in a narrow strip west of the Bao Bolon from Keur Moussa Poste and Mbitiyène along the Saloum to Delbi. The slopes are very gentle. The elevation ranges from 20 to 40 m.

This unit encompasses the transition between the plateaus to the east and the lower plains to the west, and the soil association is irregularly distributed. These soils are also generally truncated and reworked. In the southern portion, from near Nioro du Rip north to

Mabo, multiphased, rubefied soils dominate, while in the northern portion, leached ferruginous tropical soils dominate.

The rubefied soils (sols rubifiés) are intergrades between the ferruginous tropical soils and the ferralitic soils. They are usually reddish brown (very slightly humic) near the surface and red at depth. The texture is sandy (sand to loamy sand) at the surface, then becomes sandy loam and sandy clay with depth. The structure, though massive at the surface, shows a weak subangular blocky tendency at depth. The pH varies from rather neutral to slightly acid; the organic matter content is very low, the chemical fertility low.

The depleted ferruginous tropical soils (sols ferrugineux tropicaux lessivés) are also more reworked than the rubefied soils; they are more yellowish in color. They have a medium texture, with loamy sand at the surface and sandy loam to nearly sandy clay at depth. Similarly they have a weakly developed structure at depth. Their organic matter content is also very low, as is the chemical fertility. The pH is very slightly acid.

In spite of their rather poor chemical characteristics, these two soils may be able to provide satisfactory yields of millet, groundnuts, sorghum or cotton if conservation measures are adopted, cultural practices altered and mineral and organic soil addatives applied.

Minor areas of soils from units Oa3 and Oa4 are included.

Od8: Versants, pentes et glacis d'épandage, sols ferrugineux tropicaux peu lessivés sur colluvions

This unit is lower than 50 m in elevation. It extends along the Mboune Valley downstream from Louggue Tiékodie to the Ferlo Valley. The slopes remain very gentle.

These soils are very sandy at the surface. they contain more clay at depth; Sandy clay loam and the hard pan appear at variable depths. They are weakly leached ferruginous tropical soils on colluvium (sols ferrugineux tropicaux peu lessivés sur colluvium). They generally have a single grain structure at the surface and a fine, angular blocky structure at depth. The color is often reddish. The pH is neutral to very slightly acid and the organic matter and chemical fertility contents are rather low.

These soils are highly susceptible to erosion. They often support good grazing lands where *Andropogon gayanus* grows. They are arable if organic matter and fertilizers are applied and good conservation measures are practiced.

Od9: Versants, pentes et glacis d'épandage, soils ferrugineux tropicaux lessivés sur matériau colluvio-alluvial remanié

This unit includes the slopes and very gently sloping colluvio-alluvial terraces of the Nianija Bolon. The elevation generally does not exceed 20 m.

The regosols on the upper slopes and hydromorphic soils in the valley bottoms are minor inclusions. The major component (80%) is constituted of leached ferruginous tropical soils (sols ferrugineux tropicaux lessivés) on more or less reworked colluvio-alluvial material. These soils are yellowish red with a more or less hydromorphic facies. The texture is relatively medium, with sandy loams at the surface and sandy clay loam at depth. Generally massive at the surface, the structure tends to be angular blocky at depth. A gravelly layer can be found at depth, and hydromorphic streaks may appear at medium depth. The chemical characteristics, organic matter and nutrients, remain low. The pH is neutral to slightly acid.

Millet, sorghum and cotton can possibly be grown on these soils; however, conservation measures, organic matter and mineral additives are needed. The rangeland is of good quality.

Od10: Versants, pentes et glacis d'épandage, régosols sur matériau gravillonnaire, sols ferrugineux tropicaux lessivés, sols faiblement ferralitiques

This unit includes most of the very gently sloping terraces and adjacent slopes along the Gambia River. In Senegal, it is found between the Gambia and Koulountou rivers. The distribution of the soil association components is related to the external drainage conditions. The leached ferruginous tropical soils (sols ferrugineux tropicaux lessivés) are usually found in the lower reaches on on the hills on colluvio-alluvial or on infill material (about 50%); the weakly ferralitic soils (sols faiblement ferralitiques) are found in middle or high slope positions, mainly on colluvial material (up to 20%). Regosols and lithosols are evident at breaks in slope at the edge of the plateaus (less than 25%).

The regosols are relatively deep but gravelly to very gravelly. Rather rich in humus, they have a medium organic matter content and a beneficial fine, angular blocky structure near the surface. The texture varies from sandy loam at the surface to loam (dry) at depth. The pH is neutral to very slightly acid and the chemical fertility, which is related to the organic matter content, is quite satisfactory.

Though very deep, the ferralitic soils are weakly differentiated. They are reddish brown and the texture is sandy at the surface to sandy clay loam with depth. They are often moderately gravelly. The structure is often coarse crumby at the surface, and shows a tendency to be coarse, angular blocky at depth. These soils have a low organic

matter content, low chemical fertility and slightly acid pH.

The ferruginous tropical soils are deep and have a very weakly developed structure. They have a low fertility and are strongly deficient in phosphorus. Their textures are more variable. They are sometimes gravelly or have a hard pan at depth. Their organic matter content is low, as is their chemical fertility. The pH is acid. Overall, these soils are arable; yet, organic matter and fertilizers are generally needed to assure a good level of fertility, balance the phosphorus deficiency of the ferruginous soils, improve their structure or, in the case of the regosols, prevent its degradation by mineralization of the organic matter. Deep rooted crops have greater potential on the ferralitic soils. Thus, millet and groundnuts can grow well on the regosols or the ferralitic soils, and groundnuts and sorghum are possible on the ferruginous soils. Conservation measures remain necessary.

Od11: Versants, pentes et glacis d'épandage, régosols sur matériau gravillonnaire, sols faiblement ferralitiques, lithosols sur cuirasse

This unit comprises a series of valleys that run into the Koulountou Valley or the Gambia River. The slope breaks are very often the site of an outcropping hard pan ledge, but, below the escarpment, slopes are very gentle.

The valley heads are usually occupied by weakly developed erosional soils (sols peu évolués d'érosion) (over 40%) on gravelly material of the same type that of unit Od6. The terraces and slopes downstream are occupied by very deep, weakly ferralitic soils (sols faiblement ferralitiques) (less than 40%) that are weakly differentiated, rather homogeneous and red to reddish brown colored.

The texture is sandy at the surface for a few centimeters and moderately fine at depth, viz., sandy clay loam and occasionally sandy clay with a significant amount of gravel (quartz). The structure is often coarse, angular crumby at the surface and is a coarse angular blocky tendency at depth.

The chemical characteristics are rather unfavorable: very low organic matter content, low chemical fertility with a strong deficiency in phosphorus, and slightly acid pH. This is somewhat compensated by the rather good physical properties, but organic matter and mineral fertilizers are necessary. Crops with a deep root system have a greater ability to utilize the deeper mineral reserves of this type of soil. Although the regosols introduce additional limitations that affect the general agricultural value of the unit, millet and groundnuts can be grown on the ferralitic soils. The natural vegetation is an open forest with Terminalia sp. and Combretum sp.

BASSES PLAINES ET CUVETTES, Oe

The mapping units grouped under this heading have an elevation usually lower than 40 m. The physiography includes a series of buttes or very flattened, low plateaus as well as large depressions, all connected by very gentle slopes.

Symbols: Oe1, Oe2, Oe3

Description

Oe1: Basses plaines et cuvettes, sols ferrugineux tropicaux lessivés plus ou moins remaniés sur matériau dunaire, tronqués, indurés, sols peu évolués

This unit corresponds to low plateaus and buttes (dunes) that form the higher reaches of these formations.

The soils are more or less reworked ferruginous tropical soils (sols ferrugineux tropicaux, remaniés) (about 60%) on dune material. They may be locally truncated or inundurated (30%) and, near hard pan outcrops, they are accompanied by weakly developed erosional soils (sols peu évolués d'érosion). These soils are very sandy (loamy sand over fine sandy loam) and are usually red and massive. The organic matter content and chemical fertility are low. They are, however, suitable for groundnuts or millet cultivation, but their erosion susceptibility must be taken into account.

Oe2: Basses, plaines et cuvettes, sols ferrugineux tropicaux lessivés parfois hydromorphes

This unit covers most of the alluvio-colluvial accumulations of the lower plains of the Saloum River. The morphology and the sedimentation forms are rather unclear.

The soil has a fine sandy texture, with loamy sand over sandy loam at depth. Again, the organic matter and nutrient contents are relatively low. The pH is slightly acid but quite variable. These soils are suitable for the cultivation of groundnuts and millet; although they are less susceptible to erosion than those of the preceding unit, overcultivation necessitates conservation measures. These leached, ferruginous tropical soils (sol ferrugineux tropicaux lessivés) are also called sols beiges because of their typical color. They become hydromorphic in the vicinity of the depressions of the next unit (Oe3), where they have a slightly heavier texture: sandy loam over sandy clay loam with a gravelly horizon at depth. They are lighter colored and show signs of long periods of moisture saturation, but their other characteristics are similar, though more suitable for "cereal cultivation" (sorghum).

Oe3: Basses plaines et cuvettes, sols hydromorphes et sols vertiques

This unit comprises the elongated clayey depressions which are found at the bottom of fossil valleys and are separated from each other by sandy thresholds. There is practically no external drainage. While the soils are mainly hydromorphic (80%), a vertic tendency is found. They usually have a massive structure. Except in the case of a very dark vertic topsoil, the color is light gray with numerous hydromorphic mottles. In the hydromorphic soils the texture quickly changes from sandy loam to sandy clay loam and sandy clay. The vertic soils are mainly developed in sandy clay loams. Though the organic matter content is low for hydromorphic soils, it is relatively higher for the vertic soils. The pH is rather neutral to slightly acid. Although cotton might grow well on vertic soils, these soils are very difficult to work and are generally uncultivated. They are unsuitable for groundnuts. Flood control is difficult here, but a forest management plan could be easily implemented. The natural vegetation is basically composed of Acacia seyal.

BORDURES DE PLATEAU, Of

The eastern or northeastern boundary of the Ferlo plateau is marked by an escarpment a few meters high. Along this margin two units are mapped on the basis of morphological differences.

Symbols: Of1, Of2

Description

Of1: Pente de raccordement, régosols sur matériau gravillonnaire, sols ferrugineux tropicaux, sols bruns

This unit occurs near the northeastern edge of the Ferlo plateau. It is irregularly shaped, rather wide (7 to 8 km, average) and incised by several talwegs.

The unit is mainly constituted of ferruginous tropical soils (sols ferrugineux tropicaux) (70%) but the contact with the plateau can, in certain areas, be gradual, and scattered buttes introduce a regosolic component (about 10%) on gravelly material. In the field, the transition between the regosols and the brown soils (sols bruns) of the adjacent mapping units is also not very clear. The importance of accumulated sand is shown by two symbols: "s" and "ss", significant and very significant sand encroachment, respectively.

These soils are usually deep and are sandy over loamy sand or sandy loam, with a massive structure that tends toward an angular blocky structure. They have a rather low fertility and are susceptible to erosion. They support fair grazing lands.

Of2: Piedmont de falaise, sols ferrugineux tropicaux lessivés

This narrower unit, usually less than 2 km wide, constitutes the eastern edge of the Ferlo plateau at the foot of the escarpment.

The soils are deep, leached, ferruginous tropical soils (sols ferrugineux tropicaux lessivés). Their color varies between yellow and red; they are sandy over loamy sand or even sandy loam and well drained. Their structure is massive, though a tendency toward angular blocky occurs.

The chemical fertility is rather low, and the erosion hazard high.

B. Formations sur roches marno-calcaires (Paléocène-Eocène), P

These formations on marly, calcareous rocks correspond to Paleocene and Eocene deposits. Outcrops are found at the low plateaus of Thiès and Bargny and in the Matam strip. They also provide the parent material for soil formation in the Somone valley. Four physiographic types were recognized:

P1-the lower plateaus with elevations higher than 50 m (Thiès), shown as plateau de Thiès, Map 4.4.

P2-the lower plateaus with elevations lower than 50 m (Bargny and the vicinity of the Sine Valley), shown as plateau de Bargny, Map 4.4.

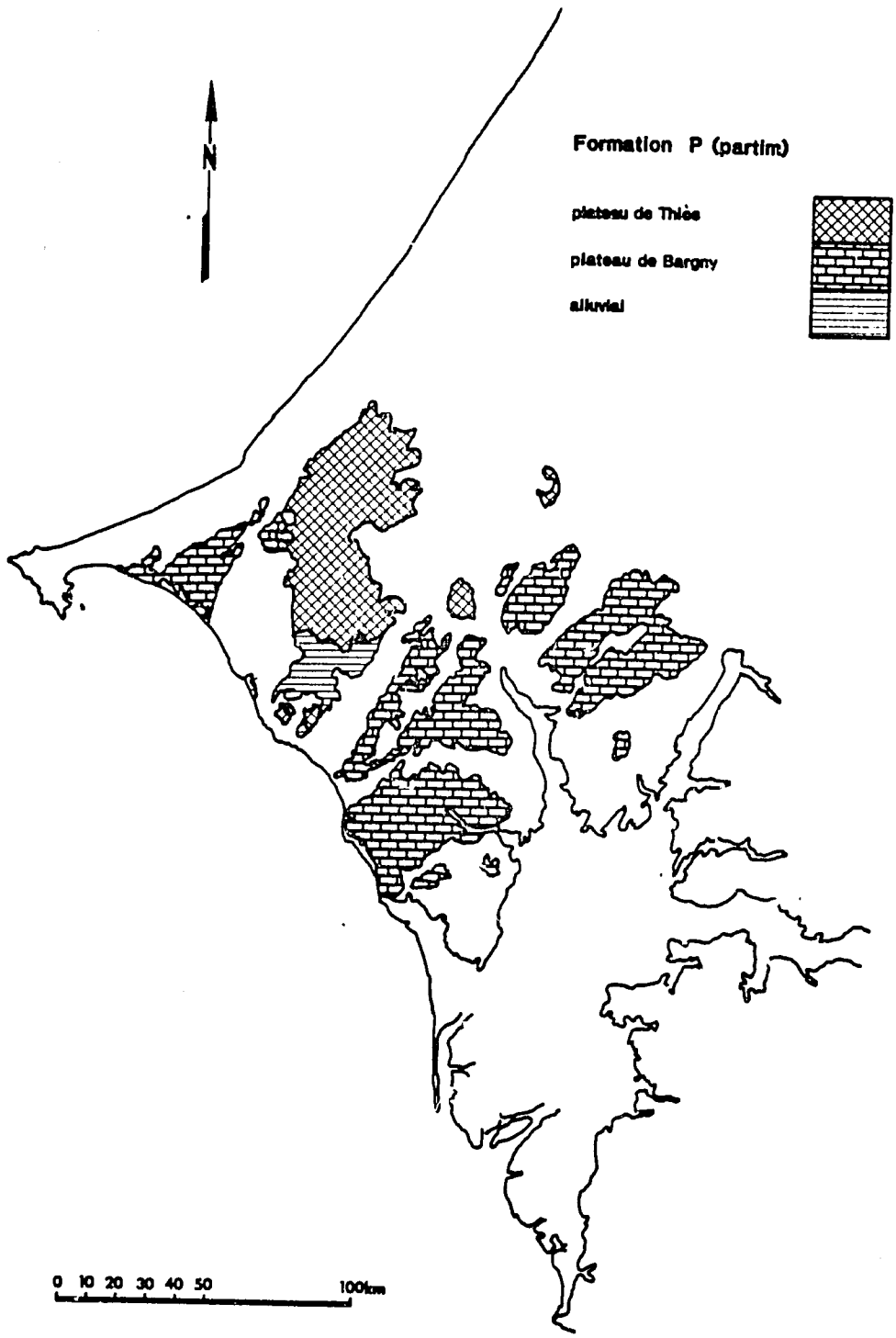
P3-the lower alluvial plain (Somone River), shown as "alluvial", Figure 4.4.

P4-the low hilly glacis of the Matam strip.

BAS PLATEAUX D'ELEVATION SUPERIEURE A 50 M, P1

These formations occur in to the Thiès area. The plateau is subhorizontal; it reaches an elevation of 140 m near the escarpment but barely reaches 50 m in the east where it dips under sand deposits. In the west, the escarpment, which actually is a cuesta located on a fault line, shows a hilly to steeply dissected relief, while the piedmont slope is again relatively flat.

Two units were recognized on the plateau according to the depth at which the hard pan is found. The escarpment and the peidmont slope make up two more units.



Map 4.4 Formation P

Symbols: P1a1, P1a2, P1b, P1c

Description

P1a1: Plateau, sols ferrugineux tropicaux rouges ou lithosols sur cuirasse à moins d'un mètre de profondeur

This unit covers most of the Thiès plateau. It is hard pan buttes near Keur Samba Kane, Diak Bodokhane and Nguékokh. The soils are red, loamy in texture and shallow over a ferruginous or phosphatic hard pan with frequent outcrops. This fossil crust is subhorizontal (like the relief), pisolitic near the surface and quite thick (several meters). Weakly developed erosional soils on gravelly material are present as inclusions. The thorny vegetation is characterized by *Acacia ataxacantha*. Millet or groundnuts can be cultivated in areas of sand encroachment, where the soil is somewhat deeper or in areas where the soil has been broken up by erosion, but the natural shrub vegetation should be protected and reforestation could be attempted.

P1a2: Plateau, sols ferrugineux tropicaux rouge-brun, sur cuirasse à plus d'un mètre de profondeur

This unit encompasses transitional zones with the neighboring units. It is found north and south of unit P1a1.

The soils are deeper and more similar to those of unit E2az.

P1b: Falaise, sols d'éboulis de pente, colluvium, affeurements

This extremely narrow mapping unit (3 km wide at the most) includes the escarpment of the Thiès plateau. Screes include various sizes of boulders and have a complex composition. Lateritic boulders are mixed with marl and other calcareous debris. The soil color at the surface varies from grayish white to black. Termite mounds are frequent. The relative accumulation of fine material below the surface leads to the formation of generally poorly drained, weakly developed deposited soils. Since this material swells and seals up during the rainy season, the resulting prolonged periods of moisture saturation cause a certain amount of ferruginous and calcareous concretions to develop. Furthermore, these soils are extremely erodible, and since slopes are steep, solifluction occurs frequently.

These slope screes usually support a dense shrub vegetation of mainly *Acacia ataxacantha*. The best use of this land remains forest preservation.

P1c: Piedmont, sols hydromorphes, sur matériaux divers

This unit extends to the west of the preceding unit in a wide strip that, in places, reaches 6 km wide. It seems to be constituted of two levels of very gently sloping glacis. The colluvial parent

material is complex, and oblique leaching from the ferralitic hard pan of the Thiès plateau has transformed it into a new hard pan formation.

The profile has a variable depth (usually less than one meter, frequently 70 cm). Soils are most often black or dark gray and are sandy clay loams with a neutral or very slightly acid pH and a rather well-developed structure indicative of a vertic tendency. Ferruginous concretions may be present, occurring practically from the surface.

These moderately fertile soils may support a favorable shrub vegetation. Their shallow useful depth and their tendency to waterlogging during the rainy season are, however, such strong limiting factors that these soils are best suited to forestry.

BASSE PLATEAUX D'ELEVATION INFERIEURE A 50 M, P2

These formations are lower in elevation than the preceding ones, usually between 20 and 40 m. They seldom reach 50 m. They bear signs of a strong influence of marl and other calcareous parent materials. Five mapping units have been delineated. Two of these correspond to the higher reaches or plateaus, while another corresponds to the lower reaches, and two others include the slopes surrounding the plateaus.

Symbols: P2a1, P2a2, P2b, P2c1, P2c2

Description

P2a1: Plateau, sols hydromorphes vertiques, sur matériau argileux marno-calcaire, plus ou moins tirsifiés

This mapping unit has a roughly triangular shape. It is relatively level and extends from the Petite Côte between Rufisque and Yenne to about half way between Bayakh and Keur Moussa Mbougane. The soils are black or dark brown hydromorphic soils with occasionally very strong vertic characteristics. Their clay content is, however, often too low to classify them as vertisols. They even show a tendency to evolve into brown calcareous soils, and typical brown calcareous soils are also present as minor inclusions. The topsoil, which has a sandy clay loam texture, is actually often enriched by siliceous sand that gives it an often well-developed, crumbly structure near the surface, which becomes quickly coarser and massive at depth where the texture is sandy clay. The soils are also heavier and more massive on the inner plateau. Marl and other calcareous debris are often present in the profile sometimes starting from the topsoil. The substratum is usually found between 80 and 125 cm in depth.

The vegetation is an open shrub savanna with *Acacia seyal* and with *Schoenefeldia gracilis* in the herbaceous strata. The area is cultivated (sorghum, millet and shrub fallow), but considering they have a medium organic matter content, these soils have a rather poor chemical fertility. The depletion is very strong on the higher

reaches, while the lower parts of the plateau are relatively enriched by lateral transportation. The texture is somewhat heavy and does not make agricultural practices easy, but production is possible at some cost, notably the use of fertilizers and the implementation of conservation measures.

P2a2: Plateau, sols hydromorphes vertiques, sur matériau argileux marno-calcaire, fortement tirsifiés

This small unit is located north of Pout. The soils are usually very dark brown and similar to the soils of the preceding unit P2a1, but they are deeper, with small calcareous concretions at more than one meter in depth, and the marl begins at about 2 m in depth. They are richer in clay with very strong vertic characteristics. They have a clay content that is high enough to classify them as vertisols. Their heavy texture and overly massive structure severly handicap soil preparation. The dense shrub vegetation (with Acacia seyal or Acacia albaxacantha) on these soils is, however, exploitable for firewood and charcoal.

P2b: Dépressions ensablées, sols calcimorphes ou sols bruns hydromorphes, sur matériau à lits gravillonnaires

This unit includes a series of irregular strips that are elongated in a northeast-southwest direction; it is located in the area between Tasset Ouolof to the west, the Khombole-Bambey axis to the north and the Sine Saloum Delta to the east and the south. The strips are usually lower in elevation than the surrounding E2a2 unit and have a relatively flat topography. The soils are sandy and rather dark brown. They support a rather dense savanna with Acacia seyal and with Schoenefeldia gracilis in the herbaceous strata. The presence of marl at depth is responsible for temporary periods of moisture saturation which vary greatly and often cause concretion pans (iron and manganese) to form at depth. A moister horizon that is slightly richer in clay is present between 20 and 60 cm. The clay content increase is, however, insufficient to classify these soils as leached soils (sols lessivés). The structure is massive.

These soils are quite similar to the surrounding ferruginous tropical soils. Though they are arable and can produce quite good yields, their strong tendency to form a crust is a serious limitation.

P2c1: Bords de plateaux et pentes, rendzines d'érosion sur roches marno-calcaires

This unit covers soils that have a calcic mull and are developed on the erosional slopes where marl or other calcareous outcrops occur. It is confined to small areas around the Bargny plateau.

These soils most often support a xerophytic grassland. The profile is shallow (less than 50 cm), stony, dark colored, clayey and has a well developed structure, especially near the surface. The organic matter content is remarkably high compared to the other soils of the region, but it is still comparable to values commonly obtained for typical rendzinas. The pH is alkaline.

Although these soils are locally cultivated, their unfavorable characteristics (shallow depth, physiographic position and erosion susceptibility) suggest that reforestation is a better alternative.

P2c2: Bords de plateaux et pentes, sols hydromorphes sur colluvions calcaires

This unit surrounds the Bargny plateau in a narrow, almost continuous, strip. It also extends north of Rufisque and east of Bayakh. Its topography is slightly undulating.

The soils are deep and loose, blown, more or less calcareous with a very often alkaline pH. They are usually sand covered and their texture varies from sandy clay loam to loamy sand. The vegetation is often degraded. Although chemically deficient, these soils are suitable for the cultivation of vegetables in the lower reaches; yet, they are in general highly susceptible to erosion. Slopes should preferably be reforested or shrub and/or tree crops grown.

BASSE PLAINE ALLUVIALE, P3

This formation corresponds to a single unit that covers the alluvial plains of the Somone, an intermittant stream.

Symbol: P3

Description

P3: Basse plaine alluviale (Somone), sols hydromorphes de profondeur, sur alluvions

The topography of this unit is relatively flat. The unit covers the recent alluvium of the Somone.

The soils are generally brown colored and characterized by a surface pseudogley. Rusty streaks along the root channels in the topsoil are evident. At depth, the texture is typically sandy clay loam and the soil has typical hydromorphic mottling with also a tendency to form concretions due to the mobilization of iron and manganese. The structure is generally rather coarse and rather weakly developed.

This unit also covers the "Forêt Classée de Bandia". Although this area was cultivated (sorghum) before it became a forest reserve, during the rainy season these soils are normally too wet for cultivation. Since their other physical and chemical characteristics are still rather favorable, though the potassium level might be insufficient, forest management should be able to provide acceptable yields.

BAS GLACIS COLLINAIRE, P4

The low glacis is bordered to the southwest by the Ferlo Plateau and to the northeast by the Senegal River Valley. It extends in a quite wide, continuous strip from Fadaria to Ngoui where it becomes narrower, discontinuous and eventually disappears under the eolian formations near Guede.

Many hilly massifs are present on the glacis, but since their spectral signatures are often quite similar relative to the number of soil associations represented, only three units are shown on the map. The glacis itself constitutes a fourth unit, while the talwegs cutting through the formation jaune are the fifth one.

Symbols: P4a1, P4a2, P4a3, P4b, P4c

Description

P4a1: Massifs collinaires, lithosols sur cuirasse, sols bruns subarides, sols ferrugineux tropicaux lessivés

This unit is made up of of crusted buttes that rise above the level of the glacis by about 10 to 30 m. They are covered with various kinds of stones and boulders. The sandy formations extending between the hills correspond to those of unit P4b, but here erosion is much more intensive. Erosion and the shallow useful depth constitute major limitations for these soils.

P4a2: Massifs collinaires, lithosols sur cuirasse, régosols sur matériau gravillonnaire, sols bruns subarides plus ou moins vertiques, sols vertiques, rendzines

Various kinds of soils are grouped in this mapping unit. Most of the hills are crusted or covered by various kinds of stones or boulders. They may also show weakly developed erosional soils and regosols on ferruginous gravelly material or on gravelly sand. The soil characteristics vary in relation to their parent material. They are usually shallow and susceptible to water erosion, and they often support poor rangeland. The erosional glacis surrounding the hills has brown subaridic soils that are most often slightly vertic and ocassionally have quite good agricultural capabilities. Irrespective of topographical position, when calcareous parent material is near the surface, vertic soils or rendzinas develop. They have rather good

chemical and physical properties (texture, structure). Their physiographic position often exposes them to erosion, even though the natural vegetation grows more thickly there. Only the toe slopes of these hilly massifs are reasonably arable; everywhere else the quality of the soils is often poor or the erosion hazard is too great.

P4a3: Massifs collinaires, lithosols sur cuirasse, sols bruns subarides

This unit also covers crusted hills of the same type as in unit P4a1, but the erosional glacis cuts through the clay layers of the formation jaune. As in unit P4c, the soils are brown subaridic soils (sols bruns subarides) on clayey material or are weakly developed erosional soils (sols peu évolués d'érosion) on gravelly clay material. Erosional features and self-sealing are evident throughout the unit. Grazing lands are poor to very poor.

P4b: Glacis de raccordement, sols bruns subarides et sols ferrugineux tropicaux appauvris

This unit largely corresponds to the "premier remblai" defined by P. Michel (1973). The major soils found on this embankment are brown subaridic soils (sols bruns subarides), but soils marking the transition toward ferruginous tropical soils (sols ferrugineux tropicaux) are also found. The topography is almost flat.

The soils are deep, loamy sand over sandy loam. They are brown at the surface and yellowish at depth. The ferruginous soils, are somewhat reddish with signs of prolonged periods of moisture saturation with depth, and they become truly hydromorphic near the Senegal River. A sand encroachment phase ("s") is also shown on the map. The pH is often relatively neutral and becomes alkaline at depth possibly because of the presence of carbonates. The structure is most often massive with a tendency toward angular blocky. The organic matter content is low, as is the chemical fertility, especially in the case of the ferruginous tropical soils. In the field, however, these soils are not easily distinguished from other soils by their surficial expression.

P4c: Vallées d'érosion, sols bruns subarides sur matériau argileux et regosols sur matériau gravillonnaire

This unit is observable in some areas near Kellol. The clay layers of the formation jaune are cut through by the glacis and by erosional valleys. Gravel is very often exposed at the surface and the gravelly areas alternate with self-sealed soils. These soils are brown, clayey and have a platy structure at the surface and blocky with depth. They are gravelly at shallow depth. The pH is very slightly acid.

This unit corresponds to an active erosional surface and supports only poor rangeland.

C. Formations sur grès maestrichtians (Crétacique), C

These formations extend on the subhorizontal Maestrichtian sandstones of the Ndiass Massif. Two mapping units were delineated: first, the strongly crusted hills that result from the dissection of a low plateau (their elevation is usually higher than 40 m and may exceed 80 m) and second, extending in the lower reaches (usually between 20 and 40 m in elevation) the valleys on colluvial material washed in from the upper unit. The overall topography of these formations is slightly undulating to rolling.

Symbols: Ca, Cb

Description

Ca: Plateaux, lithosols et regosols, sur cuirasse démantelée sur grès

These ancient erosional surfaces are relatively level. Soils are strongly crusted, eroded and reworked. They are the final result of significant water erosion that acted on ancient crusted ferralitic soils which developed during a more humid climate (Fig. 4.14).

Fig. 4.14 Erosional surface: Massif de Ndiass; lithosols and regosols; unit Ca.

The useful depth is usually less than 50 cm. The soil surface locally shows hard pan outcrops, but the hard pan may also be found at greater depth. This platy crust type on sandstones is seldom pisolitic. The fine earth fraction is made up of red sandy clay; the coarse fragments comprise a gravel of dismantled hard pan and sandstone products. The pH is usually acid.

The hard pan supports a poor thorny shrub vegetation, but in places where the soil is relatively deep, a rather dense bush of Acacia ataxacantha can grow. The areas with dryer soils are sometimes cultivated (millet), but the erosion hazard is high. Thus, conservation measures are indispensable and the best possible use of the land in this area is reforestation. If not, shrub or tree crops, such as citrus, should be considered.

Cb: Vallons, sols ferrugineux tropicaux non ou peu lessivés, sur colluvions

The colluvial material that constitutes these soils is more or less reworked and leached. It is proportionally richer in clay fractions and redder in the higher areas but becomes lighter colored and frequently mottled as the transportation distance increases.

The topsoil is usually sandy; the texture of the lower horizons is sand or sandy loam and is slightly heavier (sandy clay loam) in the moderately well drained, infilled low grounds. These soils have a rather good structure, although the topsoil structure is weakly developed. They are slightly gravelly and thus millet or groundnuts are usually cultivated. There is, however, a risk in terms of erosion--the sandy topsoil is susceptible to eolian erosion and the upper slopes show signs of water erosion. Brown calcareous soils (sols bruns calcaires), recognizable near Popenguine, form a minor inclusion of little agricultural significance.

4.3.3.3 Formations sur socle primaire ou roches volcano-sédimentaires anciennes

A. Formations sur roche d'origine essentiellement sédimentaire, S

Covering most of Senegal Oriental (they occupy the entire western portion), these formations extend into the Haute Casamance as far north as Bakel and Tianiato.

Formations on more or less metamorphized, folded rocks are first separated from those on subhorizontal rocks, which are actually limited to the cliffs of the Fonta Djalon. Further subdivisions are based on parent material and physiography. Five groups of formations on folded rocks and two on subhorizontal rocks are recognized:

-On folded rocks, map 4.5

S1 - Hills and crusted glacis on hard schists, paleovolcanic facies (Mont Bassari); see "schist", map 4.5.

S2 - Hills and glacis on fragile clayey sandstones and on quartzites; see "sandstone, quartzite", map 4.5.

S3 - Multilevel glacis and plains on clayey sandstones and pelites; see "sandstone, pelite", map 4.5.

S4 - Lower plains and valleys on pelites, paleovolcanic facies; see "pelite", map 4.5.

S5 - Lower plains and valleys on metamorphic schists; see "schist, quartzite", map 4.5.

- On subhorizontal rocks, map 4.6 (see formation M)

S6 - Schist cuestas: see "schist", map 4.6.

S7 - Sandstone cuestas; see "sandstone", map 4.6.

ROCHES PLISSEES

COLLINES ET GLACIS CUIRASSES SUR SCHISTES DURS, FACIES PALEOVOLCANIQUE, S1

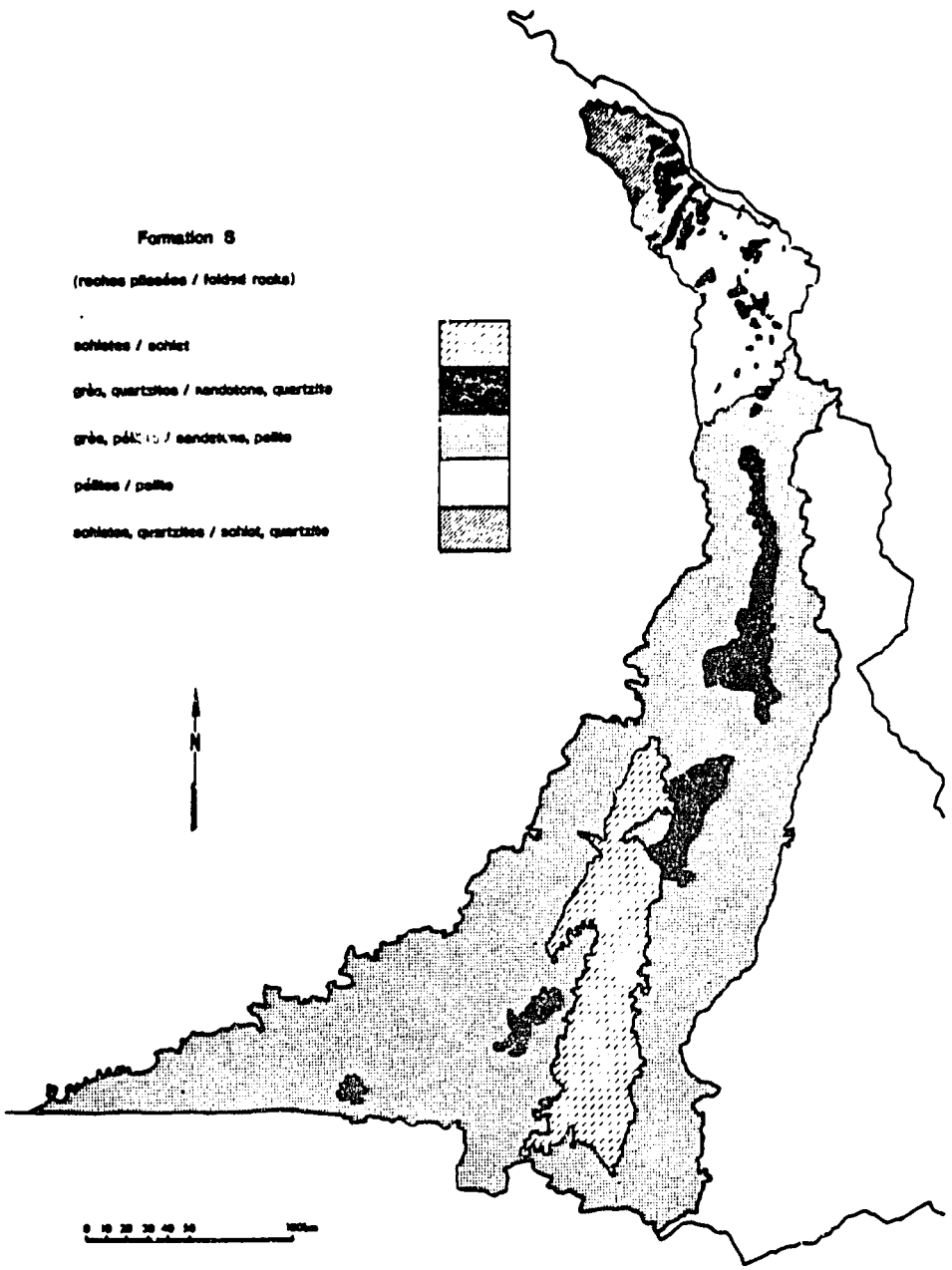
These formations which are wedge-shaped pointing from Salémata to near Bokolako, occur in the Mont Bassari area. The parent material is mainly hard schists from the lower Paleozoic era. Three groups of hills with different levels of elevation were recognized, along with a crusted glacis and a group of erosional valleys.

Symbols: S1a1, S1a2, S1a3, S1b, S1c

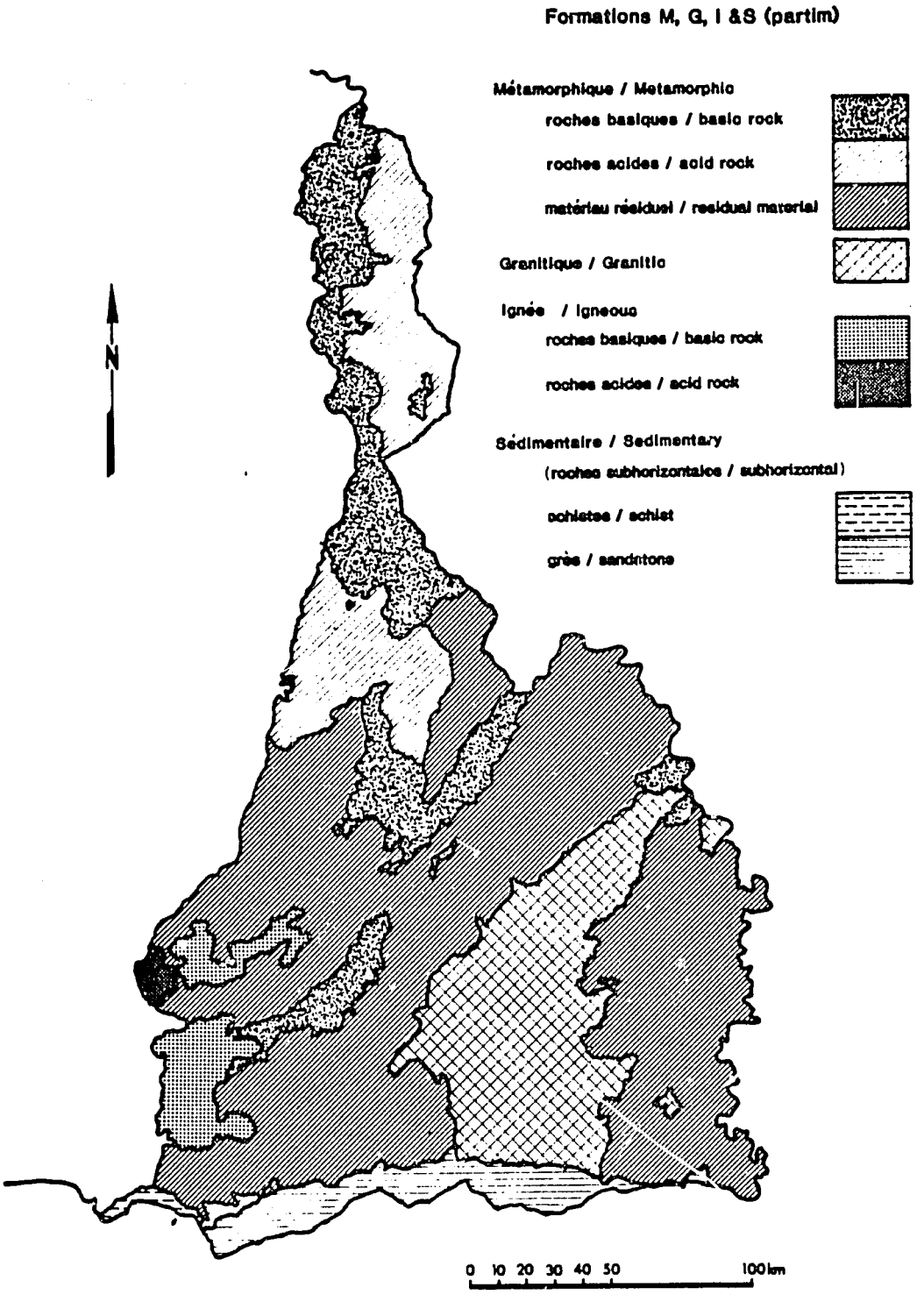
Description

S1a1: Collines élevées, regosols bruns eutrophes et sols bruns eutrophes, sur matériau d'altération argileuse de roches basiques variées

This unit covers the group of highest hills of the Bassari area. The hills, which may reach over 400 m in elevation, are located south of the Gambia River. The slopes may be steep, but the relief is most often undulating to rolling.



Map 4.5 Formation S



Map 4.6 Formations M, G, I & S (partim)

The most common soils (over 50%) are regosols on debris of various kinds of basic rocks, with a eutrophic brown soil facies. The soil surface is very stony. The soil is shallow and from just below the surface is generally made up of weathered stones and small fragments of beige schist. The fine earth fraction is red-brown, sandy clay loam with a very fine, angular blocky structure that shows a crumbly tendency near the surface. Very friable weathered rock occupies most of the soil volume at shallow depth. The organic matter content is medium to rather high. The chemical fertility is also medium to rather high with very satisfactory values for phosphorus and potassium (usually deficient). The pH is very slightly acid. These soils remain permeable due to the stones and friable rock. Thus, the erosion hazard is lower but should still not be neglected. Organic matter is needed to maintain the structure and prevent the oblique leaching of the fine fractions.

The minor component (about 20%) has characteristics very similar to soils described above. These eutrophic brown soils (sols bruns eutrophes) are also shallow, well drained and have a well developed structure, but are a little less stony. Vertic intergrades of weakly developed soils are found among the minor inclusions. They are more heterogeneous and often fertile, but have rather unfavorable physical characteristics.

Although very stony, these soils are well suited to millet, which is traditionally grown on the highest and steepest slopes. Cotton and groundnuts are grown on the lower slopes. The quality of the rangeland is fair to good.

S1a2: Collines moyennement élevées, régosols sur matériau gravillonnaire et sols peu évolués d'apport vertiques sur matériau argileux gonflant

This unit which may exceed 200 m in elevation, such as Mont Hassirik covers the hills located north of the Gambia River. The relief is hilly in certain areas but is most often undulating to rolling. Some areas with lithosols on hard pan are included as minor inclusions. The major soils of this unit are either regosols on gravelly material or vertic, weakly developed, deposited soils (sols peu évolués d'apport vertiques) on swelling clay material.

The vertic, weakly developed soils (about 40%) are rather heterogeneous and poorly drained. Hydromorphic mottles usually appear just below the surface. The structure is massive to prismatic. A gravelly horizon is most often present at shallow depth and the weathered rock may be found at medium depth. The pH is most often neutral and the chemical fertility high to very high (but with a phosphate disequilibrium). The organic matter content is low. These soils are less favorable than the regosols because of their heterogeneity and typically unfavorable physical characteristics.

The regosols (about 40%) are shallow and gravelly to very gravelly with a hard pan at medium depth. Their texture varies from sandy loam at the surface to clay loam at depth. The pH is neutral to very slightly acid. The organic matter content and the chemical fertility are medium. Although difficult to work and easily degradable, these soils are favorable for the cultivation of millet or groundnuts, but organic matter and fertilizers are still indispensable. The rangeland is fair to good.

S1a3: Collines peu élevées, régosols sur matériau gravillonnaire et sur matériau argileux d'altération

This unit covers the lowest hills of the Mont Bassari area. These hills seldom exceed 180 m in elevation; their slopes are moderately steep to steep and a few summits are crusted. Most of the unit has an undulating topography with many hard pan ledges.

Most soils are regosols on gravelly material (about 40%) and regosols on weathered clayey material (about 40%). Lithosols on hard pan make up a minor component (less than 20%).

The regosols on gravelly material are similar to those described for unit S3a3. Frequently a layer of clay material, resulting from the weathering of various kinds of rocks, is exposed at the surface by erosion, and the soils that are gravelly in their upper horizons show a lithological discontinuity at a shallow or very shallow depth. Hence, the fine earth fraction changes from a sandy to clayey texture and the ferruginous gravel is replaced by weathered stones. These soils have quite variable characteristics: they may sometimes be more fertile chemically than the regosols on gravelly material, but the lithological discontinuity constitutes a restrictive horizon for the penetration of roots. They are thus marginal for cultivation. Regosols require regular organic matter and fertilizer applications to maintain their structure and fertility. Natural grazing lands are rather poor during the dry season.

S1b: Glacis cuirassé, lithosols sur cuirasse

This unit includes the extension of the Bassari hills on the northern side of the Gambia River. This region is somewhat higher in elevation than the neighboring areas to the east or west, but its elevation does not exceed 200 m. Although these surfaces are relatively level, they are strongly crusted and the hard pan forms a ledge at the nickpoints.

The soil is either made up of hard pan pavement that is covered with abundant stones and boulders, or it is completely gravelly at the surface. Termite mounds, which are small and mushroom-shaped, are rare.

These soils are unsuitable for agriculture and they provide very poor grazing land. Protective measures and possible reforestation are the land use alternatives. The intensity of water erosion is dramatically increased due to the intensity of runoff on such impermeable cuirassed surfaces.

S1c: Vallons d'érosion, régosols sur débris de roches diverses

Several erosional valleys that cut through a heterogeneous geological substratum are grouped in this mapping unit, which is limited to a small area along the Gambia River north of Tiankoye.

These regosolic soils on debris of various kinds of rocks are shallow and extremely strong. The often clayey, fine earth fraction presents a favorable chemical fertility, but the gravel content and the minimal useful depth render any type of cultivation nearly impossible. The area is also extremely susceptible to water erosion.

COLLINES ET GLACIS SUR GRES TENDRES ARGILEUX ET QUARTZITES, S2

These formations include the hills and glacis on the red clayey sandstones of the upper Cambrian and on the white sandstone of the Gothlandian. This material is metamorphized near Bakel, where the hills become quartzitic.

Hills are mapped separated from the piedmont slopes, and a glacis on sandstone crust becomes the third mapping unit.

Symbols: S2a, S2b, S2c

Description

S2a: Collines, lithosols sur grès ou sur quartzites

This unit occurs on sandstone and quartzitic hills and outcrops. The white Gothlandian sandstone outcrops occur in two places in the Niobolo Koba. The sandstone hills form a line from the vicinity of Dalafi to near Kidira, where they become more dispersed. North of Bakel, the hills most often become quartzitic. These rolling hills reach up to 125 m in elevation. They are of no agricultural interest.

S2b: Piedmonts, lithosols sur grès et sols peu évolués d'apport hydromorphes de profondeur sur matériau derivé des grès

The valleys and piedmont slopes surrounding the sandstone hills are generally occupied (about 70%) by weakly developed, deposited soils that are hydromorphic with depth. Lithosols make up a minor component.

Though these soils are very deep and rather light in texture, ranging from sand to loamy sand near the surface to sandy loam at depth, they quickly seal up because of the high proportion of fine sand

that influences their textural composition. Often massive or prismatic in structure, they are moderately cohesive near the surface and increasingly cohesive with depth. They are frequently ochre, though brownish gray in the humiferous horizon, with hydromorphic mottles at medium depth. A gravelly layer or a crust may be present with depth. The organic matter content is medium to low, the chemical fertility low, and the pH neutral.

These soils can be cultivated (groundnuts or millet), but their hydromorphic characteristics may limit crop success.

S2c: Glacis régosols sur carapace gréseuse

These very gently sloping glacis cover small areas near Bountougou Fara. Their elevation reaches about 100 m.

These soils are very shallow, sandy, humiferous, massive and moderately cohesive. They are limited at depth by a gravelly horizon with crust debris over a ferruginized sandstone crust which acts like regosolic material; therefore, the soil remains permeable (Fig. 4.15).

These soils have fertility characteristics similar to those of the regosols on gravelly material and thus have a similar agricultural potential. Since they are particularly suitable for reforestation, this alternative is preferable. Such natural tree crops as Pterocarpus erinaceus and Combretum sp. would grow well.

GLACIS ETAGES ET PLAINES SUR GRES ARGILEUX ET PELITES, S3

These formations surround the preceding units and cover most of the territory south of Séroudébou. The characteristics of the Paleozoic parent material are less visible in these soils than in those of the preceding formations. Three physiographic levels have been delineated: interfluves and multilevel glacis, valleys and lower slopes, and lower plains. Based upon data from the available documents, the various soils associations were defined for each level. Of the eight total units, five occur on interfluves, two on valleys and slopes and one on the plains.

Fig. 4.15. Close-up view of a carapace layer in sandstone.

Symbols: S3a1, S3a2, S3a3, S3a4, S3a6, S3b1, S3b2, S3c

Description

S3a1: Interfluves, glacis étagés, lithosols sur cuirasse

These nearly level and extremely crusted glacis and interfluves are well represented on both sides of the Gambia River. Their elevation ranges between 80 and 120 m and very seldom reaches or exceeds 150 m. Hard pan outcrops alternate with areas of skeletal soil covered with many stones and hard pan boulders. The gravelly material is then found at the surface, though its extent but it is shallow. The numerous termite mounds are low (less than 50 cm high) and are typically mushroom shaped (Fig. 4.16).

Fig. 4.15. Mushroom-shaped termite mound on gravelly soil (gravel starts from the surface).

These soils are unsuitable for cultivation and they provide only poor to very poor rangeland during the dry season. Forestry potential is also limited; possible reforestation should be undertaken only for site protection. Because of the impermeable surface, runoff causes severe erosion.

S3a2: Interfluves, glacis étagés, lithosols sur cuirasse et régosols sur matériau gravillonnaire

This unit occurs on the almost flat or gently sloping glacis that mainly extend east of the formations on sedimentary rocks and do not exceed 150 m in elevation.

The soils are either lithosols on hard pan or weakly developed erosional soils (regosols) on gravelly material. Since their spectral signatures indicate the possible dominance of one or the other of these components, two phases are added to this mapping unit. The soils characteristics generally correspond to the soils of one of these two phases.

The hard pan phase "c" with a majority of lithosols (over 60%) compared with about 25% regosols) is rated unsuitable for cultivation, as is the case for unit S3a1, while the regosolic or gravelly phase "g" with a majority of regosols (about 50% compared with less than 40% lithosols) is considered suitable for cultivation under the same conditions listed below for unit S3a3.

S3a3: Interfluves, glacis étagés, régosols sur matériau gravillonnaire

This mapping unit has a level (0-1%) or very gently sloping topography. It extends southwest on the rock sedimentary formations, usually on both sides of the Gambia River Valley and to Gamon to the north. A few areas are also mapped further north bordering the sandstone hills of unit S2a. The soils are weakly developed erosional soils (regosols) on gravelly material (sols peu évolués d'érosion régosoliques sur matériau gravillonnaire). They are shallow humiferous soils, and, though they are gravelly, roots can nevertheless penetrate until meeting the hard crust, usually at 50 m in depth. They are generally permeable and have a low water holding capacity. The humiferous horizon has a well developed, fine, angular blocky structure; the fine earth fraction is generally loam, ranging from sandy loam at the surface to clay loam with depth. While neutral at the surface, the pH is very slightly acid at depth. The organic matter content is medium.

The fine earth fraction of these soils is often sufficiently fertile due to the organic matter content. Unfortunately, when these soils are cultivated, the organic matter content decreases and fertility consequently drops. Although difficult to work, they are suitable for groundnuts and millet. As they are generally very fragile and become very quickly degraded, they need regular applications of organic matter to maintain their structure and fertility. The natural vegetation provides satisfactory grazing.

S3a4: Interfluves, glacis étagés, lithosols sur cuirasse et sols peu évolués d'apport hydromorphes sur matériau gravillonnaire

This unit extends from the Kagan-Sintiou Kotie axis north along the formations on the "Continental Terminal" to somewhat past Sambakolo. The slopes are generally sloping and the elevation does not exceed 100 m.

This unit is an association similar to the that of unit S3a3; though in this case, the lithosols on hard pan are associated with hydromorphic, weakly developed, deposited soils on gravelly material (sols peu évolués d'apport hydromorphes sur matériau gravillonnaire). They are gravelly soils with a rather fine texture, clay loam to silty clay, and a strongly indurated hard pan at shallow depth. The upper horizons are generally massive and the soil is rather strongly cohesive. The color is light gray. The organic matter content and chemical fertility are rather low, and the pH is slightly acid.

On the basis of spectral signatures, it was possible to further characterize this unit with two phases on the soilscape map, crusted (c) and gravelly (g), which are represented as "c" and "g", respectively. These designations were not used on the land capability map, though a single "g" area was considered (with about 60% regosols and 30% lithosols). These soils present unfavorable physical properties, indicating groundnuts and sorghum might be cultivated using ridge tillage. They support fair grazing lands during the dry season. The crusted phase is unsuitable for agriculture.

S3a5: Glacis étagé, lithosols sur cuirasse, sols peu évolués d'apport hydromorphes sur matériau gravillonnaire, sols ferrugineux tropicaux lessivés sur matériau de colmatage

This unit corresponds to the glacis at the edge of the sedimentary rock formations. It is located between Gamon and Niokolo Koba and is also found in the southeastern corner of the Haute Casamance. Although the landscapes are very gently sloping, the elevation can still exceed 100 m, with the highest point in the Haute Casamance even exceeding 150 m.

The major component (about 50%) is made up of hydromorphic, weakly developed, deposited soils on gravelly material (sols peu évolués d'apport hydromorphes sur matériau gravillonnaire) of the same kind as those described for unit S3a4, from which this unit differs by the introduction of a minor component. The secondary component is formed of lithosols on hard pan (about 25%). The hard pan most often shows as ledges at the nickpoints and can also be found in certain areas as hard pan pavement or a very strong soil. The minor component (about 20%) is a ferruginous tropical soil on infill material of the glacis (sols ferrugineux tropicaux sur matériau de colmatage). Compared to other ferruginous tropical soils of Senegal Oriental, these have a significant silt fraction (clay loam over clay). The hard pan, which is found at about one meter in depth, ocassionally supports a gravelly layer or a crust. Many streaks and concretions occur starting from a depth of 50 cm. The structure ranges from coarse prismatic near the surface to angular blocky with depth. These soils have hydromorphic characteristics and physical properties that are unfavorable for the cultivation of cotton or groundnuts.

On the soils of unit S3a5 sorghum can be grown using ridge tillage. The rangelands are fair during the dry season.

S3b1: Vallons, basses pentes, régosols ou sols peu évolués d'apport hydromorphes sur matériau gravillonnaire

This unit occurs on valleys and very gentle slopes. The elevations almost never exceed 100 m. This unit includes a few irregularly shaped areas north and south of the Gambia River in the eastern Niokolo Koba region and east of Tionkoye.

The soils of the very gentle slopes are mainly regosols on gravelly material similar to those described for unit S3a3. The soils of the drainageways are hydromorphic weakly developed, deposited soils on gravelly material (sols peu évolués d'apport hydromorphes sur matériau gravillonnaire); though similar to those of unit S3a4, these soils are deeper. They are formed on dismantled hard pan material that fills the lower reaches. They are lighter in color, always massive and strongly cohesive. The clay content increases with depth (sandy loam over sandy clay). The gravelly horizon overlies a subrecent crust at medium depth. The organic matter content and the chemical fertility are rather low, and the pH is slightly acid near the surface to very acid at depth.

In general, these soils have a low potential, but it does vary according to the external drainage conditions. Groundnuts and sorghum can be grown in the better drained sites and on the erosional regosols, while rice might be tried in the less drained depressions. The quality of the rangeland is fair during the dry season.

S3b2: Vallons, basses pentes, sols hydromorphes sur matériau colluvio-alluvial

This mapping unit, which surrounds Kayar, has a slightly undulating topography that usually nears 120 m in elevation. It is clearly identifiable on the imagery.

These hydromorphic soils on colluvio-alluvial material are normally confined to valley bottoms and are thus present in the alluvial formations. The Kayar area is a particular case where these soils occupy a large infilled surface. The soils most often have a whitish color and is slightly bluish grey near the surface and beige at depth. Ochre and rusty mottles are found just below the surface, and many red concretions occur at medium depth. The structure, prismatic near the surface, is variable with depth, either massive or angular blocky. The texture varies from sandy loam at the surface to sandy clay loam with depth. The organic matter content is low. The chemical fertility is low and the pH is neutral near the surface to slightly acid at depth.

These soils are difficult to cultivate. They require organic matter and fertilizers to grow millet, sorghum or groundnuts. Cotton might be grown using ridge tillage, which is recommended for other crops as well. The rangeland is of good quality.

S3c: Basses plaines, sols halomorphes à alcalis non lessivés ou sols hydromorphes

This unit extends east of the sandstone hills of unit S2a, west of the Gandamaka Valley and north along the Falémé Valley to Nayé. The elevations do not exceed 80 m and the relief is almost flat. Lithosols on hard pan, regosols on gravelly material and hydromorphic weakly developed soils on material derived from sandstones are present as minor inclusions.

The major component (up to 70%) is an alkaline sodic soil (sol halomorphe à alcalis non lessivés). Their sodic characteristics originates from the nature of the parent material which releases sodium, and, through weathering, produces montmorillonitic clays. Since these soils are located in an important infill area, they are covered by shallow or very shallow accumulations of fine sand. The profile shows signs of very long periods of moisture saturation due to the presence of the impermeable sodic clay layer which has a low rate of hydraulic conductivity. Thus, the waterlogging is only superficial and these soils actually are "dry" soils. The discontinuity between the infill material and the sodic material is characterized by a stone line or a gravelly layer at very shallow depth. The color varies, but it is most often pale with red and yellow mottles. Though the structure is most often prismatic and the gravel content varies, the soil is always very gravelly at the discontinuity. The texture of the infill material is loamy sand, while the texture at depth is sandy clay loam. The organic matter content is low to very low as this latter layer thickens. The pH, which ranges from neutral near the surface to slightly acid where the infill material thickens, becomes strongly alkaline at depth.

The minor component (about 20%) is formed of hydromorphic soils on colluvial material (sols hydromorphes sur matériau colluvial). They have a coarse prismatic structure and are often gravelly at medium depth. Their organic matter content is low. Since these soils are covered by the same infill material as the sodic soils, both soils are difficult to differentiate in the field.

Cultivation of such soils is difficult. Preparing the soil is easier when the infill material is thicker, but the chemical fertility is then also low. The physical properties are generally unfavorable. These soils support a shrub savanna with *Acacia* spp. and can best be used as rangeland.

Basses plaines et vallées sur pelites, faciès paléovolcanique, S4

These formations occupy the plains that extend between Bakel and Kidira. The parent material has a paleovolcanic facies which is evidenced in the soils by a eutrophic brown facies. Two physiographic units were delineated: the lower plains and the valleys. Each was then subdivided according to the soil associations present; thus, a total of five mapping units are used: three for the plains and two for the valleys.

Symbols: S4a1, S4a2, S4b1, S4b2

Description

S4a1: Basses plaines, régosols sur matériau gravillonnaire, sols ferrugineux tropicaux peu profonds, sols bruns eutrophes tropicaux hydromorphes et intergrades

This unit occupies the plains that extend south from Bakel to Séoudji. Some interfluves may exceed 80 m in elevation. They are occupied by more or less hydromorphic regosols and shallow ferruginous tropical soils which support a rather well stocked, open forest vegetation. They are usually extremely gravelly at shallow depth with a crust at medium depth. They have very low fertility, and cultivation will lead to degradation through erosion.

The major component (about 70%) is made up of hydromorphic tropical eutrophic brown soils on gravelly material (sols bruns eutrophes tropicaux hydromorphes sur matériau graveleux). A vertic tendency is noticeable in the north and a tendency toward hydromorphic ferruginous tropical soils exists in the south and toward the cliff of the "Continental Terminal". These soils are brown; their texture ranges from fine sandy clay loam at the surface to clay loam then clay with depth. The structure varies from strongly developed, coarse to fine, angular blocky. Signs of prolonged moisture saturation are evident at a very shallow depth, and the soil becomes gravelly and stony at shallow depth. These soils offer a satisfactory chemical fertility that is somewhat limited by unfavorable physical characteristics. Some chemical deficiencies may exist with depth. Organic matter and fertilizer applications will improve crops. The vegetation is a tree or shrub savanna of *Acacia seyal*, and rangeland is fair to good throughout the year.

S4a2: Basses plaines, sols vertiques

This unit is limited to the nearly level area near Gabou. The soils have a very strong vertic tendency. They are formed on swelling clay material that results from the weathering of schists. They are thus very dark colored and often show typical dessication cracks. The upper horizon may nevertheless have a clay loam texture, but deeper horizons are very clayey. Quartz or quartzite stones are frequently

found and these soils are also very gravelly. The organic matter content is medium and the chemical fertility quite high. While the structure is angular blocky near the surface, it is prismatic at depth.

These very cohesive soils often have very unfavorable physical properties and poor drainage. Sorghum may, however, be grown and, if proper fertilizers are applied, maize or cotton may also be grown.

The vegetation is characterized by Acacia seyal and Schoenefeldia gracilis. The rangeland is of rather poor quality.

S4a3: Basses plaines, sols hydromorphes et solonetz

This unit covers the very gently sloping glacis found between Kidira and Dialiguel.

These hydromorphic soils have textures varying from sandy loam to clay loam, and reduced gley is ocassionally present at shallow to medium depths. The pH is neutral to acid near the surface, but always increases at depth because of the alkalinity. The solonetz soils have a typical columnar structure and often a loamy texture. Their pH increases with depth and can become strongly alkaline.

In both cases, the organic matter and the chemical fertility are low. Sheet erosion is significant and the soil surface is generally sealed. The physical properties are generally unfavorable, especially those of the sodic soils; thus, they are of very little agricultural interest. The natural grazing lands are also most often poor or very poor.

S4b1: Vallées, bruns eutrophes tropicaux hydromorphes, sols peu évolués d'apport hydromorphes

This unit covers the valley slopes and bottoms of the plains between Gabou and Kidira.

The major soil associations in this unit is similar to the soils of surrounding plains of unit S4a1. The major component remains the hydromorphic, tropical, eutrophic brown soils on gravelly material (sols bruns eutrophes tropicaux hydromorhes sur matériau graveleux), and has a vertic tendency downstream and a ferruginous tendency upstream. More or less hydromorphic, weakly developed deposited soils on alluvial material (sols peu évolués d'apport plus ou moins hydromorphes sur matériau alluvial) occupy the valley bottoms.

These soils often have a fine texture, beneficial structure and satisfactory chemical characteristics. They are, however, limited by a shallow useful depth and, where they are deeper, they become somewhat chemically deficient. Organic matter and fertilizers are thus needed for any type of crop to be grown. The vegetation is a shrub savanna of Acacia seyal, and the natural rangeland is fair to good.

S4b2: Vallées, sols peu évolués d'apport hydromorpphes et sols hydromorphes

This unit includes the group of valleys joining the Falémé River near Sénoudébou. The generally pale, yellowish-brown soils have a variable texture, though fine clay loam is the average. The high silt content is responsible for sealing tendency and for most often massive or generally weakly developed structure (although a crumby tendency may be noticed at the surface and a angular blocky tendency can be discerned at depth). These soils are always hydromorphic to some degree. The pH is normally slightly acid, the organic matter content rather low and the chemical fertility rather high.

These soils are relatively suitable for cultivation if organic matter is applied to reduce the structural limitations and to prevent the encrusting. Sodicity problems may be locally found.

The grazing lands are fair to good quality.

BASSES PLAINES ET VALLEES SUR SCHISTES METAMORPHISES, S5

These formations extend north of Bakel on metamorphic material (sericite schists). Soil associations correlating to two physiographic divisions, the plains and valleys, were delineated.

Symbols: S5a, S5b

Description

S5a: Plaines, régosols plus ou moins hydromorphes sur matériau gravillonnaire, sols ferrugineux tropicaux peu profonds sur matériaux divers, sols bruns subarides

This unit occupies the plains north of Bakel, where the elevations range from 40 to 50 m.

The interfluves are occupied by the minor component (about 20%) which includes regosols and shallow ferruginous tropical soils. They are often stony and strongly eroded and support only poor vegetation. The major component (about 70%) comprises a majority of the remaining slopes and depressions. It is made up of slightly alkaline, brown subaridic soils (sols bruns subarides faiblement alcalinisés) and other brown soils with diverse facies.

The soil surface is largely sealed. The color and texture are a homogeneous, yellowish-brown, sandy loam, lacking in clay at the surface. Signs of prolonged moisture saturation appear near the surface. Calcareous nodules and ferruginous gravel are found at shallow depths. The structure is prismatic with a columnar tendency in the upper horizon; the soil is massive and compact with depth. The organic matter content is rather low and nil at depth. The chemical

fertility is medium, and the pH is strongly alkaline starting from the first few centimeters.

The major component has little agricultural interest and cultivation is confined to the rare favorable areas. The modal brown subaridic facies has satisfactory properties; the hydromorphic eutrophic brown facies has a shallow useful depth.

The grazing potential of this mapping unit is also particularly poor.

S5b: Vallées, sols bruns eutrophes tropicaux hydromorphes, sols bruns subarides, sols peu évolués d'apport hydromorphes

This unit includes the slopes and valley bottoms between Tianialo and Oldouldou.

The soils association of this unit is the same as that of the surrounding plains (unit S5a). The major component is composed of slightly alkaline, brown subaridic soils (sols bruns subarides faiblement alcalinisés) and various other facies of brown soils which have a stronger hydromorphic tendency. The valley bottoms are also occupied by generally hydromorphic, weakly developed deposited soils on alluvial material (sols peu évolués d'apport, peu ou moins hydromorphes sur matériau alluvial).

This unit has little agricultural potential: cultivation is possible in only a few areas. The quality of the rangeland is also particularly poor.

ROCHES SUBHORIZONTALES

The only formations on subhorizontal rocks occupy the cliffs of the Fouta Djalon. The differences in elevation can reach 300 m, and the cuestas are steeply sloped. The cuesta on schist to the west and the cuesta on sandstone to the east are differentiated by lithology and physiography.

Symbols: S6a, S6b, S7a, S7b

Description

S6a: Côte schisteuse, lithosols sur schistes et sur cuirasse

The cuestas on schists forms the edge of the Mali Massif in Guinea. This hilly relief follows the border approximately from Nepen Diakha to Yéronguéto. Some crusted areas are noticeable in the schist outcrops. This unit has no agricultural potential.

S6b: Piedmont de côte schisteuse, sols peu évolués d'apport intergrades vertiques sur matériau argileux gonflant

In this unit the cuestas on schist are bordered by a piedmont slope about 1 km wide. Hard pan outcrops and regosols on gravelly material or on debris of various kinds of rocks are also included.

The soils are mainly (about 70%) vertic intergrades of weakly developed deposited soils on swelling clay material (sols peu évolués d'apport intergrades vertiques sur matériau argileux gonflant). To the west they have more pronounced vertic characteristics. They are a chestnut brown color and usually massive with a tendency toward an angular blocky structure in the first few centimeters and then toward a prismatic structure in the remainder of the upper horizon. Signs of prolonged moisture saturation are visible just below the surface and stones are also found. A mixed gravelly and stony horizon is most often present at shallow depth, and weathered rock is found at medium depth. The organic matter content is low, the chemical fertility very high and the pH neutral to very slightly acid. To the west, there is a tendency toward the lithomorphic vertisols with a fine crumbly structure at the surface (grumosolic horizon) and a remarkably increased organic matter content. The grumosolic horizon, however, is shallow, and with depth the profile becomes very similar to that of the soils described above. Clayey textures do not occur consistently; sandy clay loam or clay loam are also frequent. The phosphorus levels are very low.

These soils often have unfavorable physical characteristics, except in the shallow grumosolic horizon. These heterogeneous soils allow only erratic agricultural successes. They are suitable for sorghum, and cotton or maize can also be grown if fertilizers are applied to correct the phosphate and potassium deficiencies.

S7a: Côte gréseuse, lithosols sur grès, sols peu évolués ferrugineux tropicaux sur matériau dérivé des grès, lithosols sur cuirasse

The cuestas on sandstone form a steep relief in the Fouta Djalon region, and it follows the Guinean border from Yéronguéto toward the Falémé Valley (Fig. 4.17).

The major component (about 60%) is formed in lithosols on sandstone and have no agricultural potential. Lithosols on hard pan or regosols on debris of various kinds of rocks make up the minor inclusions.

Fig. 4.17. A cuesta (sandstone).

The minor component (up to 25%) is formed of ferruginous tropical weakly developed soils (sols peu évolués ferrugineux tropicaux) on material derived from sandstone. These very stony soils occupy infill areas on the backslope of the cuesta (Fig. 4.18). They are sandy at the surface (loamy sand) and clayey at depth (sandy clay). The pH is neutral to slightly acid. The organic matter and nutrient contents are medium to high.

The soil characteristics reflect a precarious equilibrium, and it seems certain that to cultivate these soils would lead to their irreversible degradation. Protective reforestation is the only advisable use.

Fig. 4.18. Lithosol on sandstone; backslope of a cuesta (unit S7a).

S7b: Piedmont de côte gréseuse, sols peu évolués d'apport hydromorphes sur matériau gravillonnaire et sols ferrugineux tropicaux lessivés sur matériau dérivé des grès

The piedmont slopes of the cuestas on sandstone are relatively narrow and are often not present, except between Sakhcuya and the Koila Kabe Valley where they may reach a width of 2 km.

Various inclusions are present: lithosols on hard pan, lithosols on sandstones, lithosols on various kinds of rock debris, ferruginous, tropical weakly developed soils and regosols on gravelly material. As described below, two soils occupy most of the unit (about 40% each).

The first component is the hydromorphic, weakly developed deposited soils on gravelly material (sols peu évolués d'apport hydromorphes sur matériau gravillonnaire), and it has a rather fine texture, clay loam to silty clay. They are usually massive over a strongly indurated hard pan at shallow depth. The organic matter content and the chemical fertility are rather low and the pH is slightly acid. These soils are found especially on the lower glacis (slope).

The second component includes the upper glacis which is covered with thicker deposits and whose soils are leached, ferruginous tropical soils on material derived from sandstone (sols ferrugineux tropicaux lessivés sur matériau dérivé des grès). These sandy loams on sandy clay loams are somewhat stony at depth. The structure is often weakly developed with a prismatic tendency, and the soil is moderately cohesive. The color is mainly red with signs of prolonged moisture saturation at depth. The hard pan may, in certain areas, appear at variable depths. The chemical fertility and the organic matter content are low, and the pH is neutral to slightly acid.

These soils are easily degraded. They normally can support various kinds of crops (groundnuts, millet, cotton, sorghum) if organic matter and fertilizers are applied. The hydromorphic, weakly developed soils on gravelly material have less favorable characteristics, especially their physical properties, and groundnuts or sorghum should preferably be cultivated using ridge tillage.

The natural vegetation is a tree savanna of Combretum spp.

B. Formations sur roches essentiellement métamorphiques Birrimien), M

Extending east of the Oussounkalo-Sitabanta axis (Senegal Oriental), these formations include hills, multiple levels of glacis, erosional valleys and low undulating plains. Three groups of formations were delineated according to the nature of the parent material (Map 4.6). First are the soils on basic rocks and on swelling clay material produced by weathering; second are the soils on acid rock types and on arenaceous, weathered material; third are the soils on eroded residual material which no longer clearly retain any evidence of the geologic parent material.

SOLS SUR ROCHES BASIQUES DIVERSES ET MATERIAU ARGILEUX GONFLANT D'ALTERATION, M1

The formations on basic rocks commonly referred to as "green rocks" (roches vertes) extend in a discontinuous arc from the Bandafassi Massif to the level of Sitabanta. Two small areas showing similar spectral signatures at the northern tip of the Saraya Massif were included in these formations, although their texture and moire are not so typical.

The nature of the basic rocks, readily observable in the case of the lithosols, is apparent by the weathered products and by the development of eutrophic brown soils or vertic soils on swelling clay material. Five units have been delineated for this group; they each occupy different physiographic positions and indicate a particular soil association.

Symbols: M1a, M1b, M1c, M1d, M1e

Description

M1a: Collines, lithosols sur roches basiques diverses et régosols bruns eutrophes sur débris de roches basiques diverses

This unit includes the hills exceeding 300 m in elevation around Sandikouba and over 400 m near Mamakhonon. The relief is rolling to hilly. Soils are lithosols on various kinds of basic rocks (about 50%), with outcrops and rockfalls; the summits and steep slopes have no agricultural potential. On the lower slopes and on the more gentle slopes they are most frequently associated with weakly developed deposited soils (up to 30% regosols) with a eutrophic brown facies. These soils are extremely stony; the fine earth fraction is loamy to clayey, but the stony weathering material that makes up these soils has a high permeability and a relatively high water holding capacity. The upper 10 or 20 cm are dark brown and humiferous with a medium organic matter content. They often show a tendency toward a fine, angular blocky or crumby structure. The pH is slightly acid, the chemical fertility remarkably high, and the potassium level occasionally low. Typical eutrophic brown soils are included as a minor component.

These soils have excellent agricultural potential, though some areas are extremely stony or have very steep slopes. The erosion hazard is low because of the high permeability, but organic matter inputs are indispensable to maintain good structure. Erosion control practices should be considered. Overall, these soils are suitable for millet, groundnuts and cotton.

M1b: Pentes, régosols sur débris de roches basiques diverses et sols vertiques sur matériau argileux gonflant

This unit includes the small rounded hills that, east of Diguinkili, surround the hills of the preceding unit.

Weakly developed, eroded soils on debris of various kinds of usually basic rocks (sols peu évolués d'érosion sur débris de roches basiques diverses) dominate this association (about 60%). These soils are not as stony near the surface as those of the neighboring hills, but they are poorer chemically and have fewer favorable hydraulic properties. They have a humiferous loamy topsoil with an angular blocky structure and become extremely stony at a shallow depth.

The minor component (about 30%) comprises lithomorphic vertic soils on swelling clay material (sols vertiques lithomorphes sur matériau argileux gonflant). This are moderately deep to very deep and have a moderately fine or fine texture (sandy clay loam). The organic matter content is medium and the chemical fertility is high, though low phosphorus and potassium levels are limiting factors. They become slightly stony or gravelly at shallow depth. The pH is slightly acid.

Overall, these soils are arable; however, they need fertilizers and mineral additives may occasionally require management to improve their hydraulic properties. The risk of erosion from runoff on the lower slopes should not be underestimated. The grazing lands are of rather good quality during the dry season.

M1c: Vallons, sols vertiques sur matériau argileux gonflant

This unit can be found between the hills of unit M1a. It covers dells and inner plains.

The soils are primarily lithomorphic vertic soils on swelling clay material (about 70%). They often show the microrelief characteristic of thin vertic properties and are moderately deep to very deep. The texture is moderately fine to fine. At the surface, the structure varies from medium prismatic to fine crumby; it becomes angular blocky below, then strongly prismatic with depth. The color varies from gray to olive. These soils have a medium organic matter content and high chemical fertility. They become slightly stony or gravelly at shallow depth, and surface gravel may be found in certain areas. The pH is slightly acid.

The soils are arable, if organic matter and fertilizers are applied to correct the phosphorus and potassium deficiencies. The occasionally less favorable hydraulic properties of these soils should preferably be taken into account, in land management and agricultural practices. The erosion hazard is continually present. The natural vegetation may offer good rangeland during the dry season. Inclusions of regosols or vertic eutrophic brown soils on swelling clay material also occur in this unit.

M1d: Glacis, régosols sur matériau gravillonnaire et sur matériau argileux d'altération

This nearly level erosion surface extends from both sides of the Gambia River between Bantata and Bounsankhoba.

The soils are of the regosolic type: weakly developed eroded soils on gravelly material and weakly developed eroded soils on clayey weathered material. The regosols on gravelly material are similar to those described in the preceding formations. The soils on clayey weathered material are also gravelly and sandy at the surface, though at a shallow depth, chemical weathering is synthesizing secondary clay minerals, resulting in an impermeable horizon. The mineralogical and chemical characteristics vary greatly. These two soils occasionally have contradictory properties; regosols on gravelly material are permeable and well drained, while those on clayey material are relatively impermeable and poorly drained due to the restrictive horizon at shallow depth. Both soils have a low water holding capacity.

Overall, these soils are marginal for cultivation because of their s' allow useful depth, yet very good results can be obtained if organic matter and fertilizers are applied. The quality of the rangeland is quite poor during the dry season.

M1e: Plaines, sols vertiques sur matériau argileux gonflant et sols halomorphes à alcalin non lessivés

This unit occupies the extremely flat, lower plains bordering the Falémé River between Sabousiré and Takoutala. Their elevation does not reach 100 m.

These plains are characterized by an association of vertic soils on swelling dry material (sols vertiques sur matériau argileux gonflant), similar to that described for unit M1c, and alkaline sodic soils (sols halomorphes à alcalis non lessivés). The sodic soils are formed in situ and the exchangeable sodium is derived from the weathering of the parent rock. They share with the vertic soils a fine texture (clay), but the dispersion of the clay by the sodium does not allow the development of vertic characteristics. The sodic soils are gray or olive, and hydromorphic mottles are found just below the surface. The structure is usually prismatic, with gravelly or stony pockets in certain areas. The organic matter content is medium and the pH is neutral to slightly alkaline.

In this unit, the vertic component is arable under the same conditions as mentioned for unit M1c. The poor structure of the sodic soils constitutes a limitation that makes them unsuitable for cultivation. They can only be used as rather poor grazing land during the dry season.

SOLS SUR ROCHES ACIDES, MIGMATITIQUES, M2

These formations follow the basic rocks from north south to near Bransan. A small area showing a similar spectral signature has been delineated west of Segou at the foot of the cuesta of the Fouta Djalon.

The nature of the acid rocks is evident mainly in the lithosols and in the soils on gravelly arenaceous material. Three physiographic divisions are each represented by one mapping unit: hills, a multiple level glacis and lower plains.

Symbols: M2a, M2b, M2c

Description

M2a: Collines, lithosols sur roches diverses

This unit includes the small hills ranging in elevation from 100 to 120 m to the east of the Falémé River. These lithosols on various kinds of rocks are very shallow and very gravelly, and some of the summits may also be crusted. Only protective measures are applicable in this case.

M2b: Glacis étagé, lithosols sur cuirasse, régosols sur matériau gravillonnaire, sols ferrugineux tropicaux lessivés sur matériau dérivé des migmatites

This unit occupies the western part of the formations on metamorphic rock and extends approximately between Bransan and Sandikouba. The elevations usually ranges from 100 and 120 m and the topography is slightly undulating.

The association is mainly composed of regosols (about 40%) on the slopes and interfluves, with a tendency toward hydromorphic, weakly developed, deposited soils on gravelly material in the south. The soils are gravelly to very gravelly, especially in the case of the regosols. Their physio-chemical properties are satisfactory: medium organic matter content; medium texture; well developed, fine, angular blocky structure at the surface; neutral to very slightly acid pH at depth. Nutrients are available in sufficient amounts. However, because these soils are very easily degraded when cultivated, organic matter and fertilizers are indispensable. The hydromorphic, weakly developed soils have less favorable characteristics, except for a slightly lower gravel content in the upper horizon (though the structure then already becomes massive). The secondary component (about 30%) is made up of lithosols on hard pan with outcrops on glacis, especially at the nickpoints. They have no agricultural potential.

The minor component (about 20%) is either a ferruginous tropical soil on material derived from the migmatites (which, because they are often often truncated by erosion, are not very useful for agriculture), or more often a ferruginous tropical soil on infill material with many concretions at shallow depth and an unfavorable structure beginning in the upper horizons.

The natural vegetation offers fair rangeland during the dry season.

M2c: Basses plaines ondulées, lithosols sur migmatites, sols peu évolués d'apport hydromorphes sur arène graveleuse, régosols sur débris de roches diverses

This unit overlooks unit M1c from the east and surrounds the small hills of unit M2a. The elevations often reach from 80 to 100 m. The major component (about 40%) is made up of hydromorphic, weakly developed, deposited soils on gravelly arenaceous materials (sols peu évolués d'apport hydromorphes sur arène graveleuse). These soils are sandy at the surface and arenaceous at depth, with a crust level at shallow depth, which supports a stony layer. The pH is acid. The secondary component (about 30%) is formed of regosols on debris of various kinds of rocks. They have a finer texture (sandy clay), but are very stony starting from the surface. The pH is very slightly alkaline. The chemical fertility is in this case rather high with a rather high organic matter content, but the physical properties of these soils are extremely unfavorable.

The minor component (about 20%) is a lithosol on migmatites, devoid of agricultural potential.

The physical properties of the three components are the major limitation to agricultural potential. The quality of the rangeland is generally poor.

SOLS SUR MATERIAU RESIDUEL GRAVILLONNAIRE, CUIRASSE, M3

These formations on residual erosional material include most of the metamorphic province. Two physiographic divisions were recognized: multiple-level glacis and low, undulating plains. Two soil associations were defined for the glacis and one for the plains.

Symbols: M3a1, M3a2, M3b

Description

M3a1: Glacis étagés, sols peu évolués d'apport hydromorphes ou régosols, sur matériau gravillonnaire, lithosols sur cuirasse

This unit includes nearly the entire territory to the east of the Saraya Massif, as well as a small area to the west, north of Samékouta. The relief may in some areas be hilly; some units approach 400 m in elevation, but the elevation is generally lower than 200 m with an undulating relief.

The major component (about 40%) is hydromorphic, weakly developed, deposited soils on gravelly material (sols peu évolués d'apport hydromorphes sur matériau gravillonnaire) which preferentially occupies the lower reaches and drainageways. This soil is fine textured (sandy clay loam to sandy clay), more or less gravelly and has developed on dismantled hard cap products brought as infill material to the lower

reaches. Their color is light gray; structure is massive with a very cohesive consistency. A subrecent crust is usually present at medium depth. The fertility and the organic matter content are low; the pH is slightly acid near the surface and becomes quite acid at depth.

The second component (about 30%) is composed of lithosols on hard pan: it is found on the steep slopes and some interfluves. The hard pan forms a ledge at the nickpoints, but it is most often present as boulders and stones on the steep slopes around the buttes or on the gently sloping glacis. Like all hard pan, it has no agricultural potential and it increases the likelihood of water erosion in the adjoining areas.

The minor component (about 20%) is a weakly developed, eroded soil on gravelly material (regosolic soil) that is found in the better drained sites. In this case, the soils are gravelly to very gravelly and the hard pan can be found at 50 cm in depth. The chemical fertility and the organic matter content then also reach medium values which are higher than those obtained for the soils of the major component.

Overall, these soils are fragile and have low agricultural suitability. They require regular applications of organic matter and fertilizers. Groundnuts and sorghum can be grown in the better drained areas and on the regosols; rice may be tried in the less well drained depressions. The quality of the rangeland is fair during the dry season.

M3a2: Glacis étagés, lithosols sur cuirasse et régosols sur matériau gravillonnaire

This unit corresponds to the level or very gently sloping glacis that extends between the Bandafassi Massif and the Saraya Massif from Fouta Djalon to the hills of unit M1a near Bransan. They may exceed 200 m in elevation and include small crusted buttes (Figs. 4.19 and 4.20).

Two phases are noted on the map because the spectral signatures suggest the predominance either of the lithosols on hard pan (phase "c", about 60% lithosols for 25% regosols) or the weakly developed, eroded soils on gravelly material (phase "g", over 40% regosols). Since the characteristics of these residual soils do not greatly depend on the nature of the geologic parent material, it is thought that these soils are similar to those described earlier for unit S3a2 and are characteristic of unit S3a1 for the lithosols and of unit S3a3 for the regosols. These phases, which are not agriculturally significant, are represented on the land capability map.

Fig. 4.19. Cuirasse pavement with boulders.

Fig. 4.20. Close-up view of a cuirass pavement.

M3b: Basses plaines ondulées, régosols sur matériau graveleux de recouvrement et sols peu évolués d'apport hydromorphes sur matériau divers

This unit extends northwest of the granitic Saraya Massif, from near Bembou to Ouassangara and Soréto Saboussiré on the Falémé River. The topography is slightly undulating and the elevations frequently exceed 100 m, even reaching 200 m near the Saraya Massif. The slopes are essentially occupied by regosols in gravelly sand cover (about 50%).

These soils are very heterogeneous; they frequently have various layers, each one having a very different color and texture, as well as different amount of coarse fragments. These soils are always very gravelly (ferruginous gravel, concretions and weathered stones). The upper horizon is the only one that has any structure (angular blocky). The pH is usually slightly acid, and the chemical fertility and the organic matter content are medium.

The soils of the drainageways are predominantly hydromorphic, weakly developed, deposited soils (sols peu évolués d'apport hydromorphes) on more or less gravelly material (sandy clay loam) or on colluvio-alluvial infill material (sandy loam). The gravelly soils (about 20%) are similar to those of unit S3b1, while the infill soils (about 20%) are chemically poor and have a low organic matter content. Crusted buttes are a minor inclusion.

Only a small proportion of these soils is suitable for cultivation. These are the soils on more or less gravelly material in the drainageways. Their suitability depends on the quality of the external drainage. Groundnuts and sorghum can be grown in the better drained locations and rice can be found in the less well-drained depressions.

C. Formations sur roches de type granitique (granite d'anatexie), G

These formations on granitic rocks of Birrimian age extend in Senegal Oriental from the cuesta of the Founta Djalon between Sakhouya and Missira Dantilia north to near Limalo on the Falémé River. Some other small areas with the same type of spectral signature occur near Nafadji to the east, near Farandi to the northeast and near Ségou at the foot of the cuesta to the southwest (Map 4.6).

The morphology of this area which is called the Massif de Saraya, or Saraya Massif, is essentially a series of low hills that seldom exceed 200 m in elevation and have few crusted areas. This vacuolar type of hard pan is normally rather thin and weakly resistant to fracture. Most soils are weakly developed of various kinds and are generally shallow.

Nine mapping units were delineated: two occupy the most easily discernible interfluves in the southern part of the massif; another lies on the hilly area of the northern tip of the massif; five more include to a large extent the slopes and erosional valleys; the last one is the hydromorphic soils on the granitic weathered mantle of the drainageways.

Symbols: Ga1, Ga2, Gb, Gc1, Gc2, Gc3, Gc4, Gc5, Gd

Description

Ga1: Buttes et interfluves, lithosols sur cuirasse et sols peu évolués d'apport hydromorphes sur arène granitique graveleuse

This unit includes the interfluves in the southeastern part of the granitic formations, from Missira Dantilia to Nafadji. Lithosols on hard pan, characteristic of the plateau edges and nickpoints, are associated with strongly hydromorphic, weakly developed, deposited soils on gravelly granitic arenaceous material (sols peu évolués d'apport hydromorphes sur arène granitique graveleuse). The latter soils occur between the alternating barren areas and areas of shallow soil.

The hard pan is greatly dismantled, vacuolar and not very resistant. It is skeletal and is made up of a red or rusty colored ferruginous materials; the fine earth fraction is generally a light yellow, clayey inclusion. The weakly developed soils are also characteristic of unit Gc5; they occur in areas which have poor external drainage and have a crust of medium or shallow depth. They have a coarse texture with a single grain or massive structure. The organic matter content and chemical fertility are very low; the pH is acid to strongly acid.

The presence of hard pan outcrops exacerbates the water erosion on the adjoining soils. A shrub savanna alternates with barren areas where mushroom-shaped termite mounds exist. This unit has no agricultural potential, but protection or possible reforestation should be considered.

Ga2: Buttes et interfluves, régosols sur matériau gravillonnaire et sols ferrugineux tropicaux lessivés sur granites

This unit includes the interfluves in the western part of the massif. The soils are deeper here than those of the preceding unit. Weakly developed, eroded soils (sols peu évolués d'érosion) on gravelly material from the dismantled hard pan occur in lieu of the lithosols on hard pan. Leached, ferruginous tropical soils (sols ferrugineux tropicaux lessivés) on material derived from granite occur in places where the hard pan is at greater depth.

The regosolic soils are shallow and very gravelly, but the fine earth fraction in the upper horizon was a medium organic matter con- tent, indicating relatively good fertility. Thus, these soils are often cleared for cultivation and inevitably exposed to erosion. They then become completely degraded within a few years. The ferruginous tropical soils are arable and are the same as those described for unit Gc4.

Gb: Plaine collinaire, lithosols sur cuirasse ou sur granites, régosols sur matériau gravillonnaire, sols peu évolués d'apport ferrugineux tropicaux ou hydromorphes sur granites, sols ferrugineux tropicaux lessivés sur granites

Located in the northern tip of the massif, this mapping unit shows a higher drainage density than the rest of the massif. Lateral variations are more important: the unit is quite complex with hard pan or granite outcrops at the nickpoints, various weakly developed eroded or deposited soils on the interfluves or on the slopes of erosional valleys, and some areas of possibly leached, ferruginous tropical soils on material derived from the granites. Thus, this unit is in some respects a mosaic (complex) of units Ga1, Ga2 and Gc1, and only certain areas are arable, as is the case in unit Gc1.

Gc1: Vallons et bas de pentes, lithosols ou sols peu évolués ferrugineux tropicaux sur granites

This unit includes the southeastern valleys of the massif, as well as the small areas outside the massif. Slopes and valley bottoms have ferruginous tropical weakly developed deposited soils (sols peu évolués d'apport ferrugineux tropicaux) on material derived from the granites. Some upper, eroded slopes have exposed granite outcrops and rounded boulders and have raw mineral soils in places where the granite is only slightly disaggregated. The ferruginous, tropical, weakly developed soils (over 60%) are described under unit Gc3, where they are also the major component.

The soils of this unit are not very suitable for agriculture. The erosion hazard is increased by the presence of lithosols on the upper slopes and of crusted interfluves (unit Ga1). The fertility is low and the useful depth limited. Grazing lands are poor.

Gc2: Vallons et bas de pentes, lithosols sur cuirasse et sols peu évolués d'apport hydromorphes sur granites

This unit is located on the western side of the Saraya Massif. It is made up of the same associations as that of unit Ga1, but here the lithosols on hard pan are located on the upper slopes and the hydromorphic, weakly developed, deposited soils (sols peu évolués d'apport hydromorphes) on gravelly, granitic, arenaceous material are found on the lower slopes and at the bottom of the valleys (from 60 to

70%). The plateaus in this case have the deeper soils and placed in unit Ga2.

The agricultural characteristics of the soils of this unit are also very similar to those of the soils of unit Ga1.

Gc3: Vallons et bas de pentes, sols peu évolués ferrugineux tropicaux sur granites

This unit occupies primarily the southwestern part of the Saraya Massif. The slopes of these small valleys are occupied by ferruginous, tropical weakly developed soils (sols peu évolués ferrugineux tropicaux). The valley bottom is made up of hydromorphic soils similar to those of unit Gd, though here they are a minor component. The slopes are gentle and the soil surface is often covered with arkosic sand.

The ferruginous, tropical, weakly developed soils are beige, grayish near the surface and ochre at depth. The texture is coarse to moderately coarse and the structure ranges from massive near the surface to angular blocky with depth. However, these soils are only shallow or moderately deep, and a gravelly horizon is also found at about 50 cm in depth. The organic matter content is low and the chemical fertility is often very low. The pH is very slightly acid at the surface, becoming slightly more acid at depth.

These soils may possibly be suitable for groundnuts, but since they are very susceptible to erosion, the risk of degradation remains high. The vegetation is an open tree savanna of *Acacia seyal*.

Gc4: Vallons et bas de pentes, sols ferrugineux tropicaux lessivés sur granites

This unit occupies the central area of the Saraya Massif around Kondokhou. The soils are mainly (about 70%) leached ferruginous tropical soils on reworked granitic, arenaceous material (sols ferrugineux tropicaux lessivés sur arène granitique remaniée) with a crust at depth. Ferruginous, tropical, weakly developed deposited soils are the most common minor component.

Though these soils are occasionally deep, they are often truncated by erosion. A slightly gravelly horizon is often present at a shallow depth. These soils are covered by a few centimeters of gravelly sand. They are sandy near the surface, but become more and more clayey and massive with depth: sandy loam, then sandy clay loam. Except for the gray humiferous topsoil, the color is commonly a rather light, pinkish beige. The organic matter content and the chemical fertility are rather low, and the pH is generally slightly acid.

The vegetation is a dense tree savanna. These soils are suitable for groundnut cultivation but since they become very quickly depeleted, long fallow periods are necessary. They may be too shallow for other crops (millet, sorghum, cotton). They are already much degraded and very susceptible to erosion. The grazing lands are rather poor, and the potential for forestry is medium.

Gc5: Vallons et bas de pentes, sols peu évolués d'apport hydromorphes sur arène granitique graveleuse

This unit extends in the eastern part of the Saraya Massif and also covers some valley bottoms in the northern part.

These hydromorphic, weakly developed, deposited soils (sols peu évolués d'apport hydromorphes) are typical of flat areas having limited external drainage. They are usually shallow, with a crust at medium depth, and are developed on gravelly granitic arenaceous material. They are brown and slightly humiferous. They have a coarse to medium texture and, near the surface, have a single grain structure and the remainder of the profile has a massive structure. They have a very low fertility and are acid to strongly acid pH.

These soils have little agricultural potential. The natural vegetation is a shrub savanna which should be protected or possibly reforested.

Gd: Basses plaines, sols hydromorphes

This unit in the eastern portion of the Saraya Massif includes drainageways. They are partially infilled with a mantle of weathered granitic material. The soils are mineral, hydromorphic soils with a pseudogley with streaks and concretions (sols hydromorphes minéraux a pseudogley, à taches et à concrétions).

The texture is slightly finer than that of the other soils on granites. The organic matter content is occasionally medium, and the chemical fertility is low. Soil gleying is discernible near the surface, and the pH remains slightly acid. While the structure is rather well developed (angular blocky) at shallow depth, the soil becomes massive with depth.

These soils have poor capabilities and they are also waterlogged during the rainy season. Crops must be grown using ridge tillage, and organic matter and fertilizer applications are indispensable.

D. Formations sur roches ignées microgrénues, I

Though these formations have in common the igneous origin and the micrograined texture of their geologic parent materials, they belong to different geologic formations of different ages. Thus, each is mapped separately; the first division corresponds to a post-tectonic granitic

material; the second corresponds to Paleozoic dolerites and metabasites. The parent material is acid or basic rocks, respectively (Map 4.6).

Symbols: I1, I2

Description

I1: Granites post-tectoniques, sols ferrugineux tropicaux lessivés sur matériau dérivé des granites, lithosols sur cuirasse

This unit is located north of Oussounkala in a bend of the Gambia River. It has a relatively undulating topography, (rolling in some areas), with crusted summits that occasionally exceed 150 m in elevation.

Leached, ferruginous, tropical soils (sols ferruginaux tropicaux lessivés) on material derived from the granites are the major component (up to 60%). They generally correspond to the soils of unit Gc4, but they are much more degraded. The quality of the rangeland is rather poor; forest management should possibly be considered to protect this area.

I2: Diorites et métabasites, lithosols sur roches basiques diverses et sur cuirasse, sols bruns eutrophes divers, régosols bruns eutrophes, vertiques ou sur matériau gravillonnaire, sols vertiques

This unit includes the Bandafassi Massif. It extends from Ibel in the south to Mako in the north and consists of a group of steeply dissected hills and relatively flat inner plains. The hills reach an elevation of about 400 m near Bandafassi in the south, 500 m in the center, 350 m north of the Gambia River and 300 m toward Kanoumering. The unit includes various soil types: lithosols on various kinds of basic rocks on the steep slopes, lithosols on hard pan and regosols on gravelly material from dismantled hard pan, eutrophic brown or vertic regosols on the lower slopes, and eutrophic brown soils and vertic soils in the plains.

Thus, the soil characteristics are extremely variable. The erosion hazard is most often high, though some soils are reasonably arable. The grazing lands can be rather poor to good in certain areas. Crops can yield rather good, especially on the soils with eutrophic brown or vertic characteristics. Fertilizers remain indispensable to correct phosphorus and potassium deficiencies: organic matter is also needed to maintain the structural qualities of the topsoil.

4.3.3.4 Miscellaneous Land/Soils Types

Symbol: Cr

Description

Cr: Carrière

A "Cr" mapping unit is shown south of Darou Khoudos. It represents the phosphate-mining related disturbance as shown on the November 23, 1979 image.

4.3.3.5 Soil Classification

The classification appearing in the legend and in the mapping units description is the French classification used by the ORSTOM soil scientists of Dakar-Hann. The classification will only very briefly be explained below, but, if interested, one may read relevant ORSTOM publications, which are authoritative on the subject. Although the scope of this study did not require detailed correlation work, some basic indications are given for possible equivalents in the Soil Taxonomy System (STS) and in the World Soil Classification (FAO) but only in general terms. Some examples of profiles studied during this survey are given in Appendix B, Table IV-2.

The French classification (from Aubert and Duchaufour, revised by the Commission de Pédologie et de Cartographie des Sols, CPCS) is a genetic classification.

-The class is the expression of a major pedogenetic process.

-The subclass is defined by a basic ecologic factor involved in the genesis (e.g., climate, percent rock).

-The group is defined by the morphologic characteristics of the profile which are indicative of the evolutionary process.

-The subgroup is defined by a minor characteristic or by the intensity of the evolutionary process characterizing the group.

-The family is defined by the nature of the bedrock or parent material.

I. Classe des sols minéraux bruts (Immature Soils)

Sous-classe: non climatique (nonclimatic)
Groupe: d'érosion (eroded)

Two subgroups appear in the legend. The first subgroup contains the lithosols, which are slightly weathered, hard rock outcrops. The ferruginous hard pan is also considered a rock. Lithosols were found

on various rock types: ferruginous hard pan, sandstone, granite, migmatite, various basic rocks, schist and quartzite (Ustorthents, STS; Lithosols, FAO).

The second subgroup contains the regosols on loose material. The word regosol is here used within a broad definition that combines the régosols sur matériau gravillonnaire de demantèlement de cuirasse and the sols peu évolués non climatiques d'érosion régosoliques sur matériau gravillonnaire de démantèlement de cuirasse. The boundary between these two classifications is not clearly defined. Although ORSTOM publications usually refer to weakly developed soils using the second denomination, the word regosols was used here because it is conveniently short. Regosols listed include those that are more or less hydromorphic and found on gravelly material produced from dismantled hard pan, those on dismantled hard pan on sandstone, those on sandstone crust, those on various (often basic) rock debris or those with a tendency toward brown eutrophic soils or toward vertisols on clayey material that results from the weathering of various kinds of basic rocks or on schists (Ustorthents, STS; Regosols, FAO).

Groupe: d'apport (deposited or transported)

The legend mainly shows soils of marine or eolian origin, such as beaches and dunes (Quartzipsamments, STS; Regosols, FAO). Rock falls also belong to the same group.

II. Classe des sols peu évolués (Weakly Developed Soils)

Sous-classe: non climatiques (nonclimatic)
Groupe: d'érosion (eroded)

Only the regosolic subgroup is represented. Most of the soils in this subgroup have a modal facies. They occur on gravelly material produced from dismantled hard pan, sandstone or various other rocks, and clayey material that resulted from the weathering of various kinds of basic rocks. The profile (solum) is shallow or very shallow since it is either undergoing very little evolution or being constantly rejuvenated by erosion. A brown eutrophic facies can be found in Senegal Oriental on basic rock debris (Ustropepts and Eutropepts, also Ustorthents, STS; Regosols, Arenosols, Rankers, FAO).

Groupe: d'apport (deposited)

Several subgroups are represented. The modal subgroup demonstrates a leached, hydromorphic or more often ferruginous facies on marine terraces, lower colluvial slopes or valley slopes. The hydromorphic subgroup is found along the drainageways on gravelly or colluvial/alluvial material, on plateaus with gravelly material produced from dismantled hard pan and on gravelly and arenaceous granitic material (in the Saraya Massif). In the coastal formations, it is found in association with the halomorphic subgroup. The vertic

subgroup is evident in Senegal Oriental on clayey material that results from the weathering of various kinds of basic rocks.

All these soils are in an early stage of evolution and have characteristics related to those of the corresponding mature soils. In the field, however, soils on gravelly material produced from dismantled hard pan seem to proceed from both erosional and depositional process, but the classification does not allow for this case (Fluvents and Tropepts, in general, STS; Regosols, Arenosols, FAO).

III. Classe des vertisols (Vertisols)

Sous-classe: topomorphes (related to site, e.g., poorly drained depressions)
Groupe: non grumosoliques (nongrumosol)

The soils of the basins in the Senegal River Valley and the Anambe and Sine/Saloum depressions include the modal and hydromorphic subgroups (Pellusterts, also Aquepts, etc., STS; Vertisols and Gleysols, FAO).

Sous-classe: lithomorphes (with illuviated clay)
Groupe: non grumosoliques et grumosoliques (grumosol and non grumosol)

Both groups had to be mapped together, the nongrumosol being by far the most common one. These soils are mainly found in the Senegal Oriental (Monts Bassari, Bandafassi Massif) on clayey material that results from the weathering of various kinds of basic rocks or schist. Although most available documents mention the presence of vertisols, the vertic characteristics (cracks, gilgai, pressure faces) are often not very apparent in the field. The adjective "vertic" (sols vertiques) was therefore preferred in the mapping unit descriptions in order to refer to the presence of hydromorphic intergrades or paravertisols together with the true vertisols (Chromusterts, also Aquepts, etc., STS; Vertisols and Gleysols, FAO).

IV. Classe des andosols (Andosols)

This class was not mapped.

V. Classe des sols calcimagnésiques (Calcimagnesian Soils)

Sous-classe: carbonates (carbonated)
Groupe: rendzines (rendzinas)

Rendzinas are found, but they are confined to the edges of the Bargny Plateau and the hills of the Matam strip (Rendolls, STS; Rendzines, FAO).

Groupe: sols bruns calcaires (calcareous brown soils)

A tendency toward calcareous brown soils is observed south of the Thies plateau (Xerochrepts, STS; Calcic Cambisols, FAO). Calcium and magnesium dominate in the exchange complex. Rendzinas show a dark, shallow profile on calcareous material; calcareous brown soils are deeper, paler and partially leached.

VI. Classe des sols isohumiques (Isohumic Soils)

Sous-classe: à pédoclimat chaud en saison des pluies (with a warm soil climate in the rainy season)
Groupe: bruns subarides (subarid brown soils)

Various subgroups are quite common in northern Senegal: modal, rubefied (subarid reddish-brown soils) and also vertic on clayey material and solonetzic on schist in the Bakel area. Profiles are deep, and the organic matter content decreases progressively toward the base of the profile. Degradation facies, halomorphic, tropical or ferruginous intergrades, are generally represented (Aridisols, STS; Xerosols, FAO).

VII. Classe des sols brunifiés (Brunified Soils)

Sous-classe: tropicaux (tropical)
Groupe: bruns eutrophes (eutrophic brown soils)

The weakly developed, vertic, ferruginous and hydromorphic subgroups are all related to swelling clays, rich in montmorillonitic minerals or clayey materials that result from the weathering of various kinds of basic rocks. These rocks are rather common in the eastern part of the country; the deep soils that form a mull-type humus, a well-developed structure and an exchange complex rather saturated in calcium (Eutrochrepts and Ustochrepts, STS; Eutic Cambisols, FAO).

VIII. Classe des sols podzolisés (Podzols)

This class was not mapped.

IX. Classe des sols a sesquioxydes (Sesquioxides Soils)

Sous-classe: ferrugineux tropicaux (tropical ferruginous)
Groupe: non on peu lessivés (not leached)

The modal and weakly developed subgroups are often found on reworked sandy material, which is typical of the northern part of the country, viz., in the dune area and in the Groundnut Basin (Ustropepts, STS; Nitosols and Aerisols, FAO).

Groupe: lessivés (leached)

Several subgroups are also found: modal; weakly differentiated on hard pan; indurated and hydromorphic with streaks or concretions. They are generally found on colluvio-alluvial material in the valleys, on material derived from the "Continental Terminal" sandstones or infill material on the plateaus, or on material derived from granite (Saraya Massif). These soils are primarily found in the southern part of the country: Casamance, Senegal Oriental, South Ferlo (Ustox, Ustults, STS; Nitosols and Acrisols, FAO).

Tropical ferruginous soils are typical of ancient weathered surfaces; they are deep and rich in sesquioxides, but with no free aluminum.

X. Classe des sols ferralitiques (Ferralitic Soils)

Sous-classe: faiblement désaturés (slightly desaturated)
Groupe: appauvris (depleted)

The modal subgroup is found on dry material derived from the "Continental Terminal" and hard pan or colluvio-alluvial material. Ferralitic soils only occur in the Casamance and The Gambia. They are usually very deep and are characterized by strong weathering, which leads to the occurrence of free iron and aluminum sesquioxides (Ustox, STS; Ferralsols, FAO).

XI. Classe des sols hydromorphes (Hydromorphic Soils)

Sous-classe: minéraux ou peu humifères (inorganic)
Groupe: à pseudogley (pseudogley)

This class is primarily represented by one subgroup, which contains streaks and concretions on infill material from plateaus or on colluvio-alluvial material.

Groupe: à gley (gley)

The deep to shallow and saline gley subgroups are found primarily on colluvio-alluvial material in valleys.

Groupe: à gley salé (saline gley)

This group is restricted to coastal formations and terraces.

Sous-classe: moyennement organiques (moderately organic)
Groupe: à gley salé (saline gley)

This group is found on mudflats (clay).

Sous-classe: organiques (organic)
Groupe: tourbeux (peaty soils)

In functional mangroves, the eutrophic subgroup is found in the very humic mudflat clays.

Although hydromorphic soils vary greatly, they have in common an evolution controlled by the oxidation-reduction process. This process is due, at the least, to temporarily waterlogged conditions which are evidenced by the presence of typical colors (Aquepts, etc., STS; Fluvisols and Gleysols, FAO; also Histosols, STS and FAO).

XII. Classes des sols sodiques (Sodic Soils)

Sous-classe: à structure non dégradée (nondegraded structure)
Groupe: salins (saline)

All of the following subgroups are found in the coastal formations: afflorescence or crust; friable, surficial horizon; with sulfates or acidified (Halaquepts, Sulfaquepts, etc., STS; Solontchaks, etc., FAO).

Sous-classe: à structure dégradée (degraded structure)
Groupe: à alcalis non lessivés (alkaline)
Groupe: solonetz (solonetz)

Both groups are also present in the coastal formations but as a minor component. A majority of these soils are found in the Senegal Oriental on material derived from the weathering of sericite schists (Natrargids, etc., STS; Solonetz, FAO).

The evolution of saline soils is characterized by the presence of salts (chloride or sulfates), while alkaline soils are characterized by an excess of sodium.

4.4 PRODUCTION OF DERIVED MAPS

4.4.1 Introduction

The informational content of the soilscape map was converted into parameters and tables, which provided a basis for redefining the mapping units. Hence, two maps were derived from the soilscape map, e.g., a land capability map and a soil degradation map.

The procedure followed will here be described in detail.

4.4.2 Land Capability Map

4.4.2.1 Criteria

A. Introduction

The Remote Sensing Institute follows a parametric approach in the preparation of land capability maps.

This procedure consists of transforming soil data (provided by literature or by field work) into first order parameters. These first order parameters include a number of simple characteristics that are normally directly observable or measurable in the field or are the results of laboratory analysis. The following characteristics were selected in the frame of this study:

1. slope
2. useful soil depth
3. texture (topsoil and subsoil)
4. stoniness
5. rockiness
6. coarse fragments
7. drainage
8. pH
9. salinity
10. sodicity
11. actual erosion

The second order parameters which correspond to combined characteristics are then inferred from the first order parameters on the basis of additional laboratory results or other available observations. These data are generally converted into parameters by means of conversion tables. The second order parameters obtained or derived within the frame of this study are as follows:

1. water holding capacity
2. permeability
3. potential irrigability
4. workability
5. seeding establishment
6. potential mechanization
7. wind erosion susceptibility
8. water erosion susceptibility
9. erosion hazard
10. chemical fertility

When available, additional data are also introduced into the system. Soil climate characteristics were defined based on the results of a study published by Cornell University, SMSS Technical Monograph No.3, 1982 and on the available rainfall data for Senegal. Four soil climate zones were recognized.

One should bear in mind that only the characteristics of the major component are considered in the computation of the parameter of the mapping units. When within the same mapping unit more components are represented by a rather high percentage, the computed value should take this fact into consideration. Several values may be given to show variations of equal importance or an incidental value may be mentioned in parentheses. Parameters for all mapping units are presented in tabular form for easy comparison in Appendix B, Tables IV-3 and IV-4.

B. First Order Parameters

Definition

First order parameters, which correspond to simple characteristics, are often directly observable or measurable in the field or readily available from laboratory analyses. Each characteristic will be discussed individually. The numerical values (ranks) attached to classes normally increase from the most favorable to the least favorable level but the number of classes may vary according to the characteristic considered. Although some authors have used "0" as a rating, it is not used here.

1. Slope

The slope parameter takes into account the relief of the mapping unit. Seven classes are defined; the range in slope for each class is given in percentage (rise overrun). Classes were selected on the basis of the United States Department of Agriculture Soil Survey Manual guidelines. The attribution of a slope class to a mapping unit means that most slopes stay within the indicated range. However, a given slope in the field may exceptionally be steeper or, as is more likely, more gentle than indicated.

In class 1, the relief is flat or almost flat. In the text, one may also read about level, or nearly level, topography. In this case, slopes do not reach 2%.

Class 2 relief is slightly undulating; slopes are gentle and range from 2 to 6%.

Class 3 corresponds to a strongly undulating relief; the slopes are moderate and range from 6 to 9%.

Class 4 corresponds to a rolling relief with moderate to steep slopes that range from 9 to 15%.

Class 5 corresponds to a hilly relief, with moderately steep to steep slopes that range from 15 to 30%.

Class 6 corresponds to a steeply dissected relief, with steep slopes that range from 30 to 50%.

In class 7, the relief is very steeply dissected, with steep slopes, steeper than 50%.

Rank	Description: Relief	Description: Slopes	Limits
1	flat, almost flat	level, nearly level	<2%
2	slightly undulating	gentle	2-6%
3	strongly undulating	sloping	6-9%
4	rolling	sloping to moderately steep	9-15%
5	hilly	moderately steep to steep	15-30%
6	steeply dissected	steep	30-50%
7	very steeply dissected	very steep	>50%

2. Useful Soil Depth

The useful soil depth parameter relates to the depth of possible root development. It is similar to the parameter proposed in the Soil Survey Manual and corresponds to the profile thickness which can easily be penetrated by the roots. It represents a profile depth (in centimeters). to a restricting horizon (e.g., a water table or a compacted, crusted, extremely gravelly or saline layer).

In class 1, no restricting horizon is present unless at a very great depth--below 120 cm--and soils are very deep.

Class 2 soils are deep with restrictions at great depth, or between 100 and 120 cm.

In class 3, a restricting horizon is found at medium depth, between 80 and 100 cm, and soils are moderately deep.

In class 4, soils are shallow with a restricting horizon appears at a shallow depth, 25 to 50 cm.

Soils in class 5 are very shallow with a restricting horizon at a very shallow depth, within 25 cm from the surface.

Rank	Description	Depths
1	very deep	>120 cm
2	deep	100-120 cm
3	moderately deep	50-100 cm
4	shallow	25-50 cm
5	very shallow	<25 cm

3. Texture

Texture refers to the relative proportions of the various mineral particles (clay, loam and sand) that comprise the fine earth. It is either determined by feel or ascertained through laboratory analysis. Textural classes used here are those defined in the Soil Survey Manual. Class boundaries are fixed by percentage values for each component, but a textural triangle as shown in Table 4.1 gives a much more convenient representation. Each polygon in the triangle is given a name covering that particular range in texture. Because it would be quite unrealistic to decide on a definite hierarchy on the basis of the agricultural value of these different textures, they are arbitrarily ranked from coarse to fine. Class 1 corresponds to soils "with no earth" such as rubble, boulders, rock and crust or hard pan outcrops, and extremely stony soils are in class 2. Ranks 3 to 7 correspond to the various classes of the textural triangle. The classification and terms used are summarized in the table below.

Rank	Description	Textures
1	concrete	rubble, boulders, rock and crust or hard pan outcrops
2	very coarse, gravelly	extremely stony
3	coarse	sand, loamy sand
4	medium	sandy loam, fine sandy loam, very fine sandy loam, loam, fine loam loam, fine clay fine loam loam, silt
5	moderately fine	sandy clay loam, clay loam, silty clay loam
6	fine	sandy clay, silty clay, clay
7	very fine	fine clay (with over 60% clay particles)

4. Stoniness

Stoniness takes into account the varying presence of coarse fragments (stones) on the soil surface. Class intervals are defined in percentage and the average distance between large stones about 25 cm in diameter is given as an example. The classes are those defined by the FAO.

Soils with no or very few stones (less than 0.01% stones on the surface) belong to class 1.

Soils in class 2 are slightly stony. Stones cover from 0.01 to 0.1% of the soil surface, and large stones are 10 to 30 m apart.

Soils in class 3 are stony. Stones cover from 0.1 to 3% of the soil surface, and large stones are only 1.6 to 10 m apart.

TABLE 4.1
CONVERSION TABLE

PARAMETERS	CLASSES			
	A1	A2/C2	A3/C3	N.
Slope	1,2	3,4	5,6	7
Depth	1,2	3	4	5
Texture (topsoil)	...	...	...	1,2&7
Stoniness	1,2	2,3	4	5,6
Rockiness	1	2,3	3,4	5,6
Coarse Fragments	1	2,3	4,5	6
Drainage (I,II)	4,5	3	1,2	6
(III,IV)	1,2	3,4	4,5	6
pH	1	1,2	2	3
Salinity	1	2	3	4,5
Sodicity	1	2	3	4,5
Efflorescence	-	-	-	E
Actual Erosion	1	1	2	3,4
Water Holding Capacity	1,2	3	4	5
Permeability (I,II)	3	2	1,2	4
(III,IV)	1,2	2	3	4
Potential Irrigability	(1)	1	2	3
Workability	1	2	3	4
Seeding Establishment	1	2,3	4	5
Mechanization	1	2	3	4
Wind Erosion Susceptibility	2,3	4,5	6,7	1&8
Water Erosion Susceptibility	1	2	3,4	5
Erosion Hazard	1	2	3	4
Fertility	1	2	2	3

In class 4, the soils are very stony, with from 3 to 15% stones on the surface,; large stones are only 75 to 160 cm apart.

In class 5, soils are exceedingly stony and are 15 to 90% covered with stones. The distance between large stones is less than 75 cm.

Class 6 corresponds to rubble land with more than 90% stones.

Rank	Description	Percentage	Distance between big stones (25 cm)
1	no or very few stones	<0.01	----
2	slightly stony	0.01-0.1	10 - 30 m
3	stony	0.1-3	1.6- 10 m
4	very stony	3-15	75-160 cm
5	exceedingly stony	15-90	< 75 cm
6	rubble land	>90	----

5. Rockiness

Rockiness describes the occurrence of rock outcrops and is expressed as a percentage. The classes chosen are those recommended by the FAO.

In class 1, rock outcrops cover less than 2% of the soil surface with no or very few rocks. These outcrops do not significantly influence agricultural practices.

In class 2, soils are slightly rocky and 2 to 10% of the soil surface is covered by rock outcrops about 35 to 100 m apart.

In class 3, soils are rocky; rock outcrops extend over 10 to 25% of the soil surface and are 10 to 35 m apart. Agricultural practices are practically impossible to implement; exceptions are very rare.

In class 4, rock outcrops cover from 25 to 50% of the soil surface; they are about 3.5 to 10 m apart. The use of machinery is prohibited on such rocky soils, except for light machinery in specific cases.

In class 5, soils are extremely rocky; outcrops are usually only 3.5 m apart at the most and cover 50 to 90% of the soil surface. The use of any kind of machinery is impossible.

In class 6, rock outcrops cover over 90% of the soil surface.

Rank	Description	Frequency	Spacing
1	no or very few rocks	< 2%	----
2	slightly rocky	2-10%	35-100 m
3	rocky	10-25%	10-35 m
4	very rocky	25-50%	3.5-10 m
5	extremely rocky	50-90%	<3.5 m
6	outcrops	>90%	----

6. Coarse Fragments

The coarse fragments parameter is defined by the relative amount of course fragments present in the soil profile. The classification designed by RSI is somewhat more detailed than those recommended by the Soil Survey Manual or by the FAO. It constitutes six classes--class limits are expressed in gravel percentage--and it is summarized in the table below.

Rank	Description	Gravel Content
1	no or very few fragments	< 5%
2	slightly gravelly	5-15%
3	moderately gravelly	15-35%
4	gravelly	35-60%
5	very gravelly	60-80%
6	gravel	>80%

7. Drainage

Soil drainage describes the moisture conditions within the profile. Because water movement with a soil profile is reflected in the oxidation reduction process, the drainage condition can be inferred from the color of the soil or from the presence of typical mottlings in relation to depth. The classification adopted within the frame of this study is similar to the one in use at the International Institute for Aerial Survey and Earth Sciences, ITC, Enschede, The Netherlands. Compared to the one developed in the Soil Survey Manual or by the FAO, it has the advantage of presenting a more quantitative approach. Classes are determined by the depth at which mottle or reducing conditions are observed.

Class 1 soils are somewhat excessively drained; mottle or reducing conditions do not appear in a normally deep profile (150 cm). In this case, the slope may also play a role in the excessive runoff.

In class 2, soils are well drained. Mottles may be found at 30 cm and deeper, but reducing conditions do not appear within 150 cm.

In class 3, soils are moderately well drained. Mottles are observed from 50 cm, but reduced conditions start at 120 cm.

Class 4 corresponds to imperfectly drained soils. Mottles and reducing conditions are observable at 50 cm.

In class 5, soils are poorly drained, and mottles and reducing conditions can be observed within the topsoil.

In class 6, soils are very poorly drained and very strongly reducing conditions occur at or very near the surface.

This classification is summarized in the following table.

Rank	Description	Depth of the Mottlings	Depth of the Reduction
1	somewhat excessively drained	<150 cm	<150 cm
2	well drained	> 90 cm	<150 cm
3	moderately well drained	< 50 cm	<120 cm
4	imperfectly drained	< 50 cm	< 50 cm
5	poorly drained	> 50 cm	≥ 50 cm
6	very poorly drained	surface	surface

8. pH

The pH value to some extent reflects the chemical fertility of soils. It is an important parameter since most crops are unable to grow well under too acid or too alkaline conditions. The classification adopted for this study had to be simple because pH data were available from very different sources, and classes had to therefore be broad enough to absorb the variability due to the various pH measuring techniques. Five pH levels were thus selected. The ranking does not actually follow the pH scale, but a suffix was used to show the acidity or the alkalinity ("alc" stands for the French alcalin). The classification is detailed in the table below.

Rank	Description	pH
1	neutral	6.1-7.3
2ac	acid	4.5-6.0
2alc	alkaline	7.4-8.2
3ac	strongly acid	<4.5
3alc	strongly alkaline	>8.2

In the text, the terms "slightly acid" and "quite acid" were used to designate pH values ranging from 5.5 to 6.0 and 4.5 to 5.0, respectively. Only the pH of the topsoil is used in the final ratings.

9. Salinity

The salinity parameter refers to soluble salts in the topsoils as it may be expected to affect normal plant growth. Class limits are set by electric conductivity measurements (in mmhos/cm) of saturation

extracts at 25°C. Classes are based on the Soil Survey Manual recommendations. When a soil was at least slightly saline, but analytical data were lacking, the salinity parameter was rated "X" in the table of characteristics, Appendix B, Table IV-3. The symbol "E" was also used to show the possible presence of salt efflorescenes on the soil surface. Salinity classes are summarized in the table below.

Rank	Description	Electric Conductivity in mmhos/cm
1	nonsaline	<2
2	very slightly saline	2-4
3	slightly saline	4-8
4	saline	8-16
5	strongly saline	>16

10. Sodicity

The sodicity parameter refers to the amount of sodium in the soil cation exchange complex. Classes are defined by Exchangeable Sodium Percentage (ESP) and Sodium Absorption Ratio (SAR) for the topsoil. Either one or the other of those two values is normally computed immediately by the soil analysis laboratories and can thus be considered as a first order parameter. As for salinity, the "X" rating was used when figures were lacking (Appendix IV-3). The table below summarizes the sodicity classes.

Rank	Description	ESP	SAR
1	nonsodic	<4	<4
2	very slightly sodic	4-10	4-8
3	slightly sodic	10-20	8-18
4	sodic	20-35	18-38
5	strongly sodic	>35	>38

11. Actual Erosion

The intensity of the actual erosion readily noticeable in the field is expressed as a parameter simply by giving the percentage of the area affected by erosion. Classes follow the Soil Survey Manual guidelines.

In class 1, soils are slightly eroded; less than 25% of the soil surface shows erosional features.

In class 2, soils are considerably eroded; 25 to 75% of the soil surface is affected by erosion.

In class 3, soils are severely eroded, over 75% of the soil surface are affected by erosion.

Extreme or spectacular cases (e.g., Badlands), where the entire soil surface is permanently affected by remarkable active erosion, are listed as class 4.

Rank	Description	Area Affected
1	slightly eroded	<25%
2	considerably eroded	25-75%
3	severely eroded	>75%
4	extremely eroded	100%

C. Second Order Parameters

Definition

Second order parameters correspond to complex characteristics and are most often obtained by combining first order parameters. Other nonparametric criteria or computations are involved so that some data processing is needed before establishing those parameters.

The conversion tables used here were developed by RSI during years of national and international experience. The values of the various parameters considered are introduced in the table, which then visually or arithmetically shows the value (class) of the new parameters. It may be necessary to consider certain readings in light of particularly limiting factors; thus, the use of the tables is not purely mechanical: one should take into account any available, often nonquantifiable, information. Each characteristic is individually discussed here and the conversion table is given for each case.

1. Water Holding Capacity

Experience and literature show that for any kind of texture, an average value expressed as a percentage can be given for the corresponding water holding capacity. The water holding capacity takes into account the useful depth of the profile, and it is calculated in centimeters of water on the basis of the texture of each horizon for the upper 150 cm of the profile or to the level of a restricting horizon (e.g., hard pan). Class limits are set by the centimeters of water given in the table below.

Rank	Description	Water Holding Capacity (cm/150cm)
1	very high	>23
2	high	16-23
3	medium	12-16
4	low	8-12
5	very low	<8

The choice of these values rests on empirical observations and the knowledge of the water requirements of common crops. The method is used quite extensively by many authors. The classification given here is similar to that in use at the International Institute for Aerial Survey and Earth Science.

2. Permeability

Since infiltrometer measurements are seldom available and always questionable, permeability is inferred from the influence and interaction of such characteristics as texture, amount of coarse fragments, presence of a restricting layer. The classification is therefore rather subjective, and its use is also difficult. A well-drained soil, for instance, can be less favorable than a less permeable soil in an arid region where irrigation is a must, while it would become more favorable in a wetter climate. Classes can still be summarized below.

Class 1 soils have high permeability; they are generally coarse or moderately coarse textured (sand, loamy sand, sandy loam, very fine but well-flocculated loam) and are always deep. Rapidly draining, gravelly soils also belong to this class.

Class 2 soils have moderate permeability; they are often moderately fine to moderately coarse textured (sandy loam, fine loam).

Class 3 soils have low permeability; they are heavier with an often moderately fine to fine texture (clay loam, very fine loam), which may be coarser though if a restricting layer is present at depth.

Class 4 soils have very low permeability, which may be due to a high water table, shallow to very shallow depth, restricting layer at shallow depth, or if combined with abundant rainfall, a very heavy texture, viz., expanding clays.

Rank	Description
1	high
2	moderate
3	low
4	very low

3. Potential Irrigability

The parameter considers the physical properties of the soil in view of potential irrigation. The class is determined by comparing a soil's parameters to those listed as corresponding to the most favorable conditions, e.g., level or nearly level to very gently sloping slope, deep soil, medium to moderately fine textured topsoil, well drained soil, medium water holding capacity, moderate permeability and, at the most, slightly saline soil. The soil is rated 1,

irrigable, if all its parameters equal those listed as optimum.

The soil is rated 2, conditionally irrigable, if deviations are few and of small amplitude. Thus, a soil which is little too light in texture and too permeable could still be irrigated by sprinkling, but the level of investment would then be much higher.

The soil is rated 3, nonirrigable, if too many parameters significantly deviate from the values listed as optimal or an extreme deviation for at least one of them (which is considered as a major limitation).

More intensive soil surveys should be undertaken in the areas where the 1 (or 2) rated soil occur. This will guarantee exact location and description of soils with high potential.

Rank	Description
1	irrigable
2	conditionally irrigable
3	nonirrigable

The Appendix B, Table IV-4 ratings are mentioned in brackets when the soil climate zone does not necessarily require crop irrigation.

4. Workability

The soil workability expresses the quality of the soil in view of the use of manual or animal tractional agricultural tools. Several factors are involved, but the three most important ones are stoniness, coarse fragments and topsoil texture. These factors are considered in the conversion table below. The lowest ranking factor determines the placement of any given soils for any of the second order parameters, e.g., a soil with stoniness -3, coarse fragments - 3, and texture - 1 places that soil in rank 4 - very poor.

		Rank of the Combining Factors		
Rank	Description	Stoniness	Coarse Fragments	Texture
1	good	1-2	1-2	3
2	fair	3	3	4
3	poor	4	4	5-6
4	very poor	5-6	5-6	1-2 & 7

5. Seedling Establishment

This second order parameter refers to the degree to which the physical characteristics of the topsoil are favorable to the establishment and development of seedlings. In the table below, the coarse fragments parameter is combined with soil structure, consistency, and the likelihood of crust formation, although these critera are more subjective than quantitative.

		Physical Characteristics			
Rank	Description	Structure	Consistence Moist/Dry	Crust Formation	Coarse Fragments (rank)
1	very good	granular crumbly fine, (sub)angular angular blocky	loose	nil	1
2	good	medium (sub)angular angular blocky	v. friable/ soft	occasional	2
3	fair	coarse, (sub)angular angular blocky	friable/ slightly hard	slight	3
4	poor	prismatic massive	firm/hard	moderate	4
5	very poor	platy	v. firm/ v. hard	strong	5-6

6. Potential Mechanization

The potential mechanization parameter considers the possibility of using mechanical agricultural equipment. Mechanization depends mainly on the type of relief--described in general terms and with slope classes--as well as on parameters already defined, such as stoniness, rockiness and topsoil texture. The conversion table is given below.

Relief		Rank of the Combining Fators				
Rank		Description	Slope	Stoniness	Rockiness	Texture
1	high	flat, undulating	<8%	1-2	1	3-(4)
2	medium	rolling	8-16%	3	2	4-5
3	low	hilly	16-30%	4	3-4	6-7
4	very low	steeply dissected (+ swamps)	>30%	5-6	5-6	1-2

7. Wind Erosion Susceptibility

Wind erosion susceptibility indicates the sensitivity of soils to deflation. It takes into account primarily the texture of the topsoil.

Class 1 soils are not susceptible; they are stony or gravelly soils and outcrops that are not subject to wind erosion.

Class 2 soils have very low susceptibility. They are loamy soils with 18 to 35% clay and less than 5% finely divided calcium carbonate and include silty clay loams with less than 35% clay and less than 5% finely divided calcium carbonate. Crops can easily be grown without major wind erosion hazard.

Class 3 soils still have low susceptibility. They are loamy soils with less than 18% clay and less than 5% finely divided calcium carbonate, as well as sandy clay loams or sandy clays with less than 5% finely divided calcium carbonate. Crops can be grown under control.

Class 4 soils have moderate susceptibility. clay loams and silty clay loams with over 35% clay. Crops can be grown on these soils, and, to present serious erosion, appropriate control measures should be implemented.

Class 5 soils have a fairly high susceptibility. They are calcareous loamy soils with less than 35% clay but more than 5% finely divided calcium carbonate. Crops may be grown if intensive protection measures are implemented.

Class 6 soils have high susceptibility; they include all of the sandy loams, and crops should only be grown if intensive protection measures are in place.

Class 7 soils have very high susceptibility; they include all of the loamy sands, which should only be cultivated if intensive protection measures are taken.

Class 8 is characterized by extremely high susceptibility. They include all sandy soils (coarse, fine or very fine sand). Natural vegetation does not grow easily on such mobile sands, which are usually unsuitable for agriculture.

Rank	Description	Texture Group
1	none	stony
2	very low	loams
3	low	loams, sandy clays
4	moderate	clays and loams
5	fairly high	calcareous loams
6	high	sandy loams
7	very high	loamy sands
8	extremely high	sands

8. Water Erosion Susceptibility

The water erosion susceptibility (soil surface) refers to intensity of the erosion by rainfall and runoff. The important criteria are the grade of the structure (of the topsoil), the slope, and the surface texture. The conversion table is given below.

Rank	Description	Grade of Structure	Rank of Combining Factors	
			Slope	Texture
1	very low	moderate to strong	1	3
2	low	moderate	2-3	4
3	moderate	weak	4	5
4	high	(cloddy)	5	6
5	very high	(cloddy)	6-7	7

If field observations indicate the infiltration capacity appears to be particularly low or if the structure is of an unfavorable type (e.g., prismatic), then the susceptibility rank will be increased by one point.

9. Erosion Hazard

The erosion hazard represents the intensity of the risk of erosion It is defined by combining slope, actual erosion, and wind and water erosion susceptibiliy parameters and taking into account the grade of the topsoil structure and the extent of the vegetative cover. The conversion table is given below.

Rank of the Combining Factors

Rank	Description	Slope	Actual Erosion	Erosion Susceptibilities Wind	Erosion Susceptibilities Water	Grade of Structure	Vegetative Cover
1	low	1	1	1-2	1	med.-strong	75-100%
2	moderate	2-3	2	3-4	2	medium	50-75%
3	high	4-5	3	5-6	3	weak	25-50%
4	very high	6-7	4	7-8	4-5	very weak, unfavorable	0-25%

Rank 4 actually corresponds to an extremely degraded area.

10. Chemical Fertility

The chemical fertility is estimated from the results of laboratory analyses. It is a theoretical concept which combines those parameters that influence plant growth. A bilevel conversion table is used here since the number of classes is different for the various parameters. The table combines pH, organic matter content (expressed by the carbon content) and the carbon/nitrogen ratio of the organic matter, which is used as a mineralization index in three class levels, the cation exchange capacity (CEC) and the type of structure are combined in five class levels. The final rating lists three classes.

a.

Rank	pH	Carbon %	Carbon/Nitrogen Ratio
1	6.5-7.5	>2.5	10 (mineralized humus)
2	4.5-6.5 or 7.5-8.5	0.6-2.5	20 (active humus)
3	<4.5 or >8.5	<0.6	30 (inactive humus)

b.

Rank	Cation Exchange Capacity	Structure
1	very high: >16 meq/100 g	granular, crumbly, fine (sub)angular blocky
2	high: 12-16 meq/100 g	medium (sub)angular blocky
3	moderate: 6-12 meq/100 g	coarse (sub)angular blocky
4	low: 2-6 meq/100 g	prismatic, massive
5	very low: <2 meq/100 g	platy; self-sealing

c.

Rank*	Description
1	fertile (no improvements needed), (a + b) = 2 or 3
2	arable (with improvements), (a + b) = 4-5 or 6
3	poor, (a + b) = 7 or 8

*Field observations are taken into account in order to balance arithmetical results.

D. Soil Climate Zones

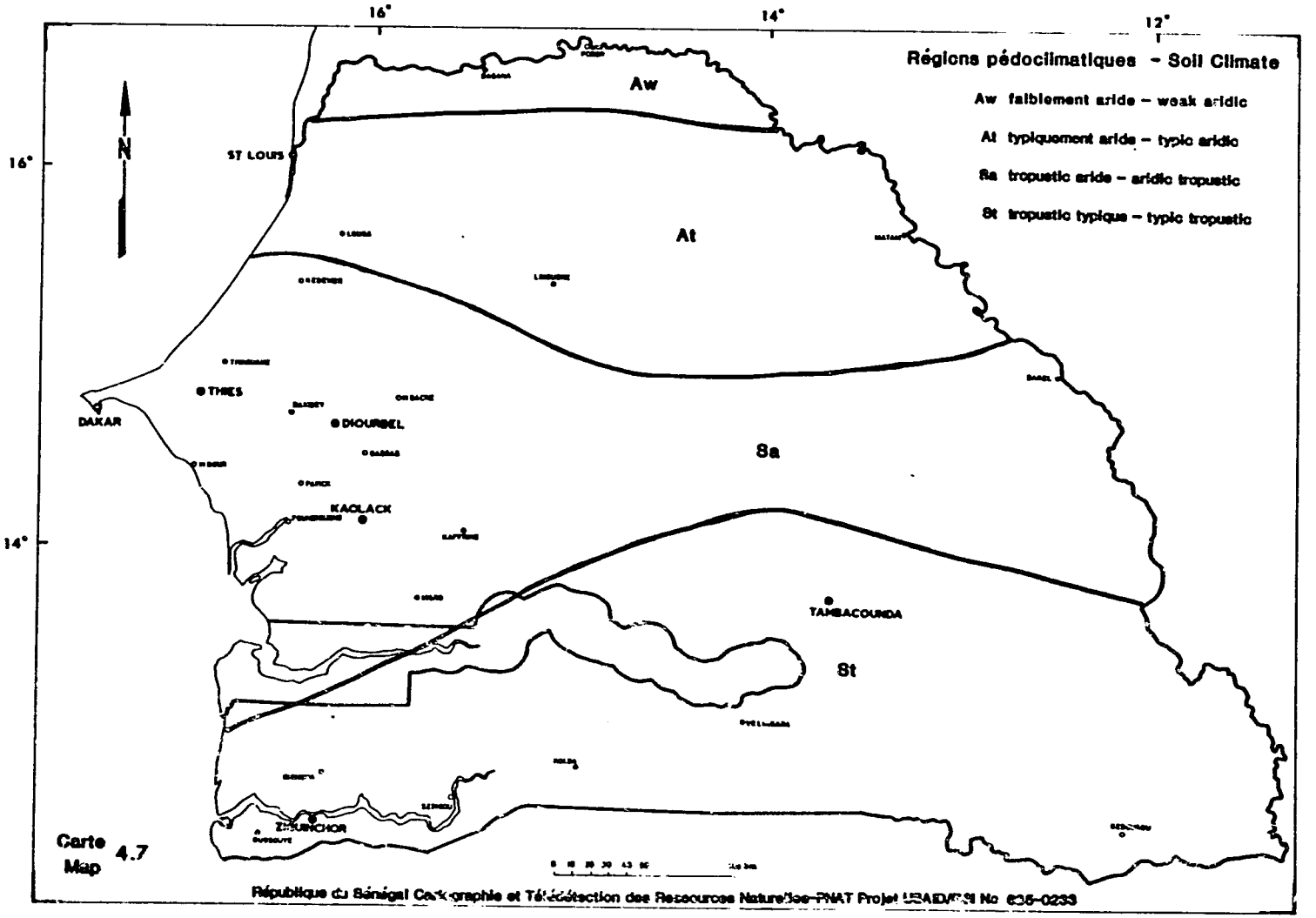
In order to take into account the influence of the climate, reference was made to a 1984 study by A. Van Wambeke of the New York State College of Agriculture and Life Sciences, Cornell University. The study defines soil climate zones for the African continent. Map 4.7 taken from this study, together with rainfall data and field observations, was the basis for the definition of four soil climate zones. Since the delineation of these zones proceeds from a theoretical model, they were not represented on the map, but the position of each soilscape mapping unit was checked in relation to them, so they do influence the final suitability rating (Appendix B, Table IV-5). The soil climate zones thus defined can be summarized as follows:

Zone I: Typic Arid. This zone runs across the northern part of the country where annual rainfall seldom exceeds 350 mm. Cultivation is in any case impossible without irrigation since soil moisture never lasts, even partially, for more than 45 consecutive days.

Zone II: Weak Arid. This zone covers most of the Ferlo on the northern side of the line joining Kebemer to Deali and Bakel. Annual rainfall seldom exceeds 600 mm. Soils retain their moisture for a longer period of time, but water will not be available for more than 3 consecutive months. Rainfed cultivation is theoretically possible, but still very hazardous, since precipitation is very erratic and very irregularly distributed within the area. Thus, irrigation is still a basic necessity for which land management planning should provide.

Zone III: Arid Tropustic. This regime is characterized by a dry season during which soils are physiologically dry for a period of 3 to 9 months. When favorable conditions last for 3 to 6 months, crops can be grown without irrigation. Annual rainfall can reach 800 mm. The Cap Vert and the Sine Saloum regions are located in this zone, which extends in a narrow strip to the Senegal River between Bakel and Kidira.

Zone IV: Typic Tropustic. This regime is also characterized by a dry season during which soils are physiologically dry for over 3 months, but they do keep their moisture without interruption for 6 to 9 months. Annual rainfall most often exceeds 800 mm. This zone covers The Gambia, Casamance and Senegal Oriental.



Régions pédoclimatiques (d'apres A. Van Wambeke)

Soil climate zones (after A. Van Wambeke)

4.4.2.2 Ratings

A. Introduction

The land capability map considers three aspects of human activity: agriculture, grazing and forestry. For each of these activities a multilevel classification was devised and represented on the map by means of hachures or a gray scale. Since they are overprinted, any type of combination is possible. Moreover, the mapping unit boundaries of the morphopedological map are also shown for easy comparison. The map can eventually be summarized in tabular form by listing the soilscape mapping unit symbols together with their suitabilities; the soil climate zones are also mentioned in the same table, Appendix IV-5.

B. Capability Classes for Cultivation

Agricultural capability classes are established by means of a classical conversion table that takes into account all previously defined parameters (Table 4.1). Due to the complexity of nature, its characteristics can of course not be limited to a series of parameters; all available sources of information should be considered in order to balance the results of what would otherwise be a purely arithmetical use of the table. Hence, in a dry climate, a physiographic position that leads to imperfect or poor drainage and low permeability can become a favorable factor.

A1, High Potential. Land in this class has very few minor limitations, which have no significant influence on productivity. Good agricultural conservation practices are of course recommended, but various crops can easily be grown. Most parameters actually rank 1 or sometimes 2. Class A1 is not significantly present in Senegal and was therefore not represented on the 1:500,000 scale map.

A2, Moderate Potential. This land has some major limitations which influence productivity. Cultivation requires investments in addition to current inputs and conservation practices. Fertilizers and organic matter are indispensable at each growing season to assure acceptable yields. Most parameters actually rank 2 or sometimes 3.

A3, Marginal Potential. This land has numerous major limitations. If cultivation is possible, significant investments are regularly made, although the resulting yields do not quite justify the expense. Yet, cultivation for local subsistence is always possible. Many parameters actually rank 3 or 4.

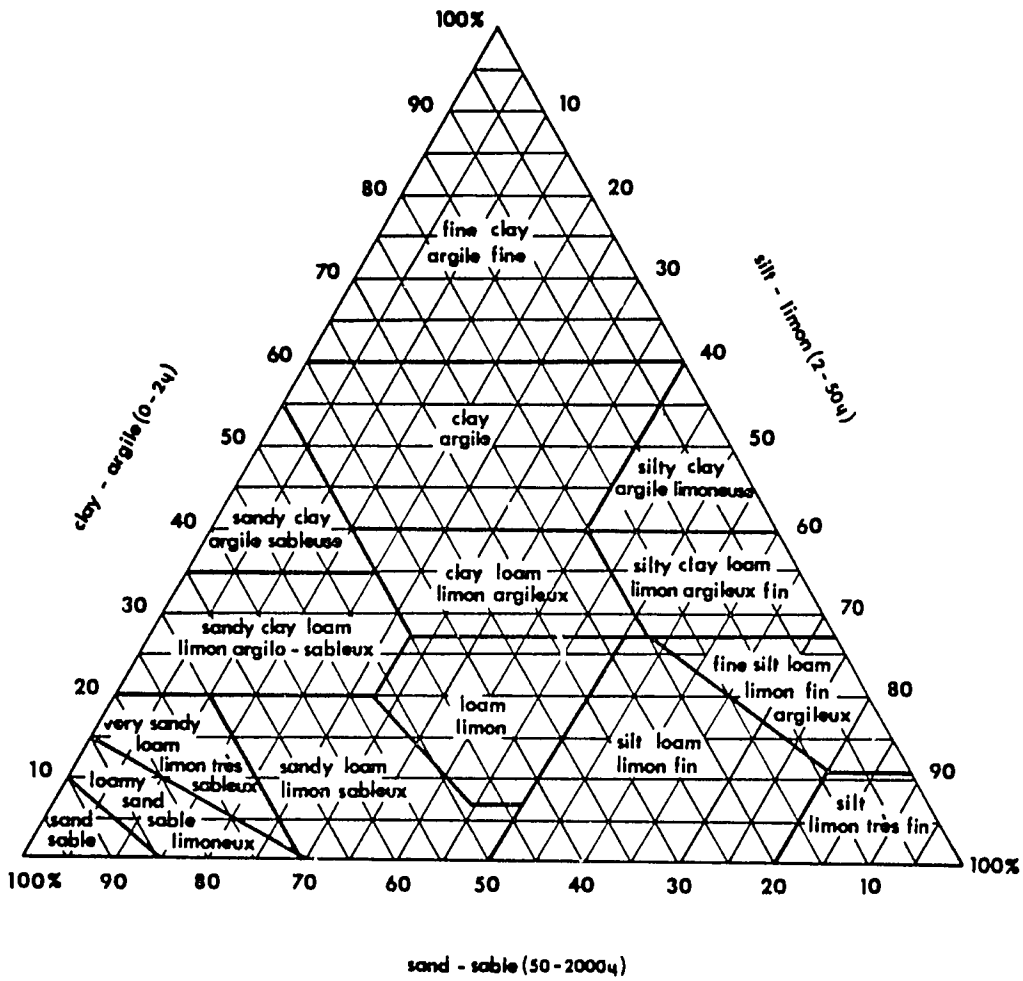


Table 4.2 Textural Triangle

C2, Conditional Moderate Potential. Although this land has one or two major limitatons, after one important initial investment (drainage, irrigation, well drilling, etc.), it may acquire qualities similar to those of land in class A2. The necessity of such an investment is particularly important in soil climate zones I and II. Excepting the major but correctable limitations, other parameters usually rank 2.

C3, Conditional Marginal Potential. Even after a major initial investment, productivity cannot be expected to be much higher than that of land in class A3. Excepting the major but correctable limitations, parameters most often rank 3 and 4.

N, Not Suitable for Agriculture. This land has too many major limitations to be cultivated; despite the amount of investment, productivity will remain poor. Most parameters rank 6 or higher.

Agricultural capability classes are shows on the map by positive hachures, of which the line density increases as the suitability increases; dashed lines are used for conditional suitabilities. The unsuitable class was left blank.

C. Capability Classes for Grazing

A typical conversion table would not show which species are present, how they are grazed by cattle or indicate their value as a forage. Because of the vast number of available agrostological reports and rangeland maps, it was felt more appropriate to correlate the mapping unit characteristics with the information provided by these documents, which are often accompanied by a soil study. The table is largely based on available figures, but because of the variety of sources, it has been decided to limit it to a qualitative classification.

P1, Good Rangeland. The quality of these grazing lands is generally fair and more often good during the dry season and good to very good during the rainy season.

P2, Fair Rangeland. The quality of these grazing lands is generally poor to fair during the dry season and fair to good during the rainy season.

P3, Poor Rangeland. The quality of these grazing lands is generally poor or even very poor during the dry season and poor to seldom fair during the rainy season.

P4, Dry Season Rangeland (inundated). The quality of these grazing lands is generally good, but they are ephemeral and of small extent, e.g., inundated valley bottoms, lower reaches of the coastal formations, or the border of the Lac de Guiers.

N, Not Suitable for Grazing. These lands are of very poor grazing quality and should be protected.

Grazing capability classes are represented on the map by means of negative hachures, the line density of which increases as the suitability decreases. The unsuitable class was left blank.

D. Capability Classes for Forestry

An approach similar to that used for grazing was followed in attempting to define forestry capability classes, though there were fewer available documents. To compensate for the lack of documents, numerous inquiries were made of staff members of the Eaux et Forets, and relevant field observations were given more weight.

F1, Good Wood Production. Forestry is economically feasible. The natural forest stock can be enriched and reforestation for wood production can be attempted.

F2, Fair Wood Production. Stock enrichment and reforestation for wood production are only locally possible, and priority should be given to the most favorable sites.

F3, Locally Exploitable. Production is limited to a very small number of sites. Protective reforestation has to be considered, and local tree crop plantations should be preferred over agriculture. The needs of the local communities can be met by a well-controlled woodlot management scheme. Stock enrichment is only very locally possible.

F4, Protective Reforestation. Areas to be protected first are found in this class. done for protective reasons. Dead wood collection is most often the only acceptable utilization.

Capability classes for forestry are shown on the map by a gray scale; the gray tone becomes darker where the conditions are less favorable to wood production.

4.4.3 The Soil Degradation Map

4.4.3.1 Introduction

The soil degradation map is actually an interpretation of the morphopedological map. The method involves grouping and generalizing (at a 1:1,000,000 scale) the soilscape mapping units which are similar in respect of criteria expressing the effects of soil degradation.

The type of representation used for the land capability map is such that a given area will appear darker if it is more limiting. The gray tone becomes darker for forestry and the cross hatching is more dense for agriculture and grazing. However, areas unsuitable for agriculture or grazing were left blank in order to simplify the representation.

4.4.3.2 Degradation Types

Four types of degradation were studied and are briefly discussed below. Parameters and criteria considered are mentioned for each case.

A. Degradation Through Water Erosion. Water erosion or physical weathering is the main agent. Soils are characterized by a shallow to very shallow useful depth, a high or very high coarse fragments content and numerous outcrops. This is the case of the erosional residual surfaces of the Ferlo and Senegal Oriental in the eastern part of the country. On the map, a boundary line shows the approximate extent of regosolic soil types, (truncated, indurated or on hard pan). This is also the area where the water erosion susceptibility is generally at its highest. A first distinction is made for parent material, since soils developed on hard pan or on dismantled hard pan products have often lower chemical fertility than those developed on the various kinds of basic rocks of Senegal Oriental. The second distinction is based on useful depth. Regosols or soils on gravelly material are still somewhat arable, but lithosols are normally not.

B. Degradation Through Wind Erosion. Wind is the main factor. Beaches and dunes of the Grande Cote are represented and show the areas where sand is being remobilized and through invasion may endanger the Niayes. Toward the east, the active dune system along the Senegal River Valley and the active sand invasion areas of the Ferlo have also been shown. Deflation is particularly active in the western part of the country and on the map the boundary shows approximatly the most active deflation area. Wind erosion susceptibility is generally high in the country as a whole (60% of the mapping units).

C. Degradation Through Salinity. Although the scale is not suited to a detailed representation of these phenomena, the salinity and sodicity parameters may be used to delineate the areas affected by the presence of salts or excess sodium. The symbol "E" was used to show the possible occurrence of saline efflorescences at the soil surface. The extent of the saline deltaic soils is emphasized on the map by using a thicker line width.

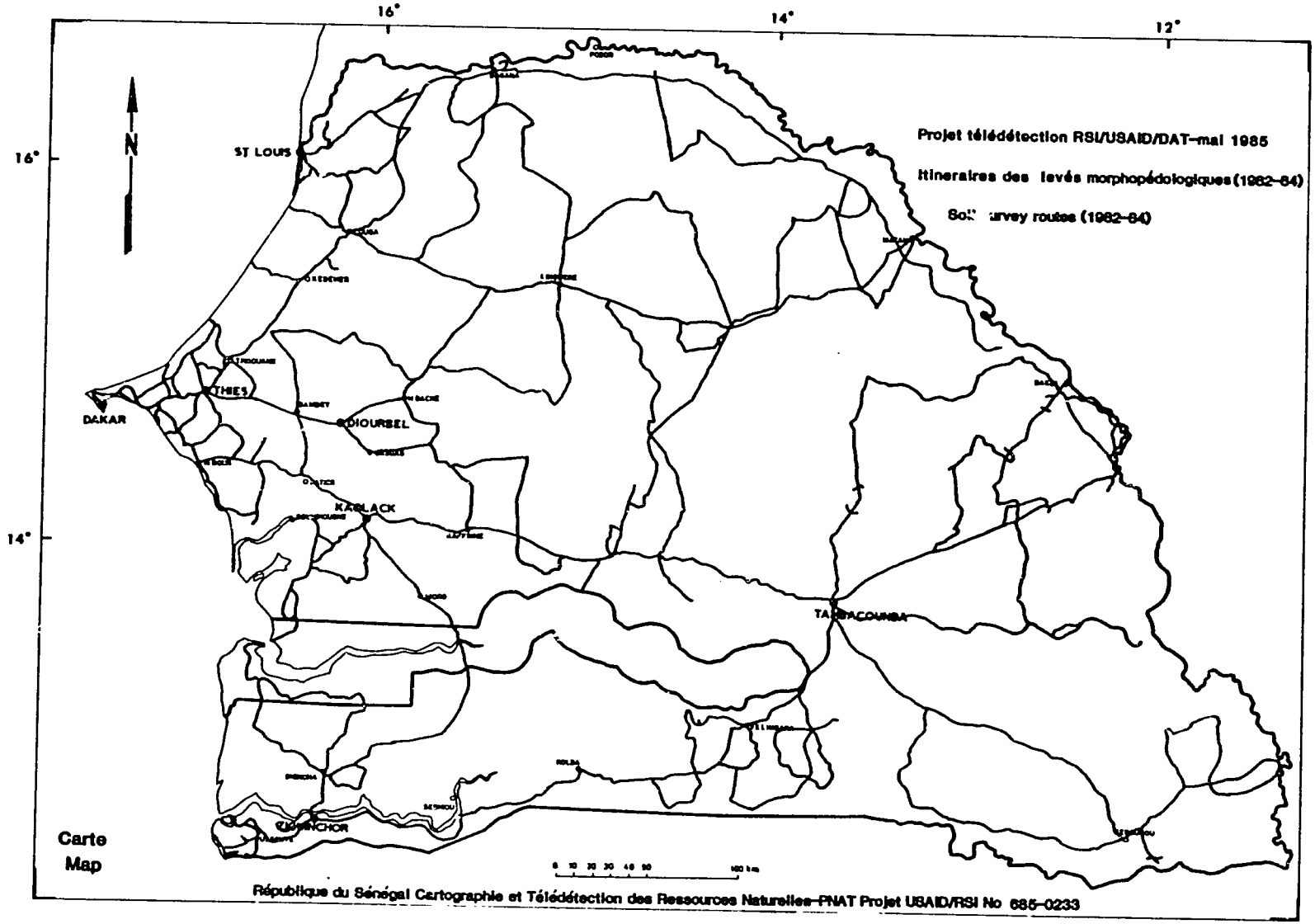
D. Degradation Through Human Activity. The first aspect studied is soil depletion through cultivation. Although the quantity of available imagery was rather small to conduct such an interpretation, it is still obvious that the areas represented on the map are overcultivated. Visible clues (both from the imagery and from field observation) are, for instance, reduced vegetative cover, lower water holding capacity, greater deflation, etc. The second aspect studied is the regression of the mangroves. The hachures cover areas which may be considered as having been lost from 1972 to 1982. This period corresponds to the recording dates of the imagery available at the time of the interpretation. Although causes for the regression are surely complex and should be studied in the field, it is quite certain that human activity plays a major role in this phenomenon.

4.5 APPENDIX B: SOILS AND LAND CAPABILITY

Map IV-1

Soil Survey Routes

Previous Page Blank



IV-1 Soil Survey Routes

APPENDIX B

Table IV-2

Examples of Profiles

(abridged descriptions)

Changes in personnel within the soils section led to major disturbances in field data collection. Data cards and field books are scattered, and most of the project's field trip data files are incomplete. Profile descriptions and analytical results given in this appendix are therefore limited to a minimum.

ABBREVIATIONS

SAR	Sodium Adsorption Ratio
EC	Electrical Conductivity
CEC	Cation Exchange Capacity
Sat.%	Saturation Percentage

Texture (mechanical analysis)

S	Sand
Si	Silt
C	Clay
SL	Sandy Loam
CL	Clay Loam
SCL	Sandy Clay Loam
SC	Sandy Clay
LS	Loamy Sand
LS-S	Loamy Sand-Sand

PROFILE: H047, sol peu évolué d'érosion sur matériau gravillonnaire

LOCATION: plateau, northwest of Thiès
reserved forest, gently sloping, 3-5%

MAPPING UNIT: P1a1 (inclusion)

CLASSIFICATION STS: Typic Ustorthent
FAO: Eutric Regosol (sols minéraux bruts d'apport)

0-43cm: dark reddish brown (5YR3/4) moist, gravelly sandy clay loam, 55% yellowish-red nodules 3 to 5mm in diameter, friable, plastic, non sticky, fine pores, frequent fine roots, few medium and coarse roots (samples: 1, 0-10cm; 2, 30-40cm)

43-75cm: dark red (2.5YR3/6) moist, gravelly clay (60%), slightly sticky and plastic, common fine pores, common fine roots, few to very few medium and coarse roots (sample: 3)

75-105cm: dark red (2.5YR3/6) moist, gravelly sandy clay loam (65%), slightly sticky and plastic, common fine pores, common fine roots (sample: 4)

105-210cm: red (2.5YR3.5/6) moist, gravelly sandy clay loam, 70% nodules 5 to 10mm in diameter, slightly sticky and plastic, few pores, few roots.

TABLE IV-2
ANALYTICAL DATA

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
H047							
1	0-10	46.12	19.72	34.16	SCL	.054	2.6
2	30-40	42.48	15.36	42.16	C	.062	.7
3	43-75	61.90	4.54	33.56	SCL	.045	.3
4	75-105	62.90	7.54	29.56	SCL	.054	.2

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
H047								
1	290	495	.46	4.85	7.58	16.82	53.87	6.30
2	240	140	.38	2.74	1.98	13.19	48.23	4.20
3	175	70	.41	4.35	2.16	15.95	46.40	4.54
4	74	70	.42	3.54	2.30	14.05	57.05	4.30

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
H047						
1	1.06	.628	.70	23.3	13.8	1.23
2	0.91	.196	.15	23.4	7.8	1.06
3	1.02	.193	-	-	-	-
4	1.05	.176	-	-	-	-

PROFILE: S102, sol peu évolué d'apport, hydromorphe sur matériau colluvial

LOCATION: cultivated valley bottom, east of Vélingara
fallow, flat

MAPPING UNIT: Aa1

CLASSIFICATION STS: Typic Ustorthent (coarse loamy, acid)
FAO: Dystric Regosol

0-30cm: dark grayish brown (10YR4/2), moist, sand to loamy sand, no structure, friable, non sticky, non plastic, common very fine roots, few pores (sample: 1)

30-75cm: pale brown (10YR6/3), moist to brown (10YR5/3) wet, sandy loam, no structure, friable, non sticky, non plastic, common very fine roots up to 65cm, few to very few pores (sample: 2)

75-135cm: very pale brown matrix (10YR7/4), moist, common medium to coarse faint rusty mottlings, sandy loam (sandier), structureless, friable, non sticky, non plastic, no roots, very few pores. (sample: 3)

>135cm: common coarse faint to distinct mottlings, structureless sandy loam, friable, very few pores

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
S102							
1	0-30	88.16	4.54	7.30	LS-S	.038	.9
2	30-75	61.94	27.90	10.16	SL	.016	.3
3	75-135	70.30	21.72	7.98	SL	.020	.2

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
S102								
1	4.5	70	.25	0.24	1.21	3.09	24.10	5.00
2	4.0	60	.24	0.27	0.97	1.77	27.93	5.50
3	3.5	55	.24	0.26	0.93	1.28	18.88	5.39

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
S102						
1	.25	.456	.50	19.2	21.2	.25
2	.38	.124	-	-	-	-
3	.45	.179	-	-	-	-

PROFILE: H253, vertisol lithomorphe à surface massive, sur marnes

LOCATION: lower plateau, west of Thiès
pasture land, Baobabs and Acacia seyal, flat (1%)

MAPPING UNITS: inclusion, typique de P2a1

CLASSIFICATION STS: Typic Chromustert
FAO: Chromic Vertisol

0-18cm: dark grayish brown (10YR3.5/2) dry to very dark brown (10YR2.5/3) wet, sandy clay loam, strong coarse to very coarse angular blocky structure, very hard, non sticky, plastic, few pores, common fine and very fine roots, few medium and coarse roots. (sample: 1)

18-83cm: grayish brown (2.5Y4.5/2) dry to dark grayish brown (2.5Y4/2) wet, clay loam, strong coarse to very coarse prismatic structure and angular blocky substructure, very hard, sticky, plastic, many fine faint reddish-brown mottlings, calcareous nodules and iron concretions present, few pores, common roots, many pressure faces, locally slightly effervescent with acid. (samples: 2, 40-50cm; 3, 70-80cm)

83-121cm: grayish brown (2.5Y4.5/2) dry to dark grayish brown (2.5Y4/2) wet, clay loam, moderate coarse angular blocky structure, very hard, sticky , plastic, many clacareous nodules and iron concretions, common pores, few fine roots, moderate effervescence with acid.

>121cm: weathering zone (parent material)

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
H253							
1	0-18	46.48	24.18	29.34	SCL	.110	2.0
2	40-50	39.12	21.54	39.34	CL	.031	.4
3	70-80	38.48	22.36	39.16	CL	.065	.2

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
H253								
1	10.0	100	.00	.00	.00	20.56	.00	.00
2	2.0	70	.75	6.20	20.24	24.64	44.01	7.60
3	1.0	70	.53	5.62	21.78	24.36	42.79	7.46

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
H253						
1	.00	.000	.41	23.5	8.9	.48
2	1.73	.700	-	-	-	-
3	.75	.628	-	-	-	-

PROFILE: H525, sol brun subaride, sur matériau colluvial

LOCATION: sand bar, near Diama
abandoned area, flat (1%), wind ripples

MAPPING UNIT: Lb2

CLASSIFICATION STS: Typic Ustipsamment (altic tendendies)
FAO: Eutric Regosols

0-49cm: yellowish brown (10YR5/4) dry to dark brown (10YR4/3) wet, sand, single grain and weak fine and medium subangular blocky structure, soft, very friable, non sticky, non plastic, common pores, common very fine roots for 10cm then few medium and coarse roots (samples: 1, 0-10cm; 2, 25-35cm)

49-88cm: yellowish brown (10YR5.5/4) dry to dark yellowish brown (10YR4.5/4) wet, loamy sand, single grain and weak fine and medium subangular blocky structure, soft, very friable, non sticky, non plastic, few pores, few fine and medium roots (sample: 3)

88-126cm: light yellowish brown (10YR6/4) dry to yellowish brown (10YR5/4) wet, loamy sand, weak medium and coarse subangular blocky structure, soft, very friable, non sticky, non plastic, few pores, very few roots, very feeble effervescence possible (sample: 4)

>126cm: very pale brown (10YR6.5/4) dry to yellowish brown (10YR5.5/6) wet, loamy sand, structureless, massive, soft, very friable, non sticky, non plastic, few pores, very few very fine roots, slight effervescence possible.

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
H525							
1	0-10	89.62	3.86	6.52	S	.079	.7
2	25-35	93.12	1.04	5.84	S	.019	.2
3	49-88	93.62	0.86	5.52	S	.011	< .1
4	88-126	94.12	0.36	5.52	S	.014	< .1

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
H525								
1	33.5	115	.34	1.79	2.60	3.18	29.54	7.40
2	16.0	70	.47	1.09	2.47	2.06	25.99	7.78
3	5.5	45	.32	1.07	1.78	2.03	25.25	8.20
4	6.0	35	.33	.81	1.78	1.58	23.42	7.90

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
H525						
1	3.33	1.554	.35	9.3	8.9	.15
2	1.83	.484	.16	9.2	4.2	.18
3	2.39	.343	-	-	-	-
4	2.95	.606		-	-	-

PROFILE: H524, sol brun subaride, sur matériau sableux colluvial souvent calcaire en profondeur

LOCATION: slightly undulating dunes, east of Louga
fallow after ground nuts, slope 1-2%, sheet erosion

MAPPING UNIT: E2ax2

CLASSIFICATION STS: Alfic Ustipsamment (Sat.% is low)
FAO: Luvic Arenosol

0-8cm: light yellowish brown (10YR5.5/4) dry to yellowish brown (10YR4.5/4) wet, sand, non coherent single grain structure, loose, no pores, few fine and very fine roots. (sample: 1)

8-42cm: dark brown (10YR3.5/3) dry to very dark grayish brown (10YR3/2) wet, loamy sand, strong medium and coarse subangular blocky structure, slightly hard, very friable, very fine pores, few fine and very fine roots (sample: 2)

42-93cm: yellowish brown (10YR5/4) dry to dark yellowish brown (10YR4/4) wet, loamy sand, strong coarse and very coarse subangular blocky structure, slightly hard, very friable, common fine pores, very few fine and very fine roots (sample: 3)

93-120cm: light yellowish brown (10YR6/4) dry to yellowish brown (10YR4.5/4) wet, loamy sand, strong coarse and very coarse subangular blocky structure, hard, very friable, few pores (sample: 4)

>120cm: very pale brown (10YR7/4) dry to dark yellowish brown (10YR5/4) wet, loamy sand, moderate fine and medium subangular blocky structure, soft, loose, very few pores.

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
H524							
1	0-8	90.76	3.72	5.52	S	.020	.4
2	8-42	86.26	4.22	9.52	LS	.023	.5
3	42-93	88.76	2.72	8.52	LS	.021	.1
4	93-120	87.12	5.04	7.84	LS	.020	< .1

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
H524								
1	45.0	45	.29	.55	2.13	2.47	23.51	7.82
2	63.5	50	.35	.86	3.62	5.7[illegible]	24.41	7.19
3	28.0	45	.30	.62	2.68	4.21	22.34	7.30
4	22.5	45	.26	.51	2.57	3.75	26.74	7.65

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
H524						
1	.45	.369	.48	6.3	8.2	.23
2	.56	.161	.55	7.3	7.4	.30
3	.72	.239	-	-	-	-
4	.52	.238	-	-	-	-

PROFILE: H071, sol ferrugineux tropical faiblement lessivé, sur sable siliceux

LOCATION: continental dunes, north of Tivaouane
fallow after millet, flat (1%)

MAPPING UNIT: E2ay3

CLASSIFICATION STS: Alfic Ustipsamment
FAO: Luvic Arenosol

0-58cm: yellowish brown (10YR5/4 dry, 10YR4/4 wet) sand, weak very coarse subangular blocky structure, very fine subangular blocky substructure, slightly hard, non sticky, non plastic, common pores, frequent fine and very fine roots, common medium and coarse roots (samples: 1, 0-10cm; 2, 30-40cm)

58-137cm: brown (10YR5.5/4) dry to dark brown (7.5YR4/4) wet, sand, same structure, soft, slightly sticky, non plastic, common pores, common fine and medium roots, few coarse roots (samples: 3, 70-80cm; 4, 110-120cm)

>134cm: reddish yellow (7.5YR5.5/6) dry to strong brown (7.5YR4.5/6) wet, sand, same structure, soft, slightly sticky, non plastic, porous, few roots.

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
H071							
1	0-10	-	-	-	-	-	-
2	30-40	91.30	4.36	4.34	S	.059	.4
3	70-80	91.12	2.54	6.34	S	.011	.1
4	110-120	91.12	2.54	6.34	S	.016	.6

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
H071								
1	-	-	.29	.80	1.78	2.38	30.17	5.35
2	13.0	45	.32	0.78	1.43	2.32	22.94	4.68
3	12.0	30	.28	2.43	1.31	2.45	24.94	4.39
4	7.5	25	.28	.53	1.14	2.16	24.68	4.60

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
H071						
1	.59	.202	-	-	-	-
2	.95	.168	.23	21.5	5.3	.21
3	.70	.134	.11	20.4	2.6	.18
4	.70	.128	-	-	-	-

PROFILE: S101, sol ferrugineux tropical lessivé à taches diffuses, sur argile sableuse du "Continental Terminal"

LOCATION: plateau, east of Vélingara
forest, flat

MAPPING UNIT: Oa14

CLASSIFICATION STS: Ultic Haplustox
FAO: Orthic or Rhodic Ferralsol

0-15cm: reddish brown (5YR4/3) moist to dark reddish gray (5YR4/2) wet, sandy loam, weak fine crumbly structure, slightly compact, rather friable, few and common fine and medium roots, porous (sample: 1)

15-35cm: yellowish red (5YR5/6 moist, 5YR4/6 wet), sandy clay loam, weak fine crumbly structure, slightly compact, friable, few fine roots, few pores (sample: 2)

35-65cm: yellowish red (5YR5/6 moist, 5YR4/6 wet), sandy clay, weak medium blocky structure, plastic and sticky, very few pores (sample: 3)

65-108cm: yellowish red (5YR5/8 dry, 5YR5/6 wet), sandy clay, very weak subangular blocky structure, friable or slightly firm, plastic and sticky, few faint mottlings (sample: 4)

>108cm: yellowish red (5YR5/8 dry, 5YR5/6 wet), sandy clay (heavier), massive, very friable

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
S101							
1	0-15	75.52	13.36	11.12	SL	.041	1.2
2	15-35	65.48	10.72	23.80	SCL	.033	.8
3	35-65	54.84	8.36	36.80	SC	.033	.5
4	65-108	45.48	10.54	43.98	SC	.030	.4

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
S101								
1	4.0	30	.27	.77	1.26	4.19	23.30	5.41
2	5.0	25	.26	.51	1.24	4.42	28.42	4.72
3	3.5	25	.28	.27	.82	5.63	37.27	4.69
4	3.0	25	.28	.00	.66	6.57	40.62	5.12

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
S101						
1	.27	.381	.26	15.0	21.3	.16
2	.49	.170	-	-	-	-
3	.60	.062	-	-	-	-
4	.49	.052	-	-	-	-

PROFILE: S104, sol ferrugineux tropical lessivé, induré sur cuirasse

LOCATION: plateau, north of Badion
forest, flat

MAPPING UNIT: Oa14

CLASSIFICATION STS: Ultic Haplustox (petroferric)
FAO: Plinthic Ferralsol

0-20cm: very dark grayish brown (10YR3/2), moist, sandy loam, weak subangular blocky structure, friable, common coarse roots, frquent medium and fine roots, few pores (sample: 1)

20-35cm: dark yellowish brown (10YR4/4), moist, sandy loam, weak subangular blocky structure, friable, common coarse roots, frequent medium and fine roots, few pores (sample: 2)

35-50cm: yellowish brown (10YR5/6 moist, 10YR5/4 wet), sandy clay loam, very weak subangular blocky structure, very plastic, sticky, few coarse roots, frequent medium and fine roots (sample: 3)

50-85cm: yellow (10YR7/6) dry to yellowish brown (10YR5/6) wet with many rather friable medium to coarse red mottles (2.5YR4/6), sandy clay loam, structureless, plastic and sticky, few medium and fine roots (sample: 4)

85-100cm: yellow (10YR7/6) dry, structureless, mainly iron concretions 0.5cm in diameter, sandy clay loam matrix

>100cm: pisolittic cuirasse, massive

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
S104							
1	0-20	71.12	19.22	9.66	SL	.049	1.9
2	20-35	66.66	16.18	17.16	SL	.038	.9
3	35-50	55.80	16.04	28.16	SCL	.038	.6
4	50-85	52.16	18.18	29.66	SCL	.038	.7

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
S104								
1	6.5	100	.32	1.21	.17	5.92	23.26	5.54
2	2.5	50	.32	.79	.96	3.72	24.72	4.71
3	2.5	40	.30	.81	1.13	5.17	31.04	5.18
4	2.0	40	.27	.00	.80	4.77	32.37	5.18

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
S104						
1	.18	1.010	.48	21.4	13.1	.19
2	.41	.342	-	-	-	-
3	.63	.116	-	-	-	-
4	.99	.077	-	-	-	-

PROFILE: H431, sol hydromorphe à pseudogley, sur matériau alluvial

LOCATION: Ferlo valley, near Barkédji
slope 1-2%

MAPPING UNIT: Acl

CLASSIFICATION STS: Typic Fluvaquent
FAO: Aquic Fluvisol

0-13cm: pale brown (10YR5.5/3) dry to yellowish brown (10YR4.5/4) wet, sandy loam, moderate coarse platy structure, pale sandy and dark loamy alternating layers, slightly hard, friable, sticky, few pores, few very fine roots (sample: 1)

13-45cm: yellowish brown (10YR5/4) wet, sandy loam, platy structure with disturbed stratification, many fine prominent strong brown (7.5YR5/6) mottlings, very friable, sticky, few pores, few roots (sample: 2)

45-78cm: dark gray (5Y3.5/1) wet, clay loam, weak medium to coarse angular blocky structure, common mottlings (7.5YR4/4), firm, very sticky, common pores, few roots (sample: 3)

78-140cm: dark gray (5Y3.5/1) wet, clay, very weak structure, common fine dark brown (10YR4/3) mottlings, very firm, very sticky, common pores, few roots (sample: 4)

Sample	Depth cm	Texture				Total N %	Organic Matter %
		sand %	silt %	clay %	name		
H431							
1	0-13	63.80	20.04	16.16	SL	.039	.5
2	13-45	74.62	13.72	11.66	SL	.013	.3
3	45-78	37.30	25.04	37.66	CL	.023	.9
4	78-140	21.32	23.64	55.04	C	.040	.6

Sample	P ppm	K ppm	Exch. Na me/100g	Exch. Mg me/100g	Exch. Ca me/100g	CEC me/100g	Sat. %	pH
H431								
1	8.5	105	.30	1.31	3.01	6.48	29.54	4.83
2	9.0	180	.32	1.35	2.94	4.30	27.77	5.40
3	16.0	150	.43	3.80	7.39	14.24	37.42	4.64
4	7.5	65	.46	5.69	10.50	18.47	43.07	5.52

Sample	SAR	EC mmhos/cm	Zn ppm	Fe ppm	Mn ppm	Cu ppm
H431						
1	.32	.524	.32	89.7	36.0	.81
2	.45	.287	-	-	-	-
3	.40	.430	-	-	-	-
4	1.06	.372	-	-	-	-

APPENDIX B

Table IV-3

Soils Characteristics

First Order Parameters

Preceding Page Blank

TABLE IV-3
SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
La1	1	1	3	3	1	1	1	1,5	$1,2^{ac}$	Sa-x	3
La2	4	1	3	3	1	1	1	1	$1,2^{ac}$		2
La3	4	1	3	3	1	1	1	1	$1,2^{ac}$		2
La4	4	1	3	3	1	1	1	1	$1,2^{ac}$		4
Lb1	1,2	2	3	3	1	1	1	2	$1,2^{ac}3^{alc}_{ac}$		2
Lb2	1,2	2	3	3	1	1	1	2	1		2
Lcx	1,2	1,2	3,5,6	3,4,5	1	1	1	2/6	$1,2^{ac}3^{ac}_{alc}$	Sa-4	1,2
Lcy1	1	1	5,6	4,5	1	1	1	6	$1,(2)^{ac}(3)^{ac}_{alc}$	Sa-4	1
Lcy2	1,(2)	1	3,6	3,6	1	1	1	6	3^{ac}	Sa-4,5 E-(x)	1
Lcz1	1	1	(3),6	(3),6	1	1	1	6	$1,(3)^{ac}$	Sa-4,5	1
Lcz2	1	1	v	v	1	1	1	6	$1,2^{ac}$	Sa-4 E-(x)	1
Lcz3	1	1	v	v	1	1	1	5	$2^{ac},(3)^{ac}$	Sa-2/4 E-x	1
Lcz4	1	1	(3)/6	(3)/6	1	1	1	(2),5	$1,2^{ac},(3)^{ac}$	Sa-(1)/3 E-x	2
Lcz5	1	2	5,6	5,6	1	1	1	5	$2^{ac},3^{ac}$	Sa-2,4 E-(x)	2
Ld	1,2	1	3,(4)	3,(4)	1	1	1	2,3	$(1),2,3^{ac}$	Sa-(2)	2
Le	1	3	(3),5,6	(3),5,6	1	1	1	4,5	$1,2^{alc}$	Sa-(x) E-(x)	1
Lfx	1	2	4,5,6	4,5,6	1	1	1	4,5	$1,2^{ac}$	Sa-2	2
Lfy1	1	1,2	4,6	4,5,(6)	1	1	1	2,4,(5)	2^{ac}	Sa-1,2,(3)	2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
Lfy2	1	1,2	4,6	4,5,(6)	1	1	1	2,4	ac 2,(3)	Sa-1,2,(3)	2
Lg1	1	2	6	6	1	1	1	5	ac 1,2		2
Lg2	1	2	6	6	1	1	1	5	ac 1,2	Sa-1,(2)	1,2
Lg3	1	2	6	5	1	1	1	5	ac 1,2	Sa-1,2	1,2
Lg4	1	2	5,6	5,6	1	1	1	5	ac 2	Sa-2,4	1
Lg5	1	1	4,6	4,6	1	1	1	5	ac 2	Sa-4	1
Lh1	1	3	3,4,5	3,4/(6)	1	1	1,(3,4)	4,5	2,3ac (2 alc)		1
Lh2	1	4	3	3	1	1	1	5,6	alc 2	Sa-x E-x	1
Aa1	1	1	4,5	5,6	1,2	1	1	3,4,5	ac 1,2		2
Aa2	1	4	(4),5	5,(6)	1,2	1	(3),4,5	4,5	ac 2		2
Aa3	1	1	5	5,6	1,2	1	1,2	5,6	ac 1,2		2
Aa4	1,2	1,2	3,4	5,6	1,2	1	1,2,(3,4)	2,3	ac 1,2		2
Ab1	1	3,4	(2),5	2,5,6	1	1	3,4	4,5	ac 1,2		2
Ab2	1	2,3	4,5	6	1	1	1	4	ac 1,2		2
Ab3	1	1	3	3	1	1	1	4,(5)	1		2
Ab4	1	1,2,3	3	3	1	1	1	4,5	ac 1,2		2
Ac1	1	1,2	3/4,5	3/3,4	1,2	1	1,(3)	2/5	alc 1,2	Sa-1,2	2
Ac2	1	1	3	3	1	1	1	2,3	ac 1,2 alc	Sa-x	2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
Adx	1	1,2	3,4,5,6	3,4,5,6	1	1	1,(3)	4,5	1,2,3ac		2
Ady1	1,2	1,2	5,6	5,6	1	1	1	5	1,2ac		2
Ady2	1,2	1,2	5	5	1	1	1	5	1,2ac		2
Ady3	1	1,2	6,7	6,7	1	1	1	5	1,2ac		1
Adz	1	1,2	5	5,6/3	1	1	1	4,5	2,3ac	Sa-3 E-x	2
E1a1	1,(2)	1	3	3	1	1	1	2,(3)	1,(2)ac		2
E1a2	1	1	3	3	1	1	1,3,4	2	1,2ac		2
E1a3	1,(2)	1	3	3	1	1	1	2	1,(2)ac		2
E1a4	1,(2)	1	3,4	(3),4,(5)	1	1	1	2	1		2
E1a5	1,(2)	1	3	4	1	1	1	2	1		2
E1a6	1,(2)	1	3	3	1	1	1	2	1		2
E1b	1,(2)	1	3	3	1	1	1	2	1,(2)ac		2
E1c1	1	1	3	3	1	1	1	2	1		2
E1c2	1,2	2/4,5	3	3	3	3,4	2,4	2	1,2ac		3
E1dx1	1	1,(2)	3	3	1	1	2,3	5	1		3
E1dx2	1	1	3,4,6	3,4,6	1	1	(2,3)	5	2ac	Sa-x	2
E1dy	1	1	6,7	6,7	1	1	1	5	1,(2)ac		1
E2ax1	2	1	3	3	1	1	1	1	1,2ac		2
E2ax2	1	1	3	3	1	1	1	3	1,2ac		2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
E2ay1	1,2	1	3	3	1	1	1	1/3	$1,2^{ac}$		2
E2ay2	1,2	1	3	3	1	1	1	1	$1,2^{ac}$		2
E2ay3	1,2	1	3	3	1	1	1	1	$1,2^{ac}$		2
E2b	4	1	3	3	1	1	1	1	$1,2^{ac}$		2,3
E2cx1	4	1	3	3	1	1	1	1	$1,2^{ac}$		2
E2cx2	4,5	1	3	3	1	1	1	1	$1,2^{ac}$		2
E2cy	4	1	3	3	1	1	1	2,3	2^{ac}		2
E2d	1/2,3,4	2,3	3	3	1	1	1	4,5	$1,2^{ac}$	E-(x)	1
E2e1	1	1	3	3	1	1	1	3	1		1,2
E2e2	1	1	v	v	1	1	1	4,6	$1,2,3^{ac}_{alc}$	$Sa-2,4_{So-3,4_{E-x}}$	1
V	1	1,5	3,4	5,6	1,2	1,2	1,4	1,2	1	$Sa-(1)_{So-(1)}$	
Oa1	1	5	1,2	1	5,6	2	5,6	1	$1,2^{ac}$		3,4
Oa2	1	2,3/(5)	2,4/5	1,4,5,6	2/4,5/6	1,2	4,5,6	1/4	$1,2^{ac}$		3
Oa3	1	2,3/(5)	2,4/5	1,4,5,6	2/4,5/6	1,2	(1),4,5,(6)	1/4,(5)	$1,2^{ac}$		3
Oa4	1	2,3/(5)	2,4/5	1,4,5,6	2/4,5/6	1,2	3,4,5	1/4,5	$1,2^{ac}$		3
Oa5	1	4,5	1,2,4,5,6	1,2	3,4	5,6	4,5	(1),5	$1,2^{ac}$		3
Oa6	1	4	4,5	6	2	1,2	(3),4,5	4,5	2^{ac}		2
Oa7	1	3,4	3,4	2	3	2	4	3	$1,2^{ac}$		2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
0a8	1	2	3	4	1	1	1	2	1,2ac		2
0a9	1	3,4	3	3	2,(3)	1	2,4	3	1		2
0a10	1	1	3	3	1	1	1	1,2	1,2ac		2
0a11	1	2	3,4	5,6	1	1	1, (4)	2,3	2ac		2
0a12	1	1	3	3,4	1	1	1	2,3	1,2ac		2
0a13	1	4	3,4	1	1,2	1	1,2	5	1,2ac		2
0a14	1,(2,3)	1,2,3,4	3	4,5,(6)	1,2	1	2,4	2,3,4	1,2,3ac		2
0a15	1,(2,3)	1	3	6	1,2	1	1	1	1,2ac		2
0b1	1	3	4,5	6	1	1	1,2	3	1		2
0b2	1	1	5,6	6	1	1	1,2	4	2ac		1
0b3	1	2	6	6	2,3,4	1	3,4	5	(3alc) 2ac		1
0c	2	1	3	3	1	1	1	1	2ac		2
0d1	1,2	2,3/(5)	2,4	1,4,5,6	4,5	1,2	4,5,6	1	1,2ac		3
0d2	1	4,5	(2)/4,5	1/6	2/(5,6)	1,2	4,5,6	(1),4,5	1,2ac		3
0d3	1	1,2,3/(5)	2,3,4	1,4,5,6	1,2/5/6	1,2	1,2/4,5,6	1/2,3	1,2ac		(2),3
0d4	1,2	1,2,3/(5)	2,3,4	1,4,5,6	1,2/4,5	1,2	1,2/4,5,6	1/2,3	1,2ac		(2),3
0d5	2	3	3	5	2	1	(2)	3	1		2,3
0d6	1,2	2,3	2,4	1,4,5,6	4	1,2	4,5	1	1,2ac		2
0d7	1	1	3	5/6	1,2	1,2	1	2,3	1,2ac		2
0d8	1	2,3,4	3	5	1,2	1	1,2	2,3,(4)	1,2ac		2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
Od9	1	1	4	5	1,2	1	1,2	3	$1,2^{ac}$		2
Od10	1	1/2,3	2,3/4	5	1,2/4	1	1,2,3,4,5	1,2/4,5	$1,2^{ac}$		2
Od11	1	1/2,3	2,3/4	5	1,2/4	1	3,4,5	1/4,5	$1,2^{ac}$		2
Oe1	1	1	3	4	1	1	1	1	$1,2^{ac}$		2
Oe2	1	1,2	3,(4)	4,(5)	1	1	1,(3)	3,4	2ac		2
Oe3	1	1	4,5	5,6	1	1	1	5	1,2ac		1
Of1	1	1	3	3,4	2	2	1	2	1		2
Of2	1	1	3	3,4	2	2	1	2	1		2
P1a1	1,(2)	(3),4,5	4	1,2	4,5	4,5	3,4	(2)	$1,2^{ac}$		2
P1a2	1	1,2	3,4	3,4	1,2	1	1	2	$1,2^{ac}$		1,2
P1b	4,5,6	(3),4,5	5,6	5,6	4,5	3,4	3,4	5	2^{alc}		3
P1c	1	3,4,5	5	5	2,3	2,3	2,3	(3),4,5,6	1		1
P2a1	1,2	2,3	5,6	5,6	1	1	1,2,3	3,4,5	$1,2^{alc}$		2
P2a2	1	1	6	6	1	1	1	3	2^{alc}		1
P2b	1	1	3	3	1	1	1	3,4	1		1
P2c1	4,5	4,(5)	(5),6	(5),6	1	1	4	5	2^{alc}		2
P2c2	1,2	1	3,5	3,5	1	1	1	3	2^{alc}		2
P3	1,2	1,2	4	5	1	1	2,(3)	4,5	1		1
P4a1	2	1/4,5	3	4	5,6	5	(2)	3	$1,(2)^{ac}_{alc}$		2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
P4a2	2	4	v	v	5,6	5	(2)	3	1		2
P4a3	2	4,5	6	6	5,6	5	4	2	1		2
P4b	1	1	3	4	2	2	2	3	1,(2)$^{ac}_{alc}$		2
P4c	1	4	6	5,(1)	2	2	4	2	1		2
Ca	1,2	(3),4,5	5,6	1	4,5	3,4	3,4	4	2		3
Cb	1,4	1,(2)	3	3,5	1	1	1,2	1,2,(3)	1,2^{ac}		2
S1a1	1,2,3,4,5,6	4,5	2/5	2/5,6	4	2,3,4	5,6	2	2^{ac}		2
S1a2	1,2,3,4,5	3,4	2,4,5	1,4,5,6	4	1,2	4,5	1/5	1,2^{ac}		2
S1a3	2,3,(5)	4,5	(1)3,4	5,6(1)	2	2	4,5	2/5	2^{ac}		2
S1b	1,2	5	1,2	1	5	4,5	5,6	1	2^{ac}		3
S1c	1,2	5	1,2,(5,6)	1,2	5	2,3	6	1	1		2,3
S2a	3,4	5	1,2	1	5,6	5,6	5,6	1	1,2^{ac}		2,3
S2b	1,2	1,(5)	3,(1)	4,(1)	1,2	1	1	3,4	1		2
S2c	1	4,5	3	2,(4)	2,3	1,(2)	4,5	1	1,2^{ac}		2
S3a1	1	5	1,2	1	5	4,5	5,6	1.(6)	2^{ac}		3
S3a2	1,2	3,4,5	1,2,4	1,4,5,6	4,5	1,2/4,5	4,5,6	1	1,2^{ac}		2,3
S3a3	1	3,4	2,4	1,4,5,6	4	1,2	4,5	1	1,2^{ac}		2
S3a4	1	4,5	(2),4,5	1/6	2/(5,6)	1,2	4,5,6	(1),4,5	1,2^{ac}		3

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Unit	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
S3a5	1,2	(3),4,5	(2),4,5	1/6	2,(5,6)	1,2	(3),4,5,6	(1),4,5	$1,2^{ac}$		3
S3b1	1	3,4	2,4/5	1/2,4,5,6	2/4	1,2	3,4,5	1/4	$1,2,(3)^{ac}$		2
S3b2	1	1	4	5	1	1	1,(2)	5	$1,2^{ac}$		2
S3c	1	(3),5	3	5,6	1,2	1	4,5	5	$1,2^{ac}3^{alc}$	$Sa-1_{So-x}$	2
S4a1	1	2	4	2/5,6	1,2	1	2,(3,4)	5	$1,2^{ac}$		2
S4a2	1	1,2	5	6	3,4	1	2,3	4	$1,2^{ac}$		2
S4a3	1	3,4,5	4,5	4,5	1,2	1	1,(2)	4,5	$1,2^{alc}_{ac}3^{alc}$	So-x,3,4	2
S4b1	1	(1),2	4,5	2/4,5,6	1,2	1	1,2,(3,4)	5	$1,2^{ac}$	So-(x)	2
S4b2	1	1	4,5	4,5	1	1	1,2	5	2^{ac}	So-(x)	2
S5a	1	1	4	4	1,2	1	2,(3,4)	5	3^{alc}	So-x,3	2
S5b	1	1	4,5	4,5	1,2	1	1,2,(3,4)	5	$2^{ac}3^{alc}$	So-x,3	2
S6a	1,2/5	5	1,2	1	6	6	6	(6)	-		2,3
S6b	1,2	4	5,6	5,6	1	1,2	3,4	5	$1,2^{ac}$		2
S7a	1,2/5	(3,4),5	1,2(3)	1,2(6)	(4),6	(4),6	4,5	(6)	$1,2^{ac}$		2,3
S7b	1,2	1,2,3	4/5	5/6	1,2	1	1/4,5	2/4	$1,2^{ac}$		2
M1a	4,5	3,5	1,2,4	1,2,5	5	4,5,(6)	5,(6)	2	2^{ac}		2
M1b	1,2,(3)	(1),2,3/4	4/5,6	1,2/5,6	2	2	2/5	3/4	2^{ac}		2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Units	Slope	Useful Soil Depth	Texture top.	Texture sub.	Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
M1c	1	(1),2,3	5,6	5,6	2	2	2	4	2^{ac}		2
M1d	1	(4),5	3,4	5,6	2	2	4,5	2/5	2^{ac}		2
M1e	1	2	6	6	2	2	1,(3)	4,5	2^{ac}_{alc}	So-x	2
M2a	2,(3)	5	1,2	1	4	4,5	5	5	$1,2^{ac}$		2
M2b	1,2	1,2,3,5	1,2,(3) 4,5,(6)	1,4,5,6	2,4/5,6	1,2	(2),4,5/6	1,(2)/4	$1,2^{ac}$		2
M2c	1,2	(3),4	1,2,3,6	3,4,6	4	(4,5)	5	5	2^{ac}_{alc}		2
M3a1	2,3,(5)	3,4,5	1,2,4/5	1,2,4,5,6	2/4,(5)	1,2,(4,5)	3,4,5	1/4	$(1),2,3^{ac}$		2,3
M3a2	1,2	3,4,5	1,2,4	1,4,5,6	4,5	1,2/4,5	4,5,6	1/4	$1,2^{ac}$		2,3
M3b	1,2,3	2,3	4,5	4,5,6	2	2	(1)/4	3,4	$2,(3)^{ac}$		2
Ga1	1	4,5	1,2,3	1	4,5	3,4,5	3,4	4	$2,3^{ac}$		2
Ga2	1	2,3,4	3,4	4,5	3,4	1,2	2,3,4,5	2,3	$1,2^{ac}$		2
Gb	1,2	2,3,4,5	1,2,3,4	1,4,5	3,4,5	1,2,3,4,5	2,3,4,5	2,3,4	$1,2,3^{ac}$		2
Gc1	1,2	3,4,5	3,4	1	3,4,5	2,3,4	3,4	3,4	$(1),2^{ac}$		2
Gc2	1,2	4,5	1,2,3	1	4,5	3,4,5	3,4	4	$2,3^{ac}$		2
Gc3	1,2	3,4	3,4	1	3	1	3,4	3	$(1),2^{ac}$		2
Gc4	1,2	2,3	3,4	4,5	3	1	2	2	2^{ac}		2
Gc5	1	3,4	3,4	1	3,4	1,(2)	3,4	4	$2,3^{ac}$		2
Gd	1	1	4	5	3	1	4	5	2^{ac}		2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (first order parameters)

Mapping Units	Slope	Useful Soil Depth	Texture		Stoniness	Rockiness	Coarse Fragments	Drainage	pH	Salinity Sodicity Efflorescence	Actual Erosion
			top.	sub.							
I1	3,(4)	2,3,(4)	3,4	4,5	(1),3	1	2,3	2	2^{ac}		2,3
I2	1/6	1,5	1,6	1,6	2/5	2/5,6	2/5	2,3,4,5	2^{ac}		2,3

APPENDIX B

Table IV-4

Soils Characteristics

Second Order Parameters

Previous Page Blank

TABLE IV-4

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potential Irrigability	Work-ability	Seeding Establish-ment	Potential Mechanization	Susceptibility to Erosion		Erosion Hazard	Chemical Fertility
							Wind	Water		
La1	4	1	3	1	1	1	8	1,2	4	3
La2	4	1	3	1	1	1	8	1,2	3,4	3
La3	4	1	[3]	1	1	1	8	1,2	3,(4)	3
La4	4	1	[3]	1	1	1	8	1,2	4	3
Lb1	5	1	[3]	1	1	1	8	1	3,4	3
Lb2	4	1	2	1	1	1	7,8	2	3,4	2,3
Lcx	(2)/5	1/4	[(2),3]	1/3	1/5	1/4	(4),8	1,2	2,3,4	(2),3
Lcy1	(2)	4	[3]	3	5	4	(4)	2	2	(2),3
Lcy2	2	4	[3]	3	5	4	4,8	2	3	(2),3
Lcz1	(3)	4	[3]	3	5	4	4,(6)	2	2	3
Lcz2	2	4	[3]	3	5	4	6	2	2	(2),3
Lcz3	v	3,4	[3]	3	5	4	4,7	2	2,(3)	(2),3
Lcz4	3	3	[3]	3	5	4	7	2	3	2,3
Lcz5	3	3,4	(2),3	3	5	4	4	3	3	2
Ld	5	1	[3]	1	1	1	8	2	3	(2),3
Le	3	3,4	[3]	2,3	3	2	4	3	2	2
Lfx	(2),3,(4)	3,4	(2),3	3	4	2,3	4	3	3	(2)
Lfy1	2	3	(2),3	2,3	4	2	4	3	3	2
Lfy2	2	3	(2),3	2,3	4	2	4	3	3	2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potential Irrigability	Work-ability	Seeding Establish-ment	Potential Mechanization	Susceptibility to Erosion		Erosion hazard	Chemical Fertility
							Wind	Water		
Lg1	4	4	(3)	3	4,5	3	4	3	2,3	2
Lg2	3	4	(3)	3	4	2,3	4	3	2,(3)	2
Lg3	3	4	(3)	3	4	3	4	3	2,(3)	2
Lg4	3	4	(3)	3	4	3	4	3	2,(3)	2
Lg5	3	4	3	2,3	4	2	4,6	3	3	(2)
Lh1	2	3,4	[3]	2,3	3	2	3,4,7	1,2	2	2
Lh2	(5)	4	[3]	1	(1),5	1	8	1	2	(2),3
Aa1	4	(2),3,4	[3]	2,3	4	2	6/7,8	3	3	2
Aa2	4,5	4	[3]	3,4	4,5	2	2	3	2,3	2
Aa3	3	4	[3]	3	4,5	2	3	3	2	2,3
Aa4	3	3	[2]	2	3,4	1	6,7	3	3,(4)	2,3
Ab1	4	3,4	3	2,3	4	2	2,3	3	3	2
Ab2	3	3,4	(2),3	2,3	3	2	2,3	2	2	2
Ab3	3,(4)	1	[(2),3]	1	1	1	7,8	2,3	3	2
Ab4	3,(4),5	1	[3]	1	1	1	7,8	2,3	3	2
Ac1	3/4,5	1/4	2/3	1/2,3	1/5	1/2	(2),6/8	1/3	3	2
Ac2	3,4	1	[2]	1	4	1	7,8	2	3	2
Adx	3	3,4	[3]	v/3,4	v/3,4,5	v/2,3	3,4	2,3	2,3	2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potential Irrigability	Work-ability	Seeding Establish-ment	Potential Mechanization	Susceptibility to Erosion		Erosion Hazard	Chemical Fertility
							Wind	Water		
Ady1	2,3	3,4	[3]	2,3,4	2,3	2,3	2,4	3	2,3	2
Ady2	2	3	[2]	2,3	2,3	2	2	3	2,3	2
Ady3	3	4	[(2),3]	4	3	3	4	3	2	2
Adz	3	4	[3]	3	3,4	2	2,3	3	2,3	2
E1a1	4	1	2	1	4	1	7,8	2	3	2,3
E1a2	4	1	2	2	4	2	7,8	2	3	2,3
E1a3	4	1	2	1	4	1	7,8	2	3	2,3
E1a4	3	2	1	1,2	3,4	1	7,8	2	3	2,3
E1a5	3	1,2	1,2	1	3,4	1	7,8	2	3	2,3
E1a6	4	1	2	1	3,4	1	7,8	2	3	2,3
E1b	4	1	2	1	3	1	8	2	3	2,3
E1c1	4	1	2	1	3	1	8	2	3	2,3
E1c2	4,5	1	3	2,3	4	2,3	8	4	3,4	2,3
E1dx1	4	2	3	2	3,4	1	7,8	2,3	3,4	2,3
E1dx2	3,4	3,4	3	2	3,4	2	6	2,3	3	2,3
E1dy	3	4	(3)	3,4	5	3	2	2	1,2	3
E2ax1	4	1	2	1	1	1	8	2	3	2,3
E2ax2	3	1	[2]	1	3	1	8	2	3	2,3
E2ay1	3/4	1	2	1	1/3	1	8	2	3	2,3

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potential Irrigability	Work-ability	Seeding Establish-ment	Potential Mechanization	Susceptibility to Erosion		Erosion Hazard	Chemical Fertility
							Wind	Water		
E2ay2	4	1	[2]	1	1	1	8	3	3	2,3
E2ay3	4	1	[2]	1	1	1	8	2	3	2
E2b	4	1	3	1	1	2	8	3	3,4	2,3
E2cx1	4	1	3	1	1	2	8	3	3,4	2,3
E2cx2	4	1	3	1	1	2	8	3	3,4	2,3
E2cy	4	1	[3]	1	1	1,2	8	2,3	3,4	2
E2d	4,5	2,3	[3]	1	1	1,(2)	7,8	2,(3)	2	2
E2e1	4	1	2	1	1	1	8	1	2,3	2,(3)
E2e2	v	v	3	v	4,5	v	v,2/8	1	2	2,3
V	2	3	[(2),3]	1,2	1,2	1,2	(5),6,7	3	2,3	1,2
Oa1	5	4	3	4	5	4	(7)	(4)	(3)	3
Oa2	5	1/4	[3]	2,3/4	3,4/5	2,3/4	3	3,4	2,3	2,3
Oa3	(3),5	1/3,4	[3]	2,3/4	3,4/5	2,3/4	3	3,4	2,3	2,3
Oa4	3/5	3,4	[3]	2,3/4	3,4/5	2,3/4	3,4	3	2,3	2,3
Oa5	5	4	[3]	4	5	4	3,4	3	2,3	(2),3
Oa6	5	4	[3]	3	4	2	3	3	3	2,3
Oa7	3,4	3	3	3	4	2	7	2	3	2,3
Oa8	4	2	2	1	3	1	8	2	3	2

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potential Irrigability	Work-ability	Seeding Establish-ment	Potential Mechanization	Susceptibility to Erosion		Erosion Hazard	Potential Fertility
							Wind	Water		
Oa9	3	3	3	3	4	2	7	3	3	2,3
Oa10	4	1	[,2]	1	1,2	1	7,8	2,3	3,(4)	2,3
Oa11	3	3	[2]	1,2	1,2	1,2	6,7	2	3	2,3
Oa12	3,4	2	[2]	1	1	1	7,8	2	3	2,3
Oa13	5	4	[3]	2	2,3	2	7,8	3,4	3,(4)	3
Oa14	3,4	3,4	[3]	2,3	1,2	2	7,8	1,2,3	2,3	2
Oa15	2,3	1,2	[2]	1	1	1	7	1,2,3	2,3	2
Ob1	3	3	(2),3	2,3	4	2	3,4	3	2,3	2
Ob2	2	3	[3]	2,3	3	2,3	3,4	2,3	2	2
Ob3	3	4	[3]	3	3,4	3	4	(2)	2	2
Oc	4	1	3	1	1,2	1	8	1	3	2
Od1	5	1,(4)	[3]	2,3	3,4	2,3	3	3,4	2,3	2,3
Od2	5	4	[3]	3,(4)	4,(5)	2,4	3	3,4	3	2,3
Od3	3/5	1,(3)	[(2),3]	2,3,(4)	3,4,(5)	(1),2,3,(4)	3/6,7	3,4	3,(4)	2,3
Od4	3/5	1,(3)	[(2),3]	2,3,(4)	3,4,(5)	(1),2,3,(4)	3/6,7	3,4	3,(4)	2,3
Od5	4	3	(2),3	1	2	1	8	4	4	2
Od6	5	1	[3]	2,3	3,4	2,3	3	2	2,3	2
Od7	2,3	2	[2]	1	4	1	7,8	3	3	2,(3)
Od8	3,4	2,3	[2]	1	1,2	1	7	1,2	3,(4)	2,(3)

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potential Irrigability	Work-ability	Seeding Establish-ment	Potiental Mechanization	Susceptibility to Erosion		Erosion Hazard	Chemical Fertility
							Wind	Water		
Od9	2	2,3	[2]	2	3	1,2	6	3	3	2,3
Od10	2/3,4/5	1/2,3	[2]	1,2/3	1,2/3,4	1,2,3	3/7,8	2/3	3	2,3
Od11	1,2/5	1/2	[3]	2/3	2/3,4	2,3	3/7,8	2/3	3	2,3
Oe1	4	1	[2]	1	3	1	7	2	3	2
Oe2	3	1,2	[2]	1,2	3	1	6,7	3	3	2
Oe3	4	3	[3]	3	4	2	4	2	2	2
Of1	(3),4	1,2	2	1	2,3	1	7	2	3	2
Of2	(3),4	1,2	[2]	1	2,3	1	7	2	3	2
P1a1	5	4	[3]	3,4	3	3,4	1	3	(2),3	(2)
P1a2	2,3	1,(2)	[(2),3]	1,2	1,2	1	6,7	2	3	1,2
P1b	5	4	[3]	3	4	3,4	4,5	4	3,4	(2)
P1c	4	3,4	[3]	2,3,4	2,3	2,3,4	2	2,3	2	(1),2
P2a1	3	3	[3]	3	2	2	3,4	2,3	2,3	2,(3)
P2a2	4	3,4	[3]	3	2	3	4	4	1,4	2
P2b	4	2	[(2),3]	1	3,4	1	7	1	2,4	2
P2c1	4,5	4	[3]	3	3	2,3	4	4	3	2
P2c2	1,2,3	2,3	[3]	1,2	1	1,2	6	3	3	2
P3	2	3,4	[3]	1,2	3,4	1,(2)	6	3	1,3	2
P4a1	3	2	(2),3	3,4	3,4	3,4	7	3	3,4	2,3

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potiental Irrigability	Work-ability	Seeding Establish-ment	Potiental Mechanization	Susceptibility to Erosion		Erosion Hazard	Chemical Fertility
							Wind	Water		
P4a2	v	v	(2),3	3,4	3,4	3,4	v	v,(3)	3	2
P4a3	5	4	3	3,4	5	4	4	4	3,4	2,3
P4b	3	2	2	1	3,4	1	7	2	3	2
P4c	5	4	(2),3	3	5	2	4	4	3,4	2,3
Ca	5	3,4	[3]	2,3	3,4	3	4,5	3	3,4	2,3
Cb	3	1	[2,(3)]	1	1,2	1,(2)	3,6,7	2,3	2,3	2,3
S1a1	2	1	[3]	3	1,2	3	2	3	3	1,2
S1a2	2/5	1/4	[3]	2,3	3,4	2,3	3	2	2,3	2
S1a3	5	1/4	[3]	3,4	3	3	7,8	3	3	[illegible]
S1b	5	4	[3]	4	5	4	1	5	3,4	3
S1c	5	4	[3]	4	5	4	1,2/4	3,4	3	(1),3
S2a	5	4	[3]	4	5	4	1	3,4	3,4	3
S2b	2,3	2	[(2),3]	1	3	1	7,8	3	3	2
S2c	5	1	[3]	3,4	3,4	2	7,8	3	3	2
S3a1	5	4	[3]	4	5	4	1	5	3,4	3
S3a2	5	1/4	[3]	2,3,4	3,4,5	2,3,4	1/3	2/4,(5)	2,3,4	2,3
S3a3	5	1	[(2),3]	2,3	3,4	2,3	3	2	2,3	2
S3a4	5	4	[3]	3,(4)	4,(5)	2,(4)	3	3,4	3	2,3
S3a5	5(3)	(3)4	[3]	3,(4)	4,(5)	2,(4)	3	3,4	3	2,3

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potiental Irrigability	Work-ability	Seeding Establish-ment	Potiental Mechanization	Susceptibility to Erosion		Erosion Hazard	Potiental Fertility
							Wind	Water		
S3b1	3/5	1/3	[3]	3	4	2,3	2,3	3	2,3	2
S3b2	1,2	3,4	[3]	2	4	2	6	3	3	2
S3c	5	4	[3]	3,4	4	2	6	3	3	(1),2
S4a1	4,5	3	[(2), 3]	2	3	2	2,3	3	3	2
S4a2	2,3	4	[(2), 3]	3	4	3	4	3	(2),3	2
S4a3	3,4	3,4	[3]	2	5	2	6	3	3	2,3
S4b1	3,4,5	3	[2, (3)]	2,3	3,4	2	2,3,4	3	3	2
S4b2	1,2	3	[3]	2,3	4	2	(2),3,4	3	3	2
S5a	4	4	[3]	2	4	2	6	3	3	2,3
S5b	1,2/4	3,4	[3]	2,3	4	2	3,4/6	3	3	2,3
S6a	5	4	[3]	4	5	4	1	4	4	3
S6b	3	4	[(2), 3]	3	(1),3,4	3	4	4	3,4	2
S7a	5	4	[3]	4	5	4	(7)	4	4	2
S7b	2/4	3,4	[2, (3)]	2,3	4	2/3	3/6	3,4	3	2
M1a	2,3	1	[3]	3,4	2	4	1	2	2	1,2
M1b	3/4	4	[(2),3]	2/3	2/3	1/2	2,4	2,(3)	2,3	2
M1c	3	3,4	[(2) ,3]	3	3	2	2,4	3	3	2
M1d	5	1/4	[3]	3,4	3	3	7,8	2	3	2
M1e	3	4	[(2), 3]	3	3,4	2	4	3	3	2
M2a	5	4	[3]	4	5	4	1	3	3	3

SOIL CHARACTERISTICS OF THE MAPPING UNITS (second order parameters)

Mapping Units	Water Holding Capacity	Permeability	Potiental Irrigability	Work-ability	Seeding Establish-ment	Potiental Mechanization	Susceptibility to Erosion		Erosion Hazard	Chemical Fertility
							Wind	Water		
M2b	(3,4),5	1,(3)/4	[(2),3]	2,3,(4)	3,4,(5)	2,3,(4)	3,(7)	3,(4)	3,(4)	2,3
M2c	5	4	[3]	4	5	4	1,4,(7)	2	2,3	2
M3a1	3,5	(1),3,4	[3]	2,3,4	3,4,5	2,3,4	(1),2,3	2,3,4	3,(4)	2,3
M3a2	5	1/4	[3]	2,3,4	3,4,5	2,3,4	1/3	2/4,(5)	2,3,4	2,3
M3b	3,4	3	[(2),3]	3	4	3	2,3	3	3	2,3
Ga1	5	3,4	[3]	(3),4	4,5	4	6,7	3,(4)	3	3
Ga2	3,4,(5)	2,3	[2,(3)]	2,3,4	3,4	2,3,4	6,7	3	3	2,3
Gb	3,4,5	2,3,4	[(2),3]	2,3,4	3,4,5	2,3,4	6,7	3,4	3	(2),3
Gc1	5	3,4	[3]	2,3	3,4	2,3	7	3	3	3
Gc2	5	3,4	[3]	(3),4	4,5	4	6,7	3,(4)	3	3
Gc3	5	3,4	[3]	2	3	2	7	3	3	(2),3
Gc4	3,4	3	[2,(3)]	2	3	2	7	4	3,4	2,3
Gc5	5	3,4	[3]	3	4	4	6	3	3	3
Gd	2,3	2,3	[(2),3]	3	4	2	6	3	3	2,3
I1	3,4	3	[3]	2	3	2	7	[illegible]	3,4	2,3
I2	2,3,4,5	1/3,4	[3]	2,3,4	2,3	1,2,3,4	1,2,3/7	2,3,4	2,3	(1),2

APPENDIX B

Table IV-5

Land Capability

TABLE IV-5
LAND CAPABILITY

MAPPING UNIT	SOIL CLIMATE ZONE	RATINGS
La1	II	F4
La2	II	F4
La3	III	F4
La4	III	F4
Lb1	II III IV	F3 P3
Lb2	II	F3 P3 C3
Lcx	III IV	F4
Lcy1	III IV	F4
Lcy2	IV	F4
Lcz1	III IV	F4
Lcz2	III IV	F4
Lcz3 SS°/BC+	III IV	F4 P4
		F3 P4 C3
Lcz4	III	F3 P3 C3
Lcz5	II	F4 P4 C3
Ld	II III IV	F3 P3
Le	III	F3 P3 A2
Lfx	I	F4 P4 C3
Lfy1	I	F4 P3 C3
Lfy2	I	F4 P3 C3
Lg1	I	F4 P4 C3
Lg2	I	F4 P4 C3
Lg3	I	F4 P4 C3
Lg4	I	F4 P4 C3
Lg5	I	F4 P4 C3
Lh1	III	F3 P4 A2
Lh2	III	F4 P4
Aa1	IV	F3 P2 A3
Aa2	IV	F2 P1 A3
Aa3	IV	F3 P1 A3
Aa4	III IV	F3 P1 A2
Ab1	II	F4 P2 C3
	III	F3 P2 A3
Ab2	II	F3 P1 C2
Ab3	III	F3 P1 A2
Ab4	III	F3 P4 A2
Ac1	II	F4 P1 C3
Ac2	III	F4 P2 A2
Adx	IV	F3 P4 A2
Ady1	I II	F3 P4 C2
Ady2	I II	F3 P4 C2
Ady3	I II	F4 P4 C2
Adz	III IV	F4 P4 C3
Ela1	II	F3 P1 C3
Ela2	I	F3 P2 C3
Ela3	II	F3 P1 C2
Ela4	I	F3 P2 C2
Ela5	I	F3 P2 C2
Ela6	II	F3 P1 C2
Elb	II	F3 P1 C2

MAPPING UNIT	SOIL CLIMATE ZONE	RATINGS
Elc1	I	F3 P2 C2
Elc2	II	F4
Eldx1	I	F3 P3
Eldx2	I	F3 P4
Eldy	I	F4 P4 C2
E2ax1	II	F3 P2 C3
E2ax2	II	F3 P2 C2
	III	F2 P2 A2
E2ay1	II	F3 P1 C2
E2ay2	III	F3 P2 A2
E2ay3	III	F3 P2 A2
E2b	I	F4
E2cx1	II	F3 P2
E2cx2	II	F3 P2
E2cy	III	F3 P2
E2d	III	F3 P4 A2
E2e1	II	F3 P1 C2
E2e2	II	F4 P4
V	III	F3 P2 A2
Oa1	II	F4 P3
Oa2	III IV	F3 P3 A2
Oa3	IV	F3 P3 A2
Oa4	IV	F2 P2 A2
Oa5	III	F3 P3
Oa6	IV	F3 P2 A3
Oa7	II	F4 P2 C3
Oa8	II	F3 P2 C2
Oa9	I	F3 P3 C3
Oa10	III	F3 P1 A2
Oa11	III	F3 P1 A2
Oa12	III	F3 P1 A2
Oa13	III	F3 P3 A3
Oa14	IV	F2 P2 A2
Oa15	IV	F1 P2 A2
Ob1	II	F3 P2 C2
Ob2	IV	F2 P2 A2
Ob3	IV	F3 P4 A2
Oc	II	F4 P2 C3
Od1	IV	F3 P3 A2
Od2	IV	F3 P3 A3
Od3	IV	F3 P3 A2
Od4	II	F4 P3 C3
	III IV	F3 P1 A2
Od5	II	F4 P2
Od6	IV	F3 P2 A2
Od7	III	F2 P2 A2
Od8	III	F3 P2 A2
Od9	IV	F3 P1 A2
Od10	IV	F2 P2 A2
Od11	IV	F3 P2 A2

° SS: Sine Saloum
+ BC: Basse Casamance

LAND CAPABILITY (cont.)

MAPPING UNIT	SOIL CLIMATE ZONE	RATINGS
Oe1	III	F2 P2 A2
Oe2	III	F2 P2 A2
Oe3	III	F3 P4 A2
Of1	II	F3 P2 C2
Of2	III	F3 P2 A2
P1a1	III	F4 P3
P1a2	III	F3 P3 A2
P1b	III	F4
P1c	III	F2 P2
P2a1	III	F3 P1 A2
P2a2	III	F2 P1 A3
P2b	III	F2 P2 A2
P2c1	III	F4 P2
P2c2	III	F4 P2 A2
P3	III	F3 P4
P4a1	II	F4 P3
P4a2	II	F4 P3 C3
P4a3	II	F4 P3
P4b	II	F3 P3 C2
P4c	II	F4 P3
Ca	III	F4 P3
Cb	III	F3 P3 A2
S1a1	IV	F4 P2 A3
S1a2	IV	F2 P2 A2
S1a3	IV	F3 P2 A3
S1b	IV	F4 P3
S1c	IV	F4 P3
S2a	III IV	F4 P3
S2b	IV	F3 P2 A2
S2c	IV	F2 P3 A3
S3a1	IV	F4 P3
S3a2 c°/g+	IV	F4 F3 P2 A2
S3a3	IV	F2 P2 A2
S3a4	IV	F3 P2 A3
S3a5	IV	F2 P2 A3
S3b1	IV	F3 P2 A2
S3b2	IV	F3 P2 A2
S3c	IV	F3 P2 A3
S4a1	III	F3 P1 A2
S4a2	III	F3 P2 A2
S4a3	IV	F3 P3
S4b1	III	F3 P1 A2
S4b2	III	F3 P1 A2
S5a	III	F3 P3
S5b	III	F3 P3
S6a	IV	F4 P3
S6b	IV	F3 P1 A2
S7a	IV	F4 P3
S7b	IV	F3 P2

MAPPING UNIT	SOIL CLIMATE ZONE	RATINGS
M1a	IV	F4 P3 A3
M1b	IV	F4 P1 A2
M1c	IV	F2 P1 A3
M1d	IV	F4 P2 A3
M1e	IV	F3 P2 A3
M2a	IV	F4
M2b	IV	F3 P2 A3
M2c	IV	F3 P3
M3a1	IV	F3 P2 A3
M3a2 c°/g+	IV	F3 F2 P2 A3
M3b	IV	F4 P3
Ga1	IV	F2 P3
Ga2	IV	F2 P3 A3
Gb	IV	F2 P3
Gc1	IV	F2 P3 A3
Gc2	IV	F2 P2
Gc3	IV	F2 P2 A3
Gc4	IV	F2 P3 A3
Gc5	IV	F4 P2
Gd	IV	F4 P4 A3
I1	IV	F2 P3 A3
I2	IV	F2 P2 A3

° c: cuirass (phase)
+ g: gravelly (phase)

4.6 BIBLIOGRAPHY

Audry, P. (1962) Etude pédologique du Centre de Recherches Zootechniques de Dahra-Djoloff (République du Sénégal). tomes I and II. ORSTOM, Centre de Dakar-Hann.

_____. (1972) Etude des pâturages naturels du nord Sénégal: Etude agrostologique. Lab. Nat'l de l'Elevage et de Recherch. Vet., Dakar-Hann. 311 p.

_____. (1972) "Etude des pâturages naturels du Ferlo Boundou (zone Matam-Kidira-Tambacounda)". ISRA, Dakar-Hann. pp. 28-96.

Baldensperger, J., et al. (1968) Notice explicative de la carte pédologique du Sénégal: Moyenne Casamance; échelle 1/200 000e. ORSTOM, Centre de Dakar-Hann. 134 p.

Barreto, S. (1964) Reconnaissance pédologique du Ferlo sud. ORSTOM, Centre de Dakar-Hann. 42 p.

_____. (1968) Reconnaissance pédologique des Terres Neuves (zone d'intervention immédiate). ORSTOM, Centre de Dakar. 35 p.

_____. (1982) Rapport de reconnaissance des sols de cinq périmètres de la région de Diatta-Counda en vue de leur plantation en bananeraies. ORSTOM, Centre de Dakar-Hann. 31 p.

Bertrand, P. (1973) "Contribution à l'étude hydrologique, pédologique, et agronomique des sols gris sableux hydromorphes de Casamance (Sénégal)". L'Agronomie tropicale, 28(12):1145-192.

Bertrand, R. (1972) "Morphopédologie et orientations culturales des régions soudaniennes du Sine Saloum (Sénégal)". L'Agronomie tropicale, 27(11):1114-901.

Beye, G. (n.d.) Dégradation des sols au Sénégal: Situation actuelle et perspective. ISRA. 23 p.

Blot, C. (1980) L'Altération climatique des massifs de granite du Sénégal. ORSTOM

de Boissezon, P., et al. (1973) Les sols ferralitiques. Tome IV: La matière organique et la vie dans les sols ferralitiques. ORSTOM, Paris. 146 p.

Boudet, G., et Orve, J. (1966) Etude des pâturages naturels du Ferlo oriental (République du Sénégal). Etude agrostologique. No. 13. 175 p.

Boyer, J. (1982) Les sols ferralitiques. Tome X: Facteurs de fertilité et utilisation des sols. IDT No. 52. ORSTOM, Paris. 384 p.

Brandeau, E., et al. (1982) Etude pédologique des forêts classées du centre Sénégal (région de Kaffrine-Koumpentoum). Convention SEEF. ORSTOM, Centre de Dakar-Hann. 69 p.

Chamard, P., et Barbey, C. (1970) "Contribution à l'étude de la côte occidentale de la presqu'île du Cap Vert: Indices morphométriques et morphoscopiques des galets de plages." Bull. de l'IFAN. Sér. A. No. 4. pp. 859-68.

Charreau, C.I. et Fauck, R. (1965) Etudes sénégalaises No. 9: Connaissance du Sénégal. CRDS, Sénégal Saint Louis. 214 p.

Chatelin, Y. (972) Les sols ferralitiques. Tome I: Historique-développement des connaissances et formation des concepts actuels. ORSTOM, Paris. 98 p.

_____. (1974) Les sols ferralitiques. Tome III: L'Altération. ORSTOM, Paris. 144 p.

Chauvel, A. (1967) Carte pédologique du Sénégal Oriental à l'échelle du 1/200 000e: Notice explicative des feuilles de Kédougou et de Kéniéba-Kossanto. ORSTOM, Centre de Dakar. 153 pp.

_____et Hanrion, C.I. (1969) Observations pédologiques sur des zones témoins pour l'opération Terres Nouvelles. ORSTOM, Centre de Dakar-Hann. 41 p.

_____. (1977) Travaux et documents de l'ORSTOM: Recherches sur la transformation des sols ferralitiques dans la zone tropicale à saisons contrastées; évolution et réorganisation des sols rouges de Moyenne Casamance (Sénégal). ORSTOM, Paris. 534 p.

Delvigne, J. (1965) Pédogenèse en zone tropicale: La Formation des minéraux secondaires en milieu ferralitique. ORSTOM. Paris: Dunod Pub. 117 p.

Dewis, J. et Freitas, F. (1972) Méthodes d'analyse physique et chimique des sols et des eaux. Bull. Péd. No. 10. FAO, Rome. 280 p.

Duchafour, P. (1970) Précis de pédologie. Paris: Masson et Cie. 481 p.

_____. (1978) Ecological atlas of soils of the world. Trans. by G.R. Mehuys et al. Paris: Masson Pub. 178 p.

Dunsmore, J.R., et al. (1976) Land resource study 22: The agricultural development of The Gambia: An agricultural, environmental, and socio-economic analysis. Min. of Overseas Develop., Surrey, Eng. 450 p.

FAO (1976) A framework for land evaluation. Soils Res. Dev. and Conserv. Ser., Land and Water Dev. Div., Rome. 72 p.

_____. (1977) Directives pour la description ds sols, éd. seconde. Org. des Nations Unies pour l'Alimentation et l'Agriculture. Rome. 71 p.

FAO-UNESCO.(1974) Soil map of the world 1/5 000 000. Vol. I. Paris. 59 p.

Fauck, R., et al. (1963) Etude pédologique de la Haute Casamance. ORSTOM, Centre de Dakar-Hann. 178 p.

Fauck, R. (1972) Les Sols rouges sur sables et sur grès d'Afrique occidentale. Mém. No. 61. ORSTOM, Paris. 257 p.

Feller, C. (1974) Etude pédologique de la région de Panal (Sénégal Oriental). ORSTOM, Centr de Dakar. 27 p.

_____. (1975) Etude des pâturages naturels du Ferlo Boundou (Matam-Kidira-Tambacounda). ORSTOM, Centre de Dakar. 27 p.

Gaucher, G. (1976) Plaidoyer pour la pédologie agricole. L'Agronomie tropicale. 213 p.

Giffard, P.L. (1974) "L'Arbre dans le paysage sénégalais". Cent. Tech. For. Tropical. Dakar. pp. 61-79.

Gooser, D. (1967) Aerial photo interpretation in soil survey. Soils Bull. No. 6. FAO/UN, Rome. 55 p.

Hannon, C., et al. (1971) Projet pilote des Terres Neuves: Etude pédologique du périmètre sud Koumpentoum. ORSTOM, Centre de Dakar. 75 p.

Henin, S., et al. (1969) Le Profil cultural: L'Etat physique du sol et ses conséquences agronomiques. Paris: Masson et Cie. 332 p.

Join, P. (1982) Etude pédologique d'une zone fluvio-marine à Dakar Bango (delta du fleuve Sénégal). ORSTOM, Centre de Dakar-Hann. 26 p.

Kolaga, B. (1966) Notice explicative: Carte pédologique du Sénégal au 200 000e: Dalafi. ORSTOM, Centre de Dakar-Hann. 102 p.

Leprun, J.C. (1967) Les Sols de la région de Goudiry (Sénégal Oriental): Inventaire, relations génétiques et mise en place de matériaux. ORSTOM, Centre de Dakar-Hann. 133 p.

_____. (1979) Sciences géologiques: Les Cuirasses ferrugineuses des pays cristallins de l'Afrique occidentale sèche. Centre Nat'l. de la Recherch. Sci. No. 58. 224 p.

Louis Berger Int'l, Inc., et al. (1983) Land Classification/Soil Survey Project of the Syrian Arab Republic. Remote Sensing Institute, Brookings, SD, SDSU-RSI-83-02, Contract AID/NE-C-1644. Vols. I-X.

Loyer, J.Y. (1981) Conception et réalisation des cartes d'utilisation des sols dans la vallée du fleuve Sénégal: La Carte factorielle. ORSTOM, Centre de Dakar. 5 p.

Maignien, R. (1959) Les Sols de la presqu'île du Cap Vert. Office de la Recherch. Sci. et Tech. ORSTOM, Centre de Dakar-Hann. 163 p.

_____. (1959) "Les Sols subarides au Sénégal." Agronomie tropicale, 15 (5):536-71.

_____. (1965) Notice explicative carte pédologique du Sénégal au 1/1 000 000e. ORSTOM, Centre de Dakar-Hann. 63 p.

_____. (1969) Manuel de prospection pédologique. ORSTOM, Paris. 132 p.

Marius, C. (1977) Notice explicative de la carte pédologique au 1/50 000e: Iles du Saloum. ORSTOM, Centre de Dakar. 47 p.

_____. (1977) Propositions pour une classification et cartographie des sols de mangroves tropicales. ORSTOM, Centre de Dakar. 28 p.

Michel. P. (1973) "Les Sols et leurs rapports avec le modelé." Mém. No. 63. ORSTOM. pp. 257-88.

Millot, G. (1977) Géochimie de la surface et formes du relief présentation. Sci. géo. T. 30, Fas. 4.

Ministère de l'Economie Rurale. (1966) Notice explicative carte pédologique du Sénégal au 200 000e: Kédougou-Kossanto-Kéniéba. ORSTOM, Centre de Dakar-Hann.

Mohr, E.C.J., et al. (1972) Tropical soils: A comprehensive study of their genesis, 3rd ed. Mouton-Ichtiar Bani-Van Hoeve, ed. The Hague. 481 p.

Morin, S. (1973) "Le plateau de Bargny (Sénégal Oriental) et son évolution au Quaternaire récent." Bull. de l'IFAN, 35 (4):764-811.

_____. (1974) "Glacis et cuirasses de la falaise de Thiès (Sénégal occidental)". Bull. de l'IFAN. Sér. A. 36 (4): 757-88.

Munsell color company (1971) Baltimore: Munsel soil color charts. 20 p.

Nalovic, L. (1977) Recherches géochimiques sur les éléments de transition dans les sols. T. and D. No. 66. ORSTOM, Paris. 235 p.

ORSTOM, Section de Pédologie. (1984) Inventaire des études pédologiques effectuées à l'ORSTOM au Sénégal de 1946 à 1984. ORSTOM, Paris. 41 p.

Orue, J., et al. (1967) Les Pâturages naturels de la région de Gallayel (République du Sénégal). Etude agrostologique No. 18. 137 p.

_____. (1968) Pâturages naturels du Ferlo sud (République du Sénégal). Min. du Dév. Rural. 173 p.

_____. (1970) Pâturages naturels de Haute et Moyenne Casamance (République du Sénégal). Lab. Nat'l de l'Elevage de Recherch. Vét. Etude agrostologique No. 27. 239 p.

Pieri, C. (1969) Etude pédologique de la région de Nioro du Rip. Vol. I. Centre Nat'l de Recherch. Ag. de Bambey, Sénégal. 134 p.

Pitty, A.F. (1978) Geography and soil properties. London: Methuen and Co. 287 p.

Remote Sensing Institute. (1982) Inventaire des ressources du sud-ouest mauritanien: Géologie, sols, forêts, pâturages. SDSI-RSI-82-03. Contract: AID/afr-c-1619. 391 p.

Roose, E. (1977) Erosion et ruissellement en Afrique de l'Ouest: Vingt années de mesures en petites parcelles expérimentales. No. 78. ORSTOM, Paris. 108 p.

_____. (1981) Dynamique actuelle des sols ferralitiques et ferrugineux tropicaux d'Afrique occidentale. No. 130. ORSTOM, Paris. 569 p.

Sall, D. (1967) Etude de deux toposéquences à l'ouest de Dialakota (Sénégal Oriental). ORSTOM, Centre de Dakar-Hann. 198 p.

Sall, M. (1959) Projet fixation des dunes. Unpublished report.

Sedagri, . (1973) Etude hydro-agricole du bassin du fleuve Sénégal. USAID. Agl: DP/RAF/65/061. 241 p.

Segalen, P. (1964) Le fer dans les sols: Initiations, documentations techniques. ORSTOM, Paris. 149 p.

_____. (1973) L'Aluminium dans les sols: Initiations, documentations techniques. ORSTOM, Paris. 281 p.

Soil Survey Staff. (1975) Soil Taxonomy: Basic system of soil classification for making and interpreting soil surveys. USDA Ag. Handbook No. 436. 754 p.

Staimesse, J.P. (1967) Contribution à l'étude des sols jaunes de Basse Casamance. ORSTOM, Centre de Dakar-Hann. 112 p.

Turenne, J.F. (1963) Etude pédologique d'une zone inondable dans la région de Pira (Haute Casamance). ORSTOM, Centre de Dakar-Hann, 57 p.

US Dept. of Ag., Soil Survey Staff. (1977) Soil survey manual. Ag. Research Admin. Handbook No. 18. 503 p.

Valenya, J. (1977) Etude des pâturages naturels du Ferlo Boundou. ISRA, 119 p.

Van Sleen, L.A. ed. (1979) Cours de télédétection. VISP. Remote Sensing Institute, Brookings, SD. 109 p.

_____. (1980) Comptes-rendus du séminaire de télédétection. Tomes I et II. SERST, Dakar.

Vieillefon, J. (1975) Notice explicative No. 57: Carte pédologique de la Basse Casamance (domaine fluvio-marin) au 1 000 000e. ORSTOM, Centre de Dakar. 58 p.

_____. (1977) Les sols des mangroves et des tannes de Basse Casamance (Sénégal). ORSTOM, Paris. 291 p.

Vizier, J.F. (1963) Etude d'une toposéquence au sud de la Kayanga (Haute Casamance). ORSTOM, Centre de Dakar-Hann. 65 p.

van Wambeke, A. (1984) SMSS technical monograph No. 3: Calculated soil moisture and temperature regimes of Africa. SMSS. 16 p.

Zante, P. (1984) Etude de reconnaissance des sols aux aptitudes forestières: Projet Louga. ORSTOM, Centre de Dakar-Hann. 38 p.

CHAPTER V

VEGETATION AND LAND USE

CHAPTER V: VEGETATION AND LAND USE

5.1 Introduction..... 485
5.2 Literature Consulted..... 485
5.3 Mapping Procedure..... 486
5.3.1 Vegetation and Land Use Reconaissance Surveys..... 486
5.3.2 Vegetation Classification..... 486
5.3.3 Land Use/Land Cover Classification..... 487
5.3.4 Interpretation..... 488
5.3.5 Field Data Collection..... 490
5.3.6 Other Means of Verification..... 493
5.3.7 The Vegetation Legend..... 493
5.3.8 The Land Use/Land Cover Legend..... 494
5.4 Description of Cover Types..... 495
5.4.1 The Sahelian Phytogeographic Region..... 495
5.4.1.1 The Senegal River Valley..... 497
A. General Characteristics..... 497
B. Cover Types..... 499
Units A14 and Ac14
Unit AE12
Unit EF
Unit P3
Unit F4
Unit Ca
Unit A7
Unit Ac15
Unit TAc
Unit T2
Unit P4
Unit M
Unit H
5.4.1.2 The Northern Coastal Area..... 506
A. General Characteristics..... 506
B. Cover Types..... 507
Unit Ac12
Units V1 and Vc1
Unit V7
Unit P1
Unit AE9
5.4.1.3 The Dakar Region..... 512
A. General Characteristics..... 512
B. Cover Types..... 512
Unit A8
Unit Vd2
Unit V10
Unit VS8
Unit B2
Unit BV3

5.4.1.4 The West-Central Agricultural Environment (Sahelian Region)..... 515
A. General Characteristics..... 515
B. Cover Types..... 517
Unit A13
Units AEc10 and AE10
Unit AE11
Unit E2
Unit V8
Unit V9
Unit VS10
Unit S1
Unit S2
Unit Sd3
Unit Sc4
Unit S5
Unit S6
Unit S7
Unit S8
Unit S10
Unit S11
Unit S21
Unit S22
Unit B1
Unit B11
Unit BV1
Unit BV2
Unit N
Unit Cr
5.4.1.5 The Pastoral Domain..... 532
A. General Characteristics..... 532
B. Cover Types..... 535
Unit Ac1
Unit Ac2
Units Ac3 and Acm3
Unit Ac4
Unit Acm5
Unit Ac6
Unit A9
Unit Ac10
Unit AE1
Unit AE2
Unit AE3
Unit AE4
Units AE5 and AEc5
Unit AEc6
Unit AE7
Unit AE8
Unit AET
Unit Ec3
Unit Vc3

Units Vd4 and Vdm4
Units V5, Vc5 and Vd5
Units V6 and Vc6
Unit Vcm13
Unit VS1
Unit VS2
Unit VSm3
Unit VS4
Unit VSc9
Unit VS17
Unit VSc18
Unit VS19
Unit SB5
Unit F1
5.4.2 The Sudanian Phytogeographic Region..... 558
5.4.2.1 The West-Central Agricultural Domain (Sudanian)..... 560
A. General Characteristics..... 560
B. Cover Types..... 561
Unit V11
Unit Vd12
Unit VS11
Unit VdS12
Unit VS13
Unit VS14
Unit VS15
Units VS16 and VdS16
Unit S9
Unit Sc12
Unit Sd13
Unit S14
Unit ST
Unit SB4
Unit B3
Unit B4
Unit B6
Unit BV4
Unit BV5
Unit M
Unit T1
Unit X
Unit P2
5.4.2.2 The Eastern Transition Zone..... 576
A. General Characteristics..... 576
B. Cover Types..... 577
Unit VdS5
Unit VS6
Unit VS7
Unit VdSm20
Unit VS21
Unit S15

Unit SB1
Unit SB2
Unit SB6
Unit B5
Unit Bd9
Unit Bd12
Unit BF4
5.4.2.3 The Region of the Shield..... 588
A. General Characteristics..... 588
B. Cover Types..... 589
Unit A11
Unit A16
Unit AE13
Unit Ed1
Unit S17
Unit B7
Unit Bd8
Unit Bd10
Units B13 and Bd13
Unit B14
Unit BdH1
Unit BdH2
Unit BdF7
Unit G
Unit FBH
5.4.2.4 The Casamance..... 600
A. General Characteristics..... 600
B. Cover Types..... 600
Unit VP
Unit S16
Unit S18
Unit SP
Unit SBd3
Unit BdF1
Unit BdF2
Unit BdF3
Unit BF5
Unit BFh6
Unit F2
Unit F3
Unit J
Unit Fh5
Unit T3
Unit TP
Unit XP
5.4.3 The Guinean Phytogeographic Region..... 613
5.4.3.1 The Casamance..... 614
A. General Characteristics..... 614
B. Cover Types..... 614
Unit S19
Unit S20

Unit FhL
Unit FD
Unit LJ
Unit Dh
Unit I
5.5 The Vegetation Degradation Map..... 619
5.6 Appendix C: Vegetation and Land Use.. 622
5.7 Bibliography..... 629

CHAPTER V

VEGETATION AND LAND USE

5.1 INTRODUCTION

This chapter presents the results of the vegetation and land use/land cover mapping effort. Accompanying this chapter is the Map of Vegetation Cover at 1:500 000 scale, the Land Use/Land Cover Map at 1:500 000 scale and the Map of Vegetation Degradation at 1:1 000 000 scale. These maps cover all of Senegal and The Gambia.

This survey represents an up-to-date, nation-wide spatial presentation of the actual vegetation and land use. This effort was made feasible through the analysis of Landsat satellite data, which has provided a fresh approach to inventorying earth resources and monitoring changes in the landscape.

Landsat imagery served as the primary basis for delineating all map units. Approximately 160 individual vegetation types were identified, mapped and described, as well as fifty land use/land cover types. Extensive field surveys and aerial surveys were conducted to relate the map units interpreted from the Landsat imagery to actual ground conditions, including vegetation physiognomy, floristic composition and land use practices.

This chapter of the report describes the mapping procedures, including classification of vegetation and land use, interpretation, field data collection, other means of verification and development of the legends. Also presented is a description of the phyto-geographical regions of Senegal. Each region is further divided into eco-geographical environments. The various cover types shown on the vegetation maps are described in detail (5.4), giving additional information which could not be shown on the map legend. This section is followed by a set of observations and recommendations which derive from our field surveys and interpretations (Chapter 6). Further information on definitions of vegetation types found in Senegal are included in the Appendix C.

5.2 LITERATURE CONSULTED

Considerable effort was made to acquire as much literature as possible. Although excellent bibliographies have been published on the vegetation and land use of West Africa, we experienced many of the same difficulties in obtaining documents and maps encountered by the other survey teams (refer to section 3.3).

The main sources of published informaiton evaluated and integrated into our survey were the works of the Institut d'Elevage et de Medecine Véterinaire des Pays Tropicaux (IEMVT), the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM), and The Institut

Français d'Afrique Noire (IFAN). A listing of these and other works we consulted can be found in the bibliography.

5.3 MAPPING PROCEDURE

This section summarizes the mapping procedures used to derive the vegetation map, the land use map, and the vegetation degradation map. Briefly described are all major steps of the methodology used, from the initial reconnaissance surveys to the preparation of map worksheets and legends. The steps involved in the final map production (mosaicking, artwork, etc.) will not be described here, as they are dealt with in section 1.5.1.

5.3.1 Vegetation and Land Use Reconnaissance Surveys

Following a preliminary examination of the literature and Landsat imagery, including a general interpretation of the major physiographic regions of Senegal, a two-week reconnaissance survey of the country was conducted. Two major circuits were taken, a northern and a southern, encompassing the north and south halves of Senegal, respectively. Conducted at the end of the 1982 rainy season at the peak of vegetative growth, this survey provided the team with the following insights:

- an overall picture of the vegetation, its physiognomic and floristic diversity.

- a better understanding of the relationships between variations in vegetation cover observed on the ground and the corresponding variations seen on the Landsat imagery (in terms of tone, texture, etc.).

- an approach to a systematic method of collecting field data.

- an approach to vegetation mapping, which included determining whether the vegetation maps would be primarily formation (physiognomy) oriented, floristically oriented, or a combination of the two. The latter approach was adopted.

- an inventory of the various land use practices and a basic approach for land use mapping.

5.3.2 Vegetation Classification

Numerous systems of vegetation classification have been used in vegetation mapping around the world, including physiognomic, ecological, areal-geographical and floristic systems. The approach adopted for this study is a combination physiognomic-floristic system, which has the advantage of greatly extending the scope and usefulness of the map.

The fundamental map units are based on a physiognomic (structural) classification. Physiognomic classifications are particularly valuable in that the maps can be used and interpreted by a wide variety of people in various disciplines, as they do not presuppose a taxonomic knowledge of the vegetation. Furthermore, this approach lends itself to vegetation mapping using Landsat and aerial photography, since the vegetation formations described within a physiognomic approach can often be distinguished on remotely sensed data. However, the relationship between vegetation formations and their appearance on aerial photographs and, particularly, on Landsat imagery is not always clear until it is established through field observations. This approach is also valuable for comparative studies and can be used on maps of any scale. On the other hand, the physiognomic description is only a beginning from which deeper investigations should lead, including studies of floristic composition, ecological succession, historical changes, etc. (Küchler, 1967).

While there are numerous systems used to map and describe the physiognomy of vegetation, the "Yangambi" approach is particularly tailored to Africa (Trochain, 1957) and has been adopted for this survey. This approach is based on an inter-African accord on the nomenclature of the types (formations) of vegetation of tropical Africa. The definitions of vegetation types are essentially physiognomic. The various formations found on the vegetation map of Senegal are briefly defined in Appendix C.

Our efforts have not been merely limited to mapping the vegetation formations of Senegal, but also its "plant communities", which are defined here as a part of the vegetation that is relatively uniform in structure and floristic composition and consists of competing plants which both depend on and affect the environment (Küchler, 1967). While in the physionomical approach, the emphasis rests on the appearance of the vegetation, regardless of its floristic composition, the physiognomic-floristic approach to vegetation mapping endeavors to combine the floristic features of the vegetation with its physiognomic characteristics. The units shown on the map are plant communities characterized in the legend by certain species combinations, usually the dominant or characteristic species. The main limitations of presenting the floristic descriptions of a community on a map rests on the fact that the number of important species in a given unit may be so large that it is impossible to give a complete description of the vegetation. In our case, only two to three key species that form each stratum are listed in the legend. A more detailed description of the floristic composition is given in section 5.4, Description of Cover Types.

5.3.3 Land Use/Land Cover Classification

While there are instances in which vegetation units and land use/ land cover units are nearly synonymous, e.g., mangroves, the approach and focus of the land cover map differs from that of the land use map.

The term land cover relates to the types of features present on the surface of the earth. Lakes, urban areas, dune fields, millet fields, and woodlands are all examples of land cover types. The term land use relates to the human activity associated with a specific land surface (Lillesand and Kiefer, 1979). Examples include agricultural use, residential use, rangeland use, etc. From a practical standpoint, it is common to mix the two systems when the map is based on remote sensing data. While land cover information was directly interpreted from the Landsat imagery of Senegal, information about human activity on the land (land use) relied heavily on field data and existing statistics on agricultural production in Senegal.

The land use/land cover classification of Senegal was designed to apply to extensive areas of West Africa and to have categories that are divisible into more detailed subcategories. Two levels of information have been mapped. Most of the first-level information was derived directly from the Landsat interpretations, e.g., rainfed agriculture. Most of the second-level information was obtained from field data and other sources. Examples of this information type include data on crop types and mixtures.

5.3.4 Interpretation

Upon completion of the reconnaissance survey and the design of the classification approach, Landsat interpretation began on a scene by scene basis. Most of the interpretations made use of 1:250,000 scale false-color composite imagery. The image exhibiting optimum quality and which provided the best contrast between various vegetation formations and land cover types was selected for the base interpretation. It was found that image acquisitions taken shortly after the end of the rainy season were most useful overall, since the herbaceous cover senesces before most woody species shed their leaves, resulting in good spectral contrast between the open herbaceous formations and the dense woody formations. Furthermore, bush fires are less extensive in the early dry season, making interpretation more straightforward. Most of the dry season imagery was quite useful despite the numerous fire scars. A direct relationship was found between the optical density (tone) on all Landsat MSS bands and the density of the leafless (deciduous) woody cover. Also, riparian vegetation and vegetation of depressions generally exhibited strong contrast with slope and upland formations on dry season imagery, particularly where evergreen species occur. Wet season imagery, while less useful for delineating natural vegetation formations, proved to be valuable for detecting and mapping deforested and agricultural areas. Cloud cover, however, caused problems, and the availability of imagery was limited.

In summary, the vegetation and land use/land cover map units were delineated on transparent overlays to the Landsat prints of 1:250,000 scale. This process was done on large light tables constructed especially to accommodate the large prints. Delineations began on the

base image, followed by a systematic (by season) analysis of all existing imagery. Conventional interpretation techniques were employed, making use of image features (tone, texture, pattern, shape, size, etc.) and relating them to the various vegetation formations and cover types.

During the interpretation an effort was made to maintain a standard level of detail over the whole country. The minimum mapping unit was set at approximately 1 cm^2 at the interpretation scale, equivalent to about 6 km^2 (600 ha). Linear features tended to be smaller, with widths as narrow as 1 km.

Most of the boundaries drawn between two map units represent concrete discontinuities observable in the field. The reasons for these boundaries are usually evident; they often result from changes in slope, aspect, soil, presence or absence of water, human activity, etc., and they result in an abrupt change in vegetation physiognomy. It is evident, however, that certain divisions between vegetation types are arbitrary and artificial. This is generally true where climate plays the dominant role in vegetation distribution (i.e., zonal vegetation), producing a transition. Such is the case in Senegal, where annual rainfall increases gradually from north to south. For example, transition between the shrub and tree savanna of the southern Ferlo and the savanna-woodlands of Senegal Oriental is gradual and nearly imperceptible. This gradation has been shown cartographically through the transitional tree savanna and savanna-woodland map unit. Boundaries are often determined through subtle changes in landscape (topography and soils) and the percent cover measurements made in the field.

Because of the close relationship between vegetation physiognomy and floristic composition, the floristic make-up of these zonal vegetation communities can be equally gradual and almost undetectable over distance. Thus, adjacent zonal communities are composed of many of the same species. While the differences between extreme ends of the transitions are clear, the differences on either side of a boundary drawn to subdivide a continuum can be imperceptible. Nevertheless, nearly all boundaries delineated on the vegetation and land use maps fall into the first class of concrete boundaries.

Based on the reconnaissance and on-going field surveys, examination of aerial photographs and ancillary documentation, interpretation keys were established for a given image. Often, these keys were not applicable to other image dates and other regions, particularly the color images which vary greatly from season to season and year to year. They were, however, useful in evaluating the spatial information presented on the Landsat imagery.

5.3.5 Field Data Collection

Field trips were organized after the completion of the multi-temporal analysis of each Landsat scene. They served to verify the map unit delineations, as well as to collect structural, floristic, and land use/land cover data to support and better describe each map unit.

An attempt was made to systematically collect field data within each distinct map unit and to cover the country in an organized manner. The number of detailed ground observations within a given unit was roughly a function of its size. Other considerations included accessibility, whether the area had been adequately mapped by other organizations, time availability for field work and the degree of complexity of the unit. The survey routes were generally preselected from the interpretations in order to optimize the number of map units traversed.

Navigation in the field was generally straightforward. Care was taken to pinpoint accurately the location of each observation site on the interpretation sheets; field position accuracies were within 500 m.

Locating the observation sites was accomplished through careful ground navigation, using topographic maps and Landsat RBV imagery to find roads, settlements and other landmarks.

In the field, the observation sites were chosen in areas considered representative of the entire map unit. If a map unit, for example, occurred over a rolling landscape with depressions and uplands, it was necessary to divide the landscape into its components, describing each as a subunit. Depending on the size of these components, the map unit would either be described as a complex of vegetation or land use types, or mapped separately if the area they cover exceeded the size of the minimum mapping unit.

Once an observation site was reached, a systematic description of the site was made. It included a description of the vegetation structure. The structure was defined by three components:

1. Vertical structure: the vertical arrangement of the species into layers or strata.

2. Horizontal structure: the spatial distribution of plants making up the vegetation cover.

3. Abundance of each species derived by estimating their distribution and frequency of occurrence.

The structural and floristic descriptions were conducted by stratum, beginning with the herbaceous cover. Structural measurements and estimations included average height of each stratum, percent ground cover of each stratum, tree density estimates (per ha) and life form types.

Although not exhaustive, the floristic inventories of each stratum concentrated on listing all but the rarest species. An abundance scale was used consistently, with the following five abundance classes:

1. Rare: very few isolated individuals.

2. Uncommon: individuals occurring occasionally.

3. Present: frequent occurrence of individuals, but the ground cover by a given species is low (generally less than 20%).

4. Common: abundant occurrence of a species; ground cover by a given species is significant, though less than 50% of the total.

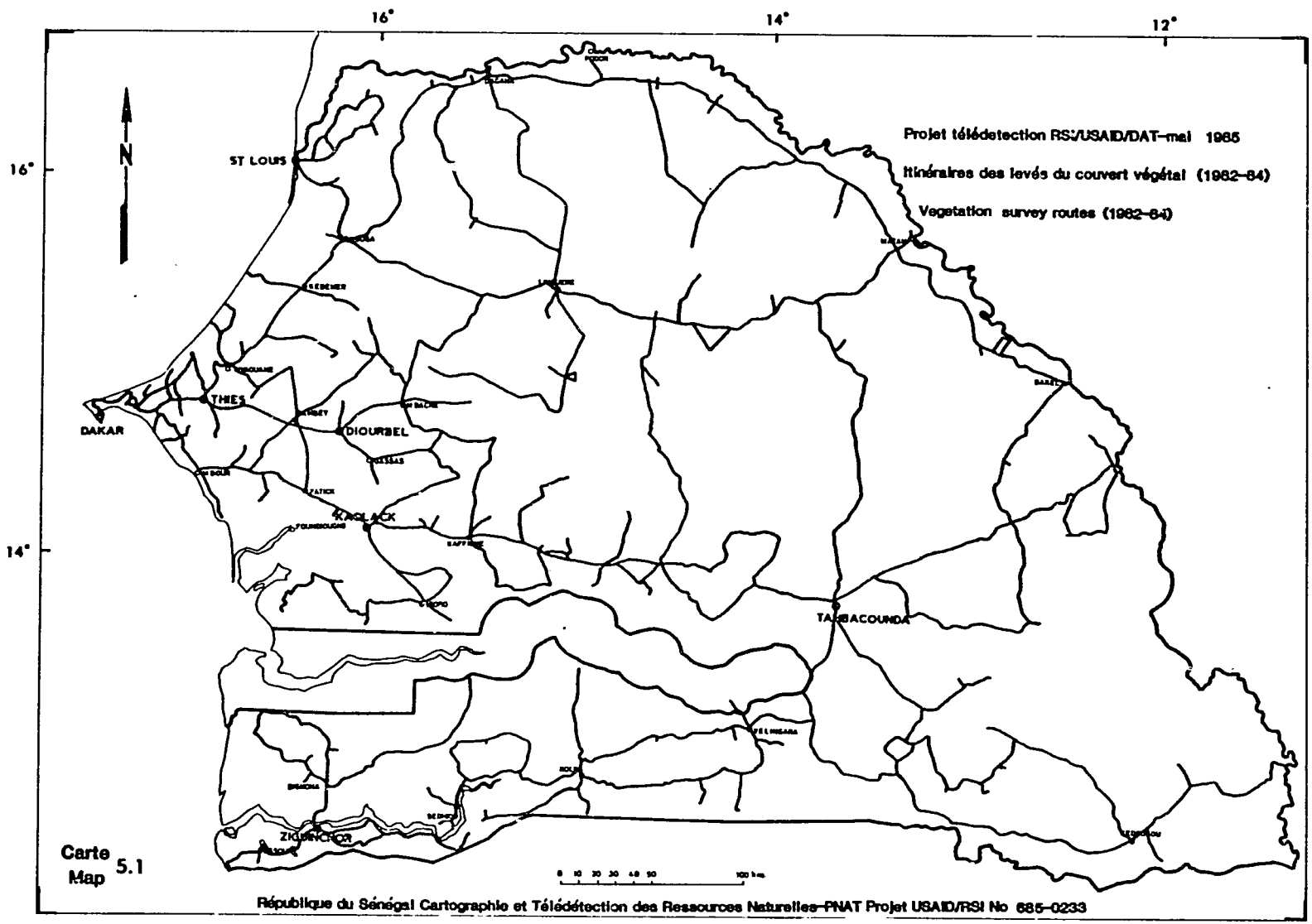
5. Very common: these species may dominate a stratum. Dominants are those species with the greatest total biomass in a particular stratum. They generally constitute over 50% of the total ground cover.

Given the large area of the survey and the time constraints, the abundance scale approach formed a realistic alternative to the extremely tedious method of determining species density by unit area.

Other field observations were noted, including plant health/vigor, grazing levels, phenological stage and amount of regeneration in progress. Data were also recorded on the land use, soil texture and color, and geomorphology. At least one photograph was taken at each observation site. Plant samples were collected, identified and later mounted each time a new species was encountered.

The size of an observation site varied somewhat, depending on the complexity and variability of the vegetation. Rather than limiting the observations to a finite quadrat or transect system, site descriptions were carried out on areas ranging from 2 to 4 ha. The observation of relatively large areas was more easily correlated with the generalized view offered by the Landsat imagery.

Between 1982 and 1984 nearly 600 detailed field observations were made. The field data are too voluminous to include in this report, but a set of these data will be delivered to USAID/Dakar and to the DAT. The survey routes along which the detailed observations were made are shown in Map 5.1.


16°
14°
12°
16°
14°
N
ST LOUIS
DAKAR
THIES
DIOURBEL
KAOLACK
TAMBACOUNDA
ZIGUINCHOR
Projet télédetection RSI/USAID/DAT–mai 1985
Itinéraires des levés du couvert végétal (1982–84)
Vegetation survey routes (1982–84)
0 10 20 30 40 50 100 km
République du Sénégal Cartographie et Télédétection des Ressources Naturelles–PNAT Projet USAID/RSI No 685–0233

Carte 5.1
Map

5.3.6 Other Means of Verification

Other means of verification of the map unit delineations from Landsat imagery came primarily from six aerial reconnaissance flights which served to provide oblique aerial photographs of many of the vegetation and land use units previously delineated from the Landsat imagery (refer also to the geology and soils survey). Subsequent analysis of the oblique photographs provided valuable data on relating surface features in the field to the same features observed on the satellite imagery. The photographs were also particularly useful in estimating the percent ground cover of the woody strata, a key element in mapping vegetation formations.

Some use was also made of conventional aerial photographs taken by the Institut Geographique National in the 1950's and the late 1970's. They served to confirm boundaries between vegetation and land use types, make measurements of percent cover, illustrate relationships between landscape position and vegetation communities, and in general, provide a level of detail unavailable on the Landsat imagery.

In deriving some of the crop mixtures for the land use/land cover map, considerable use ws made of the agricultural statistics presented in the Schéma national d'aménagement du territoire (1984). These statistics were used in support of field observations to determine dominant crops and crop mixtures by departments, so that the crops listed in the legend could be ordered by areal dominance. The crop statistics represent an average of the following years: 1968-71, 1974-75, and 1979-80. The field observations of this team served to update this information.

5.3.7 The Vegetation Legend

The vegetation legend is arranged in a hierarchical fashion such that the major divisions correspond to vegetation formations (e.g., shrub savannas). The formations fall mainly into four classes of generalized landscapes: formations on plateaus and peneplains, valley formations, formations on hills, and coastal formations.

The next division distinguishes between the natural vegetation formations, defined as those which exist in the landscape basically unaffected by man, and cultural vegetation, generally recognized as the vegetation of cultivated areas and deforested areas where human influence is clear. Man can be found within the natural formations, but his activities do not alter the vegetation to any great extent. Although many of the formations that cover the eastern half of Senegal have been altered by bush fires, they are considered natural for the purposes of this legend. Within each formation, the natural map units are listed first, followed by the anthropogenic formations of cultivated zones.

The last level within the legend is the individual map unit. The units common to a particular formation are coded by a capital letter, e.g., "S" for all tree savanna formations. Within each formation, numbers are used to distinguish one map unit from another, e.g., S1, S2, S3. Small letters are occasionally used in the code to further describe the formation. For example, "c" refers to open (low ground cover) formations, while "d" refers to dense formations.

The scientific names of the dominant and/or component species which further characterize the floristic nature of the vegetation community are given for each map unit. These species are divided into a maximum of four groups by stratum: the tree stratum species are listed in the left half of the top line; the shrub and lesser tree species are listed on the right half of the top line; the bottom line represents the herbaceous species: at left, the grasses (Gramineae), at right, the forbs. It is not feasible to list all species that occur in the community on the legend, and the listed species are not in any particular order. In communities where no apparent dominants occur, a subset of the most common component or associate species are presented. The actual choice and number of common components was sometimes arbitrary, but should give the reader the ability to visualize the vegetation. More detailed information on vegetation physiognomy and floristic composition is offered in section 5.4, Description of Cover Types.

The vegetation formations on the legend are ordered from the most open formations to the denser formations. This hierarchy reflects the progression from the more arid Sahelian formations in northern Senegal to the more humid Guinean types of southern Senegal. The map colors were carefully selected to represent this progression, with yellows and oranges for the more xeric communities, and greens and blues for the more hydrophytic communities. Lighter colors were chosen for the more open, lower formations, while darker colors represent denser, taller formations (e.g. in the valleys). Within each formation, the map units are arranged from the more arid to the more humid environments.

5.3.8 The Land Use/Land Cover Legend

The land use/land cover legend is arranged with two levels of information. The first level is divided into seven major land use/land cover classes (e.g., Rainfed agriculture). Under each heading are the individual map units. Each unit is coded as follows: the first letter refers to the major class of land use/land cover ("A" for rainfed agriculture, etc.). The next letter or letters distinguish one map unit from another. Within the forest and pastoral classes, these letters refer to the various vegetation formations (the formation codes are the same as those used on the vegetation map). In the agricultural areas, the letters refer to particular crop types and crop mixtures (e.g., "Am" represents a millet/sorghum, groundnut, and shrub/tree savanna fallow land use pattern). The crops within each map unit are listed in order of areal dominate. Thus, in the "Am" example,

millet/sorghum are the predominant crops, followed by groundnut fields, and finally fallow areas. The code suffixes "x", "r" and "z" refer to land use/land cover types occurring in valleys, on hills and rough terrain and in depressions, respectively.

5.4 DESCRIPTION OF COVER TYPES

This section is devoted to the description of the vegetation and land use cover types which appear on the maps. The descriptions of each type are based mainly on field observations conducted in Senegal between 1982 and 1984. In some cases, field observations from other investigations (cited) were added to compliment our own, particularly when drought or grass fires prevented the team from obtaining descriptions of the herbaceous vegetation. The cover types have been grouped into seven phytogeograhpic regions and domains (see map 2.5), so that units sharing a similar climatic environment can be compared. A distinction is made between cover types whose nature stems mainly from climatic factors and those which lie in a strict geographical sense within one of the bioclimatic zones but are determined primarily by the presence of water at or just below the surface (azonal vegetation). The cover types within each bioclimatic zone are presented in order from driest to wettest climatic regimes, i.e., beginning with the Sahelian Zone and ending with the Guinean Zone. Note that the map units in the vegetation legend are grouped by vegetation formation rather than by bioclimatic zone. Such grouping was done in the interest of cartographic clarity, so that units of the same formation could be grouped by color code.

5.4.1 The Sahelian Phytogeographic Region

The "Sahel" is a geographic term which originated from the Arabic word for "shore" or "border". Thus, the zone which borders the Sahara Desert on the south (as well as to the north) is called the Sahel.

Its geographic boundaries are somewhat ambiguous, as it has been defined in different ways by various investigators. Generally speaking, it extends across Africa from northern Senegal to northern Ethiopia. Some believe that it has shifted southward as a result of the on-going dry cycle. While it is convenient to define the Sahel Region in terms of isohyets of average annual rainfall, there are other climatic, geographical, and ecological indications which must be considered. Climatically, the region can be characterized by the irregularity of rainfall (which may deviate more then 30 to 40% from the average), by an ecologically dry season of 8 to 9 months, by average yearly rainfall between 200 to 300 mm and 500 to 700 mm, and by 20 to 40 days of precipitation per year. Geographically, the Sahel is generally the area where open herbaceous formations mixed with woody plants occur. The shrub and tree steppes typical of the Sahel alternate in some areas with more arid conditions (often man induced), such as sand dunes and active sebkhas (playas), and gradually merge into the true desert in the north.

J. Trochain (1940) divides Senegal into two major phytogeographic regions: the Sudanian region and the dense forest region. They are defined in terms of isohyetal-thermal contours and by an ensemble of the vegetation which exhibits similar biological, physiognomic and floristic characteristics. He subdivides each region into two domains: Sahelian, Sudanian; Guinean and sub-Guinean. Each domain is then split into sectors (e.g., the Sahelo-Sudanian sector) which describe the transition zones between each domain.

The Sahelian phytogeographic region, as defined by J.G. Adam (1966), is centered between the 300 and 500 mm isohyets and predominates between the 200 and 700 mm isohyets. Plant species associated with the Sahelian zone can be found, however, between the 100 and 900 mm rainfall extremes. Within Senegal, this region lies north of a line running from just north of Mbour to just north of Bakel, extending well into southern Mauritania. It is bordered by the Saharan Region to the north and the Sudanian Region to the south (see Map 2.5). Many investigators speak of transition domains between these phytogeographic regions. J.G. Adam (1966) divides the Sahelian Region into three domains: the Sahelo-Saharan domain (200-300 mm range), the central Sahelian domain (300-500 mm range), and the Sahelo-Sudanian domain (500 to 700 mm range). Other biogeographers have also attempted to name and classify the various regions (Chevalier, 1911, 1938; Aubreville, 1938, 1949). For the purposes of this study, the terms and regions defined more recently by J.G. Adam (1966) will be adopted.

The Sahel is the land of the acacia and of grasses from the genera Aristida and Cenchrus. The vegetation community is characterized by a relatively low number of woody species, many of which are thorny and stunted. The herbaceous species dominated by grasses form a more or less continuous cover at the end of the rainy season. The overall appearance is that of a grassland dotted with shrubs and small trees. Physiognomically, the vegetation formations in the Sahel Region of Senegal fall into two main types: a shrub pseudo-steppe in the sandy Ferlo region, and a shrub savanna in the lateritic Ferlo. The term "pseudo-steppe" is preferred by various authors over "steppe" since the latter implies a discontinuous, open herbaceous formation. The continuous herbaceous structure of the pseudo-steppe rarely exceeds a height of 80 cm. The woody stratum is composed of shrubs ranging in height from 1 to 4 m, and trees ranging usually from 4 to 6 m in height.

The present physiognomy of the Sahelian vegetation results mainly from long-term human and animal pressure and from the climatic-shift toward more arid conditions. Relic species of a more humid regime can be found throughout the area. These mesophytes are associated with the Sudanian Region to the south and suggest that a lesser tree savanna or even a savanna-woodland once occupied the area. Since the early seventies, even the hardier species have been succumbing to the long drought.

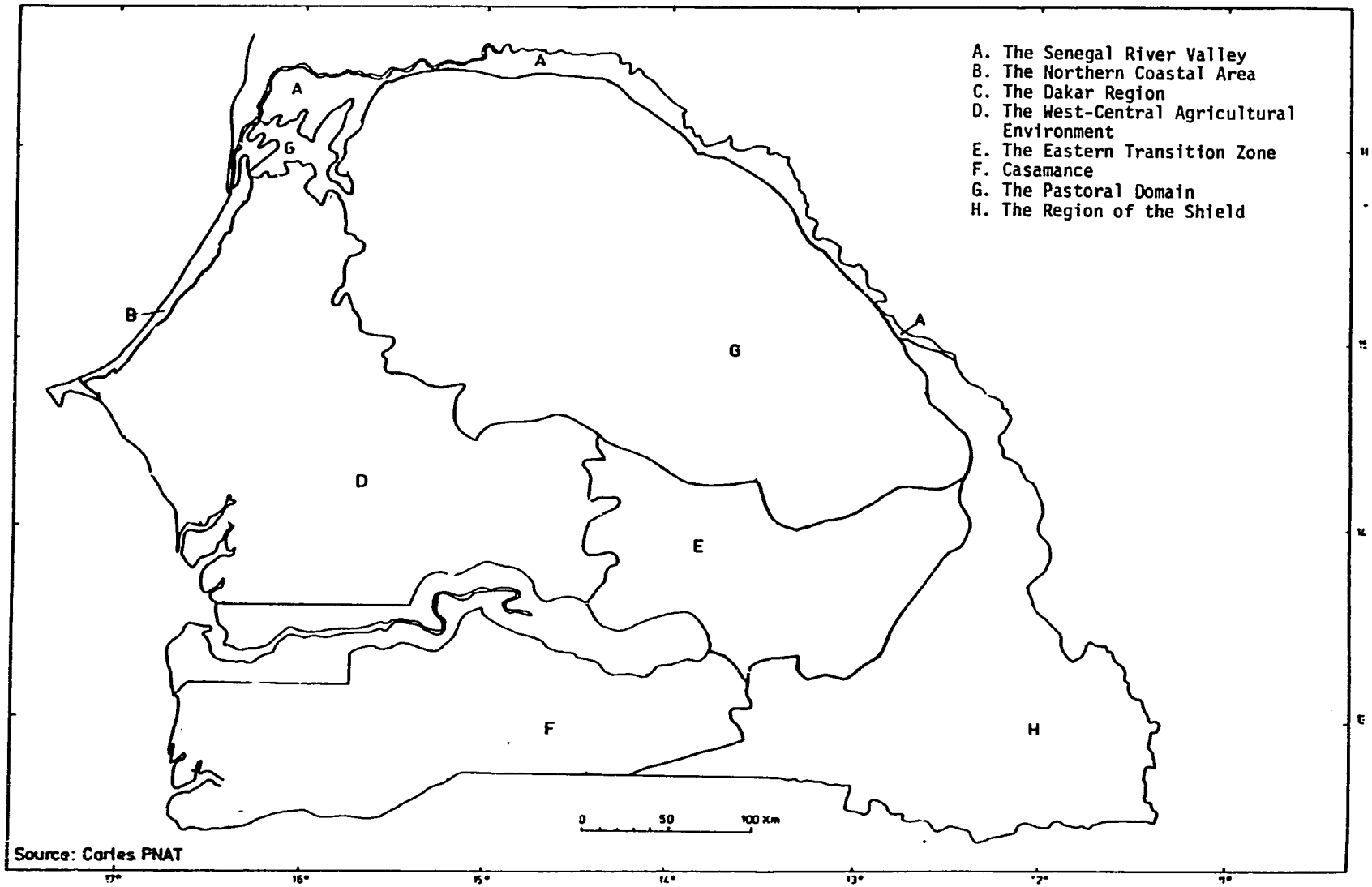
Four distinct eco-geographical environments can be identified within Senegal's Sahel Region (Schéma national d'aménagement du territoire, 1984). These areas have been defined through the integration of various components of the natural environment, such as the geomorphology, geology, soils, climate, vegetation, etc. They are the Senegal River Valley, the northern coastal area, the west-central agricultural domain, and the pastoral domain (see Map 5.2).

5.4.1.1 The Senegal River Valley

A. General Characteristics

The Senegal River Valley constitutes the first eco-geographical environment. It is azonal to the extent that vegetation communities are determined to a large degree by the hydrological/pedological conditions of the floodplain. It extends from the Mali border in the Sudanian Region to the delta of the Senegal River north of St. Louis. Remnants of a once extensive riverine woodland dominated by *Acacia nilotica* and *Acacia raddiana* are found on low-lying, clayey soils along the river. Twenty-eight of these woodlands have been designated as forest preserves, totalling 24,832 ha (Giffard, 1974). Most of the floodplain, known as the Oualo, has been cleared by man over the centuries for agriculture and for grazing purposes (Fig. 5.1). In recent years, the drought has accelerated this process, leaving behind severely degraded woodlands and extensive areas of shrub and tree steppes. They are found on lands less prone to flooding and are dominated by *Acacia adansonii* and *Balanites aegyptiaca* (tree stratum); *Borreria verticillata*, which is very common because it is not grazed and *Vetiveria nigritana* (herbaceous perennials); and *Chloris prieurii* and *Schoenefeldia gracilis* (grasses), which form a discontinuous cover in the wet season.

The delta of the Senegal River differs significantly from the rest of the valley in that the clayey, alluvial soils are often saline. This area has many depressions which are flooded much of the year (less so in recent years). The delta is interrupted by numerous river channels, which fill with sea water during the dry season. Depending on the degree of soil salinity and on the length of the flooding period, various types of vegetation formations exist, ranging from an absence of vegetation to herbaceous prairies and tree steppes.



Map 5.2 Ecogeographic Regions

Adapted from Schéma national d'aménagement du territoire (1984)

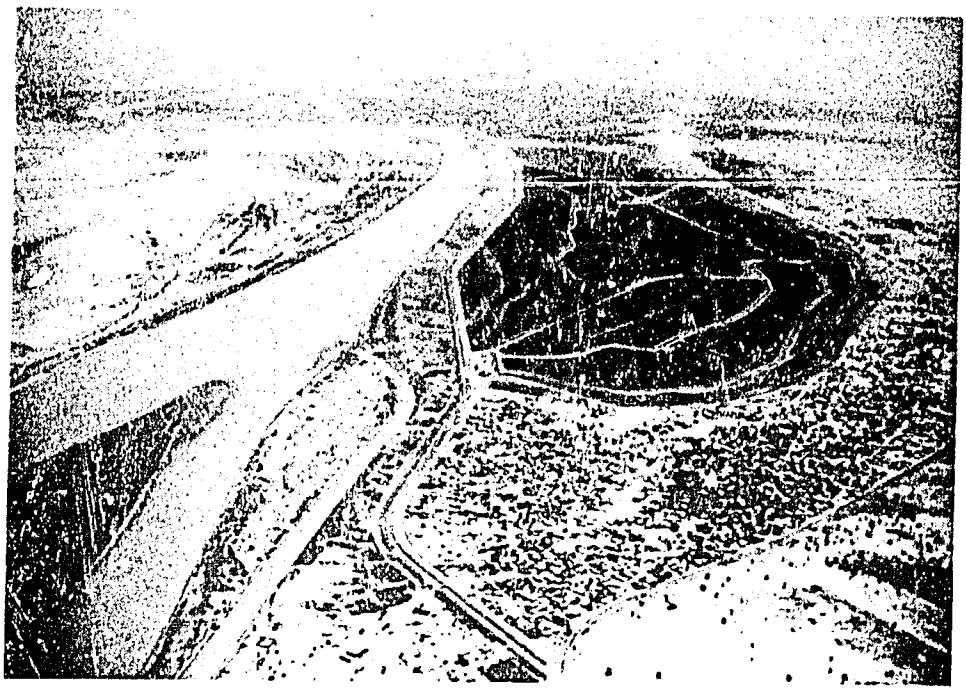


Fig. 5.1. A view east over the Senegal River valley, with Richard Toll in the foreground. Sugar cane is grown in the large, irrigated fields. In the distance are Acacia nilotica and Acacia raddiana riverine woodlands. Altitude 700 m; April 27, 1984.

B. Cover Types

Units A14 and Ac14

These two units cover large areas within the middle and lower Senegal River Valley. Physiognomically, they are shrub steppes (A14), often very open (Ac14), that occur on the hydromorphic soils that are subject to inundation for short periods during wetter years (Fig. 5.2). The woody communities are dominated by Acacia nilotica, Acacia adansonii, Balanites aegyptiaca and Zizyphus mauritiana and are often remnants of a true woodland that has been cleared over the centuries for cultivation. Varying with the micro-relief, a mosaic of communities occurs on the various soils. The herbaceous plants are dominated by the generally ungrazed Borreria verticillata, which is not grazed; Indigofera oblongifolia; and such annuals as Chloris prieurii and Schoenefeldia gracilis. Areas subject to longer periods of flooding support steppes dominated by Vetiveria nigritana.

Fig. 5.2. Shrub steppes of the Senegal River Valley, north of Haïré Lao. Unit Ac14.

These steppes are heavily grazed, though in recent years the amount of forage has been so scanty that many of the herds have moved south. Generally, annual grasses of the higher steppes are grazed down to the bare soil immediately following the wet season. As the forage disappears, the animals move to the lower and less preferred Vetiveria steppes.

Unit AE12

This unit occurs with the preceding units on hydromorphic, clayey soils prone to longer periods of flooding. The woody vegetation is somewhat denser than previous units and is characterized by a shrub and tree steppe thought to be a highly degraded remnant of the Acacia nilotica woodlands. This unit forms a transition between the true Acacia nilotica woodlands and the shrub steppes of the higher grounds. It is quite heterogeneous, with relatively dense stands of trees and shrubs alternating with relatively open areas. Acacia nilotica dominates the woody strata.

Associates include Balanites aegyptiaca, Mitragyna inermis, Piliostigma reticulatum and Salvadora persica. A discontinuous understory varies with the local relief: higher grounds support

Panicum anabaptistum and Andropogon gayanus, while lower-lying areas are dominated by such annuals as Vetiveria nigritana and Sphaeranthus senegalensis.

Much of this area has been cleared at one time or another for cultivation fo sorghum (on the lower, clayey soils) and millet and corn (on the higher loamy soils). The rangeland has traditionally been sought out by livestock, though in recent years the soil has remained relatively bare. Removal of branches from trees for livestock has accelerated in the drought years, severely damaging the tree population.

Unit EF

This unit is essentially a mosaic of the preceding unit (AE12) and unit F4. It is quite heterogeneous overall, alternating between low lying hydromorphic soils prone to long periods of flooding (during normal and wet years) and higher ground less prone to inundation. At larger scales, these components could be mapped separately. Physiognomically, the vegetation varies from a tree steppe to a woodland, with minimal understory. Refer to units AE12 and F4 for floristic composition and land use.

Unit P3

This unit covers the lowest lying depressions of the floodplain. These areas form temporary ponds and have distinct ecological groupings and are dominated by hydrophytes: Nymphaea ssp., Cyperus digitatus and Panicum anabaptistum toward the perimeters. Other forbs common to the middle valley include Echinocloa ssp. and Melochia corchorifolia. These depressions are often enclosed by nearly pure stands of Acacia nilotica. High rates of mortality were observed among the acacias.

These areas are grazed during the late dry season when surrounding rangeland is depleted.

Unit F4

Acacia nilotica predominates, almost to the exclusion of other species. The density of trees forms a true woodland, found usually on clayey soils between meanders of the Senegal River. This formation is unusual considering the latitude and the fact that these trees are well adapted to long periods of inundation. In recent years, the absence of flooding has severely stressed these woodlands, causing the highest mortality rates observed within the woodland formations of Senegal.

Principal associates include Acacia adansonii, Zizyphus mauritiana, Mitragyna inermis, Acacia albida and Balanites aegyptiaca. Another particularity of this formation is the near absense of the herbaceous understory (Figs. 5.3 and 5.4). Some overlapping of formations and species composition occurs between this formation and EF

Fig. 5.3. Aerial view of the Acacia nilotica riverine woodlands along the Senegal River in the vicinity of Dagana (lower left). Note the irrigated rice ans sugar cane fields (center and right).

Fig. 5.4. An example of a degraded stand of an Acacia nilotica riverine woodland 10 km southeast of Matam. These stands have been severely stressed by drought and a falling water table. Unit F4.

and P4 and is especially true when clearing occurs, encouraging the growth of Panicum anabaptistum, Borreria verticillata and Vetiveria nigritana.

Land use activities are restricted to wood collection, though even this is limited by the "forêt classée" status of most of these woodlands. This formation is unsuitable for grazing.

The successional position is likely a pseudo-climax (Trochain, 1940) because a change in the flooding regime will result in a new formation. In the 1970's and 1980's, the drought induced loss of Acacia nilotica has led to decreases in tree density.

Unit Ca

The natural vegetation in these areas has been completely replaced by recent agricultural crops. These areas are generally large, irrigated expanses of rice and sugar cane. Unlike the traditional agricultural lands, all woody species have been removed. Mechanized cultivation of rice was started in the 1950's, but the goal of irrigating 5 000 ha was never achieved due to a variety of problems. Sugar cane was introduced on a large scale in 1970 by the Compagnie Sucriere Senegalaise, and by the late 1970's, 7 000 ha were planted in sugar cane. Irrigated rice perimeters have increased in recent years; these fields were often detectable on the Landsat imagery but were well below the minimum mapping unit size (1 km^2) of the Project maps. These small fields are widely scattered from the Senegal River Delta to Bakel and are generally located near villages.

Unit A7

This unit is a tree pseudo-steppe on prelittoral stabilized dunes of the lower Senegal River Delta. The co-dominants are Acacia raddiana and Salvadora persica; associates include Euphorbia balsamifera and Balanites aegyptiaca. During normal and wet rainy seasons, the continuous herbaceous cover is dominated by Cenchrus biflorus, Dactyloctenium aegyptium and Indigofera diphylla. Woody ground cover ranges from 2% to 10%, with plant heights from 1 to 5 m.

This unit is a good source of rangeland during and immediately following the rainy season. During the period from 1970 to 1984, there were many years when the little or no herbaceous vegetation grew on these sandy soils due to the drought. In wetter years, most of the grazing in the delta area occurs in this area.

Unit Ac15

This unit represents an open shrub steppe on alluvial, halomorphic soils in low lying areas of the Senegal River Delta. The dominant woody species are Acacia nilotica var. adansonii, Acacia seyal, Salva-

dora persica and Balanites aegyptiaca, with Salsola baryosma and Aristida sp. growing in widely scattered tufts.

This pasture suffers from excess exploitation, increasing salinity and severe drought. The inventories of herbaceous species were very limited, as drought and salt water intrusion had reduced species abundance.

Unit TAc

Acacia nilotica, Balanites aegyptiaca, Tamarix senegalensis and Salvadora persica dominate this open shrub steppe which occurs on low lying hydromorphic and halomorphic alluvials of the delta. This unit is a mosaic of open shrub steppes and open steppes nearly devoid of vegetation. Herbaceous dominants are Salsola baryosma on saline soils and Schoenefeldia gracilis and Chloris prieurii on hydromorphic soils. During average to wet years, this area provides marginal grazing for cattle and camels during the rainy months.

Fig. 5.5. A portion of an enhanced Landsat FCC image, acquired on Nov. 6, 1977, covering a portion of the sandy Ferlo (right), the Lac de Guiers (right of center) and the diversity of cover types within the Senegal River Delta (left half).

Unit T2

This unit occupies extensive salt flats, which flood occasionally during wet years. Woody vegetation is practically absent and, if present, herbaceous species are widely scattered and dominated by Salsola baryosma and Sporobolus spicatus. On less saline soils, sparse grasses occur, including Chloris prieurii and Schoenefeldia gracilis. This land is of little or no use for agriculture or grazing.

Unit P4

This aquatic prairie is located entirely within the Parc National du Djoudj in the Senegal River Delta. This shallow depression remains inundated by brackish water for long periods. The herbaceous vegetation forms a fairly dense cover, dominated by Sporobolus ssp., Oryza barthii and Diplachne fusca. Areas less prone to flooding are colonized by Salsola baryosma and Tamariz senegalensis, both halophytes.

This prairie provides important habitat for a variety of bird life and semi-aquatic wildlife, including mammals, reptiles and amphibians. Floating and rooted aquatic plants provide a habitat for a variety of invertebrates which provide food for fish. While the drought has severely impacted this wildlife population, rapid rejuvenation of this protected zone is likely after a series of wet years.

Unit M

Mangroves colonize the delta of the Senegal River near its mouth and constitutes a coastal ecosystem adapted to brackish water. They often form an impenetrable forest. The mangroves of this delta are the northernmost of the West African mangrove formations. Three species of mangroves form communities in three regions of Senegal. Rhizophora racemosa grows in deeper waters along estuaries and brackish lagoons. Rhizophora mangle prefers somewhat shallower water and Avicennia africana grows along the shoreline reached only by the high tide.

This unit is limited to the river banks and estuaries between the river mouth and the Ile de Thiong, 20 km north of St. Louis. Associates include two hardy halophytes: Paspalum vaginatum and Sporobolus robustus.

Economically, the mangrove formations provide limited potential. These communities are stressed by increasing salinity and slow to regenerate, making them impractical as a source of firewood.

Unit H

This herbaceous steppe occurs on the gently sloping shores of Lac de Guiers, on hydromorphic soils subject to seasonal inundation. The herbaceous stratum is quite variable in composition, a function of the degree of slope, proximity to water, and period of inundation. The soils which generally flood each year support a steppe dominated by Vetiveria nigritana with Sporobolus spicatus and Eragrostis ssp., and Echinochloa ssp. The woody strata are practically absent. Borreria verticillata is quite common, resembling a small bush. Towards the low dunes of the Sandy Ferlo, small trees begin to appear, particularly Acacia senegal and Balanites aegyptiaca.

These wide shore areas offer good grazing as the waters recede during the dry season.

5.4.1.2 The Northern Coastal Area

A. General Characteristics

The second eco-geographical environment is the northern coastal area which includes the niayes. Ecologically, this zone is distinct from the agricultural lands to the east. This distinction is particularly due to the geomorphology, which includes stabilized and active red dunes, active white dunes, the beach, and the niayes (interdunal depressions with rich hydromorphic soils). This environment extends south to Cap Vert, well into the transitional Sahelo-Sudanian domain. It cannot be considered typical of the Sahelian bioclimatic region, as it is greatly influenced by the substratum and by a maritime climate. It is often referred to as the littoral Sahel or the Subcanarian Sahel. The climate, characterized by the cool, moist trade winds, also plays a role.

Excepting the niayes, the vegetation of this environment is a relatively poor shrub pseudo-steppe. This formation is a result of infertile, sandy soils, overgrazing and wood-cutting. The dominant shrubs and scattered trees are usually Parinari macrophylla, Acacia raddiana, Sclerocarya birrea, Maytenus senegalensis and Casuarina equisetifolia, which has been introduced since the 1950's as a windbreak along many of the coastal dunes. Annual grasses of the Sahel region, including Cenchrus biflorus and Chloris prieurii, emerge each year among such perennials as Aristida longiflora.

The niayes represent a complex, rich floristic environment with many relic species of the Sudanian and sub-Guinean Regions. While most of the shrub and tree species of the Sahel Zone of northern Senegal grow in these depressions, the flora is dominated by species of wide climatic distribution (42.5%), followed by species native to the Sudanian Region (27%); species of the sub-Guinean Zone make up 12.5% of the flora, while Sahelian species constitute only 10% (Reynal, 1963). This area is a true "biological crossroad". Many of the

hydrophytes associated with the more humid regions of Senegal are able to survive the Sahelian climate by tapping the near-surface groundwater. The stark contrast between the niayes and the surrounding landscape is very striking from the air (Fig. 5.6).

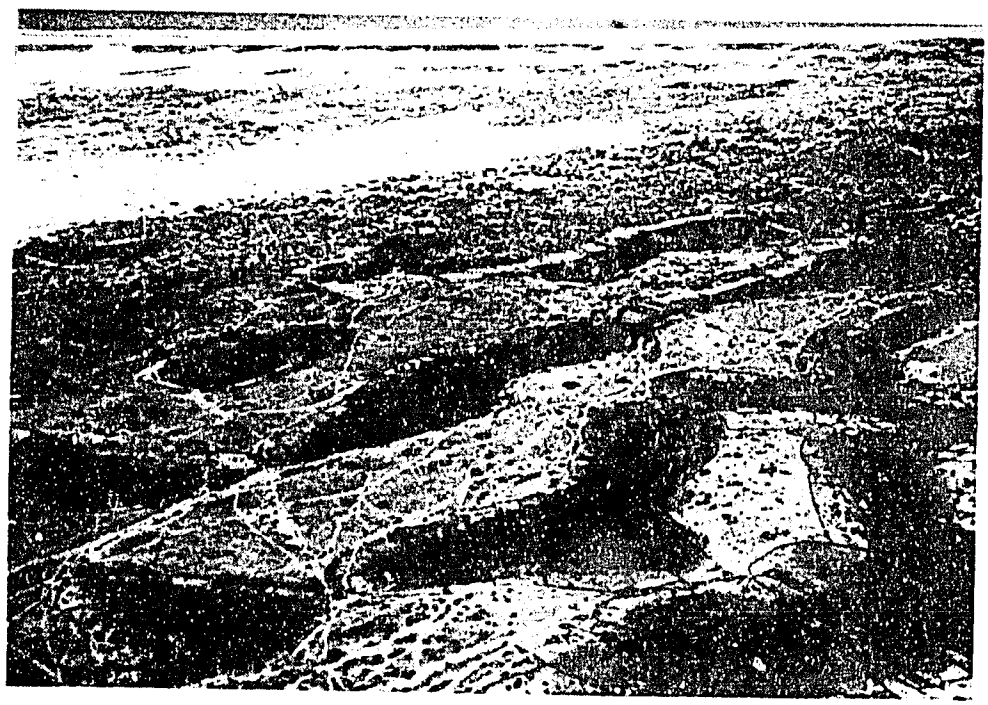


Fig. 5.6 An aerial view of the Niayes in the vicinity of Fās Boye, northern coastal area. Note the active dunes at the upper left and the dune stabilization efforts along the beach. Altitude 600 m; April 27, 1984.

B. Cover Types

Unit Ac12

This unit lies on the active coastal white dunes that stretch along the shore from Dakar to St. Louis. These dunes are generally parabolic and open to the NNW, and they extend from the beach to the semi-stabilized yellow-orange dunes several hundred meters to several kilometers to the east.

These dunes support a very open coastal steppe, and the plants found on them, halophytes and psammophytes, are able to withstand severe edaphic and climatic conditions. The low organic content of the soil, low rainfall (but high humidity), strong winds and shifting sands explain this open, floristically poor environment.

The dominants are perennial succulents and forbs: Cyperus maritimus (along the beach front), Sporobolus spicatus, Ipomaea pes-caprae and Alternanthera maritima (both parasites), Opuntia tuna (cactus) and Philoxerus vermicularis. Occasional woody species include Maytenus senegalensis, Chrysobalanus orbicularis, and Calotropis procera. The forest service has initiated a large reforestation effort, which was begun in 1945 by the French West African Government. Casuarina equisetifolia, Melaleuca leucadendron and various Eucalyptus species have been used with some success to fight eolian erosion and to increase dune stability (Fig. 5.7).

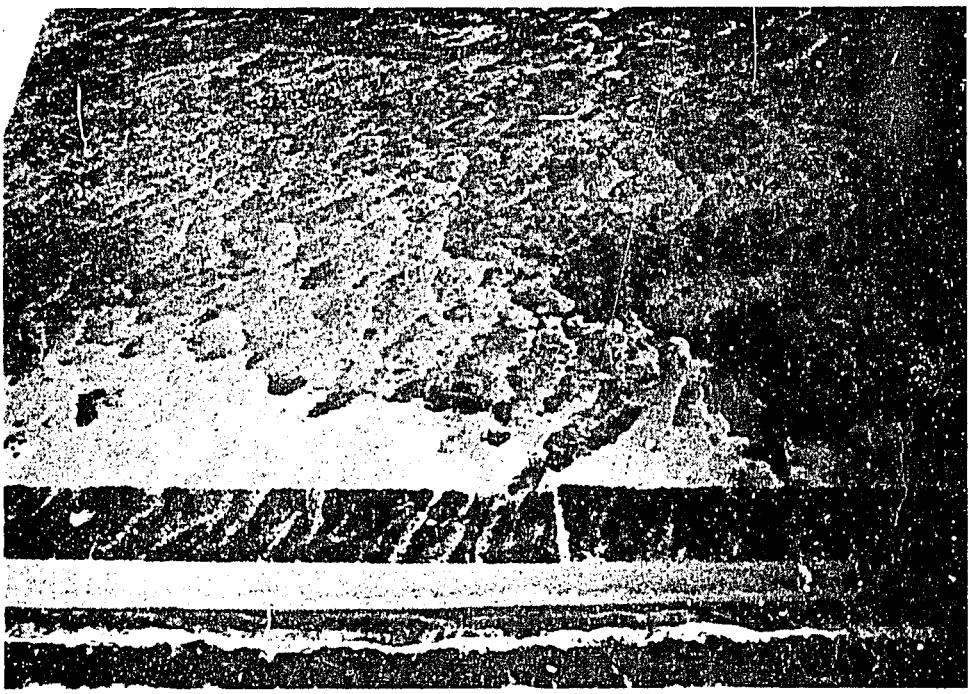


Fig. 5.7. This aerial view shows the active coastal white dunes which support a very open coastal steppe (unit Acl2), a band of reforestation ranging in cover from good to poor, and a shrub savanna (unit Vcl) on semi-stable coastal dunes (above reforestation belt). Altitude 1500 m, January 7, 1985.

Units Vl asnd Vcl

These cover types occur on transitional, yellow-orange, semi-stable coastal dunes (Vcl) that form a band just east of the white active dunes and on the stabilized red dunes (Vl) to the east of the transitional dunes. The Vcl cover type is floristically similar to the Acl2 unit, but is somewhat richer in flora. Physiognomically, it represents a transition from the coastal steppes to the shrub savanna

on the stable red dunes. Woody dominants include Mayenus senegalensis, Acacia macrostachya, Parinari macrophylla and Jatropha gossypifolia. Common annuals include Cenchrus biflorus, Chloris prieuri and numerous forbs.

The V1 shrub savanna occurs on the strongly undulating, stabilized red dunes with slopes up to 30 degrees. The shrub stratum, which is less open than the previous unit includes Acacia macrostachya, Jatropha gossypifolia, Capparis Tomentosa and Piliostigma reticulatum. Cenchrus biflorus, Chloris prieurii, Dactyloctenium aegyptium, Borreria ssp. and other grasses and forbs form a continuous herbaceous cover during the growing season in average to wet years. Scattered trees become more common as one progresses toward the interior. The dominants are Parinari macrophylla (the Cayor apple tree), Acacia raddiana and Sclerocarpa birrea (quickly disappearing with the recent dry cycle).

This cover type is used primarily for grazing, despite the poor quality of the sandy soils. Overgrazing has become a serious problem, particularly since regeneration of woody species is slow. Annuals are quick to respond to rainfall, but in recent years (1983, 1984) the pastures have scarcely greened.

Unit V7

The soils, geomorphology, climate and vegetation formation of this cover type closely resembles unit Vc1. Floristically, this unit is a variant of Vc1 in that a scattered tree stratum is dominated by Acacia albida and Parinari macrophylla. Less common associates are Deutarium microcarpum, Ficus ssp., Acacia macrostachya and Annona senegalensis. The annuals are essentially the same ones found in unit Vc1.

Unit P1

Known as the niayes, this unit is composed of a succession of elongated, interdunal depressions within the stable and semi-stable coastal dunes between Cap Vert and the mouth of the Senegal River. Many of these depressions lie below sea level. Temporary ponds often form during the rainy season, and evidence suggests that many result from yearly fluctuations of the water table.

The niayes resemble true oases within the typically semiarid Sahelian environment. Their vegetation is part of a fragile, complex ecosystem, that is protected from the strong ocean winds. The unique flora of the niayes owe their survival to the shallow water table and periodic flooding of the fertile, hydromorphic soils. J. Trochain (1940) considers these communities to be relics of a subguinean forest.

A clear succession of vegetation types, too small to map at a 1:500 000 scale, occurs from the centers to the slopes of the depressions. Halophytes dominate the central areas, forming an aquatic prairie. The less saline, constantly moist soils around the edges of the depressions support a great variety of Sahelian, Sudanian, and Guinean species, which physiognomically range from a palm grove to a degraded moist evergreen forest. The most characteristic species is the Elaeis guineensis (oil palm) of the Guinean region. Thickets often grow on the dune slopes surrounding the niayes. Figure 5.8 shows the succession of these vegetation types.

Fig. 5.8. A view of a large niaye, with herbaceous hydrophytes in the foreground and trees dominated by palms at the foot of the dunes. This azonal vegetation is composed of species from the three phytogeographic regions of Senegal.

The halophytes of the depression centers are dominated by Cyperus sp., Imperata cylindrica, Philoxerus vermicularis, Sporobolus robustus and Sesuvium portulacastrum; on soils of decreasing salinity Paspalum vaginatum, Leersia hexandra and Cynodon dactylon (Adam, 1966) dominate. The palm groves and degraded forest stands are dominated by Elaeis guineensis, Cocos nucifera and Ficus ssp., with many associates, including the Guinean species of Detarium senegalensis, Syzygium guineense and Lardolphia heudelotii; common Sudanian associates include Cassia sieberiana, Prosopis africana, Entada africana and Celtis integrifolia. Sahelian species include Acacia raddiana and Parinari macrophylla (usually above the dune slopes). The thickets are commonly composed of Dalbergia ecastaphyllum, Alchornea cordifolia and Fagara xanthoxyloides (Michel, et al., 1969).

Despite the presence of shallow ground water, the vegetation of the niayes has been severely stressed by the drought. Increasing salinity has killed many of the hydrophytes, particularly Elaeis guineensis. Increasing cultivation of fruit trees and vegetables in the 20th century has also reduced the extent of the relic communities.

The moist, fertile soils of the niayes are ideal for market-gardening, which is practiced extensively in the Cap Vert area. In recent years, many market-gardens have been abandoned due to increasing salinity. A variety of pasture types occur within the niayes; the lack of forage on the nearby dunes has led to increased grazing of the niayes vegetation.

Unit AE9

This cover type occurs on the semi-stabilized coastal dunes in the Gandiol area, south of St. Louis. The unit is a mosaic of dunes and of salt flats, which are occasionally inundated by brackish water.

This shrub and tree steppe is dominated by Prosopis chileensis (an exotic introduced by the French) and Acacia raddiana; Acacia albida occurs occasionally. The shrub stratum is characterized by Euphorbia balsamifera, Grewia tanax and Prosopis chileensis, and Tamarix senegalensis occurs on saline soils bordering on the flats. Chloris prieurii, Panicum turgidum, Cenchus ssp., and other grasses cover the slopes and dune uplands (during the growing season), while Sporobolus sp., Cyperus sp., Salsola baryosma and other halophytes occur near and within the depressions.

This unit is unsuitable for most types of cultivation given the low precipitation levels and erratic rainfall pattern. The dune grasses have potential for supporting livestock, though in recent years herbaceous biomass levels have been extremely low.

5.4.1.3 The Dakar Region

A. General Characteristics

The Dakar Region, which occupies the Cap Vert peninsula, is distinguished from the neighboring regions by its urban character, dense population and types of associated human activities (predominance of secondary and tertiary sectors).

Although the Dakar Region lies within the Sahelo-Sudanian Domain of the Sahelian Region, many of the vegetation types are azonal, a characteristic that results from a wide range of morphopedological landscapes and the moderate maritime climate. The vegetation varies considerably in formation and in floristic composition from one cover type to another.

The largest cover type is found on the semi-stable coastal dunes which parallel the coast several kilometers inland. A shrub and/or tree savanna with typically Sahelian species occurs on this undulating topography. Rich in species from all biogeographic regions, the niayes of the Northern Coastal Zone extend into this unit.

Along the coast, there lies a band of active dunes that supports a psammophytic shrub steppe. To the south of the coastal dunes, a unique "Baobab forest" has formed on hydromorphic soils overlying calcareous rocks of the Bargny Plateau.

B. Cover Types

Unit A8

This unit occupies the western tip of the peninsula, north of the rapidly spreading Dakar suburbs. The fertile but rocky soils are of volcanic origin. Due largely to human and animal intervention (the area has been cultivated periodically since the nineteenth century), the present vegetation can be described as a shrub steppe. The original flora has largely disappeared, making it extremely difficult to reconstruct its original form. Although the peninsula lies strictly within the Sahelo-Sudanian Domain of the Sahelian Region, many of the species associated with this region are rare. While the floristic composition is relatively rich, it is difficult to identify dominants. The most representative shrubs include Boscia senegalensis, Euphorbia balsamifera (planted as a fence to delineate field boundaries), Maytenus senegalensis, Zizyphus mauritiana, Calotropis procera, Opuntia tuna (cactus), Acacia seyal and Acacia albida. Trees are generally absent, though scattered individuals occur in some areas: Adansonia digitata is present, especially near the Mamelles. Acacia seyal is concentrated along the drainages. Several exotic species have been planted for shade or as windbreaks, particularly Prosopis chileensis and Casuarina equisetifolia.

The herbaceous composition appears to be quite rich, though difficult to characterize. The most common species appear to be Schoenefeldia gracilis, Andropogon pinguipes (on slopes), Cenchrus biflorus, Aristida stipoides, Pennisetum pedicellatum (all Gramineae), with Leptadenia hastata, Borreria ssp., Waltheria indica, Centaurea perrottetii, Indigofera secundiflora, Indigofera linearis and numerous other forbs.

Unit Vd2

This unit occurs on vertisols of the Bargny Plateau, that overlie marl-calcareous clayey soils. This formation constitutes a dense shrub savanna, with nearly pure stands of Acacia seyal (favoring clayey vertisols). Adansonia digitata (baobab) appears to be the main, though widely scattered tree associate, which also grows in relatively dense clusters. Less common associates include Acacia adansonii, Zizyphus mauritiana and Dicrostachys glomerata. Numerous herbaceous species occur, commonly Aristida stipoides, Andropogon gayanus, Schoenefeldia gracilis (does well on these compact soils), Tephrosia linearis, Centaurea perrottetii and Indigofera astragalina.

The predominant land use is the grazing of livestock, though in the last few decades considerable expanses have been cleared to cultivate millet and sorghum. The grazing grounds are generally of good quality, though they are limited by the relatively dense cover of Acacia seyal and the scanty rainfall of recent years.

Unit V10

This unit occurs both east and west of Rufisque on the soils of the Bargny Plateau similar to those described in unit Vd2. The vegetation formation consists of a highly degraded shrub savanna that has been exposed to over a century of intense human and animal pressure. This unit is a variant of unit Vd2 and is similar in composition: Adansonia digitata is the only tree and is scattered among a near monoculture of Acacia seyal. Shrub associates include Dicrostachys glomerata, Zizyphus mauritiana, Acacia senegal and Tamarix senegalensis (a halophyte growing in low lying areas). Schoenefeldia gracilis dominates the grasses and Andropogon ssp. and Aristida stipoides are common associates. Comprising the rest of the herbaceous cover are numerous forbs, including Sesbania leptoclada, Corchorus trilocularis, Leptadenia hastata, Indigofera astragalina and Centaurea perrottetii.

The land use is essentially that of unit Vd2, though cultivation of millet/sorghum is rarer.

Unit VS8

Covering much of the northern half of the peninsula, this unit occurs on gently rolling, stabilized coastal dunes. The physiognomy is that of a shrub and tree savanna (though the herbaceous cover can become a steppe on less stable dunes towards the coast). This essentially anthropogenic formation is kept cleared for cultivation. Smaller, often flagform, trees constitute the scattered upper layer, with Acacia albida, Elaeis guineensis (in the hydromorphic, interdunal depressions), Mangifera indica (introduced for its fruit) and scattered large trees, particularly Adansonia digitata and Ficus elasticoides. Introduced in the 1940's, Casuarina equisetifolia serves as windbreaks. The shrub layer forms the predominant woody cover (5 to 15% shrub cover and 1 to 5% tree cover) and is dominated by Maytenus senegalensis, Piliostigma reticulatum and juvenile Acacia albida. Numerous Sahelian and Sudanian associates occur, including Annona senegalensis, Guiera senegalensis, Parinari macrophylla (becoming more common to the north), Balanites aegyptiaca, Zizyphus mauritiana and Commiphora africana.

Generally forming a continuous cover during the rainy season, the herbaceous stratum is dominated by Eragrostis tremula and Cenchrus biflorus (Gramineae) and Leptadenia hastata, Waltheria indica (forbs).

In order of importance, the main crops are millet/sorghum, and groundnuts, with one or several years of fallow. Fruit trees, particularly mango, are also grown. Since the sandy soils have little organic content and rainfall passes quickly to the subsurface, the rangeland tends to be poor.

Unit B2

This unit is centered on the Botanical Preserve of Noflaye, just north of Sangalkam. Physiographically, it includes both interdunal depressions with hydromorphic soils, or niayes and the gently rolling topography of the adjacent stable dunes. The special biological ensemble of this niayes vegetation has been protected from deforestation and other human-related activities. This unit is essentially a mosaic of units P1 and Vs8, though this niaye is especially rich in flora. The predominant tree is Elaeis guineensis, whose mortality rate has become alarmingly high during the drought years. The most common associates include Khaya senegalensis, Dialium guineense, Ceiba pentandra, Antiaris africana, Lonchocarpus sericeus, Lannea reticulata, Adansonia digitata and Landolphia heudelotii. The shrub stratum is even more diverse, with numerous species of all the West African bioclimatic regions. Refer to unit P1 for some common species of the shrub and herbaceous strata.

Unit BV3

This unit represents the Mbao Reforestation Area, which occurs on attenuated, stable, coastal dunes. This artificial formation can be described as a shrub and lesser tree woodland. The average height of the woody layer is 2 m, with a cover of about 40%. Anacardiem occidentale, or cashew tree, is the sole dominant and an important source of fruit that have considerable commercial value. The forest service has used this tree extensively for reforestation of active dunes and for windbreaks. Other trees used in this reforestation effort include Casuarina equisetifolia (introduced from Oceania), Mangifera indica and Eucalyptus sp. A number of associate shrubs, characteristic of the surrounding VS8 unit, also occur throughout the rows of Anacardium occidentale. They include Maytenus senegalensis, Commiphora africana, Parinari macrophylla, Piliostigma reticulatum, Acacia ataxacantha, Acacia albida, Balanites aegyptium, Macrosphyra longistyla, Crataeva religiosa and other less common species. The herbaceous stratum consists mainly of Aristida stipoides, Andropogon gayanus, Cenchrus biflorus, Dactyloctenium aegyptium, Tephrosia purpurea, Tephrosia lupinifolia, Borreria chaetocephala, Hibiscus asper, Sclerocarpus africanus and others.

5.4.1.4 The West-Central Agricultural Environment (Sahelian Region)

A. General Characteristics

The west-central agricultural environment of the Sahel Region includes the northern part of the Groundnut Basin, including the administrative regions of parts of Louga, Diourbel and Thiès. The main criterion used in defining this zone is the presence of intensive agricultural activity (Schéma national d'aménagement du territoire, 1984). Through his agricultural activities, man has completely transformed the natural vegetation and caused considerable soil degradation. The cultivation of groundnuts since the early 1800's has played a major role in this transformation, though in recent years this crop is being replaced more and more by millet.

The area is covered by an ancient erg. Several periods of dune formation have occurred, beginning in the lower Quaternary, and result today in a gently rolling landscape. Generally, red-brown soils and brown soils are generally found on the stabilized, flattened dunes, while colluvial brown and hydromorphic soils occupy the interdunal depressions.

Not a single remnant of the original woodland that covered this area has been spared. Trees that did not interest the farmers were eliminated. The vegetation takes the form of a tree pseudo-steppe in much of the northern agricultural area and a tree savanna in the transitional Sahelo-Sudanian Zone (Fig. 5.9). The landscape is dominated by two acacias--the Acacia raddiana in the north and the Acacia albida in the south. Protected by the farmers, Acacia albida

forms a quasi-monoculture of trees unlike any other area in Senegal. Other tree species scattered through this zone include Adansonia digitata (the Baobab), Tamarindus indica, Balanites aegyptiaca and Parinari macrophylla. They are all spared largely because of the edible fruit they produce. Fallow fields are often invaded by such shrubs as Guiera senegalensis, which dominates the shrub cover, and Combretum glutinosum. These fields are favored by grasses such as Cenchrus biflorus and Aristida adscensionis, both of which are grazed by livestock.

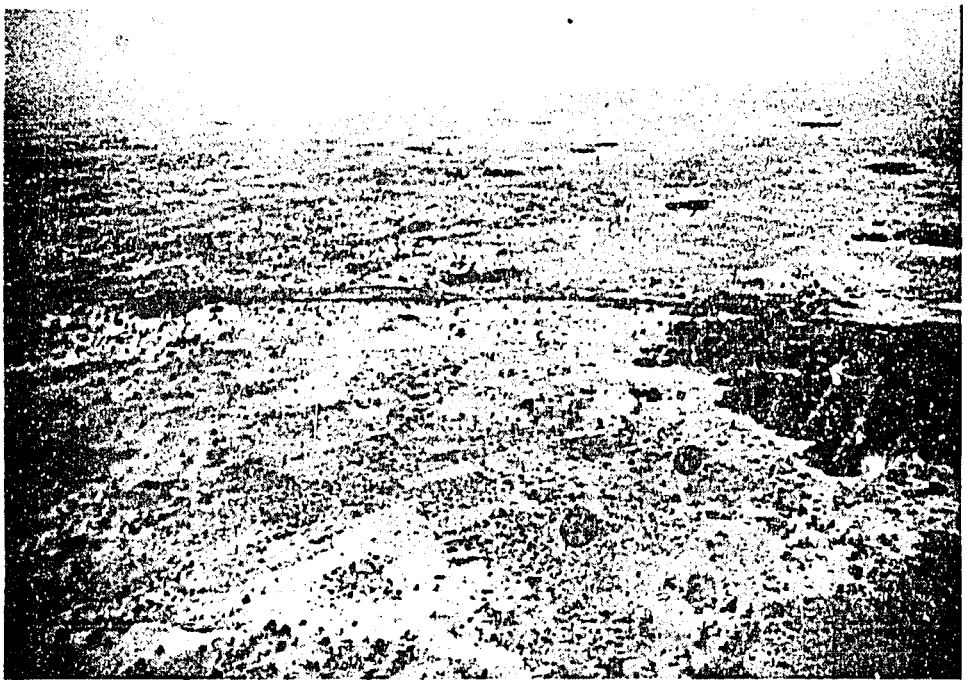


Fig. 5.9. An aerial view of the Groundnut Basin in the Khombole area (seen at right). The original woodland that once covered this area has been replaced by an anthropogenic tree savanna, dominated here by Acacia albida. Altitude 800 m; April 27, 1984.

B. Cover Types

Unit A13

This shrub pseudo-steppe occurs on the shallow, lateritic soils of the Thies plateau. The low, woody shrub stratum is dominated by acacias (Acacia seyal, Acacia ataxacantha, Acacia adansonii), with Euphorbia balsamifera occurring in abundance around abandoned fields. Other associates include Boscia senegalensis, Boscia angustifolia, and Combretum micranthum. Trees are scattered throughout, mainly Adansonia digitata and Borassus aethiopium in the north. The lateritic soils support a few annuals: Digitaria velutina, Dactyloctenium aegyptium and Indigofera suffructicosa.

Human and animal pressure on this marginal land has led to severe degradation of the woody cover, which was once as dense as the shrub woodlands and thickets of the Forêt Classée de Thiès. This area presently serves as a marginal pasture for the scattered Peul settlements of the Thiès plateau.

Units AEc10 and AE10

The predominant cover type of the northern Groundnut Basin is an open shrub and tree pseudo-steppe (AEc10). It lies on sandy ferruginous soils of an ancient erg which extends from the Trarza region (Mauritania) to the Saloum.

Few vestiges, if any, remain of the original vegetation cover. Beginning in 1885, Wolof farmers have methodically cleared all the dior soils for cultivation, which has resulted in one of the most deforested landscapes of Senegal. An aerial view (Fig. 5.10) illustrates the vast patchwork of a mosaic of fallow, millet and groundnut fields which expose the soils to eolian deflation.

The original vegetation resembled the present day shrub savannas of the sandy Ferlo to the east. The only remnants of the woody strata that have been spared are the distinctive parasol-shaped Acacia raddiana trees, which dominate, and the hardy Balanites aegyptiaca. Acacia albida occurs more frequently as one progresses south. Other widely scattered associates include Tamarindus indica, Ficus ssp., Adansonia digitata and Parinari macrophylla in the west. Shrubs occur mainly in fallow fields and are invaded by the ubiquitous Guiera senegalensis, which can survive on the poor, sandy soils; Combretum glutinosum, also associated with cultivation, is very common. Other associates include Boscia senegalensis, Combretum aculeatum, and Maytenus senegalensis.

The herbaceous cover is dominated by annuals, namely, Cenchrus biflorus, Aristida adscensionis and Eragrostis ssp. Numerous forbs grow among the grasses, including Tribulus terrestris, Zornia glochidiata and Borreria stachydea.

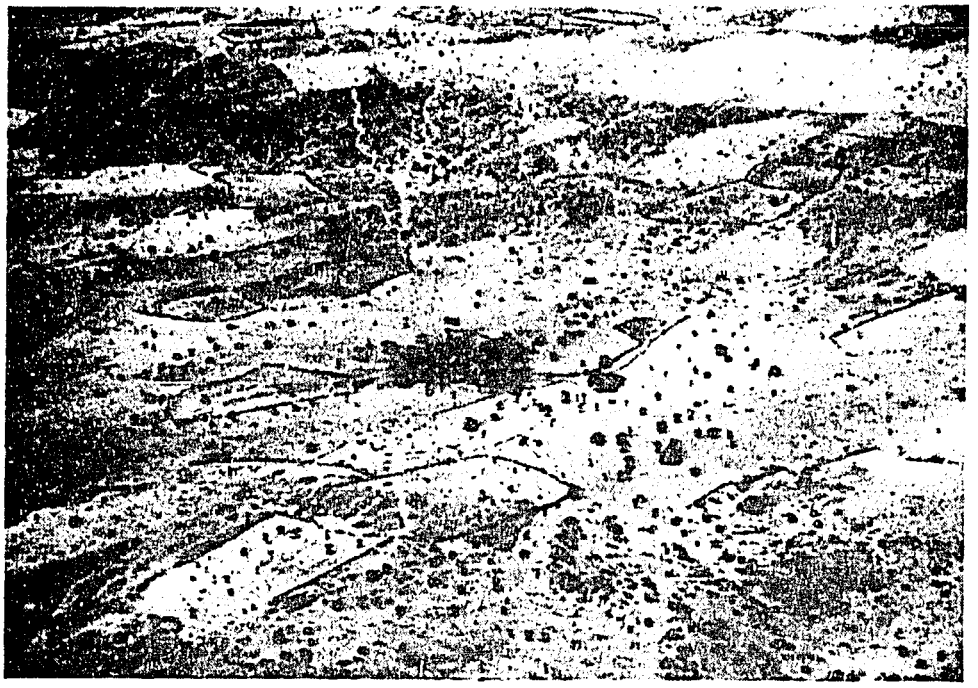


Fig. 5.10. An aerial view of the open shrub and tree pseudo-steppes of the northern Groundnut Basin, between Kébémer and Lompoul. The darker fields are fallow, while the lighter fields were cultivated in groundnuts or millet during the previous wet season. Altitude 700 m; April 27, 1984.

Unit AE10 is a variant of AEc10. This area was cleared for cultivation more recently (since the early 1900s) and is somewhat more densely wooded. The amount of ground cover for trees ranges from 3 to 5%, as compared to 1 to 2% for unit AEc10. Cultivation of millet and groundnuts is the predominant land use.

In recent years, the reduced and erratic rainfall has made farming difficult, if not impossible. A new agricultural policy has discouraged the cultivation of groundnuts in the Louga region.

The ephemeral summer pastures among the fallow fields are generally of good quality during normal to wet years. The lush, green forage quickly yellows in September, leaving dry hay, which provides forage for livestock into the mid dry season. The grasses are usually overgrazed, and the animals turn to Guiera senegalensis and other shrubs that can sustain them until the following growing season (Fig. 5.11).

Fig. 5.11.Ephemeral summer rangeland at the end of the wet season, 15 km west of Kébémer (unit AEc10). The numerous shrubs, dominated here by Guiera senegalensis, will sustain most domestic animals after the grasses disappear.

Unit AE11

This cover type occurs on stabilized coastal dunes whose local relief is more pronounced than that of the previous unit (AEc10). The vegetation landscape is a shrub and tree pseudo-steppe in an agricultural setting. It extends from west of Louga to north of Tivaouane, parallel to the coast. Even fewer trees dot the landscape (1 to 2% cover) than to the east, and they are often stunted (averaging 5 m tall) and flagform. Acacia albida and Parinari macrophylla co-dominate. Balanites aegyptiaca and Acacia raddiana are scattered in the northern half of this unit. Woody shrub species with an average height of 1 m are relatively dense, covering 5 to 10% Guiera senegalensis is found throughout, particularly on the sandy, fallow fields. Annona senegalensis is also common. Associates include Piliostigma reticulatum, Zizyphus mauritiana and Combretum aculeatum. Cenchrus biflorus and Aristida stipoides predominate the grass cover. Numerous forbs occur, including Mitracarpus scaber and Tephrosia purpurea.

The rolling topography and the poor moisture holding capacity of the soils have discouraged intensive cultivation, though the high rural

population density to the east has been spreading into this marginal agricultural area. Remaining idle for years at a time, fallow fields dominate the ground cover.

The land is well suited to grazing, with the limiting factor to herbaceous development being insufficient rainfall.

Unit E2

This cover type occupies the wide interdunal depressions of the ancient continental erg of the northern Groundnut Basin. The soils retain moisture more readily than those of the surrounding AEc10 cover type and are therefore intensely cultivated. The vegetation formation is a tree pseudo-steppe and can be considered a subtype of the AEc10 unit. The tree composition is essentially that of unit AEc10, but the shrub stratum is relatively open (2 to 5% cover), with Euphorbia balsamifera being used as live fences to delineate field boundaries (Fig. 5.12). Guiera senegalensis domiates the fallow fields; associates include Annona senegalensis and juvenile Acacia albida. (Refer to unit AEc10 for the herbaceous composition and land use practices.)

Fig. 5.12. Aerial view illustrating the use of Euphorbia balsamifera as live fences to delineate field boundaries. Note that most cultivation occurs within the interdunal depressions (unit E2). Louga area; altitude 700 m; April 27, 1984.

Unit V8

This shrub savanna north of Sébikhotane occupies a gently rolling terrain formed from stabilized coastal dunes. Occasional trees include Acacia albida, Tamarindus indica, Ficus gnaphalocarpa and Khaya senegalensis. The shrub stratum predominates, with a ground coverage of about 10%. The dominants are Guiera senegalensis and Piliostigma reticulatum. Associates include Annona senegalensis, Boscia senegalensis and Capparis tomentosa. Annuals predominate the herbaceous cover, including Eragrostis tremula and Pennisetum pedicellatum.

Scattered fruit tree farms and market-gardens occur in the lower lying areas, where mangos, citrus fruits and various vegetables are cultivated. Rainfed crops include millet, cowpeas and manioc.

The ephemeral vernal pastures which dominate the slopes and higher areas are of good quality given adequate rainfall.

Unit V9

This cover type occurs on ferallitic laterites overlying sandstones of the Massif de Ndiass. The present day shrub savanna was covered by a guinean forest in the recent past. This is supported by the large number of relic species. A few remaining stands have been set aside as forest preserves (F. de Popenguine, F. de Ndiass, and F. de Sébikhotane).

Two main cover types occur on the Ndiass Plateau--the relatively dense shrub woodland (Unit BV2) and the relatively open shrub savanna (V9). Unit V9 represents the areas which have been cleared for cultivation, which generally occur on the slopes and talwegs of the dissected plateau.

The dominant shrubs are Combretum micranthum, Zizyphus mauritiana, Boscia senegalensis and several acacia associates: Acacia ataxacantha, Acacia macrostachya and Acacia albida. Numerous other Sahelian, Sudanian and even Guinean shrubs grow here. Woody ground cover ranges from 5 to 20%. Scattered trees are the rule, commonly Acacia albida, Adansonia digitata and such relics as Parkia biglobosa, Celtis integrifolia and Ceiba pentandra near the villages. Mangifera indica is grown for its fruit.

Annual grasses predominate including Pennisetum pedicellatum and Eragrostis tremula. The main land use is farming. Rainfed millet, sorghum, manioc, cowpeas and fruit trees (mango and citrus trees) are grown.

Unit VS10

This mixed shrub and tree savanna formation is a remnant of a dense acacia woodland growing on the vertisols east of Mbour. Shrubs dominate the ground cover (10 to 30%) and are dominated by Combretum micranthum, Piliostigma reticulatum and Guiera senegalensis (a recent invader). Associates include Acacia seyal, which is commonly found on vertisols, and Combretum aculeatum.

The scattered trees are dominated by Acacia seyal, Acacia albida and Adansonia digitata, with occasional Ficus exasperata and Anogeissus leiocarpus, a species which has suffered many losses during the dry period.

The extensive fallow fields are covered with annuals, primarily Aristida adscensionis and Schoenefeldia gracilis. Cultivation of millet predominates, as the soils are too compact for groundnuts.

Unit S1

This cover type lies on the piedmont west of the Thies escarpment, on hydromorphic soils overlying calcareous rocks. It consists of a tree savanna with three strata of woody species; the highest stratum consists only of large Adansonia digitata (baobabs); the smaller trees are dominated by the reddish Acacia seyal, occurring in nearly pure stands. Less common associates include Acacia senegal and Acacia adansonii. The shrub stratum is also monopolized by Acacia seyal, with occasional Ximenia americana, Feretia apodanthera and Acacia ataxacantha.

The ephemeral summer pastures are dominated by such annuals as Schoenefeldia gracilis and Aristida adscensionis. The grazing potential is good given adequate rainfall. Furthermore, leaves of the predominant Acacia seyal shrub/tree are actively sought out by most ruminants.

Unit S2

The main cover type of the Groundnut Basin, this unit extends over most of the Diourbel region, the eastern Thies region and the northern part of the Fatick region. The dior soils that cover most of the unit originated from the sands of the recent Quaternary erg. The eastern part of this unit merges into the ferruginous soils of the "Continental Terminal".

The vegetation landscape has undergone a complete transformation since the early 1800's when the cultivation of groundnuts was first introduced. Today, an anthropic tree savanna, also described as a park savanna, covers this densely populated agricultural area. One hundred fifty years of clearing the land and intensive cultivation have left few traces of the natural woodland. It is difficult to reconstruct the

previous physiognomy and composition, since even the more wooded areas found today are not relics of the original communities. The present formation and composition can be attributed almost entirely to human activity.

The characteristic tree and sole dominant of this region is the Acacia albida. Although this species constitutes a near monoculture, it did not belong to the original woodland (Giffard, 1974). Rather, it has been associated with all the old agrarian civilizations of West Africa. It is propagated by ruminants and protected by cultivators through its early growth stage. It is further distinguished by a unique vegetative cycle in that, unlike most species, it conserves its leaves during the long dry season and drops them at the onset of the rainy season.

At the turn of the century, a pseudo-climax woodland characterized the area dominated by Combretum glutinosum, with scattered Anogeissus leiocarpus, Cordyla pinnata, Khaya senegalensis, Bombax costatum, Pterocarpus erinaceus and Sterculia setigera (Giffard, 1974). It resembled the present communities found to the east in the "new lands" of the departments of Kaffrine and Tambacounda. While most of these species have disappeared from the Groundnut Basin, a number of typically Sahelian and Sudanian specimens have survived in the fields. The northern part of this cover type takes on a Sahelian aspect and gradually assumes a Sudanian character as one progresses south toward the Saloum River. Any map boundary drawn to separate the Sahelian from the Sudanian zones of influence would be arbitrary and artificial, given the gradual, almost imperceptible, transition.

Common associates of the Acacia albida in the northern reaches of this unit include Balanites aegyptiaca, Acacia raddiana and Tamarindus indica. Farther south (particularly below the Thies-Diourbel road) common associates are Anogeissus leiocarpus, Diospyros mespiliformis, Ficus gnaphalocarpa (in or near villages) and Mitragyna inermis (in depressions). Adansonia digitata is found throughout. The average height of the tree stratum is 8 m, with ground cover ranging from 1 to 5%. Tree density averages 4 to 6 trees per ha. This figure has been slowly decreasing over the decades.

A few meager shrub species are all that remain after the field clearing and cultivation of groundnuts and grains. Guiera senegalensis, a small Sudano-Sahelian shrub which quickly invades the exhausted, sandy soils of fallow fields, predominates throughout (Fig. 5.13). Other common associates include Piliostigma reticulatum, Combretum micranthum, juvenile Acacia albida and Balanites aegyptiaca.

Fig. 5.13. Guiera senegalensis, a small Sudano-Sahelian shrub, quickly invades the exhausted, sandy, fallow fields and predominates throughout the Groundnut Basin. 6 km east of Diourbel.

The fallow and abandoned fields have been invaded by a heterogeneous mix of Sahelian and Sudanian herbaceous species. It was not possible to determine which of these were indigeneous to the area. The dominants, Eragrostis tremula and Cenchrus biflorus, are sought out by ruminants. Other common associates are Aristida adscensionis and Schzachyrium exile. Two ubiquitous invaders are Mitracarpus scaber and Cassia obtusifolia (formerly Cassia tora). These forbs are rarely grazed and grow on the most infertile soils. Other common forbs are Hibiscus asper, Corchorus tridens, Alyssicarpus ovalifolius and Leptadenia hastata. During the rainy season, the landscape undergoes a striking transformation (Figs. 5.14 and 5.15). The lush, continuous, herbaceous cover often exceeds 80 cm in height during years of average or above average rainfall.

Figs. 5.14 and 5.15. Taken from the same photo-point, this pair of photographs illustrates the striking contrast in the vegetation cover between the dry season and wet season. Acacia albida predominates. Note that it loses its leaves during the wet season and maintains them throughout the dry season. East of Nadangalma.

Unit Sd3

This unit occurs within the northern (Sahelo-Sudanian) area of unit S2, west of Mekhe. It occupies slight interdunal depressions on less well-drained, sandy and clayey soils. The moisture retention of these soils is somewhat better than that of the upland soils, which results in a denser tree savanna, a variant of unit S2.

Acacia albida is predominant; the composition takes on a Sahelian aspect from the associated species: Balanites aegyptiaca, Acacia raddiana and the ever-present Adansonia digitata. Tree composition differs significantly from the surrounding cover type by the presence of Acacia seyal, which favors the heavier soils. The ground cover averages 5%, with a height of 6 to 8 m. A thorny shrub stratum that covers 5 to 10% of the soils is dominated by juvenile Balanites aegyptiaca, Acacia albida and Acacia seyal. The herbaceous cover was not found to be significantly different from that of unit S2.

The land use practice consists of millet, sorghum (predominant) and groundnut cultivation. The density of fallow fields relative to the surrounding S2 unit is high.

Unit Sc4

Occurring mainly on a moderately rolling terrain of the recent Quaternary erg in the vicinity of Tyilmakha and Touba, this cover type is a less dense variant of unit S2. It consists of an open tree savanna with tree cover averaging from 1 to 2%. Acacia albida is dominant; Acacia raddiana is more prevalent than in the surrounding S2 unit and occurs with Balanites aegyptiaca. Other species include Combretum glutinosum and Tamarindus indica. The shrub stratum is predominated by Guiera senegalensis, which invades the fallow fields. Common associate are Piliostigma reticulatum, Combretum aculeatum, juvenile Acacia albida and Balanites aegyptiaca. The shrub cover ranges from nul in cultivated fields to 20% in abandoned and fallow fields. The herbaceous cover varies in quality and percent of cover from year to year, mainly in response to rainfall. The co-dominant annual grasses are Eragrostis tremula and Cenchrus biflorus. Forbs include Mitracarpus scaber, Corchorus ssp., Hibiscus asper and Cassia ssp.

Intensive cultivation of groundnuts and millet/sorghum is the rule, the latter crops becoming more widespread in 1985. The exploitation of trees for fuel and construction has led to a critical shortage of wood and a very low tree density (4 to 6 trees per ha). None of the original woodland remains.

Unit S5

Distinguished by eolian sands overlying vertisols within a slight depression (Bambey area), this cover type is a variant of unit S2. The vegetation community reflects this soil difference through the presence of the indicator species, Acacia seyal, and the relative abundance of Adansonia digitata, which favors soils developed from the underlying marl. Acacia albida still dominates this anthropogenic tree savanna, as does Guiera senegalensis, a small shrub invading sandy, fallow fields. Combretum micranthum is another characteristic species of this unit. Other shrubs include Bauhinia rufescens, Piliostigma reticulatum and Maytenus senegalensis. The continuous herbaceous cover of the late wet season is a mixture of Sahelian and Sudanian species, commonly Eragrostis tremula, Aristida adscensionis, Schoenefeldia gracilis (grasses), Cassia obtusifolia, Mitracarpus scaber, Corchorus trilocularis and Hibiscus asper (forbs).

Particularly in recent years, millet and sorghum fields dominate groundnut fields. The fallow fields are grazed by local herds.

Unit S6

This unit occurs along the Thiès-Tivaouane road, on red-brown ferruginous soils overlying laterite approximately one meter below the surface. It forms part of the western border of the extensive S2 unit; the vegetation community is distinguished by the Borassus aethiopium palms (Fig. 5.16), which formed a relatively dense grove until the early to mid 1900's. Three species dominate the tree stratum: the characteristic Borassus aethiopium, the Acacia albida in its westernmost extension and Adansonia digitata, which occurs in unusually high density. Other characteristic associates are members of the fig family: Ficus gnaphalocarpa, Ficus platyphylla and Ficus iteophylla. The shrub cover consists mainly of juvenile Borrassus aethiopium, Acacia albida and Boscia senegalensis. The herbaceous stratum of this tree savanna is dominated by Eragrostis tremula (on sandy soils), Pennisetum pedicellatum (in shady locations) and Eragrostis ciliaris.

Unit S7

Unit S7 covers a transitional area between the rocky, red ferruginous soils of the Thies plateau and the sandy ferruginous soils of the Groundnut Basin. Laterite occurs at or just below the surface, limiting the density and diversity of this anthropogenic tree savanna. Though difficult to map, this cover type varies from a Guiera senegalensis shrub savanna in the west to the Acacia albida tree savanna in the east. Associate trees include the small Parinari macrophylla, maintained for its fruit, and the ever-present Adansonia digitata (baobab). Guiera senegalensis, the most common of the Groundnut Basin shrubs, forms a relatively dense cover (up to 20%) on the extensive abandoned fields of this unit. Characteristic shrubs include Combretum micranthum (known locally as quinquiliba) and

juvenile Acacia albida. Eragrostis tremula and Cenchrus biflorus dominate the fallow fields in the east, while Dactyloctenium aegyptium and Aristida ssp. prefer the rockier, shallow soils toward the Thiès escarpment.

Fig. 5.16 Remnants of a dense Borassus aethiopium (rhun palm) grove that has been overexploited for decades. It lies between Thiès and Tivaouane, marking the western border of the Groundnut Basin (unit S6).

The soil is marginal at best for cultivation, though the eastern part of this unit is used for groundnuts and millet. The rocky soils support a poor to medium quality rangeland.

Unit S8

This cover type is a variant of unit S2, differing primarily by the lack of rolling topography and near absence of depressions. Like unit S2, the vegetation consists of an anthropogenic, tree savanna dominated by Acacia albida with a canopy cover of 1 to 5%. Lying at the east edge of the Groundnut Basin, this community is further distinguished by the appearance of Combretum glutinosum in the upper and lower woody layers, which is indicative of more recent clearing and less intensive cultivation of sandy soils. This unit has both a

Sahelian aspect due to Balanites aegyptiaca, and a Sudanian character due to Cordyla pinnata. Associates include Adansonia digitata and Anogeissus leiocarpus and the western extension of inedible Sterculia setigera. Guiera senegalensis predominates on the sandy fields, as do annual grasses, particularly Eragrostis tremula, Cenchrus biflorus and Schizachyrium exile. Forbs include Mitracarpus scaber, (a non-palatable invader), Zornia glochidiata (highly sought by livestock) and numerous others.

The land use is basically the same as unit S2, though it is less intensively cultivated and benefits from longer fallow periods.

Unit S10

Unit S10 is the cultivated counterpart of unit S1. It lies on the piedmont of the Thies escarpment in the vicinity of Mont Rolland. Basically, all of the original vegetation has been cleared, with the exception of Adansonia digitata which forms a "baobab forest". Acacia albida, introduced during the initial cultivation of this area, co-dominates. Scattered associates include Tamarindus indica, Borassus aethiopium and Anacardiem occidentale. Numerous shrubs constitute the lower level, including Bauhinia rufescens, Zizyphus mauritiana, Feretia apodanthera and Calotropis procera. Annuals include Pennisetum pedicellatum (very common) and Aristida adscensionis, and the perennial Andropogon gayanus is common.

Millet and sorghum are the principal crops.

Unit S11

This small unit occurs on the Somone alluvial plain where deep hydromorphic soils have formed and includes the southernmost reaches of the "baobab forest" that parallels the Thiès escarpment. Adansonia digitata is found in nearly pure stands, with a density of about 5 individuals per ha. The shrub layer is very open, with scattered Combretum aculeatum, Piliostigma reticulatum and Acacia seyal in clayey depressions. Cassia obtusifolia and Panicum sp. dominate the herbaceous stratum. The land is used to both cultivate millet/sorghum and graze livestock.

Unit S21

This community occupies the fossil valley near Khombole and Tataguine. The soils are hydromorphic, overlie alluvial sands and produce a vegetation community that is a variant of unit S2. Acacia albida and Balanites aegyptiaca co-dominate with the characteristic associates: Acacia seyal and Anogeissus leiocarpus. The shrub layer consists mainly of Guiera senegalensis, Maytenus senegalensis and Acacia seyal. Numerous Sahelian and Sudanian herbaceous species occur, particularly Schoenefeldia gracilis and Chloris prieurii (in very open areas), Aristida adscensionis, Eragrostis tremula and such forbs as

Cassia obtusifolia, Leptadenia hastata and Borreria verticillata.

Unit S22

This tree savanna occurs within the fossil Sine Valley, on soils similar to those associated with Unit S21. The tree stratum consists of Acacia albida (dominant), Adansonia digitata and Balanites aegyptiaca, with Combretum glutinosum appearing to the east of the Diourbel region. The shrub layer consists of the ubiquitous Guiera senegalensis (dominant) and Piliostigma reticulatum, which form a denser cover than the surrounding terrain (10 to 20% cover). The Eragrostis tremula/Cenchrus biflorus association dominates the herbaceus stratum.

The land use is essentially that of unit S2, with millet as the principal crop.

Unit B1

This savanna-woodland occurs solely within the confines of the Centre Agronomique de Bambey. This formation has been protected for decades from both man and animal by a fence, resulting in a relatively dense woody cover. Acacia seyal dominates both the tree and shrub layer. Most of the shrubs and small trees are Sahelian. Associates include Guiera senegalensis, Combretum aculeatum, Combretum micranthum, Balanites aegyptiaca, Acacia Senegal and Ximenia americana. These species form a ground cover of about 30%. Common annuals are: Digitaria velutina, Aristida stipoides and Chloris prieurii. Common forbs include Merremia aegyptiaca and Indigofera astragalina.

Unit B11

This unit is confined to a few narrow fossil valleys in the Thiès region where higher soil moisture has led to the relatively dense woody growth of a savanna-woodland. The original vegetation has been replaced by fruit trees, particularly Mangifera indica. Other fruit trees include Citrus nobilis, Anacardium occidentale and Cocos nucifera. Eucalyptus sp. has been introduced recently. The shrub layer is quite sparse, consisting mainly of Guiera senegalensis. Grasses include Chloris prieurii and Dactyloctenium aegyptium. Many species of forbs were found; Ipomaea aegyptiaca and Cassia obtusifolia were most common, though more information is needed to determine the characteristic dominant species.

The shallow water table makes limited market-gardening possible. Plots are irrigated by hand from shallow wells (Fig. 5.17).

Fig. 5.17. An aerial view of a narrow valley near Noto, unit B11. Note the series of shallow wells for irrigating gardens. Altitude 700 m; April 27, 1984.

Unit BV1

This unit comprises the Forêt Classée de Thiès, which occupies the western part of the Thiès plateau (red ferruginous soils and rocky soils over laterite) and the Thiès escarpment (rocky slopes with calcareous and lateritic outcrops). The vegetation formation has the diversity of a savanna-woodland, but the grasses are discontinuous and the shrub layer dominates the few scattered trees. Therefore, we have described it as a shrub woodland, though other investigators have used the term "thicket". The woody strata ranges in cover from 20 to 50%. The dominant small trees and shrubs are Acacia ataxacantha, Acacia seyal (on clayey soils), Combretum micranthum and Boscia senegalensis. Other typically Sahelian associates include Grewia bicolor, Zizyphus mauritiana, Boscia angustifolia and Ximenia americana. Occasional baobabs (Adansonia digitata) and the small Acacia seyal emerge above the shrub layer. Annual grasses dominate the herbaceous cover, particularly Digitaria velutina and Dactyloctenium aegyptium, both highly palatable. Cassia obtusifolia predominates the clayey soils.

Until the development of Dakar, this unit was likely covered by a woodland of Sudanian nature, as evidenced by a few relic species. The woodland was overexploited in order to furnish the capital with wood,

leaving a degraded shrub-woodland with a Sahelian aspect. Although this zone is a protected forest preserve, its potential for furnishing wood products other than firewood is very limited. The herbaceous cover forms a good pasture in the wet season, though the quantity of forage is limited by the dense woody cover and by the poor, rocky soils.

Unit BV2

Unit BV2 is a shrub-woodland that occurs together with unit V9 on the ferrallitic soils with laterite of the Massif de Ndiass. The BV2 unit is found mainly on the slopes and uplands of this plateau, with the lower areas having been cleared for cultivation.

The dominant species of shrubs are Acacia ataxacantha, and its main associate is Combretum micranthum, which is typically found on lateritic soils as far south as Guinea. Common associates include Boscia senegalensis, Boscia angustifolia, Grewia bicolor (often growing on termite mounds), Feretia apodanthera and Dichrostachys glomerata. Tree remnants of the Sudanian woodland that once covered this plateau include Albizzia zygia, Adansonia digitata and Parkia biglobosa (quite rare), as well as Sclerocarya birrea of the Sahel region. Growing among numerous forbs, Panicum sp. appears to dominate the grasses.

Like the Forêt de Thiès, this shrub formation is the result of overexploitation for wood production. Its principal potential today is the furnishing of firewood; given the patchy herbaceous cover and the density of the woody layer, the rangeland is marginal.

Unit N

This cover type represents areas whose vegetation has been completely removed for mechanized agriculture. This unit occurs in two main areas--west of Déali at Darou Ndiaye and at the Agricultural Experimentation Center at Boulel.

Unit Cr

This unit represents the open pit mines in the Thiès region. These mines have led to a total removal of vegetation type AE11, particularly at the Taïba phosphate mines. It is not a vegetation unit and has been classified under "other areas".

5.4.1.5 The Pastoral Domain

A. General Characteristics

The pastoral domain can also be defined by anthropic criteria, namely, the raising of livestock. It is clearly distinguished from the preceding environment, which is heavily cultivated, and from the Senegal River Valley, which is geomorphologically and pedologically

distinct. The southern limits of this zone are vague in that there is a gradual transition of land use, climate and vegetation between the Sahelian and Sudanian Regions. As defined in the Schéma national d'aménagement du territoire (1984), the pastoral domain descends partially into the Sudanian Region. This section will consider only the area within the Sahelian Region (including the Sahelo-Sudanian transition zone).

Most of this area is underlain by sands of the "Continental Terminal". Northwest of a line passing through Yaré Lao, Lagbar and Linguère, the sandstones are covered by sand deposits that form a gently rolling peneplain. Nutrient-poor, red-brown soils cover the ancient dunes, while better developed, ferruginous soils have developed over the "Continental Terminal" sands further south. This area is known as the sandy Ferlo. To the east of the line, the sand deposits disappear, while gravelly soils and laterite outcrops predominate. This region is called the lateritic Ferlo. Here, the plateau rises to an average elevation of 90 m. The surface is dissected by an ancient drainage network.

As a whole, the herbaceous vegetation of the pastoral domain covers the ground more or less continuously at the peak of its yearly development. In relatively wet years, the grasses, (composed mainly of annuals), can reach a height of 1 m, though pre-drought averages ranged from 60 to 80 cm. Woody species are scattered throughout and vary in density as a function of climate, soils, geomorphology and animal pressure. Physiognomically, the vegetation of the sandy Ferlo is a shrub pseudo-steppe, while that of the lateritic Ferlo is usually referred to as a shrub savanna. While shrubs less than 4 m in height dominate the woody stratum, numerous species of trees associated with the more humid Sudanian region tower above the shrub stratum. Throughout much of the sandy Ferlo, small depressions in the lower areas of the peneplain exist. They collect runoff from the rains, forming temporary ponds in wetter years. These depressions often support a relatively dense vegetation cover that resembles a woodland savanna. The depressions are generally elongated and form a series of stripes known in West Africa as la savane tigrée (Fig. 5.18). The present character of the vegetation is largely a result of the influences of man and his herds, which have caused severe losses of vegetative cover, particularly around the watering points. The severe aridity of the past one-and-a-half decades has accelerated the degradation in vegetation cover, stunting and even killing the woody species, and drastically reducing the amount of herbaceous biomass. The drought has also effected the floristic composition, and many of the mesophytic species are beginning to disappear.

Fig. 5.18. Aerial view of the striped savanna (savane tigrée) formed by dense stands of vegetation growing in interdunal depressions. The Pastoral Domain, southwest of Linguère. Altitude 700 m; August 8, 1984.

The sandy Ferlo of the northern and eastern pastoral domain is dominated by acacia trees, particularly Acacia raddiana and Balanites aegyptiaca, which are greatly affected by man and fire. The latter species survives despite its exploitation by man because of its ability to quickly regenerate and multiply . Besides Balanites aegyptiaca, the shrub stratum is generally dominated by Acacia senegal (in the Lac de Guiers area), Boscia senegalensis and Zizyphus mauritiana. Common grasses include Cenchrus biflorus, Schoenefeldia gracilis and Dactyloctenium aegyptium.

To the south, in the transitional Sahelo-Sudanian domain, Combretum glutinosum shrubs and trees of the Sudanian Region begin to appear, while Acacia raddiana disappears from most areas. Acacia seyal, in association with Combretum glutinosum, dominates the lower lying silty and clayey soils. To the west of a line passing through Linguère and Podor, a scattered population of Sclerocarya birrea trees becomes significant; this species is a living testimony to an earlier wet period.

The lateritic Ferlo in the east and southeast is characterized by relatively dense populations of Pterocarpus lucens, often found in relatively pure stands. Several other associates include Acacia seyal, Combretum micranthum, Combretum nigricans and Adenium obesum (the "little baobab of the jackal"). The understory is dominated by Loudetia togoensis, which is found commonly on gravelly soils.

B. Cover Types

Unit Ac1

This open shrub pseudo-steppe occurs on gently rolling terrain derived from dunes of an erg. The soils are poorly differentiated ferruginous sands. The unit runs northeast to southwest through Kadia and Gueye Kadar in the sandy Ferlo.

While small trees and shrubs dominate the woody strata, scattered trees are found. The principle species are Sclerocarya birrea, Combretum glutinosum and Balanites aegyptiaca. The small trees and shrubs include the above (all common), plus Commiphora africana, Boscia senegalensis, Guiera senegalensis (very common) and Acacia seyal in the lower areas. Annuals are dominated by Cenchrus biflorus, Dactyloctenium aegyptium, Digitaria lecardii, Eragrostis tremula and Aristida adscensionis. Common forbs include Zornia glochidiata, Alysicarpus ovalifolius and Tribulus terrestris.

The ephemeral summer grazing lands produce excellent quality forage given adequate rainfall.

Unit Ac2

This cover type borders the middle Senegal River Valley, along the road between Haïré Lao and Hore Fôndé. The level of degradation as a result of human and animal activity and poor soils is quite striking (Fig. 5.19). What remains of the vegetation is a floristically poor open shrub type, on shallow clayey soils with gravel deposits. The few scattered trees are usually Balanites aegyptiaca. The shrub population consists of the dominant Balanites aegyptiaca, Zizyphus mauritiana and Acacia seyal, which is gradually disappearing. The principal grasses are Dactyloctenium aegyptium and Eragrostis tremula, mixed with such forbs as Tribulus terrestris, Leptadenia hastata and Indigofera senegalensis.

The herbaceous cover is discontinuous due to the eroded, compact and gravelly soils. In recent years, the rainfall has been too scanty to support more than a meager scattering of grasses. Even in wetter years, the rangeland is fair to poor.

Fig. 5.19. This open shrub pseudo-steppe occurs on the diéri, bordering the Senegal River Valley near Horé Fóndé. This formation is floristically poor, a result of human and animal pressures.

Units Ac3, Acm3

Lying on the remnant of an erg, these units represents the main cover type of the northern sandy Ferlo. The soils are degraded, red-brown, clayey sands of eolian origin.

Like most of the sandy Ferlo, this open shrub pseudo-steppe, dotted with wooded depressions is a result of long-term human and animal pressure on the vegetation. Most of these pastures have been cultivated at one time or another, greatly reducing the woody cover (Fig. 5.20). Ruminants have traversed this zone to and from the river for centuries, taking their toll as well. The recent drought has laid bare the soil and as a result it has undergone severe wind erosion. Drastic changes in the woody cover have taken place in the last 30 years (De Wispelaere, 1981). Great decreases in the density of the woody strata have occurred on the upper areas of this gently rolling landscape, while the depressions have remained relatively dense. The increasing contrast between the wooded depressions and the open uplands is especially striking from the air (Fig. 5.18).

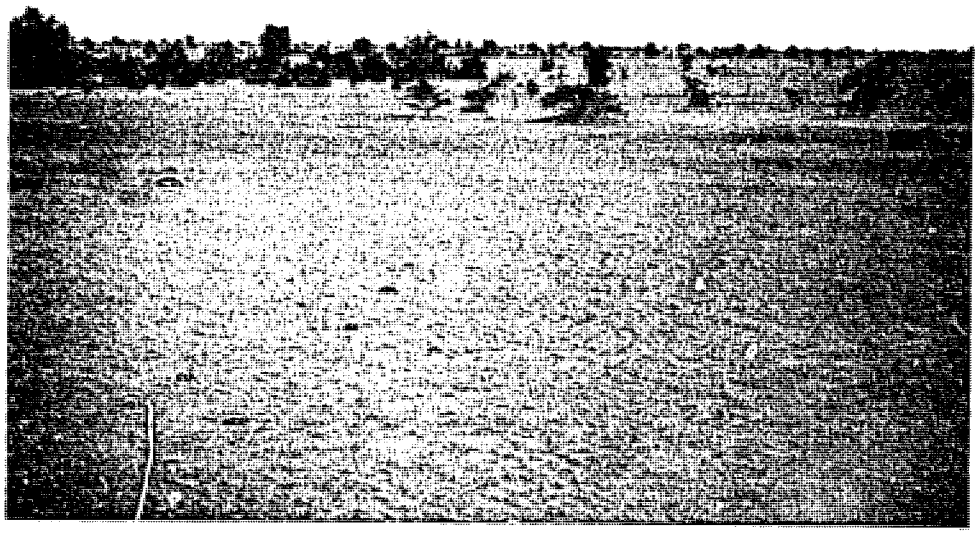


Fig. 5.20. An open shrub pseudo-steppe of the northern sandy Ferlo, 24 km south of Ndioum. Vegetation is concentrated in depressions (left). Drought and animal and human pressure have all contributed to reducing the cover.

The dominant trees and small trees of unit Ac3 and Acm3 (upland areas) are Balanites aegyptiaca and Acacia raddiana, both widely scattered. Small trees and shrubs include the above with the following associates: Boscia senegalensis (common), Acacia senegal (source of gum Arabic) and Calotropis procera. Less common associates are Zizyphus mauritiana and Combretum aculeatum, which are found mainly in the depressions. The herbaceous vegetation was basically absent at the time of our field observations. According to the work of J. Valenza and A. Diallo (1972), the herbaceous stratum is composed mainly of Chloris prieurii, Cenchrus biflorus, Dactyloctenium aegyptium and Schoenefeldia gracilis (less common), with such forbs as Alysicarpus ovalifolius and Zornia glochidiata. The more clayey soils are dominated by Aristida adscensionis and Eragrostis ciliaris.

The main potential of this unit is grazing, but this activity is severely limited by insufficient and erratic rainfall. In 1984 for example, the productivity level of this unit was well below 100 kg of herbaceous biomass per hectare, according to a memorandum (1984) of the "Projet Pilote d'Inventaire et de Surveillance Continue des Ecosystèmes Pastoraux Sahéliens".

Unit Ac4

This open shrub pseudo-steppe covers much of the former erg, which flattened over time, has been giving rise to a peneplain with wide, elongated ridges and troughs. Unit Ac4 is generally found on sandy soils to clayey sands of eolian origin and covers the slopes and rises in the southern part of the sandy Ferlo.

Most of the vegetation is protected from cultivation practices since much of this cover type lies within the Reserve Sylvo-Pastorale des Six Forages. This reserve and others restrict agriculture to the growing of subsistence crops by the herders, as well as the grazing of the rangeland. A series of fire breaks crosses this zone. They were introduced to help protect the forage from grass fires, which are usually started by man (Fig. 5.21). In the past thirty years, the environment has been considerably modified by the presence of animal herds throughout the year. This change is especially acute around the watering holes; constant trampling, overgrazing and the cutting of tree branches have led to severe degradation, both qualitative and quantitative, of the vegetation cover.

Fig. 5.21. An open shrub pseudo-steppe with sparsely scattered trees (Sclerocarya birrea, Balanites aegyptiaca, and Combretum glutinosum) in the Réserve Sylvo-Pastorale des Six Forages (unit Ac14).

Sparsely scattered trees are the rule and are dominated by Sclerocarya birrea, Balanites aegyptiaca and Combretum glutinosum. Smaller trees and shrubs are also dominated by the above species, with Guiera senegalensis a common invader of disturbed areas; other associates include Boscia senegalensis, Acacia senegal, Calotropis procera and Terminalia avicennoides. The herbaceous vegetation includes Eragrostis tremula, Cenchrus biflorus and Dactyloctenium aegyptium (grasses), and Alysicarpus ovalifolius, Zornia glochidiata and Borreria radiata (forbs). The amount of woody species cover ranges from 2 to 3%, with tree heights of 5 to 7 m and shrub heights of 1 to 3 m.

Many of the above species have disappeared from the degraded areas surrounding the water holes. Hardy species and less palatable species remain, such as Boscia senegalensis, Zizyphus mauritiana, Guiera senegalensis (an invader), Balanites aegyptiaca (fire resistant) and Combretum glutinosum (rarely sought out by animals).

Unit Acm5

This unit occurs with the previous unit (Ac4) in the wide elongated troughs of the sandy Ferlo peneplain. The soils are compact sandy loams. Within these troughs are a multitude of depressions, some of which flood during the rainy season. The vegetation communities differ significantly from those on higher ground. The depressions support a dense woody cover resembling a savanna-woodland, while the compact soils between these depressions (still within the troughs) support a very open shrub steppe (Fig. 5.22). The trees of these depressions or consist mainly of Balanites aegyptiaca (a constant throughout northern Ferlo), Acacia seyal, Adansonia digitata (a relative giant in this community), Acacia adansonii and Sclerocarya birrea. Shrubs and lesser trees dominate the woody strata, with Boscia senegalensis, Balanites aegyptiaca, Guiera senegalensis and Calotropis procera (all common) and Zizyphus mauritiana, Commiphora africana and Grewia bicolor (associates). The herbaceous stratum is composed commonly of Schoenefeldia gracilis, Eragrostis tremula, Alysicarpus ovalifolius and Zornia glochidiata.

These wooded depressions are generally less degraded by animals and man than the higher grounds. The rangeland is of good quality around the edges of the depressions and of poor quality on the compact loams between depressions.

Fig.5.22. An example of relatively dense vegetation occurring within interdunal depressions which collect rainwater; Réserve Sylvo-Pastorale des Six Forages, unit Acm5.

Unit Ac6

This very open shrub pseudo-steppe occurs on relatively recent, semi-active dunes along the south side of the Senegal River Valley between Podor and Ndioum. The tree and shrub strata consist of widely scattered Acacia raddiana, Balanites aegyptiaca and Acacia senegal (1% cover). Associates include Boscia senegalensis and Zizyphus mauritiana (becoming rarer). The short-lived vernal pastures are characterized by species growing on fallow and abandoned fields, namely Cenchrus biflorus, Dactyloctenium aegyptium, Eragrostis tremula (grasses), Leptadenia hastata and Tribulus terrestris (forbs) (Valenza and Diallo, 1972).

This unit has been highly degraded through decades of human and animal pressure, which has resulted in the reduction of Acacia species while Balanites aegyptiaca has become more widespread.

Unit A9

This degraded vegetation formation occurs on the piedmont and buttes between the Senegal River Valley and the lateritic Ferlo in the vicinity of Ouro Sogui. The brown subarid soils range in texture from sandy clays to clayey sands. The vegetation formation is shrub steppe, generally quite open, which has resulted from a history of cultivation and exploitation for firewood.

The scattered shrub species are dominated by Balanites aegyptiaca and Combretum glutinosum, and such characteristic associates as Acacia seyal, Acacia raddiana, Capparis decidua and Zizyphus mauritiana. Herbaceous species are typically those found in abandoned fields, namely Schoenefeldia gracilis, Cenchrus biflorus, Zornia glochidiata and Tribulus terrestris.

The rangeland is of little value due to the limited, discontinuous cover, unreliability of adequate rainfall and rapid disappearance of grasses and forbs shortly after the rains.

Unit Ac10

This unit comprises an open shrub pseudo-steppe situated on recent dunes which have encroached upon laterite soils of the lateritic Ferlo. The unit stretches from Linguère northeast to Tiaski.

The southwestern portion of this unit has been subjected to both overgrazing and exploitation for wood products by the Linguère population. Many of the original species have been replaced by Balanites aegyptiaca and Combretum glutinosum, the former being fire-tolerant and prolific, the latter being a hardy invader rarely grazed by ruminants. Toward the northeast, the community is also dominated by the above, along with a richer set of associates. Among others, they include Guiera senegalensis, Acacia raddiana, Terminalia avicennoides, Maytenus senegalensis, Combretum micranthum, Combretum aculeatum, Feretia apodanthera, Boscia senegalensis and less commonly Sclerocarya birrea.

The herbaceous stratum also varies according to the yearly rainfall pattern and the intensity of human and animal pressure. Commonly one finds Cenchrus biflorus (sought out by ruminants despite its irritating burrs), Aristida stipoides, Tephrosia purpurea, Alysicarpus ovalifolius, Indigofera aspera and numerous less common associates.

This rangeland varies in quality from one area to another, but is generally of moderate to good quality.

Unit AE1

This cover type is the southwest extension of unit Ac1 and occurs on the same soil associations--rolling terrain derived from dunes of a stabilized erg, with poorly differentiated ferruginous sands. Slightly higher annual rainfall has resulted in a mixed shrub and tree pseudo-steppe in which the dominant trees are Sclerocarya birrea, Balanites aegyptiaca and Combretum glutinosum; relic species of a denser tree savanna include, Sterculia setigera, Terminalia avicennoides, and Adansonia digitata. The shrub layer is dominated by Combretum glutinosum and Guiera senegalensis. Associates include Terminalia avicennoides, Boscia senegalensis, Sclerocarya birrea and Commiphora africana. The herbaceous cover includes Eragrostis ciliaris, Eragrostis tremula, Schoenefeldia gracilis, Cenchrus biflorus, Zornia glochidiata, Tribulus terrestris and Indigofera ssp.

This good quality rangeland offers more forage than its counterpart to the northeast.

Unit AE2

This vegetative community occurs on a gently rolling landscape of stabilized dunes that date from a relatively recent erg on either side of the Ferlo Valley. The soils are of the red-brown subarid ferruginous type. The vegetation consists of a shrub and tree pseudo-steppe whose woody strata are dominated by Balanites aegyptiaca, Combretum glutinosum and in fewer numbers, Sclerocarya birrea. Guiera senegalensis dominates the shrub layer. Accompanying woody species vary in number from one area to another: Sterculia setigera (in its northern limit), Acacia raddiana, Terminalia avicennoides, Acacia senegal and Zizyphus mauritiana.

This formation appears to be attributed mainly to human activity, especially wood cutting and overgrazing. Indicative of man's intervention, Balanites aegyptiaca has nearly replaced other indigenous species in some areas.

The herbaceous stratum is also quite variable

according to the level of human and animal activity (Valenza and Diallo, 1972). The dominants are Cenchrus biflorus, Aristida stipoides, Aristida adscensionis and Dactyloctenium aegyptium, and common forbs are Zornia glochidiata, Tephrosia purpurea and Indigofera aspera. This floristic composition may vary from year to year, particularly given the precipitation extremes common to the Sahelian region. Floristic variations also occur according to landscape position: the vegetation of interdunal depressions tends to be denser with a higher frequency of Sclerocarya birrea, while Combretum glutinosum diminishes in number.

Unit AE3

This unit of limited extent occurs within the interdunal fossil valleys in the north Ferlo which are surrounded by unit Acm3. It consists of a shrub and tree pseudo-steppe on compact, sandy clay soils overlying a gravelly horizon. This unit is quite distinct on the Landsat imagery, as it is identified by its relatively low reflectance. Acacia raddiana is the sole dominant of the tree layer, though Balanites aegyptiaca occurs frequently. The trees can form a relatively dense cover, up to 15%. The shrub species and small trees consist of Boscia senegalensis and juvenile Acacia raddiana (dominants) and associates include Acacia senegal, Zizyphus mauritiana and Piliostigma rufescens. From the air, the herbaceous layer and the woody strata resemble a striped savanna, a result of the microtopography. Common grasses include Chloris prieurii, Dactyloctenium aegyptium and the forbs include Alysicarpus ovalifolius and Tribulus terrestris.

Effects of the drought have accentuated the disparity between the relatively dense vegetation in the depressions and the open vegetation of the uplands. The slightly lower areas remain relatively dense, while the higher areas are becoming increasingly bare as they are unable to retain the necessary soil moisture through the long dry season. The ephemeral grazing lands are of mediocre to poor quality, particularly in view of the limited biomass levels on these soils.

Unit AE4

This shrub and tree pseudo-steppe occurs on a stabilized, nearly level recent erg to the south and southwest of Lac de Guiers. The poorly differentiated ferruginous soils are derived from sandy material of eolian origin. The woody cover ranges from moderately open to relatively dense (5 to 15% cover), dominated by Acacia raddiana and Balanites aegyptiaca (both in the tree and shrub layers). Associate trees include Acacia seyal (in the lower interdune areas), Combretum glutinosum, Acacia albida (on the southern fringes of this unit near cultivation) and scattered Adansonia digitata. Associate shrubs commonly found are Acacia senegal, Combretum glutinosum, Combretum aculeatum, Zizyphus mauritiana and in some areas, Boscia senegalensis. The high frequency of Acacia raddiana, indigenous to the area, indicates a somewhat less degraded community.

The herbaceous cover consists mainly of Cenchrus biflorus, Aristida stipoides, Tephrosia purpurea and Indigofera aspera, all typical of sandy soils derived from dunes. These species form good to excellent rangeland given adequate rainfall (usually above 400 mm per year).

Units AE5 and AEc5

Unit AE5 covers much of the flat to slightly rolling peneplain just east of Lac de Guiers. A moderate to dense shrub and tree pseudo-steppe occurs here, on slightly leached, well differentiated, compact sandy-clay soils. The tree stratum is dominated mainly by Balanites aegyptiaca and widely scattered Adansonia digitata. In the extreme north, bordering on the Senegal River Valley, Acacia raddiana codominates with Balanites aegyptiaca, though farther south the former is practically absent. The shrub and lesser tree layer is also predominantly Balanites aegyptiaca and includes such associates as Boscia senegalensis (very common), Zizyphus mauritiana, Acacia senegal and Commiphora africana. The herbaceous stratum is largely composed of Schoenefeldia gracilis, Chloris prieurii, Eragrostis tremula, Cenchrus biflorus, Dactyloctenium aegyptium, (all gramineae), Alysicarpus ovalifolius, Tribulus terrestris (two widely sought-out forbs) and Polycarpaea linearifolia (Valenza and Diallo, 1972).

Unit AEc5 is a variant of AE5 and results from the cultivation of millet followed by a two-to-six-year fallow period, which results in an open shrub and tree pseudo-steppe. Decreasing numbers of Balanites aegyptiaca are evident, while Boscia senegalensis remains very common and the invader Guiera senegalensis becomes significant. Grasses associated with cultivated, sandy soils predominate, especially Eragrostis tremula, Dactyloctenium aegyptium and Cenchrus biflorus (Schoenefeldia gracilis is generally absent). The older fallow fields (5 to 6 years) can be identified by greater numbers of Balanites aegyptiaca.

Unit AEc6

This formation, a shrub and open tree pseudo-steppe, occurs adjacent to unit AE4; AEc6 is found on higher terrain on a more accentuated dune landscape. These stable dunes overlie an older series of nearly level dunes found between St. Louis and the Lac de Guiers. The floristic composition is essentially that of unit AE4, though the density of the woody strata is somewhat more open (1 to 3% as opposed to 5 to 10% for unit AE4).

The grazing lands are of good to excellent quality, given adequate rainfall. They are, however, quick to disappear shortly after the rains have stopped.

Unit AE7

This vegetation unit covers a large area of the western Djolof that borders the northeast side of the Groundnut Basin. The gently rolling landscape originated from an erg whose dunes have been greatly flattened over time. The soils are of the red-brown subarid type overlying sands. This shrub and tree pseudo-steppe ranges in cover from open (2% particularly in fallow fields), to moderate (10% cover).

Balanites aegyptiaca, Acacia raddiana, Combretum glutinosum and Adansonia digitata dominate the upper layer, with Acacia seyal occurring occasionally in lower lying areas. The lesser tree and shrub layer (not distinctly separate from the tree layer) includes the first three species listed above as dominants, with scattered associates, such as Acacia senegal and Acacia seyal. The herbaceous cover includes Cenchrus biflorus (often an indicator of the presence of numerous livestock), Eragrostis tremula and such forbs as Alysicarpus ovalifolius, Zornia glochidiata and Borreria radiata (Mosnier, 1967).

This rangeland is of good quality during the short wet season, though in the period from 1970 to 1985 germination was poor and growth levels low. Furthermore, this unit has been decreasing in area as more land succumbs to the expanding cultivation of the Groundnut Basin. With the nearly complete disappearance of herbaceous vegetation during the dry season,

animals begin grazing on trees and shrubs. Severe reduction in woody biomass has resulted. Balanites aegyptiaca, which can quickly recover from cutting and damage, becomes the dominant in highly degraded areas.

Unit AE8

This shrub and tree pseudo-steppe occurs on a gently rolling landscape formed from attenuated dunes of a former erg. It lies between Dara and Linguere, south of the more pronounced dunes along the fossil Ferlo Valley. Variations in the rolling topography give rise to a striped formation where relatively dense woodlands occur in elongated depressions. Even on the uplands, the trees are somewhat more dense than the more degraded cover types to the north and west. As the eolian sand deposits diminish from north to south, a gradual transition occurs from a predominance of Acacia raddiana and Balanites aegyptiaca (in the north) to Sclerocarya birrea, Combretum glutinosum and Acacia albida on clayey sands to the south (toward Afe). Common shrubs on the sandier northern soils include Boscia senegalensis, Balanites aegyptiaca and the associates Guiera senegalensis, Grewia bicolor, Acacia senegal and Acacia seyal. Species commmonly found in the depressions include Combretum micranthum, Dalbergia melanoxylon and Acacia ataxacantha. Grasses include Schoenefeldia gracilis, Digitaria lecardii and Eragrostis tremula. Zornia glochidiata often dominates the higher terrain, while Cassia obtusifolia is usually predominant in the depressions.

The predominant land use is the herding of livestock, though cultivation of groundnuts and millet is spreading fast on the sandier soils (this increase is very apparent on multitemporal comparisons of Landsat imagery).

Unit AET

This cover type is restricted to the lower fossil Ferlo Valley between Mbeuleukhe and K. Momar Sar. Determined by the topographical position and soil type, several vegetation formations occur.

The slopes of the valley often are made up of dunes and a shrub and tree pseudo-steppe consisting of Balanites aegyptiaca (dominant), Acacia seyal, Acacia raddiana, Acacia adansonii and Acacia senegal. The herbaceous vegetation is dominated by Schoenefeldia gracilis and Chloris prieurii.

The higher grounds within the floodplain where hydromorphic soils have developed on heterogeneous alluvial deposits support an open shrub pseudo-steppe with Acacia seyal (dominant), Acacia adansonii and essentially the same dominant grasses as above.

The bottom of the riverbed is characterized by hydromorphic, saline soils which form a mosaic of small salt flats that are often devoid of vegetation. The vegetative cover is highly heterogeneous. When present, the woody strata consist of Acacia seyal, Acacia nilotica and Tamarix senegalensis (a halophyte). Echinochloa colonum, Sporobolus marginatus and Diplachne fusca grow on the less saline soils (Mosnier, 1967).

The primary potential of this valley is for grazing, which is restricted to the slopes and higher grounds.

Unit Ec3

This cover type occurs in the middle Ferlo valley, above and below Linguere. Like the previous unit, the vegetation is quite heterogeneous depending on the physiography and edaphic conditions. Fairly dense (10 to 20% cover) pockets of tree stands can occur within this moderately open tree pseudo-steppe. The dominant woody species are Acacia raddiana and Balanites aegyptiaca. Associates include Acacia adansonii, Acacia seyal, Acacia senegal and a few Sudanian species, such as Celtis integrifolia. Common grasses include Chloris prieurii, Dactyloctenium aegyptium and various species of Eragrostis. Zornia glochidiata and Tribulus terrestris dominate the forbs.

The grazing lands are generally of good quality (Figs. 5.23 and 5.24); temporary ponds form in depressions along the valley, providing water for the herds well into the dry season.

Figs. 5.23,24 A dry and wet season view across the Ferlo Valley west of Linguère. The rangeland is good, but ephemeral. The grass cover disappears quickly after the last rains when grazing pressure is severe. May 9, 1982 and Sept. 27, 1982; unit Ec3.

Unit Vc3

Associated with unit Vd4, this unit occurs in the lateritic Ferlo on sandy deposits that border several of the fossil valleys. It is also generally associated with Peul settlements because the sandy soils are more suitable for cultivation of subsistence crops (millet) than the poorer lateritic soils. The presence of man, livestock and frequent fires, have produced a very open, degraded shrub savanna largely dominated by Combretum glutinosum and Guiera senegalensis. The few remaining associates include Balanites aegyptiaca (fire resistant), Acacia seyal and Acacia senegal. Overgrazing is a common problem, with the herbaceous cover disappearing in the early dry season. The grasses Schoenefeldia gracilis, Aristida adscensionis and Eragrostis tremula predominate, and the forb Zornia glochidiata also dominates.

These grazing lands are better tnan those of the adjacent unit Vd4, but are limited in areal extent.

Units Vd4 and Vdm4

Unit Vd4 is the most extensive unit of the lateritic Ferlo. As the sands of the western Ferlo disappear toward the east, the ferruginous soils become gravelly, with laterite occurring either just below the surface or at the surface. The laterite overlies the sandstones of the "Continental Terminal", forming a plateau approximately 90 m above sea level, which is interrupted by a fossil drainage network (see units VS17, VSc18 and SB5).

The predominant vegetation formation of the lateritic Ferlo is that of a dense shrub savanna, which floristically forms an ecological grouping of Pterocarpus lucens (a small tree of the Papilionaceae family) and Loudetia togoensis (of the Gramineae family). These two species are highly characteristic of ferruginous laterite soils of the Sahel region The most common woody tree associates of this grouping are Adansonia digitata (present, but never common) and Combretum glutinosum (quite common). The tree stratum is never high, averaging 6 m, with a ground cover of 5%. The lesser trees and shrubs predominate the woody cover, with heights of 2 to 4 m and a ground cover of 15 to 20%. Associates of the dominant Pterocarpus lucens are usually Combretum micranthum, Combretum glutinosum, Grewia bicolor (often growing on termite mounds), Guiera senegalensis, Feretia apodanthera, Combretum nigricans, and Adenium obesum (never common). The herbaceous cover can reach a height of 50 cm to 1 m at the end of the rainy season and is commonly composed of Loudetia togoensis, Andropogon ssp., Schoenefeldia gracilis, Elionurus elegans, Aristida adscensionis (all Gramineae) and such forbs as Pandiaka heudelotii, Zornia glochidiata and Polycarpaea ssp.

These grazing lands are fair to mediocre in the rainy season, mainly because the predominant grass (Loudetia togoensis) is seldom grazed and because the grass cover is somewhat discontinuous (due to the rocky, gravelly soils and numerous termite mounds). The herbaceous cover quickly disappears at the onset of the dry season (Fig. 5.25 and 5.26), often as a result of bush fires.

A variant of Vd4, Vdm4 occurs within large depressions with hydromorphic, compact soils. It constitutes a dense shrub savanna, though the woody density can reach that of a savanna-woodland. Acacia seyal dominates the clayey soils, while Anogeissus leiocarpus, Mitragyna inermis, and Acacia ataxacantha develop on the hydromorphic soils (Valenza and Dialo, 1972). When lateritic soils occur near or at the surface, the floristic composition approaches that of unit Vd4.

Units V5, Vc5 and Vd5

Unit V5 and its variants Vc5 and Vd5 occur on the slopes between the "Continental Terminal" and the Senegal River Valley. The soils are sandy clays derived from the weathering of the sandstones to the west and eolian sand deposits occur frequently.

The vegetation ranges from an open shrub savanna (Vc5) to a relatively dense shrub savanna (Vd5) dominated by members of the Combretaceae family: Combretum glutinosum and Combretum nigricans (dominants), Combretum micranthum, Pterocarpus lucens (in dense stands on the gravelly soils bordering the Ferlo plateau) and Grewia bicolor (usually associated with termite mounds). Unit Vc5 results mainly from human and animal pressure, and Combretum glutinosum predominates while the other associates become rarer.

The herbaceous cover is floristically rich (Valenza, 1977), with the dominants being Eragrostis tremula, Ctenium elegans, Andropogon pseudapricus (more common in the south), Borreria ssp. and Polycarpaea linearifolia.

These pastures are generally very good, and are quite productive given adequate rainfall. Perennials such as those of the Andropogon tribe provide some forage throughout the year.

Figs. 5.25,26. A dry and wet season view of the Pterocarpus lucens shrub savanna of the lateritic Ferlo near Yonoféré. March 6, 1984, and Sept. 26, 1982; unit Vd4.

Units V6 and Vc6

Unit V6 and its variant Vc6 form a wide band that constitutes the northern part of the lateritic Ferlo (Fig. 5.27). The soils are gravelly and overlie laterite, with surface sand deposition occurring presently in many areas. This formation is a shrub savanna, somewhat more open than the extensive Vd4 unit which borders it to the south. It is further distinguished by its floristic composition, which is less dominated by Pterocarpus lucens, and by the absence of Loudetia togoensis, the dominant grass of laterite soils to the south. A low tree stratum (5 to 6 m) is composed of Pterocarpus lucens, Combretum glutinosum, Balanites aegyptiaca and widely scattered Adansonia digitata. Small trees and shrubs make up the majority of the woody biomass: Pterocarpus lucens, Combretum glutinosum, Guiera senegalensis, Boscia senegalensis, Commiphora africana (all common), and such less common associates as Feretia apodanthera, Grewia bicolor, Acacia senegal, Combretum aculeatum and Balanites aegyptiaca. The most common grasses include Schoenefeldia gracilis, Aristida adscensionis, Eragrostis sp. and Pennisetum pedicellatum. This composition may vary from year to year depending on the grazing pressure, fire and rainfall.

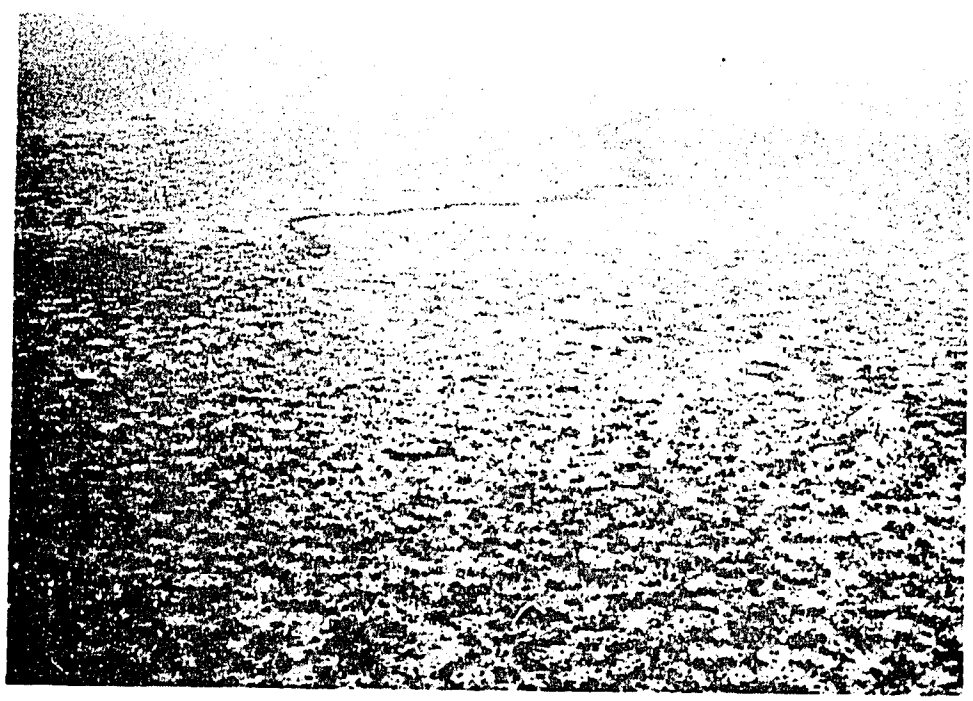


Fig.5.27. An aerial view of the Pterocarpus lucens-dominated shrub savanna of the lateritic Ferlo in the vicinity of Revane. Note the heavily wooded fossil valley and the patchy nature of the cover, a result of small depressions and defunct termite mounds. Altitude 600 m; August 8, 1984.

These grazing lands are of mediocre quality: they are limited by shallow, gravelly soils and a lack of soil moisture during the long dry period.

Unit Vc6 occurs on slopes between the Ferlo Plateau and the Senegal River Valley in the vicinity of Thilogne. It is physiognomically an open shrub savanna, floristically poorer than V6, in which Balanites aegyptiaca becomes dominant as one progresses east. Most of the associates listed above disappear, while Zizyphus mauritiana and Guiera senegalensis remain. The herbaceous composition is essentially that of V6, though species associated with cultivated fields are common (Eragrostis tremula in particular).

Unit Vcm13

The mid to upper portion of the Ferlo valley differs from the lower portions, mainly by a mosaic of hundreds of depressions in the valley floor which support dense communities of mesophytes and hydrophytes. This unit lies between Loumbel Lana and Ranérou. Overall, the vegetation of the valley floor and slopes is an open shrub savanna dominated by Combretum glutinosum and characteristic tree species: Acacia seyal on clayey slopes and Pterocarpus lucens on shallow soils with a gravelly layer near the surface. Associate shrub species include Acacia seyal, Dichrostachys glomerata, Combretum aculeatum, Zizyphus mauritiana and Boscia senegalensis. The composition on the hydromorphic soils within the valley floor depressions is quite different and includes such trees as Anogeissus leiocarpus and Mitragyna inermis and shrubs commonly found with termite mounds: Combretum micranthum, Feretia apodanthera and Grewia bicolor. The ensemble of woody species often produces dense formations that range from a savanna-woodland to a woodland.

The herbaceous stratum is quite poor, qualitatively and quantitatively (Valenza and Diallo, 1972). Panicum sp., Aristida adscensionis and Chloris sp. are common on the clayey slopes, while Andropogon pinguipes and Pennisetum pedicellatum occur in the shady, wooded areas.

Unit VS1

This extensive shrub and tree savanna occurs to the north of Tiel, and includes the Réserve Sylvo-Pastorale d'Oldou Déïokol, the R.S.P. de Linde Sud and the Forêt de Linde Est. Ferruginous soils have developed on attenuated continental dunes (in the west) and from underlying sandstones (to the east). As the sandy horizons disappear, this unit gives way to the cover types of the lateritic Ferlo to the east. Included in the Sahelo-Sudanian domain, the trees of this unit become larger (6 to 8 m tall) and more numerous in response to the higher annual rainfall (relative to the Sahelian cover types). The overall aspect of the woody strata is Sahelian: Balanites aegyptiaca and Combretum glutinosum co-dominate with the associates Sclerocarya

birrea (on clayey sands), Acacia raddiana (in the sandier northwest), and such Sudanian species as Sterculia setigera and Adansonia digitata are also present.

The small trees and shrubs form a denser cover (15% average) than the trees, dominated by the ubiquitous Guiera senegalensis, with other obiquitous species, such as Balanites aegyptiaca and Combretum glutinosum. Characteristic species include Combretum micranthum, Grewia bicolor, Acacia seyal and Acacia ataxacantha (on sandy clays and clayey soils). The herbaceous cover consists commonly of Cenchrus biflorus (in the sandier northwest) and Schoenefeldia gracilis, Andropogon pseudapricus and Eragrostis tremula on abandoned fields. Zornia glochidiata, Tephrosia linearis and Cassia obtusifolia are the main forbs.

These grazing lands are of good quality, though the annuals disappear quickly during the dry season. This area is prone to bush fires.

Unit VS2

This shrub and tree savanna occurs to the south of the preceding unit, covering much of the Reserve Sylvo-Pastorale de Doli, the R.S.P. de Sab-Sabré and the R.S.P. de Bem-Bem. This cover type takes on a more Sudanian appearance, with trees becoming more numerous. In the west, the soils have evolved from Quaternary, eolian sand deposits, with a transition toward clayey sands and clayey soils to the east. Sahelian species which occur in this unit are at the southern limit of their range, such as Acacia senegal, Boscia senegalensis, Commiphora africana and Grewia bicolor, while Sudanian species become quite common. The ground cover of the tree layer is about 3 to 5%, averaging 6 to 8 m in height. The dominants on sandy dior soils are Combretum glutinosum, Sterculia setigera and Balanites aegyptiaca, with scattered Adansonia digitata. Depressions forming temporary ponds are dominated by Mitragyna inermis, Anogeissus leiocarpus and Acacia seyal. On clayey sands and clayey soils to the east Balanites aegyptiaca disappears and new associates appear, including Bombax costatum (highly characteristic of the Sudanian zone), Lannea acida, Sclerocarya birrea and Anogeissus leiocarpus.

The shrub layer is denser than the tree layer (10 to 20% cover), with Guiera senegalensis, Combretum glutinosum and Grewia bicolor (dominants throughout). Associates on dior soils, include Balanites aegyptiaca, Dichrostachys glomerata and Acacia senegal. On the shallower soils to the east associates include Combretum nigricans, Combretum micranthum, Feretia apodanthera, Boscia senegalensis, Acacia macrostachya and Adenium obesum. Common grasses throughout include Schoenefeldia gracilis, Dactyloctenium aegyptium, with Eragrostis tremula on dior soils and Andropogon amplectens and Andropogon gayanus to the east.

The main land use activity is the grazing of livestock, which has become more intensive in recent years as Peul and Maure herders migrate south from the depleted Sahelian pastures. Particularly on the sandier soils the rangeland is of good quality, though it is prone to fire, which destroys the annual vegetation.

Unit VSm3

This is a variant of VS1, differing mainly by the numerous interdunal depressions which support a relatively dense woody cover. Species commonly associated with these hydromorphic depressions include Dalbergia melanoxylon, Mitragyna inermis (dominant small trees and shrubs), Zizyphus mauritiana, Boscia senegalensis, Combretum micranthum and Acacia ataxacantha. The herbaceous cover is commonly composed of Schoenefeldia gracilis, Digitaria lecardii, Cassia obtusifolia and Zornia glochidiata. This cover is discontinuous and short, but, since it emerges before the upland vegetation, it is an important source of forage after the first rains of the season.

The slopes and higher terrain support vegetation which is essentially the same as that of unit VS1.

Unit VS4

This unit is located between Fadiara and Orkadiere on the gentle slopes between the Senegal River Valley and the Ferlo plateau. This shrub and tree pseudo-steppe formation occurs on subarid, sandy, brown soils that have good potential for supporting relatively continuous, dense herbaceous vegetation. The composition is floristically poor since this area has often been cleared for cultivation. Combretum glutinosum and Balanites aegyptiaca make up nearly the entire woody strata, with occasional Sterculia setigera and Sclerocarya birrea (remnants of the former climax savanna-woodland). The few associate shrub species include Piliostigma reticulatum, Acacia seyal, Zizyphus mauritiana and Guiera senegalensis. Annuals are commonly found on sandy, abandoned fields: Eragrostis tremula, Cenchrus biflorus, Schoenefeldia gracilis, Zornia glochidiata, Alysicarpus ovalifolius, Tribulus terrestris, Sclerocarpus africanus and others. Even during the dry season, this herbaceous association constitutes one of the best rangelands along the Senegal River Valley. The vigor of this cover type is readily apparent on Landsat imagery.

Unit VSc9

This cover type is a variant of unit VS2; it is distinguished by the presence of cultivated fields and fallow lands, that occur along the Mboune fossil valley in the vicinity of Vélingara. The vegetation constitutes an open shrub and tree savanna found on clayey-sandy colluvial soils on valley slopes. Balanites aegyptiaca predominates since it reseeds quickly after clearing. Associates include Combretum glutinosum (an invader of old fields), Anogeissus leiocarpus, Adansonia

digitata, Tamarindus indica and Diospyros mespiliformis (tree layer). The small trees and shrubs include Acacia senegal and Piliostigma reticulatum (very common), Zizyphus mauritiana, Feretia apodanthera, Acacia seyal, with Acacia ataxacantha, Combretum micranthum and Grewia bicolor on acitive and inactive termite mounts.

Annuals such as Eragrostis tremula and Schoenefeldia gracilis and perennials such as Andropogon ssp. grow on the poor, erosion-prone soils. Overgrazing usually occurs in the fallow fields as a result of the proximity of this area to permanent settlements and water wells.

Unit VS17

This cover type is restricted to the numerous fossil valleys that dissect the lateritic Ferlo within the Sahelo-Sudanian domain. The often eroded, clayey, hydromorphic soils along the slopes of these valleys support a shrub and tree savanna (Fig. 5.28). The valley bottoms, however, are densely wooded with tree savannas, savanna-woodlands, or even woodland formations. The woody strata are dominated by Balanites aegyptiaca, Acacia seyal, Combretum glutinosum and Anogeissus leiocarpus, with numerous associates of both Sahelian and Sudanian origin: Boscia senegalensis, Pterocarpus lucens, Acacia senegal and Zizyphus mauritiana are the most common. Others include Piliostigma reticulatum, Guiera senegalensis, Feretia apodanthera and Dicrostachys glomerata.

The herbaceous cover is dominated by Schoenefeldia gracilis, Chloris prieurii and Elionurus elegans, with Zornia glochidiata being the most common forb. Other associates include Indigofera ssp. and Borreria stachydea.

This rangeland is in various stages of degradation. The eroded slopes are particularly poor. The herbaceous cover can be discontinuous, growing in small patches. The main source of forage is found in the understory of the wooded valley bottoms. The extent of grass cover varies considerably depending on the topographic position and soils. These are mainly wet season grazing lands.

Unit VSc18

This cover type occurs within the same physiographic environment as the previous unit (VS17), but the more discontinuous vegetation grows on highly eroded, poorly evolved soils. The floristic composition is somewhat poorer, with hardier Sahelian species prevailing. The dominants of the tree layer are Combretum glutinosum, Adansonia digitata and Balanites aegyptiaca, with Sclerocarya birrea, Acacia seyal, Acacia senegal and Anogeissus leiocarpus being common associates. The small trees and shrubs consist of Balanites aegyptiaca, Acacia senegal, Combretum glutinosum, Guiera senegalensis and Grewia bicolor (all common), with Acacia seyal, Boscia senegalensis, Combretum micranthum and Feretia apodanthera (fairly

common). Mitragyna inermis is a characteristic hydrophyte, as is Anogeissus leiocarpus.

Growing in discontinuous patches, annuals tend to predominate on the slopes. They include Eragrostis tremula, Schoenefeldia gracilis, Cenchrus biflorus and Dactyloctenium aegyptium. Perennials, such as Andropogon pseudapricus, are found on the valley floor.

These grazing lands are in a more advanced state of degradation than those of the previous unit. Concentrated along the valley bottoms, the forage is usually grazed throughout the summer wet season.

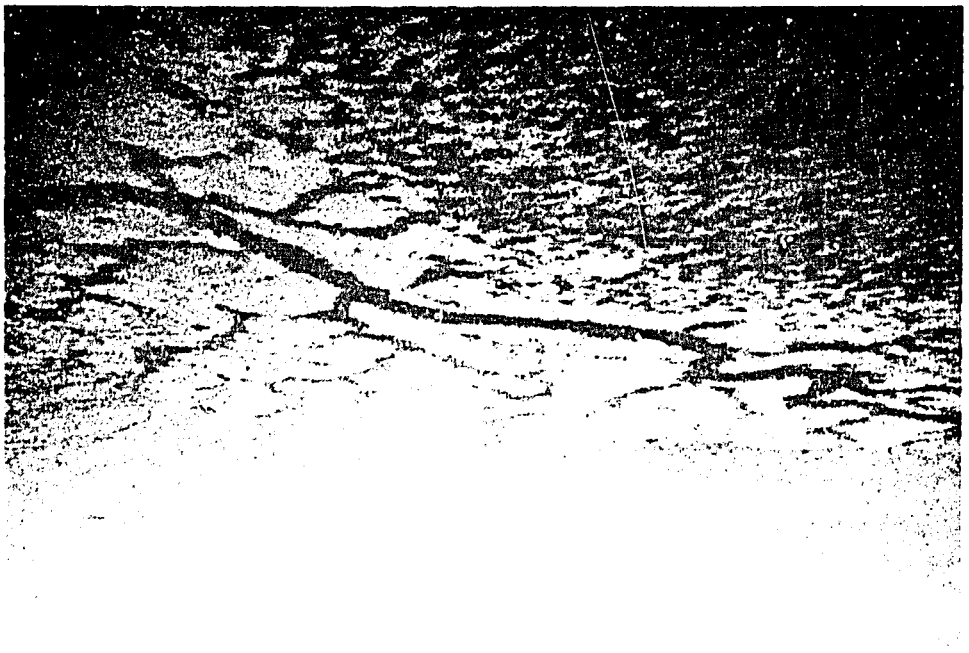


Fig.5.28. Densely wooded channels within a fossil valley of the lateritic Ferlo, east of Mboule. Unit VS17; altitude 600 m; August 8, 1984.

Unit VS19

This cover type is a mosaic of units A9 and VSc18. Like unit VSc18, it is a fossil valley (near Matam) where hydromorphic soils overlie gravelly soils along the valley floor and the valley slopes are highly eroded. While the narrow strip of vegetation on the valley floor is essentially that of unit VSc18, the degraded slope community is that of unit A9 (a discontinuous shrub steppe, with scattered cultivated areas).

The grazing lands are inadequate on the eroded, poorly evolved slope soils, where annuals grow in scattered patches. The herbaceous cover along the valley floor tends to emerge before the upland cover, providing an early source of forage in June and July.

Unit SB5

This cover type occurs within the same physiographic setting as units VS17 and VSc18 and is associated with the laterite plateau, cover type V6. The cover type of these fossil valleys tends to form in denser stands along the valley bed, often consisting of a savanna-woodland, or even denser formations, such as woodlands and thickets. The slopes are less eroded than those of the preceding three cover types, with recent sand deposits occurring over the underlying gravels.

The woody species of the floristically rich valley floor are usually mesophytes and hydrophytes: Anogeissus leiocarpus, Mitragyna inermis, Piliostigma reticulatum, Adansonia digitata and Acacia seyal (trees) and Zizyphus mucronata, Acacia ataxacantha, Commiphora africana, Zizyphus mauritiana, Boscia senegalensis, Combretum glutinosum, Cadaba farinosa, Feretia apodanthera, Stereospermum kunthianum, Grewia bicolor, Combretum micranthum, Balanites aegyptiaca, Dicrostachys glomerata, Acacia senegal and others.

The herbaceous cover is generally poor (qualitatively and quantitatively) with such annual grasses as Pennisetum pedicellatum, Schoenefeldia gracilis, Digitaria lecardii and Eragrostis tremula (on sandy soils) and a few perennials: Andropogon pinguipes and Andropogon ssp.

Unit F1

This acacia woodland is a unique formation on the diéri, the gentle slopes and plateau along the Senegal River Valley above the floodplain (northern Ferlo). This woodland appears to be a relic of a once extensive formation that bordered the valley. Acacia nilotica and Acacia raddiana co-dominate, with the former on the lower, hydromorphic soils. The few woody associates include Balanites aegyptiaca, Zizyphus mauritiana and Acacia senegal. Little or no understory was found, though this may be a result of the drought and overgrazing.

Because trees are cut for firewood and construction, the acacia are being succeeded by the hardy invader Balanites aegyptiaca.

5.4.2 The Sudanian Phytogeographic Region

Lying to the south of the Sahelian, the Sudanian Phytogeographic Region is the domain of the savanna, the savanna-woodland and the dry woodland. It predominates between the 700 and 1500 mm isohyets and is centered on the 900 to 1200 mm isohyets (Adam, 1966). Within Senegal, this region corresponds to a broad area south of a line running from just north of Mbour to just north of Bakel and north of a line defined approximately by the lower Casamance River (see Map 5.2). J.G. Adam (1966) further divides the Sudanian Region into three domains: the Sudano-Sahelian Domain (transitional, lying between the 700 and 900 mm isohyets), the central Sudanian Domain and the Sudano-Guinean Domain (transitional, between the 1200 and 1500 mm isohyets).

The Sudanian Region, which covers nearly two-thirds of Senegal, is characterized by rainfall spread over 5 to 6 months, of which July, August and September are nearly certain to have rain. Like the Sahelian Region, the rains occur during the high sun, summer months (June to October). While the Sudanian Region is often defined by average annual rainfall, other criteria should also be considered. A. Aubreville (1938) identifies 80 woodland species as being specific to this region. Sahelian species that extend into the Sudano-Sahelian domain disappear as one progresses into the central Sudanian domain. They include Acacia senegal, Balanites aegyptiaca, Boscia senegalensis, Commiphora africana and Grewia bicolor. The short, annual grasses in the steppes and savannas of the Sahelian Region are gradually replaced by tall, perennial grass savannas composed mainly of the Andropogoneae tribe. These savannas almost always have a woody component (trees, woodlands, etc.). To the south of the 900 mm isohyet, typically Sudanian species dominate, with such trees as Cassia sieberiana, Daniellia oliveri, Oxytenanthera abyssinica, Khaya senegalensis and Terminalia macroptera (Giffard, 1974).

According to J. Trochain (1940), the former climax vegetation of the Sudano-Sahelian Domain was likely a xerophytic tree savanna in which species of the Sudano-Guinean Domain are absent. Today, none of the wooded formations reflect this climax. Human occupation has greatly modified vegetation composition and structure, particularly in the Groundnut Basin. In the east, including much of Senegal Oriental, human pressure is less intense, but fire plays a major role in modifying the vegetation. Although many tree and herbaceous species of the initial climax vegetation remain, many have disappeared. J. Trochain

considers the present Sudano-Sahelian vegetation to be a series of tree savanna pseudo-climaxes dominated by the Combretaceae family on sandy soils and Acacia seyal dominated savanna-woodlands on clayey soils. These two vegetation ensembles are not always clearly separated since many edaphic, geological, climatological and human variations occur which continuously influence the vegetation formations and their floristic composition.

To the south of the 14th parallel, the savanna-woodland and woodland formations of the central Sudanian and Sudano-Guinean domains replace the more open tree savannas of the Sudano-Sahelian Zone. The transition is gradual and difficult to define. The southern boundary of this zone gives way to the Guinean Region, which is characterized by even denser forest formations.

The current secondary formations, from the open tree savanna to the dense, dry forest, represent various stages of degradation of the original dry Sudanian forest. The main characteristics of the derived formations are their decreasing tree density; the Combretaceae-dominated understory; and a continuous, tall-grass savanna.

The Sudanian and Sudano-Guinean formations tend to be more homogeneous both physiognomically and floristically than those to the north. While it is true that differences in rainfall, edaphic and hydrologic influences and human activity introduce numerous nuances in the composition and distribution of the vegetation associations, the same original forest formations with the same Guinean flora infiltrations once covered this vast region. The present landscape of the plains and plateaus is uniformly covered by the dry Sudanian woodland formations (Pélissier, 1966). The relative monotony of these formations can be explained to some extent by their botanical complexity, which derives from a floristically rich composition. On the basis of his detailed field observations, J. Trochain (1940) concluded that no one tree species presently dominates this zone. If one species appears to prevail over others in a given area, it is often replaced by another in an adjacent area despite the apparent similarity of ecological conditions. J. Trochain found it difficult to define the "elementary woody groupings", and concludes that "the Sudano-Guinean savanna-woodland constitutes a vegetation community of very extensive dimensions, nondivisible into smaller units". In brief, the extremely heterogeneous composition of the associations observed in the field is related to the uniform structure of the vegegation landscape (Pelissier, 1966). From the tree savanna to the dry, dense woodlands, the floristic composition remains remarkably constant regardless of the density of the formation. Unlike the rainforests of Equatorial Africa and the coastal forests of the Basse Casamance, the difference in the floristic composition of the "primary" associations and that of the secondary, contemporary associations is small.

Most of the contemporary natural formations can be considered a fire-climax. Both natural and man-induced fires sweep through 80% or more of the Sudanian woodlands each year, keeping the understory relatively open and modifying the floristic composition in favor of more fire-resistant species. A. Aubreville (1949) postulates that the advent of the bush fire and the clearing of land have both led to the creation of the savanna at the expense of the Sudanian woodland. The grasses which now replace the former forest understory were once limited to river banks, alluvial soils, rocky summits, rock outcrops, etc.

The plains and plateaus of the Sudanian Region are dissected by numerous shallow valleys whose diverse and rich vegetation associations break the monotony of the dry upland forests. Many of the hydrophytic species found in these valleys are typical of the Guinean Region, since favorable soil moisture conditions allow them to survive the relatively dry Sudanian climate.

Several azonal formations occur within this broad region, particularly along the coast, among the estuaries of the Saloum River and along the Gambia River. Another azonal formation is found on the bowé, where laterite surfaces form a hardened, nearly impenetrable layer, which because it severely restricts root growth produces very open formations scattered throughout southeastern Senegal.

Four distinct ecogeographical environments can be identified within the Sudanian Region of Senegal (Schéma national d'aménagement du territoire, 1984). One of them, the west-central agricultural domain, occurs in both the Sahelian and Sudanian regions and has been described under the section on the Sahel. The remaining three are the eastern transition zone, the region of the shield, and the Casamance. The cover types on the accompanying vegetation map "Carte du Couvert Végétal" and land use map "Carte de l'Occupation/Utilisation du Sol" will be described below by ecogeographic environment.

5.4.2.1 The West-Central Agricultural Domain (Sudanian)

A. General Characteristics

This section is devoted to the part of the Groundnut Basin that lies within the Sudanian Region, i.e., to the south of a line running approximately from north of Mbour to Gossas and Mbar. It includes all of the Sine Saloum, the zone of agricultural expansion to the east and the azonal formations of the Saloum estuaries.

As mentioned earlier, the transition from the Sahelian to the Sudanian vegetation associations is gradual, almost imperceptible. Nevertheless, characteristics of the Sudanian vegetation become more evident as one progresses into the southern half of this agricultural zone. More reliable rainfall, decreasing cover of Quaternary sand deposits and shallower water tables moderate the dry season and prolong

the vegetative cycle beyond the last rains (Pélissier, 1966).

Like the northern half of this agricultural zone, the southern part is made up of an anthropogenic tree and shrub savanna with few traces of the original woodland. The few remaining stands indicate that this woodland was dominated by a number of trees of Sudanian affinity, including Khaya senegalensis, Pterocarpus erinaceus, Anogeissus leiocarpus, Adansonia digitata, Cordyla pinnata and Parkia biglobosa (Pelissier, 1966). The understory was probably dominated by Combretum glutinosum and Acacia seyal, two small trees which have replaced the forest after its destruction by fire and clearing for cultivation.

The eastern portion of this zone forms a mosaic of recently cleared agricultural areas and secondary dry woodlands (in the Department of Kaffrine). As one progresses eastward into the eastern transition zone, the dry woodlands become increasingly extensive. There the pioneer colonization of the Terres Neuves, or new lands, occupies less than 10% of the land area. The dry woodlands, which are now usually confined to the marginal upland soils, still reflect the heterogeneous composition of the Sudanian climax forests. Nevertheless, the fires that sweep these savanna-woodlands every dry season have thinned out the tree stratum.

As defined by its geomorphology, the estuarial zone of the Saloum River is included as a subzone in this ecogeographical environment. The Saloum River and its major affluent, the Sine River, are sluggish streams feeding into an extensive tidal swamp with scattered salt flats that is colonized by a dense mangrove community. The incursion of sea water and the presence of saline soils precludes the establishment of agriculture.

B. Cover Types

Unit V11

This unit, a highly degraded formation, consists of a shrub savanna between Kaolack and Guinguinéo. It is a variant of unit VdS12 (to the north and east), differing by its very low tree density. The few trees that have been spared are mainly Cordyla pinnata and Adansonia digitata, with such scattered associates as Balanites aegyptiaca, Tamarindus indica, and Anogeissus leiocarpus and Mitragyna inermis in slight depressions on the relatively flat landscape. The shrub layer, which dominates fallow and abandoned fields, is predominated by Guiera senegalensis and Piliostigma reticulatum. The few Sahelian and Sudanian associates include Heeria insignis, Icacina senegalensis, Grewia bicolor, Zizyphus mauritiana and Combretum glutinosum. The principle grasses are Eragrostis tremula, Cenchrus biflorus and Schizachyrium exile. Common forbs include Mitracarpus scaber, Cassia obtusifolia (in slight depressions), Hibiscus asper and Zornia glochidiata.

Sandy soils low in organic content support mediocre rangeland useful only during and shortly after the rainy season.

Unit Vd12

Occurring northeast of Kaffrine, this variant of Unit VdS12 is distinguished by a relatively dense shrub savanna, less intensive use of the land for cultivation, and heavier, clayey soils derived from sandstones of the "Continental Terminal". The floristic composition is similar to that of the southern portion of unit VdS12, except that the density of the woody stratum is higher--(15 to 20%)--and is mainly composed of small trees and shrubs.

This unit is a degraded form of the shrub and tree savanna of the pastoral domain to the east and acts as a transition between the formation to the east and the anthropogenic shrub and tree savanna of the Groundnut Basin. The land use is split between grazing and cultivating millet, sorghum and groundnuts.

Unit VS11

Lying to the east of the mangrove formation of Joal-Fadiout, this unit is found on gently rolling, sand deposits of the interior, attenuated dunes. Physiognomically, this formation consists of a shrub and tree savanna, with palm groves occurring in the low-lying areas (particularly in the Joal and Samba Dia forest preserves). The characteristic tree of this unit is Borassus aethiopium, or rhun palm, native to the Sudanian region and widely used for construction and weaving and whose sap is extracted for making palm wine. Adansonia digitata, also native to the region, is quite common. Associates include Parinari macrophylla, Ficus gnaphalocarpa, with Acacia albida and Acacia seyal in the northern part of the unit. The localized palm groves can be quite dense, with ground cover up to 50%. The dominant shrub species are Piliostigma reticulatum, Acacia senegal, Guiera senegalensis and Combretum glutinosum. The common herbaceous species include Aristida stipoides, Aristida adscensionis, Cassia obtusifolia and Alysicarpus ovalifolius.

Cultivation of millet and groundnuts is the main land use. The rangeland is mediocre to good in fallow and old fields.

Unit VdS12

Representing an area of relatively recent agricultural expansion (1910 to 1940), this large cover type occurs over much of the eastern Groundnut Basin. It extends well into the Sahelo-Sudanian zone (east of Mbaké and Touba), as well as falling into the Sudano-Sahelian zone (north of Kaffrine). Like unit S2, this unit takes on a Sahelian aspect to the north and is gradually modified to the south by Sudanian characteristics. With further field work, this unit could probably be divided into two subunits.

The sandy soils have developed from attenuated continental dunes. Numerous depressions occur, often parallel to the longitudinal dunes.

One of the main features distinguishing this unit from S2 (to the west) is the near absence of Acacia albida, which is widespread in the central Groundnut Basin. Furthermore, fields tend to be larger, and cultivation is less intensive with a greater density of fallow fields and old fields. This pattern of land use has resulted in a denser shrub cover which produces an anthropogenic shrub and tree savanna.

The Sahelo-Sudanian sector of the unit is co-dominated by Combretum glutinosum and Balanites aegyptiaca, both small trees (5-6 m tall); associates are Adansonia digitata, Prosopis africanus and Acacia raddiana (extreme north). In the Sudano-Sahelian sector, Combretum glutinosum remains ubiquitous, with the characteristic dominants being Sterculia setigera and Cordyla pinnata. Associates include Anogeissus leiocarpus (in depressions), Adansonia digitata, Pterocarpus erinaceus and Sclerocarya birrea. The shrub stratum consists mainly of Guiera senegalensis and Combretum glutinosum, ubiquitous throughout. Characteristic associates in the northern part include Balanites aegyptiaca and Feretia apodanthera; Zizyphus mauritiana and Piliostigma reticulatum are present throughout, while the southern associates include Heeria insignis, Acacia seyal (in lower areas), Grewia bicolor and Dicrostachys glomerata.

The overall tree height is 6 to 8 m, with an average cover of 1 to 2%. The shrub height averages 1 m, with a cover of 10 to 20% in fallow and old fields. Shrub cover in cultivated fields is generally minimal.

During the rainy season, the grasses and forbs form a fairly continuous cover in uncultivated fields, though they are interrupted by termite mounds. The most common grasses are Eragrostis tremula, Schizachyrium exile, Pennisetum pedicellatum and Andropogon gayanus. Common forbs include Mitracarpus scaber, Cassia obtusifolia, Hibiscus asper, Zornia glochidiata, Borreria chaetocephala, Indigofera astragalina, Tephrosia linearis and Corchorus tridens. The rangeland is for the most part protected from fire by the mosaic of cultivated fields. Millet, sorghum and groundnuts are the principle crops.

Unit VS13

This anthropogenic shrub and tree savanna is a variant of the formation covering much of the western Sine Saloum region. It is located to the south of Kaffrine and Birkelane and has been cultivated (mainly groundnuts) since the end of the nineteenth century. The extensive Sudanian woodland has practically disappeared from this unit; some of the older scattered trees preserved in the fields may be remnants of this woodland. This unit differs from unit VS15 to the west through more intensive cultivation and the marked presence of Sterculia setigera (characteristic of the Sudanian Region). Cordyla pinnata and Sterculia setigera co-dominate; both are selectively

preserved for their food and commercial value. Common associates are Tamarindus indica, Sclerocarya birrea and Lannea acida. Bombax costatum is present at its western most area of distribution. The shrub layer which invades the fields is predominantly composed of Combretum glutinosum and Heeria insignis, with Acacia macrostachya, Guiera senegalensis, Terminalia avicennoides and Hexalobus monopetalus as the principle associates. The grasses include Schizachyrium exile, Pennisetum pedicellatum and Andropogon gayanus. Common forbs are Borreria chaetocephala, Tephrosia linearis, Cassia obtusifolia and Indigofera astragalina.

Unit VS14

This unit represents the eastern expansion of the Groundnut Basin into the savanna-woodlands of the pastoral domain, in the eastern Saloum region. Most of this agricultural expansion has occurred since 1940; the most favorable conditions for farming occur along the low, wide valleys, where hydromorphic and sandy soils occur.

The cropland is similar in character to that of the middle Saloum Region, though Cordyla pinnata, dominant tree of the middle Saloum, gives way to Bombax costatum and Sterculia setigera, which co-dominate. Associates include Lannea acida, Pterocarpus erinaceus, Sclerocarya birrea, Adansonia digitata, Prosopis africanus, Ficus ssp. and Combretum glutinosum.

The most common shrub invaders are Guiera senegalensis and Combretum glutinosum, with numerous associates also commonly found in the surrounding woodlands: Piliostigma reticulatum, Zizyphus mauritiana, Acacia macrostachya, Gardenia triacantha, Heeria insignis, Strophanthus sarmentosus, Strychnos spinosa, Feretia apodanthera, Ximenia americana, Dicrostachys glomerata, Hexalobus monopetalus and other less common associates.

In the fallow and old fields, the grass cover is dominated by Pennisetum pedicellatum, Schoenefeldia gracilis, Schizachyrium exile, Andropogon gayanus and Andropogon amplectens. Common forbs include Cassia obtusifolia, Indigofera astragalina, Asparagus africanus and Borreria chaetocephala. Grass cover is generally minimal or absent in cultivated fields.

This agricultural unit penetrates well into the pastoral zone, which is inhabited by more or less sedentary Peul whose cattle herds modify the herbaceous cover through overgrazing and trampling. Annuals invade, replacing the Andropogoneae perennials. The grazing lands are generally of good quality, with forage in the fallow fields lasting well into the dry season (fire is relatively rare in this unit).

Unit VS15

This is the predominant unit of the central Sine Saloum Region, located between the Saloum and the Gambia rivers. The vegetation consists of an anthropogenic shrub and tree savanna (Fig. 5.29) marked by the preponderance of Cordyla pinnata, remnant of the once extensive Sudanian woodland that covered this region until the mid to late 1800's. Today, only a few protected woodlands remain (Foret de Fathala, F. de Bara, F. de Djilor, F. de Ngayene, etc.). Physiographically, this area is a low, nearly level plain with poorly evolved sandy soils developed from dune deposits over sand.

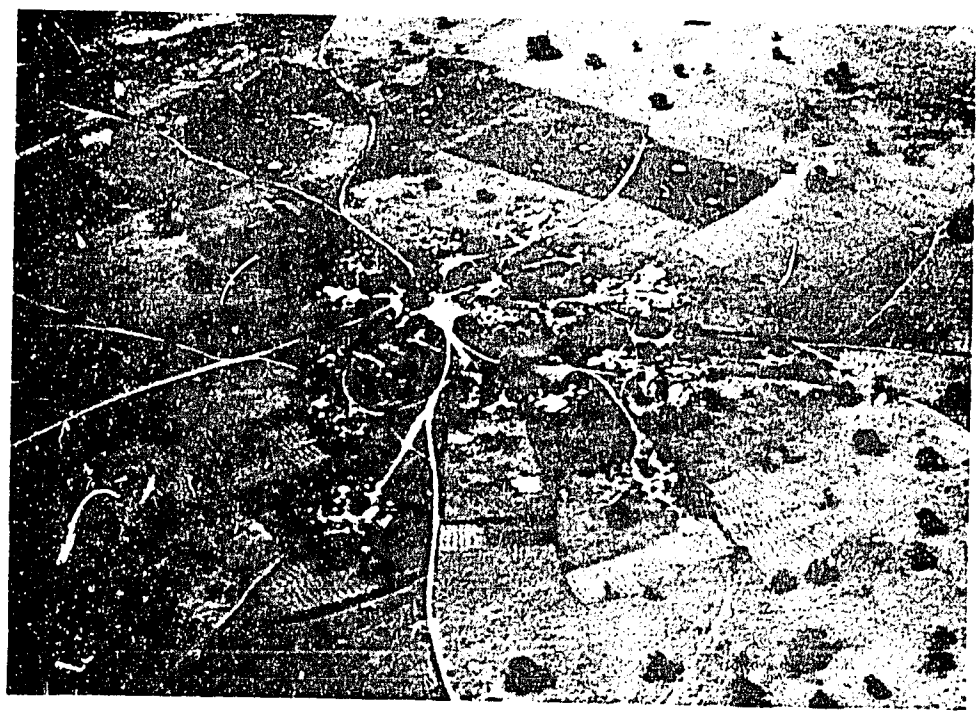


Fig. 5.29. An aerial view of the groundnut-millet-cotton growing region south of Nioro du Rip. Unit VS15; altitude 600 m; Sept. 17, 1984.

The tree stratum is widely scattered among the fields, with ground cover ranging from 1 to 5% and has an average height of 8 to 10 m. Tree density was estimated at 3 to 5 individuals per ha. Cordyla pinnata dominants, with the most common associates being Anogeissus leiocarpus and Pterocarpus erinaceus. Sterculia setigera becomes more common to the east, as does Bombax costatum. Several members of the fig tree family (Moraceae) are generally found near villages, particularly Ficus glumosa, Ficus platyphylla and Ficus gnaphalocarpa, which provides edible fruit. Less common associates include Prosopis africanus, Sclerocarya birrea, Lannea acida, Parkia biglobosa and

Tamarindus indica.

The shrub layer, which has an average height of 1 to 2 m, can become quite dense in old fields, with ground cover up to 30%. Combretum glutinosum is ubiquitous, as it is throughout most of the deforested Sudanian landscapes. Common characteristic species are Heeria insignis (common invader of fallow fields in the Sudanian region), Acacia macrostachya (characteristic of Sudanian shrub woodlands), Dicrostachys glomerata (found on a variety of soils) and Securidaca longipedunculata (also native to Sudanian dry woodlands). Guiera senegalensis, a ubiquitous invader of exhausted sandy soils, is also common. Less common associates include Piliostigma reticulatum, Feretia apodanthera, Zizyphus mauritiana, Cassia sieberiana and Annona senegalensis.

During the rainy season, the herbaceous stratum forms a continuous cover over the fallow and old fields. These fields are seldom left idle long enough for the Andropogoneae grasses to dominate. Nevertheless, Andropogon gayanus is common. Pennisetum pedicellatum co-dominates with Eragrostis tremula. The most common forbs include Hibiscus asper, Mitracarpus scaber, Cassia obtusifolia, Tephrosia linearis, Borreria chaetocephola, Indigofera astragalina and Zornia glochidiata.

The predominant land use is the cultivation of groundnuts (main cash crop), millet (main staple crop) and cotton to the south and east (introduced in the 1960's).

Units VS16 and VdS16

These cover types form the eastern extension of the Groundnut Basin into the savanna-woodlands of the eastern Sine Saloum region and into the Department of Toubacounda. This area is characterized by a mosaic of low, wide valleys, generally occupied by these two anthropogenic shrub and tree savannas; the plateaus are usually occupied by the remnants of a once extensive Sudanian dry woodland. Temporal analysis of the Landsat imagery indicates that units VS16 and VdS16 are rapidly expanding to the detriment of the upland savanna-woodland B5 (Figs. 5.30, 5.31 and 5.32).

Cordyla pinnata dominates as it does to the west; these cover types differ from unit VS15 to the west by the many associates that are nearly as numerous as Cordyla pinnata, particularly Sclerocarya birrea, Anogeissus leiocarpus, Sterculia setigera, Pterocarpus erinaceus, Bombax costatum and Combretum glutinosum. These species reflect the relatively rich composition of the Sudanian woodlands, where no one species dominates.

Fig. 5.30. A portion of a Landsat band 5 image covering much of the Dept. de Kaffrine. Agricultural lands (unit VS16), identified on this image by their mottled texture and lighter tones, are rapidly encroaching upon the savanna-woodlands (darker, more even texture). The Gambia River is visible at bottom center. Jan. 2, 1979; 1: 1 000 000 scale.

Combretum glutinosum is ubiquitous in the fallow and old fields. Common shrub associates are Acacia macrostachya, Piliostigma reticulatum, Zizyphus mauritiana and Dicrostachys glomerata. Less common associates are juvenile Sclerocarya birrea, Combretum micranthum and Grewia bicolor on termite mounds, Guiera senegalensis (less common towards the east), Heeria insignis, Feretia apodanthera, Terminalia macroptera, Combretum nigricans and Hexalobus monopetalus.

A relatively high herbaceous cover (50 cm to 1 m) develops in cover develops in the fallow fields. Composed of both annuals and perennials, it includes Panicum sp., Pennisetum pedicellatum, Schoenefeldia gracilis, Andropogon gayanus, Andropogon amplectens and Eragrostis tremula. Forbs constitute a large portion of the herbaceous cover, particularly Cassia obtusifolia, Hibiscus asper, Borreria chaetocephala, Sesbania pachycarpa, Tephrosia linearis, Asparagus africanus, Stylochiton hypogaeus and Crinum sp.

Figs. 5.31 and 5.32. A dry and wet season view of the agricultural lands in the Dept. de Kaffrine east of Koungheul. Cordyla pinnata is the dominant tree. From foreground to background the fields are fallow, groundnuts, and millet. Feb. 13, 1984 and Aug. 15, 1983.

The predominant land use is the cultivation of groundnuts, particularly toward the west, while millet, sorghum and cotton are grown toward the border of The Gambia. Herding livestock is also an important activity. The pastures are generally of good quality, with forage available through much of the dry season.

Unit S9

This unit occurs on hydromorphic brown soils and on calcium-rich soils east of Mbour. The vegetation forms an anthropogenic tree savanna like that of most of the Groundnut Basin. Acacia albida dominates as it does to the north; this unit is distinguished by the high density of Adansonia digitata and the presence of species commonly found on hydromorphic soils of depressions: Acacia seyal, Anogeissus leiocarpus, Borassus aethiopium and Diospyros mespiliformis.

The shrub and small tree stratum is dominated by the ubiquitous invader Guiera senegalensis, with characteristic associates including Piliostigma reticulatum, Combretum micranthum, Acacia seyal, Acacia senegal and Combretum aculeatum.

Most of the grasses are annuals, mainly Eragrostis tremula, Aristida adscensionis and Schoenefeldia gracilis, with the ubiquitous Cassia obtusifolia, Mitracarpus scaber on fallow fields; Alysicarpus ovalifolius and others are common on the heavier hydromorphic soils.

Millet and sorghum are the dominant crops, then groundnuts.

Unit Sc12

This unit occurs to the south of the Thiès plateau, in the vicinity of Mbour and Tasset Ouolof. The sandy ferruginous soils found in much of the northern Groundnut Basin overlie the marls and calcareous Eocene rocks which form a low plateau.

Quite degraded, the vegetation is characterized by an open anthropogenic tree savanna. Severe human pressure from the urban centers of Mbour and surrounding villages has nearly exhausted the woody resources. Essentially, only two species of trees have been spared: Adansonia digitata, which dominates on the calcareous soils and Acacia albida. The former owes its survival to the fact that its soft and spongy wood is generally useless, though uses for its bark, leaves and fruit are well known. Occasional associates include Sclerocarya birrea, Balanites aegyptiaca, Mangifera indica (grown around villages) and Tamarindus indica. The tree cover is less than 1%, overall, with 1 to 3 individuals per ha.

The shrub cover is somewhat denser (5 to 10%). It is dominated by Guiera senegalensis, and includes such associates as Combretum micranthum, Acacia seyal, Acacia senegal, Balanites aegyptiaca and Combretum glutinosum. Eragrostis tremula dominates on these sandy

soils, with numerous other annuals: Chloris prieurii, Aristida stipoides, Schizachyrium exile, Digitaria vellutina, Cenchrus biflorus. Forbs include Hibiscus asper, Indigofera ssp., Mitracarpus scaber and Cassia obtusifolia.

Fallow and old fields are quite numerous; the principal crops are groundnuts, millet and sorghum. Grazing pressure is quite heavy and has contributed to the openness of this savanna.

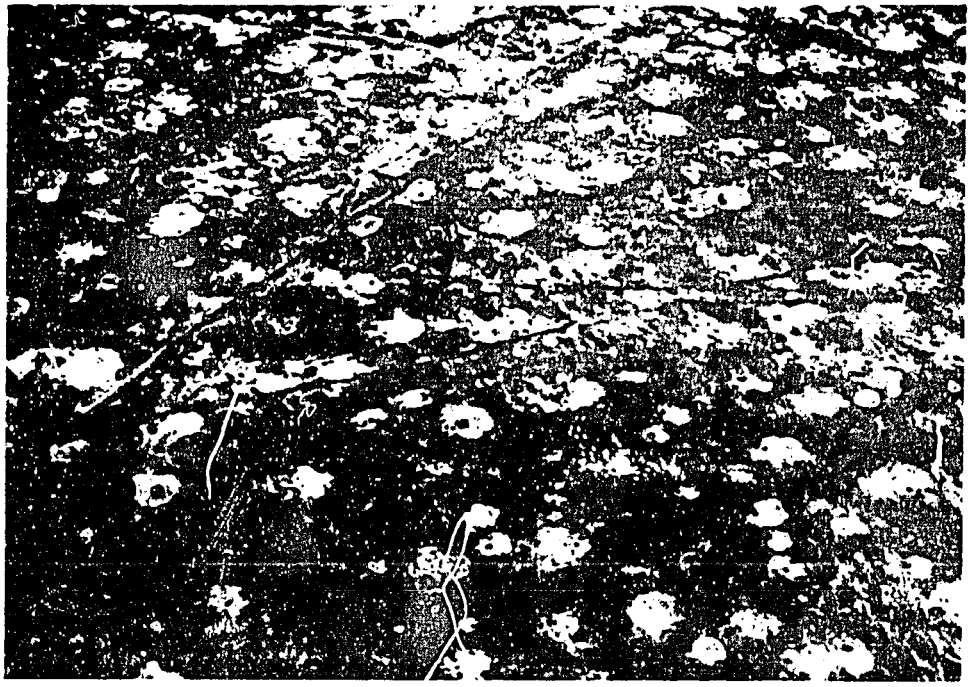


Fig. 5.33. The loss of potential cropland to termite mounds (both functional and defunct) is quite evident from the air. This area east of Mbour is presently used as rangeland. Note the several herds of cattle.

Unit Sd13

This relatively dense tree savanna is limited to two small areas northwest of Sandiara. The soils are similar to those of unit S9. Adansonia digitata dominates the tree stratum, with scattered Acacia albida and with Mangifera indica and Ficus gnaphalocarpa near the villages.

The shrub cover is relatively dense (10 to 20%), with a preponderance of Piliostigma reticulatum (typically Sudanian); Acacia albida (juvenile) and Acacia seyal are also both present. The herbaceous species are essentially those of unit S9.

The land use cover consists of numerous old fields on which the relatively dense shrub cover has matured. Millet is the principal crop.

Unit S14

This anthropogenic tree savanna occurs in the vicinity of Gandiaye, on sandy, ferruginous soils in a gently rolling topography. Numerous elongated depressions differentiate this unit from the main cover type of the Groundnut Basin, suitable for both mesophytes and hydrophytes. The upland vegetation is similar to that of unit S2: Acacia albida and Adansonia digitata co-dominate. Acacia seyal, however, dominates the depressions and often form thickets. The lower areas are also often colonized by Acacia ataxacantha, Tamarindus indica and Terminalia macroptera.

The grasses that grow throughout include Eragrostis tremula, Eragrostis ciliaris, Cenchrus biflorus and Aristida adscensionis. Cassia obtusifolia predominates in the depressions, while Mitracarpus scaber invades the sandy fields.

Particularly in recent years, the cultivation of millet and sorghum has exceeded groundnuts.

Unit ST

This cover type occupies the lower portion of the Tataguine to Khombole fossil valley. It consists of a mosaic of units S21 and T1; these cover types contain more detailed descriptions.

Unit SB4

This cover type, which occurs within the Saloum estuaries, is found on recent coastal deposits lying above the influence of the tide. The hydromorphic soils support a tree and woodland-savanna on the higher ground of these islands, surrounded by a herbaceous steppe on somewhat saline soils. Sudanian and even Guinean species of trees and shrubs colonize these high grounds. Here the most common trees of

Sudanian affinity are Prosopis africana, Terminalia macroptera, Adansonia digitata and Parinari macrophylla. Guinean species include Detarium senegalensis, Elaeis guineensis, Daniellia oliveri and Ceiba pentandra. The shrub stratum is dominated by Parinari macrophylla, with such associates as Maytenus senegalensis and Landolphia heudelotii.

The herbaceous cover is characterized by Schizachyrium compressum on the lower edges of the islands, with Chloris prieurii, Cenchrus biflorus and Aristida stipoides on the sandy uplands. Numerous leguminous forbs occur, including Tephrosia linearis, Indigofera ssp. and Alysicarpus ovalifolius.

This area is generally poor rangeland where grasses quickly lignify. Many of the species are undesirable for grazing.

Unit B3

This acacia savanna-woodland is confined mainly to the forets classees of Nianing and Balabougou, south of Mbour and occurs on vertisols that overlie marl deposits. These soils have favored the development of a near monoculture of Acacia seyal, sole dominant in these forest preserves. A few shrub species occur here, including Ximenia americana. During the rainy season, the grass cover is continuous, except where interrupted by termite mounds. Chloris robusta appears to dominate; other grasses include Aristida adscensionis and Chloris prieurii. Cassia obtusifolia is the main forb.

Although the grazing pressure is very heavy, this rangeland is only of mediocre quality. Many animals prefer the leaves and dry fruit of the Acacia seyal to the herbaceous cover that begins drying quickly in October.

Unit B4

These savanna-woodlands, which presently cover less than 20% of the western Sine Saloum region, are all that remain of the once extensive Sudanian dry woodland. Generally, these formations remain on hydromorphic soils and vertisols of the low plains and basins. They are not true representatives of the former climax woodland that once colonized the uplands, particularly since many of these formations have developed on abandoned fields.

Floristically, these savanna-woodlands are poorer than their counterparts to the east. The ubiquitous Combretum glutinosum dominates the tree and shrub strata. Common characteristic species are Sterculia setigera, Cordyla pinnata, Lannea acida and Anogeissus leiocarpus. Less common associates include Bombax costatum, Sclerocarya birrea and Acacia seyal (common in the lower areas). Chief shrub associates are Combretum nigricans, Heeria insignis (in degraded,

open areas), Guiera senegalensis, Dicrostachys glomerata, Feretia apodanthera, Acacia macrostachya, Securidaca longipedunculata, Acacia seyal and Anogeissus leiocarpus. The tree cover ranges from 20 to 40%, with heights of 6 to 8 m; the shrub cover ranges from 20 to 40%, with heights of 1 to 3 m.

The herbaceous cover is dominated by Andropogoneae, particularly Andropogon amplectens and Andropogon gayanus; Pennisetum pedicellatum is also common. Forbs include Borreria chaetocephala, Borreria stachydea, Cassia obtusifolia, Sida alba and Asparagus africanus.

Annual fires generally clear the herbaceous cover and consume a number of the shrub species. This rangeland is relatively poor.

Unit B6

Like the savanna-woodland of unit B4, this unit represents the few scattered remnants of a once extensive Sudanian dry woodland which lies in the extreme southwest part of the agricultural domain and extend into northwestern Gambia. These savanna-woodlands are less degraded than those of unit B4; they also receive slightly higher rainfall and the harshness of the dry season is somewhat moderated by the proximity of the ocean. The formations within the forests of Fathala, Sangalo, Patako, Baria and Saboya are well maintained, and large trees of Sudanian and Guinean affinity grow in densities approaching that of a dry woodland. The Fathala forest is also characterized by pseudo-galleries, formed of large sub-Guinean species that keep their leaves through the dry season. These relic gallery forests are among the northernmost of the African continent (Dupuy and Verschuren, 1982).

The characteristic trees are Khaya senegalensis, Cordyla pinnata, Bombax costatum, Pterocarpus erinaceus, Lannea acida, Combretum glutinosum. Less common associates are Hannoa undulata, Daniellia oliveri, Prosopis africanus, Detarium microcarpum, Adansonia digitata, Anogeissus leiocarpus and Ficus platyphylla.

The relatively rich shrub cover is dominated by Combretum glutinosum, and numerous characteristic species (none of which dominate), including Acacia macrostachya, Heeria insignis, Securidaca longipedunculata, Ximenia americana, Detarium microcarpum, Hexalobus monopetalus, Hannoa undulata and Albizzia malacophylla.

The herbaceous cover is dominated by tall grasses, particularly Andropogon gayanus, Pennisetum pedicellatum and Pennisetum subangustum. Numerous forbs grow among the grasses, including Borreria chaetocephala, Borreria stachydea, Cissus rufescens, Anchomanes difformis and Asparagus africanus.

The rangeland is of mediocre quality; the grasses quickly lignify after maturity and are often removed by annual burning practices.

Unit BV4

This shrub savanna-woodland occurs in the vicinity of Birkelane, and includes the Birkelane forest. Much of this formation was once cultivated. It has developed on sandy ferruginous soils on either side of the upper Saloum River Valley.

The trees that occur in this formation are small and widely scattered. The dominants are Cordyla pinnata, Tamarindus indica and Balanites aegyptiaca, with such scattered associates as Acacia seyal and Mitragyna inermis (in depressions), Adansonia digitata, Acacia senegal, Anogeissus leiocarpus, Combretum glutinosum and Sterculia setigera.

A dense shrub cover characterizes this formation. Most species are typical invaders of previously cultivated sandy soils. Combretum glutinosum, Piliostigma reticulatum and Guiera senegalensis are all common, with scattered Balanites aegyptiaca and Zizyphus mauritiana.

The common grasses are Schoenefeldia gracilis, Schizachyrium exile and Eragrostis tremula. The forbs include Zornia glochidiata, Cassia obtusifolia, Crinum sp. and Borreria ssp.

Grazing of local herds is the main land use activity. The rangeland is of mediocre quality and subject to overgrazing.

Unit BV5

This unit includes the Kassas and Sanian forest preserves to the north and east of Kaffrine. These formations are best described as a shrub savanna-woodland, a degraded form of the savanna-woodland that once covered the Sudano-Sahelian Domain. It occurs on sandy, ferruginous soils which become shallower in the east where gravelly horizons occur near or at the surface. While the shrub stratum characterizes this unit, scattered, taller trees emerge from it (dominated by Sterculia setigera). Lannea acida is present throughout, and a few associates, such as Anogeissus leiocarpus, Bombax costatum and Acacia seyal, are also present.

The shrub and small tree cover, which has an average height of 1 to 2 m, is dominated by the ubiquitous Combretum glutinosum and Guiera senegalensis. Common associates include Combretum nigricans and Grewia bicolor. Other scattered associates are Acacia macrostachya, Dicrostachys glomerata, Combretum micranthum and Maerua angolensis.

Because Andropogon, Aristida adscensionis, Zornia glochidiata and Borreria ssp. are present, the herbaceous stratum is heavily grazed. The rangeland is fair to good on sandy soils and poor on gravelly soils.

Unit M

Mangroves are the characteristic formation of the tidal estuaries and deltas. This formation occurs extensively in the Saloum estuaries, along the Gambia River, along the Casamance River, and even near the mouth of the Senegal River (described earlier). They can form a continuous cover of trees and shrubs (Fig. 5.34). This formation is composed almost entirely of three species (belonging to two families); the Rhizophoraceae are represented by two species: Rhizophora racemosa, which can reach heights of 20 m, colonize the banks of estuaries and channels on clayey soils; Rhizophora mangle forms the more extensive, shorter colonies. The second family, the Verbenaceae, is represented by only one species, Avicennia africana, or white mangrove, which grows above the other two species on higher ground.

Although high in biomass, this vegetation is almost never grazed. Many of the mangrove communities have succumbed to the drought and the increased salinity of the soils. Their decrease is particularly noticeable near Foundiougne and upriver toward Kaolack. The problem is especially acute in the Basse Casamance, where fire has wiped out the drought-stressed vegetation.

Fig. 5.34. An aerial view of the Sine Saloum estuaries, north of Toubakouta. Dense mangrove communities dominate the foreground. Units M and SB4. Altitude: 500 m; Sept. 17, 1984.

Unit T1

This unit supports little or no vegetation. These flats, known as tannes, are characterized by irregularly flooded, hydromorphic and halomorphic soils. They are scattered throughout the estuaries of the Sine and Saloum rivers. Where the salt content is high, the vegetation is absent. In other areas, herbaceous halophytes colonize these flats, known locally as herbaceous tannes. A few grasses (i.e., Chloris prieurii) grow on the sandier soils. The halophytes generally consist of Philoxerus vermicularis, Sesuvium portulacastrum and Hygrophila senegalensis. In the north along the Sine River, Tamarix senegalensis (shrub) commonly borders the tannes.

These tannes have little economical value. Near Kaolack they are used as salt pans.

Unit X

This unit supports little or no vegetation. It can be described as a denuded tidal swamp or mudflat; this environment is too wet and saline for nearly all species except the mangroves. Mangroves at one time colonized many of these hydromorphic and halomorphic soils, but their disappearance has been accelerated by the recent drought and the resulting increase in soil salinity.

Unit P2

This unit, with hydromorphic, clayey soils subject to seasonal flooding, occurs within the Bao Bolon Valley. The swamp prairie that colonizes this valley is dominated by halophytes which form a patchy cover. Only two species were noted: Philoxerus vermicularis, the dominant and Heleocharis mutata.

The principal commercial activity associated with this cover type is commercial fishing for local consumption, during the high water season (July to November).

5.4.2.2 The Eastern Transition Zone

A. General Characteristics

This region encompasses the transition zone between the west-central agricultural domain (Groundnut Basin) and the broken relief of the extreme east. It also forms a transition between the pastoral domain and the sparsely settled region of the shield (Schéma national d'aménagement du territoire, 1984).

It straddles the Sudano-Sahelian and the Sudanian domains, and the rainfall is gererally sufficient to give this region considerable agricultural potential. The agricultural lands are rapidly expanding. Known as Terres Neuves, these tracts of land are designated for

resettlement in an effort to relieve pressure on the Groundnut Basin.

The soils fall into two main groups: the gravelly plateau soils and the richer ferruginous valley soils. In the northern Sudano-Sahelian band, shrub and tree savannas of the lateritic Ferlo gradually fade as the denser tree savannas and savanna-woodlands appear. Pterocarpus lucens, so common in the lateritic Ferlo, gives way to the numerous Sudanian species, including Bombax costatum, Sterculia setigera, Anogeissus leiocarpus and Acacia macrostachya. The savanna-woodlands become increasingly dense as one progresses south into the Sudanian Domain.

The annual grasses of the Sahelian Domain give way to the perennial grasses of the Sudanian Domain, particularly Andropogon amplectens and Andropogon pseudapricus. Every dry season this dense herbaceous cover feeds bush fires which have become so repetitive that nowhere can the vegetation associations be considered primitive (Pélissier, 1966).

The homogeneity of the natural woody cover, in which no one species can be considered dominant, is highly characteristic of this zone. Man's activities, his fires and crops, contribute to the modification of the natural formations and create new landscapes through the degradation or selective preservation of certain species of the original community (Pélissier, 1966). These new formations are quite noticeable on the Landsat imagery, making the monitoring of man's impact on the natural vegetation feasible.

B. Cover Types

Unit VdS5

The dense shrub and tree savanna corresponds to the Forêt Classée de Mbegue, which in recent years has been completely surrounded by agriculture of the Groundnut Basin. The sandy soils have formed attenuated continental dunes, and numerous interdunal depressions are oriented in a northeast-southwest direction.

The vegetation of this forest preserve is quite degraded from its original state (Fig. 5.35). Overgrazing, repetitive bush fires and the recent drought have taken their toll on this floristically poor formation. The results of overgrazing are particularly severe around the Khelkom Diaga waterhole, where very little of the natural vegetation remains.

The small scattered trees consist of Balanites aegyptiaca (dominant), Sterculia setigera, Lannea acida, Combretum glutinosum and Adansonia digitata. Less common are Acacia seyal (mainly in depressions), Combretum nigricans, Anogeissus leiocarpus and Bombax costatum, which form a cover of 1 to [illegible], with 10 to 30% in the depressions. The quite poor shrub layer is dominated by Guiera

senegalensis, with Combretum glutinosum, Balanites aegyptiaca, Grewia bicolor and Zizyphus mauritiana. The herbaceous cover includes Cenchrus biflorus, Eragrostis tremula, Schizachyrium exile, Schoenefeldia gracilis (Gramineae), Mitracarpus scaber, Zornia glochidiata, Cassia obtusifolia, Alysicarpus ovalifolius, Borreria ssp., representing numerous families of forbs.

The rangeland is of moderate to good quality, though overgrazing, drought and fire often destroy the cover.

Fig.5.35. A degraded vegetation landscape in the Forêt Classée de Mbégué. Overgrazing, repetitive bush fires and drought have taken their toll on the vegetation. 13 km northeast of Mbégué.

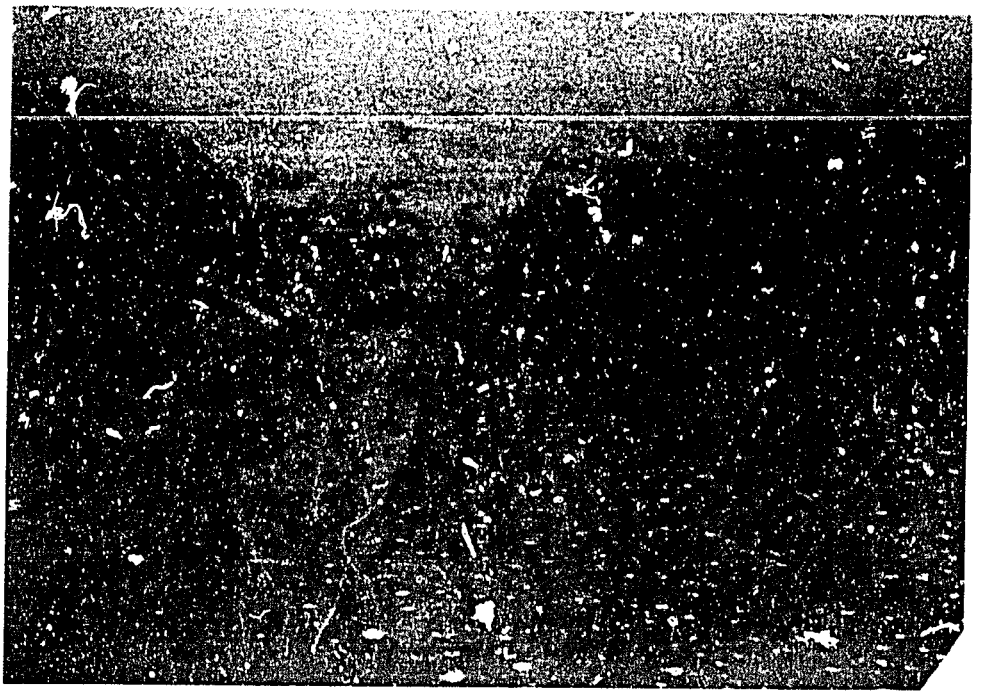


Fig.5.36. An aerial view of the sharp boundary between the dense shrub and tree savanna of the Forêt Classée de Mbégué (right) and the croplands of the Groundnut Basin (left). In other areas, croplands have encroached upon the forêts classées and réserves. Note the presence of termite mounds (foreground) and the wooded depressions. Altitude 700 m; October 29, 1983.

Unit VS6

This cover type forms a transition between the shrub savanna of the lateritic Ferlo and the tree savannas and savanna-woodlands in the south. Located to the east of Bem-Bem, this shrub and tree savanna occurs on well-drained sandy soils on a gently undulating landscape.

The few scattered tree species consist of Bombax costatum, Pterocarpus erinaceus and Combretum glutinosum, with occasional Sterculia setigera. The shrubs are dominated by Guiera senegalensis, which is common to sandy soils; characteristic species include Grewia bicolor, Feretia apodanthera, Strychnos spinosa and Grewia mollis.

Annual grasses dominate this unit, including Schoenefeldia gracilis, Aristida adscensionis and Andropogon amplectens. Forbs include Zornia glochidiata, Mitracarpus scaber and Borreria ssp.

This rangeland is of good quality, though the fine grasses are often replaced by the coarser annual grasses which are less sought out by livestock (Fotius and Valenza, 1966). Furthermore, the coarser grasses increase the destructive force of bush fires.

Unit VS7

Extending into the Sudano-Sahelian Domain, this shrub and tree savanna represents the southeastern extension of the lateritic Ferlo. Pterocarpus lucens dominates on these laterite soils, as it does to the north. This unit is floristically richer, however, than unit Vd4, with such associates as Combretum glutinosum, Combretum nigricans, Sterculia setigera, Bombax costatum and Lannea acida. The tree cover is 3 to 5%; the shrub cover is 10 to 15% and is dominated by Guiera senegalensis, Combretum micranthum, Pterocarpus lucens and Grewia bicolor. Other associates include Boscia angustifolia, Acacia macrostachya and Combretum glutinosum.

Loudetia togoensis and Elionurus elegans form a somewhat discontinuous herbaceous cover that is transitional between a steppe and a savanna. The composition of the forb cover is quite variable, with the main species being Borreria radiata, Borreria chaetocephala, Cassia nigricans and Zornia glochidiata.

This unit provides an essentially wet season rangeland whose cover senesces quickly. The value is rather poor, particularly given the high proportion of Loudetia togoensis, a species that is usually not grazed.

Unit VdSm^{2}0

This degraded shrub and tree savanna is limited to the fossil valley that traverses the northern part of the Foret Classee de Mbegue. It is a variant of unit VdS5, though the soils are hydromorphic and similar to those found in the interdunal depressions within unit VdS5.

Balanites aegyptiaca and Combretum glutinosum dominate the woody strata; hydrophytes include Mitragyna inermis. Associates often found on hydromorphic soils include Anogeissus leiocarpus, Lannea acida and Acacia seyal.

The herbaceous cover is similar to that of unit VdS5, though Cassia obtusifolia becomes more abundant and Sphaeranthus senegalensis occurs in the lowest, periodically flooded soils.

Unit VS21

This unit occurs within the upper reaches of the Nieri Ko River, to the north of Goudiri. The shrub and tree savannas that have colonized the slopes and bottoms of these valleys are quite degraded from their original form. The sandy, leached ferruginous soils are prone to erosion and support patchy vegetation that approaches that of a shrub and tree steppe. Man's agricultural activities within this unit have further degraded the natural cover, especially near settlements.

According to J. Valenza (1977), the dominant trees are Terminalia macroptera (commonly found on compact, valley soils), Cordyla pinnata (selectively preserved by man) and Combretum glutinosum. Associates include Sclerocarya birrea, Lannea acida, Sterculia setigera and Pterocarpus erinaceus. Guiera senegalensis and Combretum glutinosum make up the shrub cover, particularly in fallow and old fields.

The recent fallow fields are dominated by Pennisetum ssp.; Andropogon gayanus colonizes the four-to-five-year-old fields (Valenza, 1977).

The rangeland can be of good quality on the better soils, thus providing year-round forage.

Unit S15

This man-induced tree savanna corresponds to the Terres Neuves opened up for cultivation in the Department of Tambacounda. These areas are generally located on the better ferruginous valley soils. This unit constitutes the eastern extension of unit VdS16. It is typical of most of the agricultural lands in Senegal in that numerous trees are selectively maintained in the fields, particularly Cordyla pinnata which co-dominates with Pterocarpus erinaceus. Other common associates include Combretum glutinosum, Parkia biglobosa, Terminalia macroptera, Lannea acida and Sterculia setigera. Numerous other species occur less commonly, making this unit floristically richer than the vegetation to the west. As in the surrounding savanna-woodlands (unit B5), the shrub cover is quite heterogeneous. Combretum glutinosum dominates over the numerous associates which include Acacia macrostachya, Cassia sieberiana, Dichrostachys glomerata, Zizyphus mauritiana, Piliostigma reticulatum, Piliostigma thonningii, Guiera senegalensis, Terminalia macroptera, Annona senegalensis and others.

The principal grasses are Eragrostis tremula and Pennisetum pedicellatum, with Andropogon gayanus and Andropogon amplectens prevailing on older fallow fields. The forb cover resembles that of the surrounding natural vegetation, including Borreria chaetocephala, Pandiaka heudelotii, Asparagus africanus, Corchorus ssp., and others.

The predominant agricultural activity is the cultivation of millet, followed by groundnuts and cotton toward the border of The Gambia. Fields are commonly allowed to remain fallow for several years.

Unit SB1

This large unit extends from the Reserve Sylvo-Pastorale du Sine Saloum in the west to near the eastern edge of the "Continental Terminal" Plateau. Physiognomically, it varies from a tree savanna to a savanna-woodland within the Sudano-Sahelian transitional domain. The soils are all clayey ferruginous soils, derived from the "Continental Terminal" sandstones.

J. Trochain (1940) described the vegetation as a peniclimax dominated by Combretum glutinosum and Combretum nigricans, with edaphic facies characterized by the abundance of Bombax costatum, Sterculia setigera and Lannea acida (trees), and Guiera senegalensis, Acacia macrostachya and Feretia apodanthera (shrubs). Nearly 50 years later, this team found the same species in abundance, though the woody density had probably decreased. Sterculia setigera presently co-dominates with Combretum glutinosum. Additional associates include Adansonia digitata (ubiquitous but not abundant), Anogeissus leiocarpus and Mitragyna inermis (bordering depressions), Sclerocarya birrea, Pterocarpus lucens (where laterite occurs near the surface), and occasional Cordyla pinnata. The tree cover is 5 to 15%; the shrub cover is 10 to 30%. Other common shrub associates include Grewia bicolor (often found on termite mounds), Adenium obesum (never abundant), Gardenia triacantha and Combretum micranthum.

The principal grasses are annuals, particularly Schoenefeldia gracilis, Aristida stipoides and Pennisetum pedicellatum, though the prior climax vegetation was likely composed of perennials, particularly Andropogon gayanus whose suppression is probably the result of bush fires, overgrazing and cultivation. Common forbs include Borreria chaetocephala, Asparagus africanus, Crinum sp., Pandiaka heudelotii, and Tephrosia ssp.

This rangeland is generally of good quality providing forage throughout the year. They are, however, prone to bush fires.

Unit SB2

Forming the eastern extension of the unit SB1, this unit differs in floristic composition according to the distribution of gravelly soils and laterite which occur near or at the surface. Physiognomically, it ranges from a tree savanna to a savanna-woodland, depending on the density of the woody cover.

The tree stratum ranges in cover from 10 to 15%, having heights of 8 to 10 m. Like the previous unit, the dominants are Combretum glutinosum and Sterculia setigera; however, Pterocarpus lucens is a characteristic associate. Other common trees include Bombax costatum, Combretum nigricans and Lannea acida. Members of the Combretaceae dominate the shrub cover, particularly Combretum glutinosum, Combretum nigricans and Combretum micranthum. Common associates are Guiera senegalensis, Boscia angustifolia, Boscia senegalensis, Grewia bicolor, Maerua oblongifolia, Feretia apodanthera, Acacia macrostachya and Adenium obesum.

Andropogon pseudapricus and Andropogon pinguipes are the dominant large grasses; Loudetia togoensis is also common as are Elionurus elegans and Schoenefeldia gracilis. The principle forbs are Lepidagathis anobrya (common on gravelly soils), Pandiaka heudelotii, Borreria chaetocephala, Borreria stachydea and Borreria radiata.

This rangeland is generally of poor quality due to the coarse grasses and abundance of unpalatable species.

Unit SB6

This formation occupies the fossil valley within the Sudano-Sahelian Domain of the Transition Zone. The hydromorphic soils of these wide, shallow valleys support a formation that is variable in both structure and composition. The often degraded, quite open slope vegetation forms a shrub steppe. It can also occur as a tree savanna. The valley bottom is generally colonized by a savanna-woodland or a woodland. Mitragyna inermis and Anogeissus leiocarpus are characteristic species of this unit. While no dominants are apparent, there are numerous associates, including Combretum glutinosum, Piliostigma thonningii, Acacia seyal, Acacia senegal, Acacia nilotica (where intermittent flooding occurs) and Balanites aegyptiaca. Common shrubs include Combretum glutinosum and Guiera senegalensis (dominate in degraded areas), Acacia seyal, Zizyphus mauritiana, Piliostigma reticulatum, Boscia senegalensis, Grewia bicolor, Combretum micranthum, Mitragyna inermis and Dicrostachys glomerata.

The herbaceous layer can be discontinuous on eroded slopes, with the dominant grasses being Schoenefeldia gracilis, Pennisetum pedicellatum, Elionurus elegans and Loudetia togoensis. Common forbs are Zornia glochidiata and Alysicarpus ovalifolius.

The quality of the rangeland is as variable as its formation. The degraded surfaces with Loudetia make poor forage, while the Schoenefeldia and Zornia cover is relatively good. This area is generally used for wet season grazing (Valenza, 1977).

Unit B5

This unit is the principle plateau formation of the Transition Zone, straddling the Sudano-Sahelian and Sudanian domains. It extends from the Department of Kaffrine to the east edge of the "Continental Terminal" plateau. The climax vegetation before significant human intervention was probably a dry woodland, replaced by the present savanna-woodland (Fig. 5.37), which is thought to be a peniclimax dominated by Combretum glutinosum and Combretum nigricans (Trochain, 1940). He identifies characteristic species which once formed a heterogeneous association with no overall dominants. They are Bombax costatum, Combretum nigricans, Pterocarpus erinaceus, Sterculia setigera, Lannea acida, Crossepterix febrifuga, Strychnos spinosa, Acacia macrostachya and Feretia apodanthera. These species continue to occur throughout this large unit. The western portion of this unit is more degraded and poorer in composition. Associates to the above include Cordyla pinnata, Adansonia digitata (rarely common), Sclerocarya birrea (at the southern limit of its range), and Anogeissus leiocarpus (often in depressions).

Fig. 5.37. A view of the upland savanna-woodland (unit B5) which covers much of the Transition Zone, taken south of Toubéré Bafal (north of Tambacounda). The larger trees in this view are Bombax costatum.

The shrub and lesser tree cover is very heterogeneous. Acacia macrostachya is perhaps the most common of the characteristic species; Combretum glutinosum, ubiquitous throughout the region, dominates. Other common characteristic species are Hexalobus monopetalus, Ximenia americana, Combretum nigricans, Heeria insignis (in the more degraded formations), Feretia apodanthera, Dicrostachys glomerata, Strychnos spinosa, Guiera senegalensis, Combretum micranthum and Ostryoderris stuhlmannii (toward the southeast).

The herbaceous cover is composed principally of annual grasses, commonly Andropogoneae and scattered perennials. The dominants in the west are Pennisetum pedicellatum, Schoenefeldia gracilis, Andropogon amplectens and Andropogon gayanus. In the east, Andropogon pseudapricus, Pennisetum subangustum and Elionurus elegans become increasingly abundant. The forbs contribute to the heterogeneous cover of Cassia nigricans, Lepidagathis anobrya, Pandiaka heudelotii, Crinum sp., Sida alba and Cassia obtusifolia.

These savanna-woodlands are primarily used for grazing; they are also heavily exploited, both legally and clandestinely, for firewood and wood for charcoal production. This activity tends to reduce the number of Anogeissus leiocarpus and Pterocarpus erinaceus, leaving Sterculia setigera and Bombax costatum unexploited.

There are numerous traces of old fields and abandoned villages on the deeper plateau soils. These sites are characterized by the presence of Adansonia digitata. Today, these woodlands are being encroached upon by the increasing agricultural activities of the Terres Neuves.

Unit Bd9

This dense savanna-woodland occurs entirely within the central Sudanian Domain, mainly to the south and east of Tambacounda. The morphopedology is similar to that of the previous unit (B5): it occupies the plateaus which have gravelly soils overlying ferruginous laterites.

The vegetation is less degraded by human activity than that of unit B5, in part due to the low population density. Less than 10% of the land within this unit has been cleared for cultivation. The annual rainfall is somewhat higher (1000 to 1200 mm rainfall, using predrought figures) than that of unit B5, resulting in a denser woody cover that is floristically rich and has no overall dominants. Perhaps the most well-preserved part of this Sudanian formation is in the protected Foret de Diambour and the northern part of the Parc National du Niokolo Koba. Although the average formation is that of a dense savanna-woodland, the woody density may vary from a dry woodland to a tree savanna depending on the intervention of man (clearing and fires). The former climax formation was a dry Sudanian woodland whose composition probably does not differ significantly from the present one.

The tree stratum is characterized by the following species: Bombax costatum, Sterculia setigera, Pterocarpus erinaceus, Lannea acida, Combretum glutinosum, Cordyla pinnata, Combretum nigricans, Terminalia macroptera and Ostryoderris stuhlmannii. These trees form a heterogeneous association, with no overall dominants. Less commonly one finds Prosopis africanus, Combretum geitonophyllum, Entada africana, Detarium microcarpum, Anogeissus leiocarpus and Daniellia oliveri. The tree cover generally averages 30 to 40%, with heights of 10 to 12 m.

The shrub and lesser tree cover is equally heterogeneous, with Hexalobus monopetalus, Acacia macrostachya, Strychnos spinosa, Combretum glutinosum, Combretum nigricans, Terminalia avicennoides, Terminalia macroptera, Annona senegalensis, Piliostigma thonningii, Vitex madiensis, Ostryoderris stuhlmannii and Ximenia americana. Less common associates include Combretum geitonophyllum, Grewia lasiodiscus,

Crossepterix febrifuga, Baissea multiflora, Feretia apodanthera, Gardenia ternifolia and Securidaca longipedunculata. The shrub cover is somewhat less than the tree cover, averaging 15 to 25%, with heights of 2 to 4 m.

A tall grass savanna constitutes the herbaceous understory, dominated by Andropogon gayanus, with principle associates including Andropogon amplectens, Pennisetum subangustum and Pennisetum pedicellatum. Numerous other herbaceous families are interspersed with the grasses, including Asparagus africanus, Monechma ciliatum, Borreria chaetocephala and Pandiaka heudelotii.

The forage provided by the herbaceous cover is best used during the rainy season. The nutritional value is lost after senescence and the coarser grasses lignify. Furthermore, both naturally and man-induced grass fires affect at least 80% of this unit.

Unit Bd12

This unit occurs in the low, wide valleys of the northern half of the transition zone, within the savanna-woodland type B5 which dominates the uplands. The soils are generally formed in sandy collivium with concretions and support a denser and richer vegetation than that of the uplands (Fig. 5.38).

Physiognomically, this formation is a dense savanna-woodland, with a great variety of Sudanian trees and shrubs that form a heterogeneous mixture. The equally varied herbaceous cover is dominated by Andropogoneae.

The tree stratum consists commonly of Anogeissus leiocarpus, Terminalia macroptera, Combretum glutinosum (tends to dominate in disturbed areas), Bombax costatum, Pterocarpus erinaceus, Lannea acida, Sterculia setigera, Cordyla pinnata and less commonly, Mitragyna inermis (valley floor), Adansonia digitata and Piliostigma thonningii. The average heights are 10 to 15 m, with a cover of 25 to 40%.

The shrub cover is even richer, with Piliostigma reticulatum, Pterocarpus erinaceus (juvenile), Feretia apodanthera, Combretum glutinosum (tends to dominate in degraded areas), Combretum nigricans, Terminalia macroptera, Strychnos spinosa, Dicrostachys glomerata, Mitragyna inermis, Combretum lecardii, Zizyphus mauritiana, Ximenia americana and others.

Numerous herbaceous genera of diverse families mix with the Gramineae. They include Indigofera hirsuta, Indigofera suffructicosa, Sida alba, Borreria ssp., Tephrosia ssp., Ipomaea ssp., Cassia obtusifolia and others. Andropogon gayanus is the main perennial grass. Common annuals of smaller size include Pennisetum pedicellatum, Pennisetum subangustum, Panicum sp. and Eragrostis ssp.

Fig. 5.38. An example of the dense savanna-woodlands (unit Bd12) that occupy the shallow valleys of the northern half of the Transition Zone (north of Tambacounda). The floristic composition is richer than the upland communities, with no apparent dominants.

This rangeland is generally of good quality, with numerous highly palatable species. Grazing is possible throughout the year, except where fire has removed the cover.

Unit BF4

The southern counterpart of the previous unit, unit BF4 occurs in wide shallow valleys and along the tributaries of permanent rivers, including the Niéri Ko. The formation ranges from a savanna-woodland to a woodland, depending on the level of human intervention. As above, all strata are composed of a highly heterogeneous mixture of Sudanian species. Unit Bd9 dominates the uplands.

The composition is similar to that of unit Bd9, though the frequency of Anogeissus leiocarpus, Piliostigma thonningii, Terminalia macroptera and Mitragyna inermis is higher and the overall density is greater. The shrub and herbaceous cover is also similar to that of unit Bd12.

The rangeland is good throughout the year, though fires generally remove the herbaceous cover. Given the sparse population of humans and domestic animals, the grazing level is quite low compared with that of the northern and western valleys.

5.4.2.3 The Region of the Shield

A. General Characteristics

The principal criteria used to define this region are related to its relief and geology. It is distinguished from the adjacent regions by its old geologic formations (Precambrian and Paleozoic). The landscape is one of plateaus and hills with a dense drainage network (Schéma national d'aménagement du territoire, 1984). The complex geology and varied soils that originate from different rock types produce distinctive vegetation communities. Four community types can be distinguished in relation to landscape (Chauvel, 1967):

- Laterite plateaus which generally support a much reduced woody cover, essentially composed of Combretaceae species.

- Vegetation on the moderate to steep slopes, characterized by a great diversity of species. The density decreases from the upper to the lower slopes.

- Vegetation cover on the gentler slopes is always fairly open and is dominated by *Combretum glutinosum*, *Acacia dudgeoni* and *Maytenus senegalensis*.

- In low lying areas, the distribution of woody species relates well to the level of water saturation of the soils.

The Sudanian savanna-woodlands and dry woodlands constitute the main vegetation types of the plateaus and hills. Numerous other formations occur as a function of geomorphology, soils and human intervention.

This region straddles the three domains of the Sudanian Region: the Sudano-Sahelian, the Central Sudanian and the Sudano-Guinean.

The floristic composition is fairly typical of Sudanian vegetation--highly heterogeneous with no apparent dominants on the uplands. Species that are rare in the Eastern Transition Zone become common. To the south, the composition takes on a Sudano-Guinean character as plants from the Guinean Zone become numerous, particularly on the hydromorphic valley soils.

B. Cover Types

Unit A11

This unit occurs on the low plains adjacent to the Senegal River Valley in the vicinity of Bakel. The vegetation consists of a thorny shrub steppe on a variety of poorly evolved, subarid soils developed from quartzites and schists.

The composition is poor, probably a result of human and animal overexploitation (Valenza, 1977). The woody stratum is generally very open and the herbaceous cover is patchy and discontinuous. The dominant shrub species (trees are nearly absent) are Acacia seyal and Balanites aegyptiaca. Common associates are Acacia senegal, Feretia apodanthera, Zizyphus mauritiana, Combretum glutinosum, Guiera senegalensis and Dicrostachys[3] glomerata.

The principal herbaceous species are Schoenefeldia gracilis, Aristida adscensionis, Chloris prieurii (grasses), Zornia glochidiata, Cassia mimosoides and Cassia obtusifolia (forbs).

While these species are generally palatable, the poor, sparse cover limits the usefulness of this rangeland. This unit can be grazed only during the rainy season.

Unit A16

This shrub steppe is located on scattered buttes and residual hills in the vicinity of Bakel and Kidira. The soils are generally lithosols of various rock types with lateritic remnants.

The vegetation is similar to the types found on the laterite soils of the "Continental Terminal" plateau. The woody cover is restricted to shrubs, though occasionally Sterculia setigera and Combretum glutinosum emerge above the shrubs and lesser trees. The dominants are Pterocarpus lucens and Balanites aegyptiaca, with numerous associates of Sahelian and Sudanian affinity, including Acacia macrostachya, Acacia seyal, Boscia angustifolia, Grewia bicolor, Combretum nigricans, Feretia apodanthera, Adenium obesum and Commiphora africana.

Gramineae dominate the herbaceous cover, including Andropogon pseudapricus, Andropogon gayanus, Loudetia togoensis, Schoenefeldia gracilis, Schizachyrium sanguineum, Elionurus elegans, and Pennisetum pedicellatum. Numerous genera of forbs coexist with the grasses, including Cassia nigritana, Monechrna ciliatum, cassia mimosoides, Lepidagathis anobrya, Urginea nigritana, Zornia glochidiata and Asparagus africanus.

The composition is rich in species desirable for ruminants. While the broken terrain shields the herbaceous cover from fire, it also limits grazing because of difficult terrain (Fig. 5.39). Grazing is generally restricted to the lower slopes.

Fig. 5.39. A view of the scattered shrubs and small trees on buttes and residual hills between Bakel and Kidira.

Unit AE13

Occuping the lower Falémé River Valley, this unit is composed of woody and herbaceous cover that consists of a shrub and/or tree steppe. The soils are formed in alluvium and are clayey.

The tree stratum is dominated by three species commonly found on compact hydromorphic soils: Terminalia macroptera, Acacia seyal and Anogeissus leiocarpus. This unit differs from that of the Senegal River Valley by the absence of Balanites aegyptiaca. Other associates include Combretum glutinosum, Sclerocarya birrea, Borassus aethiopium and Adansonia digitata.

Quite rich in composition, the shrub stratum is dominated by Acacia seyal; Diospyros mespiliformis, Stereospermum kunthianum, Combretum glutinosum, Zizyphus mucronata, Guiera senegalensis (on old fields) and Piliostigma reticulatum are also present.

The main grasses are Andropogon gayanus, Schoenefeldia gracilis and Vetiveria nigritana. Common forbs are Borreria chaetocephala, Sclerocarpus africanus, Monechma ciliatum and Cassia obtusifolia.

This rangeland is generally of poor quality. It produces a limited quantity of biomass and the grasses disappear quickly during the dry season.

Unit Ed1

Representing the southern extension of unit A11 (shrub steppe), this tree steppe occurs on the low plains that slope gently toward the lower Falémé River. The soils consist of lithosols and hydromorphic clayey soils over gravels and laterite.

The vegetation composition is richer and denser than that of unit A11 due to the higher average rainfall and decreased human intervention. Trees dominate, though shrubs occur in dense stands. Acacia seyal and Sterculia setigera co-dominate, though Combretum glutinosum prevails in degraded formations. Common tree associates are Pterocarpus lucens, Lannea acida, Balanites aegyptiaca, Bombax costatum, Sclerocarya birrea, Anogeissus leiocarpus and Adansonia digitata. The shrub stratum is quite rich and heterogeneous, though Combretum glutinosum and Acacia seyal tend to dominate. The more common associates are Balanites aegyptiaca, Feretia apodanthera, Grewia bicolor, Combretum micranthum and Guiera senegalensis.

The herbaceous cover, mainly grasses, is patchy; yet there is usually enough biomass to provide forage all year. The most common grasses are Andropogon pseudapricus, Schoenefeldia gracilis, Pennisetum pedicellatum and Loudetia togoensis. Forbs include Cassia nigritana, Borreria ssp., Sclerocarya africana and Asparagus africanus.

Most of the grasses are highly palatable, making this good quality rangeland.

Unit S17

This cover type is an anthropogenic tree savanna that has resulted from the clearing of the upland (unit BdH1), and more commonly wide valley (unit BdF7), vegetation for cultivation. This unit is very limited in area and is associated with the few scattered settlements of Senegal Oriental. Most of the cultivated areas occur around Kedougou and Fongolembi.

Many large trees are preserved in the fields, usually for their fruits or shade. They include Pterocarpus erinaceus, Ficus glumosa, Ficus platyphylla, Ficus gnaphalocarpa, Parkia biglobosa, Cordyla pinnata, Ostryoderris stuhlmannii and Terminalia macroptera. The numerous shrubs which quickly emerge in fallow and old fields are very heterogeneous in species. Combretum glutinosum generally dominates and associates include Cassia sieberiana, Ficus ssp., Parkia biglobosa, Jatropha curcas, Ancistrophyllum secundiflorum, Saba senegalensis, Piliostigma reticulatum, Acacia macrostachya, Terminalia avicennoides, Annona senegalensis, Combretum nigricans, Combretum micranthum and Ostryoderris stuhlmannii.

The principal herbaceous species include Pennisetum pedicellatum, Andropogon pseudapricus, Borreria chaetocephala, Sclerocarpus africanus and Pandiaka heudelotii.

Unit B7

Occurring on hills formed from folded sandstones adjacent to the Falémé River Valley, this cover type is a variant of Bd8. The soils are generally lithosols and gravelly soils. The woody cover is slightly less dense than that of the adjacent plains, a result of the shallow soils whose ability to store moisture is poor.

This savanna-woodland is characterized by Pterocarpus erinaceus, Pterocarpus lucens, Combretum nigricans, Sterculia setigera, Anogeissus leiocarpus, Combretum glutinosum, Adansonia digitata (rare), Bombax costatum, Lannea acida and Terminalia macroptera. The cover ranges from 15 to 20%, with heights of 10 to 12 m. The shrub cover is quite heterogeneous, though several species appear frequently: Combretum nigricans, Combretum glutinosum, Combretum micranthum, Strychnos spinosa; somewhat less common are Feretia apodanthera, Grewia bicolor, Ximenia americana, Acacia polyacantha var. campylacantha.

The predominant grasses are Loudetia togoensis (common to gravelly soils), Elionurus elegans, Andropogon pseudapricus and Pennisetum pedicellatum. Common forbs are Borreria chaetocephala, Asparagus africanus and Hibiscus asper.

The potential for grazing is poor to fair and is restricted mainly to the rainy season.

Unit Bd8

With poorly evolved soils overlying gravels and laterite, this dense savanna-woodland occurs on the plains and slopes north of Dalafi.

The heterogeneous tree stratum is characterized by Combretum nigricans, Bombax costatum, Combretum glutinosum, Sterculia setigera and Pterocarpus erinaceus. The shrub species include Strychnos spinosa, Grewia lasiodiscus, Dicrostachys glomerata, Hexalobus

monopetalus, Piliostigma thonningii, Acacia macrostachya and Terminalia avicennoides. Principle herbaceous species are Andropogon pseudapricus, Andropogon amplectens, Andropogon gayanus, Pennisetum subangustum, Borreria ssp., Sida alba and Urginea sp.

While the understory provides good forage during the wet season, the coarse grasses are less palatable during the dry season.

Unit Bd10

Located within the same morphopedological complex, this unit occurs to the southwest of unit Bd8 (above). The influence of somewhat higher rainfall on the vegetation composition is the main differentiating factor of Bd8 and Bd10. Sudano-Sahelian species become rarer, while typically Sudanian species prevail. Characteristic species are Bombax costatum, Sterculia setigera, Daniellia oliveri, Pterocarpus erinaceus, Terminalia macroptera and Piliostigma reticulatum. The shrub and herbaceous species are generally those found in unit Bd8, though several additional species occur here, including Daniellia oliveri and Oxytenanthera abyssinica.

Units B13 and Bd13

The cover type is associated with the low, wide valleys that drain into the Falémé River. The vegetation generally forms a thorny savanna-woodland (B13), often dense (Bd13), with compact hydromorphic soils and vertisols. These valleys extend from Bakel to the middle Falémé north of Kossanto. The northern valleys are more open, and when the cover is degraded they form a thorny shrub steppe. To the south, species of Sahelian affinity are replaced by typically Sudanian species.

Acacia seyal is the dominant, characteristic species in the northern valleys; associates include Acacia senegal, Anogeissus leiocarpus, Adansonia digitata and Terminalia macroptera. Principal shrubs include the above acacias and Zizyphus mauritiana, Piliostigma reticulatum (very common), Combretum glutinosum, Combretum micranthum and Balanites aegyptiaca. Toward the south, the acacia species give way to Terminalia macroptera, Piliostigma thonningii and Mitragyna inermis.

The herbaceous cover is dominated by Gramineae, in particular Andropogon pseudapricus, Andropogon gayanus, Pennisetum pedicellatum and Schoenefeldia gracilis. Numerous genera of forbs make up the remaining species, including Zornia glochidiata, Hyptis specigera, Sida alba, Cassia obtusifolia, Ipomaea aegyptiaca, Monechma ciliatum, Jussiaea erecta, Sphaeranthus senegalensis and others.

This unit is quite variable in terms of forage quality. It generally provides a good wet season rangeland. The dense thorny shrubs in the north restrict access to the understory.

Unit B14

This cover type occurs on the hills, low mountains and steep slopes of Senegal Oriental and is characterized by lithosols over various basic rocks and brown regosols formed in various parent materials. The shallow soils and more xeric conditions tend to produce a more open formation than that of the surrounding units. The composition, however, does not differ greatly from the heterogeneous Sudanian woodland of the plains and plateaus. The characteristic tree species are Pterocarpus erinaceus (somewhat more common than the others), Terminalia macroptera, Sterculia setigera, Bombax costatum, Lannea acida (ubiquitous but never common), Combretum glutinosum and Acacia dudgeoni. Less commonly, one finds Adansonia digitata, Cordyla pinnata, Parkia biglobosa, Steganotaenia araliacea and Acacia sieberiana. The tree cover ranges from 15 to 30%, with a range of heights from 6 to 10 m. The quite heterogeneous shrub cover includes such common associates as Combretum micranthum, Grewia mollis, Pterocarpus erinaceus, Strychnos spinosa, Dicrostachys glomerata, Combretum glutinosum, Acacia dudgeoni, Ximenia americana, Hexalobus monopetalus, Anogeissus leiocarpus, Terminalia macroptera and Securidaca longipedunculata. Large grasses of the genus Andropogon dominate the understory, particularly Andropogon pseudapricus and Andropogon gayanus; less commonly one finds Pennisetum subangustum, Andropogon amplectens and Cymbopogon giganteus. Among the numerous forbs are Lepidagathis capituliformis, Tephrosia ssp., Indigofera leptoclada, Corchorus olitorius and Sesbania leptoclada.

Grazing potential is rather limited given the rough terrain and the unpatalability of the large grasses after lignification. Bush fires are prevalent between November and May.

Unit BdH1

Consisting of a complex of dense savanna-woodlands and open herbaceous steppes, this unit's cover is the predominant type throughout much of Senegal Oriental (Fig. 5.40). The latter formation occurs on large lateritic outcrops with red ferruginous soils forming a hardened, impenetrable surface. These iron pans, or bowé, greatly restrict woody vegetation growth and support varying quantities of grass cover during the rainy season. The savanna-woodlands occur on lithosols and regosols of gravelly texture that often overlie laterites.

Typical of the Sudanian woodland climax vegetation these dense savanna-woodlands exhibit a heterogeneous composition whose cover varies in density as a function of the soil type and the depth to the laterite.

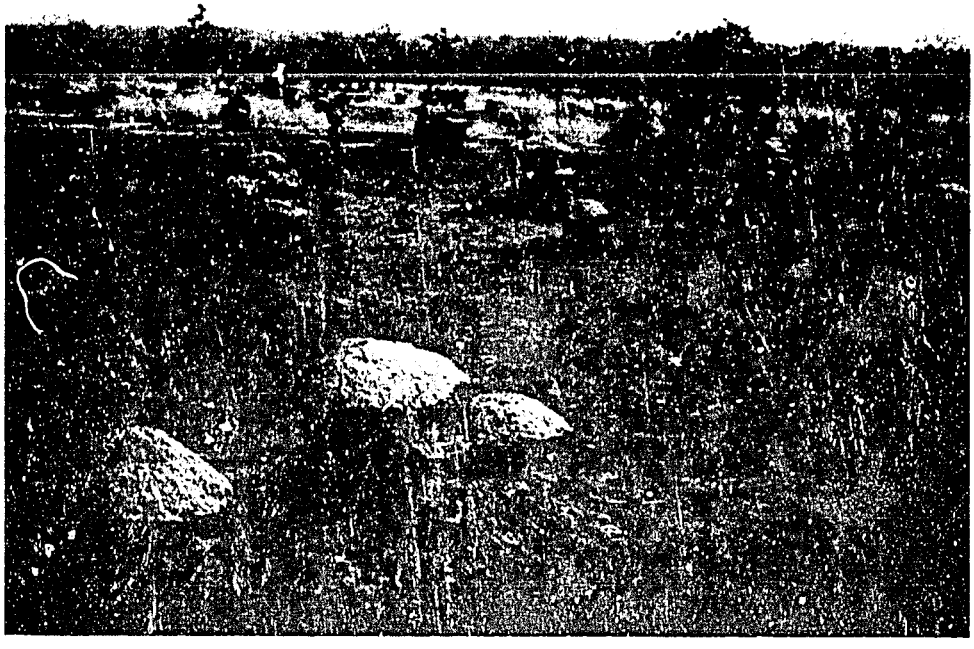


Fig. 5.40. A typical bowal or iron pan with its "mushroom" termite mounds near Saraya, Senegal Oriental. These surfaces often support a herbaceous steppe, but the soil is too compact for most woody species. In the distance is the dense savanna-woodland (unit BdH1).

The tree layer is typically composed of Pterocarpus erinaceus (somewhat more common than other trees), Bombax costatum, Lannea acida (ubiquitous, but never abundant) and Combretum[3] glutinosum. Scattered associates include Terminalia macroptera, Ostryoderris stuhlmannii, Combretum nigricans, Sterculia setigera, Afrormosia laxiflora, Cordyla pinnata, Acacia dudgeoni and Daniella oliveri (not widespread). The ground cover by trees ranges from 20 to 30%; the shrub cover is somewhat less dense at 15 to 20%. Tree heights average 8 to 10 m, while shrub heights average 2 to 4 m. Combretum glutinosum tends to dominate the otherwise heterogeneous and floristically rich shrub stratum. The most common characteristic species are Hexalobus monopetalus, Vitex madiensis, Strychnos spinosa, Lannea acida (juvenile), Pterocarpus erinaceus (juvenile), Bombax costatum (juvenile), Combretum nigricans, Combretum crotonoides, Hymenocardia acida, Acacia dudgeoni, Combretum micranthum, Ostryoderris stuhlmannii, Crossepterix febrifuga and Annona senegalensis.

The herbaceous cover is dominated by coarse grasses that, unlike the overstory, do not occur in heterogeneous communities. Tall Andropogoneae are the rule, mainly Andropogon amplectens, Andropogon

pseudapricus and Andropogon gayanus, with Ctenium villosum. Oxytenanthera abyssinica (bamboo) can form dense stands. The numerous forbs that make up a low substratum include Indigofera leptoclada, Tephrosia sp., Borreria ssp., Monechma ciliatum, Pandiaka heudelotii, Hibiscus asper, Asparagus africanus and Urginea sp.

The bowé, or herbaceous steppes on the lateritic hardcap surfaces, are usually devoid of woody vegetation. Scattered grasses and forbs can develop when a few centimeters of soil collect on the laterite. They include Ctenium villosum, Andropogon pseudapricus and particularly Lepidagathis capituliformis, which is found exclusively on the bowe. The grazing value of the bowé is poor and limited to the rainy season.

Fig.5.41. A portion of a Landsat image, band 7, covering the southern portion of the Parc National du Niokolo Koba (defined by the Gambia River). The numerous dark patches are areas where the savanna-woodland understory has been burned. The arrow indicates an actual bush fire in progress, with a smoke plume extending to the left. Over 80% of southern Senegal is burned each year.

Unit BdH2

This unit is physiognomically similar to the previous unit (BdH1), differing somewhat in the associated soils and in its floristic composition. The soils tend to be deeper and generally consist of hydromorphic vertisols overlying gravels.

The woody strata are heterogeneous and somewhat richer in composition (relative to BdH1). Daniellia oliveri, Vitex madiensis, Anogeissus leiocarpus and Ficus glumosa occur more frequently here. Refer to unit BdH1 for the characteristic shrub, tree and herbaceous species.

Certain areas have been degraded through human intervention. Here a shrub and tree savanna, where Combretum glutinosum becomes dominant, replaces the dense savanna-woodland.

Baobabs (Adansonia digitata) are locally frequent on the dolerite hills of the Ibel-Bandafassi region. This unit constitutes a rich source of timber and firewood.

Unit BdF7

This dense savanna-woodland and woodland formation occurs in the drainage channels of much of Senegal Oriental on hydromorphic, clayey soils. The riparian vegetation differs significantly from the upland vegetation by the presence of a few species of Guinean affinity. The Sudanian species are found mainly on hydromorphic soils within the denser overstory.

The characteristic tree species are Anogeissus leiocarpus, Pterocarpus erinaceus, Borassus aethiopium, Lonchocarpus laxiflorus and Piliostigma thonningii. Less abundant are Mitragyna inermis, Celtis integrifolia, Daniellia oliveri, Bombax costatum, Diospyros mespiliformis, Elaeis guineensis, Khaya senegalensis and Terminalia macroptera. The tree cover generally averages 20 to 30%. The shrub composition is even more diverse, including the juvenile trees listed above and such numerous shrubs as Combretum glutinosum, Nauclea latifolia, Cassia sieberiana, Syzygium guineense, Ficus ssp., Combretum crotonoides and Acacia dudgeoni.

As in the uplands, large grasses dominate, particularly Andropogon gayanus, Andropogon amplectens and Pennisetum subangustum. Cassia obtusifolia is the predominant forb (ubiquitous on hydromorphic soils).

This unit is an important source of timber and forage and also contributes to an important wildlife habitat whose protection should be encouraged.

Unit G

This is a unit of gallery forests, which are very rich and diverse in composition. They occur in the deeper valleys where the water table is at or near the surface. This formation is quite dense (tree cover 30 to 60%) and creates its own microclimate. The hydrophytic trees may attain heights of 30 m; it is further distinguished by the presence of numerous evergreen Guinean species. This formation can be identified from other valley formations on the Landsat imagery by the presence of year-round green biomass in the upper strata. While no dominants are apparent, characteristic tree species include Ficus capensis, Ficus gnaphalocarpa, Erythrophlaeum guineense, Piliostigma thonningii, Syzygium guineense, Elaeis guineensis, Khaya senegalensis, Parkia biglobosa, Terminalia macroptera, Ceiba pentandra and Cola cordifolia. Shrub species include Saba senegalensis, Mimosa pigra, Mitragyna inermis, Baissea multiflora, Nauclea latifolia and Raphia sudanica.

Grasses are relatively scarce under the dense overstory. The few species which occur include Panicum ssp., Andropogon gayanus (mainly on the slopes) and Olyra latifolia. Numerous forbs, requiring both shade and moisture, dominate the herbaceous cover: Lippia chevalieri, Hyptis suaveolens and many others.

Unit FBH

This dry woodland, savanna-woodland and herbaceous steppe complex occurs on gravelly and sandy soils derived from granitic rocks, with laterite occurring frequently at the surface (bowé). This unit is found in the extreme southeast portion of Senegal. The vegetation is probably near its climax.

This unit is one of the richest of the Sudanian woodlands, both in terms of tree density and composition. Many trees of commercial value occur here. This unit also represents an important wildlife habitat.

The characteristic trees include Bombax costatum, Khaya senegalensis, Daniellia oliveri, Pterocarpus erinaceus, Vitex madiensis, Combretum glutinosum, Lannea acida, Afzelia africana, Acacia dudgeoni, Afrormosia laxiflora, Parkia biglobosa, Terminalia macroptera and Cordyla pinnata. The tree cover ranges from 20 to 50%, and the shrub cover ranges from 25 to 40%, (excluding the bowe vegetation).

The shrub stratum includes many juvenile tres, plus these common associates: Hexalobus monopetalus, Grewia mollis, Combretum nigricans, Combretum crotonoides, Acacia macrostachya, Baissea multiflora, Hymenocardia acida, Strychnos spinosa, Securidaca longipedunculata, Detarium microcarpum and Ostryoderris stuhlmannii.

Within both the savanna-woodlands and the herbaceous steppes bowé, the herbaceous composition is similar to that of unit BdH1.

5.4.2.4 The Casamance

A. General Characteristics

The uniqueness of the Casamance stems generally from its ecology, which sets it apart from the rest of the country:

- Wetter climate (precipitation is generally above 1000 mm; effective wet season of 120 days or more; numerous streams).

- Denser vegetation (belonging to the Sudanian and Guinean Regions), though presently subjected to serious deforestation.

The Gambian enclave is added to this region whose ecological environment is like that of the Casamance (Schéma national d'aménagement du territoire, 1984).

Most of the Casamance, with the exception of the extreme southwest corner, falls into the Sudanian and Sudano-Guinean domains (Adam, 1966). A large part of the Casamance is covered by a dry Sudanian woodland, and well-defined gallery forests in the north and east. Toward the Moyenne Casamance the valleys become shallower and wider and the vegetation takes on a Guinean character, particularly as Elaeis guineensis begins to dominate the banks. The moist valleys support marsh vegetation and are often planted in swamp rice.

The northern half of Basse Casamance is extremely varied. Vegetation of Guinean affinity prevails as a result of the shallow water table and higher rainfall. The dry Sudanian woodlands are limited to the uplands where the watertable is too deep to influence the vegetation. Numerous azonal formations occur, particularly the mangrove communities that resemble those of the Saloum estuaries. They colonize the banks of the Gambia and Casamance rivers, penetrating 150 km up the Gambia River and along the Casamance River as far upstream as Sedhiou.

B. Cover Types

Unit VP

This unit occurs along the floodplains of the Gambia and Koulountou rivers. It consists of a mosaic of shrub savannas, tall-grass savannas on the flats and swamp prairies within numerous temporarily inundated flood basins. A narrow band of dense, evergreen riparian vegetation grows along the banks (not mapped separately), and species particular to the unique regime of a short flooding cycle followed by many dry months are present (Fig. 5.42).

Fig.5.42. The riparian vegetation of the Gambia River forms a narrow, dense band along the bank. Location: Gué de Wassadou, northern edge of the Parc National du Niokolo Koba.

The floodplains are dominated by tall Andropogon grasses, particularly Andropogon gayanus. Common associates include Pennisetum subangustum and Pennisetum pedicellatum. This savanna may be accompanied by a shrub stratum whose composition is often a function of the length of inundation and the duration of moisture in the soils. Species range from Guinean to Sahelian types. Combretum glutinosum is common in the areas degraded by fire. Numerous associates include Piliostigma reticulaturm, Piliostigma thonningii, Mitragyna inermis, Cassia sieberiana, Dicrostachys glomerata, Saba senegalensis and juvenile Borassus aethiopium. Generally confined to the banks, the dense cover of trees has a composition similar to that of the gallery forests. Characteristic species include Cola laurifolia, Borassus aethiopium, Erythrophlaeum guineense, Detarium senegalense, Garcinia livingstonii, Diospyros mespiliformis, Syzygium Guineense, Diospyros elliotii and Christiana africana.

Depending on the depth of the depressions and the duration of flooding, swamp prairies are very diverse. They are dominated by a cover of Cyperaceae or hydrophytic Gramineae, which include Heleocharis plantaginea, Oryza ssp., Brachiaria mutica and Cyperus articulatus.

This unit is an important wildlife habitat, particularly during the dry season when numerous wild animals gather here to forage on the prairie vegetation.

Unit S16

This man-induced tree savanna is the result of deforestation of both the upland and valley woodlands for various types of cultivation (Fig. 5.43). The cultivated fields generally occur within the Sudanian formations of the Haute and Moyenne Casamance. As in other regions, certain trees are preserved in the fields. On the upland fields, relics of the surrounding woodland include Pterocarpus erinaceus (dominant), Parkia biglobosa, Prosopis africanus, Cordyla pinnata and Combretum glutinosum. Diverse types of shrubs invade the fallow and/or abandoned fields. The initial shoots are Combretum glutinosum, Icacina senegalensis and Annona senegalensis. With time, numerous species of the Sudanian woodland appear, including Piliostigma thonningii, Terminalia macroptera, Terminalia laxiflora, Daniellia oliveri, Dicrostachys glomerata and others. Grasses dominate the herbaceous cover, and species of Andropogon and Pennisetum predominate.

The tree savannas of the cultivated valleys contain hydrophytes and mesaphytes typical of the region, including Parkia biglobosa, Terminalia macroptera, Daniellia oliveri, Piliostigma thonningii, Ficus gnaphalocarpa, Cola cordifolia and Khaya senegalensis. The shrub cover includes many juveniles of the above. The herbaceous cover is dominated by the genera Cyperus and Andropogon.

The upland crops are millet and groundnuts, as well as cotton, which was introduced in the early 1960's. The climate of the Haute Casamance is favorable for cotton and this region furnishes over half the national production of cotton.

Unit S18

Like the previous unit, this unit is the result of deforestation of both the upland and valley woodlands for the purpose of cultivation. Occurring mainly within the Sudano-Guinean Domain, unit S18 is surrounded by somewhat denser woodlands.

The scattered trees left in the upland fields include Parkia biglobosa, Khaya senegalensis, Ficus glumosa (dominants), with the associates Daniellia oliveri, Pterocarpus erinaceus, Cordyla pinnata, Terminalia macroptera, Adansonia digitata and Prosopis africanus. The shrub emergents in fallow and old fields include the above species and Cassia sieberiana, Annona senegalensis, Dicrostachys glomerata, Icacina senegalensis, Piliostigma thonningii, Guiera senegalensis and Lannea vellutina.

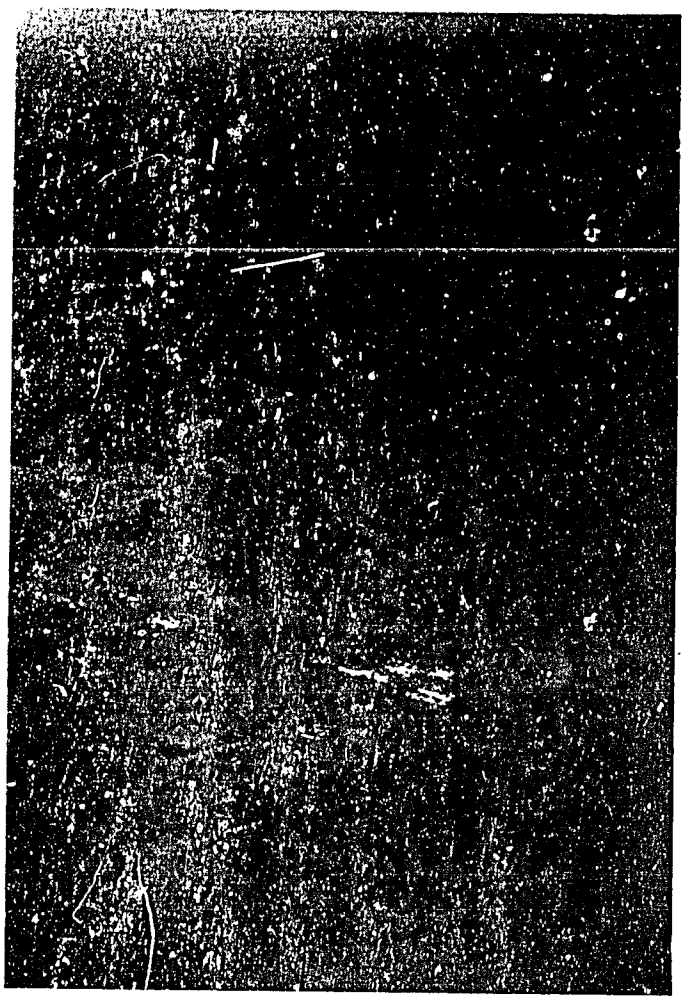


Fig. 5.43. An aerial view of cropland (unit S16) within the extensive woodlands of Moyenne Casamance (unit BdF2). The woodland here is part of the Forêt de Pata. Cropland in this area is rapidly expanding at the expense of the upland woodlands. Altitude 600 m; Sept. 17, 1934.

Herbaceous species include Eragrostis tremula, Pennisetum subangustum, Pennisetum pedicellatum and Andropogon gayanus. Various forbs invade the fallow soils, including Alysicarpus ovalifolius, Sida alba, Hyptis suaveolens, Tephrosia linearis, Cassia obtusifolia and Sesbania pachycarpa.

A somewhat different association occurs on the lower slopes and in the valleys. In addition to the above, trees include Ficus glumosa, Ceiba pentandra, Cola cordifolia, Detarium microcarpum and Elaeis guineensis. The shrub and herbaceous composition also differs somewhat, but this information was not gathered. The upland fields, tended by the men, alternate between groundnuts and millet, with a recent introduction of cotton and rainfed rice varieties. The valleys are reserved for rice fields, where the women are responsible for transplanting, weeding, flood monitoring and harvesting.

Unit SP

This tree savanna and marsh complex is located in the mid Soungrougrou Valley, on saline, hydromorphic gley soils within the floodplain. This unit is unusual in that numerous trees have been preserved in the rice fields. They include Mitragyna inermis (very common), Khaya senegalensis, Elaeis guineensis, Parkia biglobosa, Aphania senegalensis and Lannea vellutina. Small trees and shrubs include Cordia myxa, Piliostigma reticulaturm, Nauclea latifolia, Saba senegalensis and other associates.

Scattered herbaceous species grow in fallow rice paddies, including Vetiveria nigritana, Imperata cylindrica, Alysicarpus ovalifolius and Hyptis specigera. Cultivated rice is the only crop grown here.

Unit SBd3

This tree savanna and dense savanna-woodland complex is located within the Anambé Basin of Haute Casamance. This unit is found on hydromorphic soils which generally overlie lateritic deposits. The natural vegetation cover tends to be dense over most of this basin, with the exception of the lower areas that are subject to flooding, on which either a tree savanna or a herbaceous savanna occurs. The most characteristic tree is Daniellia oliveri, which grows in relatively dense stands without any apparent relationship to soil type. The most common associates are Terminalia macroptera, Parkia biglobosa, Pterocarpus erinaceus, Khaya senegalensis and Combretum glutinosum. Shrub species include Piliostigma reticulatum, Dicrostachys glomerata, Gardenia erubescens, Vitex madiensis, Hexalobus monopetalus and other less common associates.

Herbaceous species include Andropogon gayanus, Andropogon amplectens, Borreria ssp. and Indigofera capitata.

Unit BdF1

This formation ranges from a dense savanna woodland to a dry woodland; it occupies much of the northern sectors of Haute and Moyenne Casamance. It occurs on leached ferruginous soils of sandy to sandy-clay texture, overlying laterite or gravels.

This Sudanian upland woodland is characterized by the often dense stands of Oxytenanthera abyssinica (bamboo) which can occur in clusters and dominate the understory.

The woody vegetation ranges in cover from 40 to 80%, with the upper story making up about half of the cover. The numerous characteristic tree associates are Bombax costatum, Cordyla pinnata, Terminalia macroptera, Combretum glutinosum, Pterocarpus erinaceus, Prosopis africana, Burkea africana, Lannea velutina, Parkia biglobosa, Sterculia setigera and the present but rarely common Lannea acida, Daniellia oliveri, Afrormosia laxiflora and Afzelia africana. The woody understory is composed of Acacia macrostachya, Strychnos spinosa, Combretum nigricans, Combretum glutinosum, Combretum micranthum, Annona senegalensis, Hannoa undulata, Baissea multiflora, Hexalobus monopetalus, Ostryoderris stuhlmannii, Terminalia avicennoides and juvenile trees.

Besides Oxytenanthera abyssinica, which can occur in locally dense stands, the grass cover is dominated by Andropogon ssp. and Pennisetum subangustum. Forbs include Borreria ssp., Ipomaea ssp., Desmodium velutinum and Sida alba.

The rangeland can be grazed all year, though the cover is often eliminated by fire. Trees of excellent commercial value include Cordyla pinnata, Pterocarpus erinaceus, Daniellia oliveri and Bombax costatum. They need, however, to be protected from overexploitation.

Unit BdF2

This unit ranges from a dense savanna-woodland to a dry woodland, occurring on uplands of Haute and Moyenne Casamance with generally gravelly to shallow gravel soils. The tree cover, ranging from 30 to 50%, is generally greater than the shrub cover, which ranges from 20 to 30%. Tree height is generally 10 to 15 m, and the principal characteristic species are Pterocarpus erinaceus, Terminalia macroptera, Bombax costatum and Cordyla pinnata. Other associates include Combretum glutinosum (ubiquitous), Sterculia setigera, Lannea acida, Lannea velutina and Daniellia oliveri. The shrub cover tends to be dominated by the Combretaceae family: Combretum glutinosum (dominant), Combretum nigricans, Combretum geitonophyllum, Combretum micranthum and Combretum crotonoides. The shrub understory is also characterized by Vitex madiensis (common), Terminalia macroptera, Strychnos spinosa, Hexalobus monopetalus, Annona senegalensis, Hymenocardia acida, Crossepterix febrifuga and Securidaca longipedunculata.

Numerous depressions are scattered on the plateaus, with Mitragyna inermis, Saba senegalensis and other hydrophytes growing among them.

The herbaceous understory is dominated by Pennisetum subangustum, Pennisetum pedicellatum, Andropogon amplectens and Andropogon pseudapricus. Among these tall grasses are Borreria chaetocephala, Cochlospermum tinctorium, Hyptis suaveolens and many others.

These woodlands represent an important resource that is quickly dwindling as deforestation for agriculture and degradation by fire threatens its existence.

Unit BdF3

This dense savanna-woodland and dry woodland occurs to the west of BdF1 and BdF2, on uplands of central Moyenne Casamance, on poorly evolved, leached tropical ferruginous soils. Lying well within the Sudano-Guinean domain, the rainfall is somewhat higher than that of the previous units (BdF1 and BdF2). The community is generally well-preserved and can be considered climax (G. Boudet, et al., 1970).

The upper story is heterogeneous. Pterocarpus erinaceus becomes less common than to the east, and Cordyla pinnata, Bombax costatum, Ostryoderris stuhlmannii, Combretum glutinosum, Afzelia africana, Terminalia macroptera and Hexalobus monopetalus (growing larger than to the east) are the most common associates. The woody understory, less dense than the overstory, is dominated by Combretum nigricans, with the common associates: Crossepterix febrifuga, Acacia macrostachya, Grewia lasiodiscus, Lannea velutina, Vitex madiensis, Hexalobus monopetalus and juveniles of the trees listed above. The herbaceous cover is dominated by grasses with a composition similar to that of unit BdF2.

Considerable deforestation is occurring, especially on either side of the Soungrougrou River, where the woodlands are receding as agriculture expands onto the plateau.

Unit BF5

This savanna-woodland/woodland complex occurs on hydromorphic valley soils of the Haute Casamance. Unlike the gallery forests of this region, the substratum usually loses its moisture during the dry season. This moisture loss is reflected in the vegetation, which is composed of predominantly Sudanian deciduous species. On dry season Landsat imagery, these formations can be readily differentiated from the more humid, evergreen formations of the gallery forests.

The upper story ranges in cover from 20 to 40%, composed largely of Pterocarpus erinaceus, Terminalia macroptera, Daniellia oliveri, Khaya senegalensis, Parkia biglobosa, Bombax costatum, Terminalia laxiflora and Ficus ssp. A less dense shrub stratum includes Piliostigma thonningii, Mitragyna inermis (valley bottoms), Acacia

sieberiana, Terminalia ssp., Combretum glutinosum, Dicrostachys glomerata, Nauclea latifolia and Gardenia ternifolia. Oxytenanthera abyssinica can occur on the gentle slopes and often in dense clusters. Andropogon gayanus and Pennisetum subangustum dominate the herbaceous cover. Numerous forbs occur, including Tephrosia linearis, Indigcfera ssp., Hyptis suaveolens and Cassia nigricans.

These formations are usually the first to be destroyed by man for cultivation, particularly those found in the wider valleys. Grazing is fair to good throughout the year.

Unit BFh6

This unit occurs mainly in the Moyenne Casamance where the valleys become relatively wide and shallow and seasonal flooding occurs. Several formations can occur: the gentle upper slopes are generally colonized by a savanna-woodland resembling that of unit BF5, while the lower slopes are occupied by a moist evergreen riparian forest. Within the riparian vegetation bordering the valleys are aquatic prairies, many of which have been replaced by rice fields (Figs. 5.44 and 5.45).

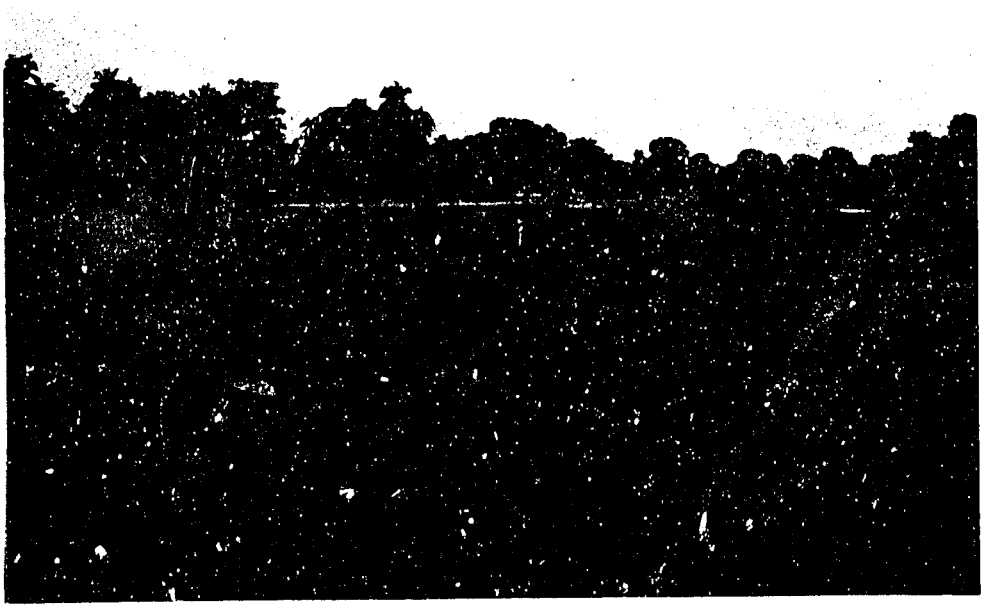
The riparian associations take on a striking Guinean character, with trees averaging 15 to 20 m. Perhaps the most characteristic tree is the oil palm, Elaeis guineensis, which lines the lower valley slopes. Common associates are Erythrophlaeum guineense, Daniellia oliveri, Pterocarpus erinaceus, Parkia biglobosa, Terminalia macroptera, Syzygium guineense, Khaya senegalensis, Ficus gnaphalocarpa, Ficus glumosa, Detarium microcarpum, Anthostema senegalense, Cola cordifolia, Afzelia africana and Mitragyna stipulosa. Even richer floristically, the woody understory is commonly composed of Nauclea latifolia, Piliostigma thonningii, Ficus capensis, Syzygium guineense, Elaeis guineensis, Saba senegalensis, Terminalia avicennoides, Anthostema senegalense, Mimosa pigra, Icacina senegalensis and other less common associates.

The herbaceous cover of the forest understory is commonly dominated by Pennisetum subangustum, Andropogon gayanus and Vetiveria nigritana. Common forbs include Hyptis suaveolens, Hyptis specigera, Urena lobata and many other genera.

The valley bottoms are the domain of aquatic herbs and grasses. If the seasonal flooding is less than 50 cm deep, Brachiaria mutica and Echinochloa pyramidalis dominate. If the water exceeds this depth, Oryza longistaminata occurs (G. Boudet, et al., 1970).

The predominant land use is the cultivation of paddy rice. The prairies provide good forage for livestock during the dry season. Most of the woody riparian vegetation observed was quite degraded, a result of overexploitation.

Figs.5.44, 45.A wet and dry season view of a wide, shallow valley typical of Moyenne Casamance. The valley sides are bordered by a moist evergreen riparian forest, often dominated by palm groves while the valley floor supports an aquatic prairie, or if cultivated, paddy rice (wet season). Note the disappearance of the large tree on the left. Location: just east of Tanaff; Oct. 4, 1982 and May 23, 1984.



Unit F2

This Sudano-Guinean woodland dominates the plateaus of southern Casamance, stretching from the Precambrian Shield in the extreme east to just west of the Soungrougrou River. The annual rainfall is about 1300 to 1500 mm (predrought), and the soils are relatively deep and slightly ferralitic, with textures that range from sandy clay to clayey sands.

This vegetation formation is significantly denser and taller than the woodlands to the north--a direct result of the higher rainfall. The vegetation can be considered climax where man has not seriously exploited its resources.

Large trees characterize this formation. The most common associates are Cordyla pinnata, Bombax costatum, Parkia biglobosa, Combretum nigricans, Prosopis africana, Pterocarpus erinaceus (less common in the southwest), Daniellia oliveri, Terminalia macroptera and less commonly Afzelia africana, Ficus glumosa, Combretum glutinosum, Burkea africana and Albizzia ssp. The tree canopy cover ranges from 30 to 60%, at a height of 15 to 20 m; the woody understory ranges in cover from 20 to 30%. It is very rich floristically and includes such common associates as Combretum nigricans, Terminalia macroptera, Lannea velutina, Holarrhena floribunda, Gardenia sp., Hexalobus monopetalus, Detarium microcarpum, Annona senegalensis, Hannoa undulata and Ostryoderris stuhlmannii.

Pennisetum pedicellatum, Pennisetum subangustum and Andropogon amplectens dominate where the tree canopy is more open. In shadier areas, the grasses include Paspalum auriculatum, Oplismenus burmannii and Schizachyrium brevifolium (G. Boudet, et al., 1970). Mixing with the grasses are numerous forbs, including Aspilia africana, Dioscorea prehensilis, Commelina sp. and Ipomaea argentaurata.

Unit F3

This Sudano-Guinean dry woodland colonizes the plateau of northern Lower Casamance and southwestern portion of The Gambia. The soils are relatively deep, slightly ferralitic and have clayey to sandy textures. This association differs somewhat from the plateau woodlands to the east by its stronger Guinean aspect, which results in part from its maritime climate. The formation tends to be quite dense, approaching that of a dense forest, with a woody cover of 70 to 80% (the upper story makes up about 50 to 60%) and an average tree height of 15 m.

While no one species dominates, common associates were identified: Daniellia oliveri, Hannoa undulata, Ostryoderris stuhlmannii, Pterocarpus erinaceus. Less common are Terminalia macroptera, Parkia biglobosa, Cola cordifolia, Detarium senegalensis, Erythrophlaeum guineense and Dialium guineense. The woody understory is very heterogeneous and includes such common species as Combretum nigricans,

Lannea velutina, Annona senegalensis, Hannoa undulata, Saba senegalensis, Acacia macrostachya and Cassia sieberiana.

Large grasses dominate the understory, particularly Andropogon gayanus and Andropogon amplectens. Among the forbs are Asparagus africana, Smilax kraussiana, Commelina sp. and Desmodium velutinum.

Typical of the Sudano-Guinean plateau woodlands, much of the herbaceous cover is burned every dry season, which maintains the formation in a more open state than one would expect to find in a climax formation.

This formation does not appear to represent climax vegetation, but rather a secondary formation. It is difficult to determine whether it evolved from clearings long abandoned by man or whether it represents the slow deterioration of a climax forest.

Unit J

This secondary forest was derived from the semi-evergreen forest that once blanketed much of the Basse Casamance. Over the centuries, and especially the last few decades, this plateau formation between Bignona, Tionk Essil and Tabor, has succumbed to the axe, destructive fire and drought. Numerous Sudanian species have invaded the clearings, growing next to Guinean species. The resulting physiognomy is very heterogeneous, with relatively dense pockets which may represent the climax forest (such as the Forêt Classée de Tendouk), and more open secondary formations which have evolved on old clearings.

The characteristic trees of this secondary forest are Daniellia oliveri, Ceiba pentandra, Erythrophlaeum guineense, Khaya senegalensis, Cola cordifolia, Parinari excelsa and Parkia biglobosa. The cover is quite variable, ranging from 30 to 60%, with a woody understory of 5 to 30%. The understory is very heterogeneous and includes many species of Combretum and such associates as Uvaria chamae, Elaeis guineensis, Moghania faginea, Cassia sieberiana, Hannoa undulata, Lannea acida, Lannea velutina and Afrormosia laxiflora.

The herbaceous cover consists of various annuals and perennials, including Andropogon sp., Pobeguinea arrecta, Olyra latifolia, Urena lobata, Hyptis suaveolens and Ipomaea azarifolia.

Numerous small clearings occur in the vicinity of villages, in which groundnuts, millet or rice are cultivated. The old fields have often developed into impenetrable thickets, from which large trees have emerged.

Unit Fh5

This moist semi-evergreen woodland occupies the wide, shallow valley of northern Lower Casamance, on hydromorphic colluvium and alluvium. It is bordered on the upland by dry woodlands of Sudanian character, forming a belt of vegetation bordering the sides of the valleys. The valley bottoms are open and support swamp prairies, or are planted in rice.

The drier soils of the valley slopes are covered by large Guinean and Sudano-Guinean trees. These include Daniellia oliveri, Khaya senegalensis, Pterocarpus erinaceus, Piliostigma thonningii, Elaeis guineensis (on lower slopes), Cola cordifolia, Terminalia macroptera, Prosopis africana, Ficus ssp. and Bombax costatum. The tree cover averages 40%, with two tiers: giants reaching 15 to 25 m and trees of shorter heights (generally Sudanian species) of 10 to 15 m. Smaller trees are generally 5 to 10 m tall and shrubs form a fourth stratum of less than 5 m; among them are Acacia macrostachya, Saba senegalensis, Hannoa undulata, Annona senegalensis, Ostryoderris stuhlmannii, Combretum micranthum, Allophylus africanus and Ficus capensis.

The herbaceous understory includes Andropogon giganteus, Andropogon gayanus, Moghania faginea, Commelina sp. and Crinum sanderianum.

The swamp prairies of the valley floor are essentially the same as those described in unit BFh6. They provide an excellent dry season pasture.

Unit T3

This unit occurs on the swamp prairies of the Moyenne Casamance which have been replaced in many areas by tannes, or salt flats, whose soils have become increasingly saline during the recent dry cycle.

A very open, discontinuous cover of halophytes colonize these flats, including Scirpus littoralis, Paspalum vaginatum, Philoxerus vermicularis and Sesuvium sp. (Adam, 1961).

Many of these tannes were, or are still, used for rice cultivation. Many have been abandoned, a result of the increasing salinity. Numerous dikes have been constructed to prevent salt water from reaching the paddies. They also serve to store rainwater.

Unit TP

This cover type is a mosaic of the tannes with their discontinuous cover of halophytes, the swamp prairies that occur in the valley bottoms and to a lesser extent, the mangrove formations that border the estuaries and channels. Refer to units T3, FhL and M for further descriptions.

Unit XP

Unit XP is a complex of swamp prairies and denuded tidal swamps which support little or no vegetation. Most of this unit was recently covered by a mangrove formation that has succumbed to drought, increased salinity, and devastating fire.

The herbaceous cover of the prairies is commonly composed of Paspalum scrobiculatum, Paspalum vaginatum, Oryza ssp., Heleocharis mutata, Sesuvium portulacastrum, Borreria verticillata, Philoxerus vermicularis and Scirpus maritimus. Shrubs and trees are generally absent, though occasional remnants of the mangrove formation may occur on the tidal swamps. These individuals are usually stressed or dead.

Fig. 5.46. An aerial view of an area west of Sêlêki showing a complex of rice paddies, mangrove communities and denuded tidal swamps. Altitude 500 m; Sept. 17, 1984.

5.4.3 The Guinean Phytogeographic Region

The Guinean Phytogeographic Region proper can be found only in the extreme southeast corner of Senegal, although characteristics of this zone begin to manifest themselves in the Sudano-Guinean domain, particularly with the appearance of Elaeis guineensis and the development of gallery forests of Guinean affinity. This is the region of the semi-deciduous dense forest; its extent has been reduced to a few remnant communities by widespread deforestation for the cultivation of rice, manioc and groundnuts.

As defined by J.G. Adam (1966), the Guinean Region predominates in the areas of average annual rainfall exceeding 1500 mm, with the central Guinean Region having precipitation levels of over 1800 mm.

The transitional Guineo-Sudanian Domain (1500 to 1800 mm) is approximately defined as lying to the south of the lower Casamance River, while the Central Guinean Domain begins to the south of Oussouye.

Despite the high rainfall, this region has a distinctly dry season of 7 to 8 months, distinguishing it from the Equatorial Region of Africa. The lush, dense vegetation of Basse Casamance owes its existence, in part, to the presence of fresh groundwater just beneath the surface.

A. Aubreville (1948) hypothesizes that the semi-deciduous Parinari and Erythrophlaeum forest once extended from the ocean to the Marsassoum estuary. Most of the present day forest formations represent more or less degraded or reconstructed evolutions of this primitive forest under the combined action of fire and deforestation (Pelissier, 1966).

The composition of the remnant or reconstituted forest communities is never homogeneous; nor are there clearly defined woody strata. The average height is 18 to 20 m, though the larger trees can reach over 30 m. The forest canopy is generally dense and closed, forming over a luxuriant, heterogeneous woody understory. The herbaceous cover is often poorly developed and dominated by nonpyrophytic, coarse grasses.

The palm groves which so characterize the lowlands and slopes of the Basse Casamance result from a prolonged, systematic human intervention (Pelissier, 1966). They are related to the system of land use in which man has selectively preserved and maintained these relatively homogeneous communities.

The natural vegetation of the estuaries and tidal swamps lies in contrast to the plateau vegetation, by its homogeneity in both form and composition. These azonal types are the mangrove and swamp prairie formations.

5.4.3.1 The Casamance

A. General Characteristics

The general characteristics of the Casamance are described under the Sudanian Phytogeographic Region. The following is a description of the cover types occurring within the Guineo-Sudanian and Guinean domains of the Casamance.

B. Cover Types

Unit S19

Carved out of the dense forest cover, this anthropogenic tree savanna occupies the low plateau of Basse Casamance. As with most of the other anthropogenic tree savannas of Senegal, these areas correspond to fallow fields, old fields and cropland (Fig. 5.47). The soils are slightly ferralitic, ranging from sandy-clays to clayey sands over sandstones of the "Continental Terminal".

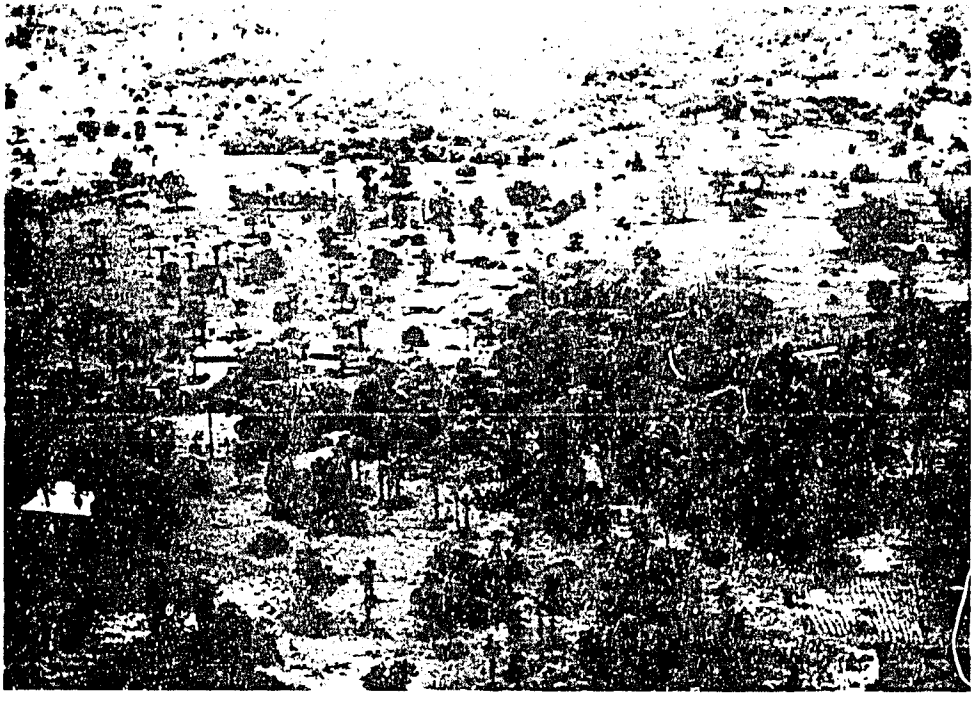


Fig. 5.47. An aerial view of deforested uplands of Basse Casamance where groundnuts, millet and upland rice are cultivated (unit S19). Altitude 100 m, Sept; 17, 1984.

Numerous large trees have been selectively preserved in the fields, particularly those which bear edible fruit. The dominants Elaeis guineensis, Borassus aethiopium (localized), Parkia biglobosa, Ceiba pentandra and Acacia albida form a cover of 5 to 10%. The lesser tree and shrub cover can become very thick and quite heterogeneous in old fields. The first invaders of fallow fields are Guiera senegalensis, Icacina senegalensis and Borassus aethiopium. Numerous associates include Cassia sieberiana, Combretum micranthum, Cnestis ferruginea, Newbouldia laevis, Annona senegalensis, Moghania faginea and Piliostigma thonningii.

The dominant grasses are Andropogon gayanus, Cymbopogon giganteus and Eragrostis tremula. Numerous forbs invade the fallow fields, including Hyptis suaveolens and Chrozophora senegalensis. Unlike the Sudanian Region, fire is relatively rare here. Actively sought out by livestock, the old fields' varied herbaceous composition provides good forage most of the year. Overgrazing was not as apparent here as it is to the north.

The predominant crops are groundnuts, upland rice and millet as a subsistence crop.

Unit S20

This anthropogenic tree savanna occurs along the coast of Basse Casamance, on poorly evolved hydromorphic soils of sandy texture.

The scattered trees which are preserved in the fields are dominated by palms: Elaeis guineensis and Borassus aethiopium. Acacia albida can dominate in areas farther inland. Other associates include Parkia biglobosa, Ceiba pentandra and Ficus gnaphalocarpa.

Shrubs vary in cover from a few scattered bushes in cultivated fields to thickets in abandoned fields. One commonly finds Guiera senegalensis (an early invader), Acacia albida, Moghania faginea, Borassus aethiopium, Bridelia micrantha, Afrormosia laxiflora and Landolphia heudelotii.

Common grasses are Andropogon ssp., Ctenium villosum and Eragrostis sp. Among the numerous forbs are Borreria verticillata, Ipomaea asarifolia, Cassia obtusifolia and Hyptis suaveolens.

The land use is like that of unit S19: mountain rice, groundnuts, millet and good rangeland in the fallow fields.

Unit FhL

Lining the low, wide valleys of southern Casamance, this unit is a complex of moist woodlands and palm groves. The usually open valley floors support either a swamp prairie or rice paddies (refer to unit BFh6). The palm groves generally occupy the lower valley slopes, often dominating the riparian vegetation as a result of centuries of human intervention (Fig. 5.48).

Fig. 5.48. An aerial view of the complex of moist woodlands and oil palm groves that border the low, wide valleys of Basse Casamance. Paddy rice is cultivated in the fields. Location: east of Ziguinchor; altitude 300 m; Sept. 17, 1984.

This deciduous moist woodland mixes commonly with the palms (Elaeis guineensis). It is generally composed of Cola cordifolia, Khaya senegalensis, Parkia biglobosa and Erythrophlaeum guineense. Associates include Detarium senegalensis, Ficus capensis, Dialium guineense, Parinari excelsa and Morinda geminata. The tree canopy ranges in cover from 40 to 60%, while a heterogeneous understory is relatively open (10 to 30%). Principal shrubs include Newbouldia laevis, Nauclea latifolia, Combretum micranthum, Cnestis ferruginea, Uvaria chamae, Cassia sieberiana, Dialium guineense and Voacanga africana.

The quite tall and dense herbaceous understory is dominated by grasses, including Oryza setigera, Brachiaria mutica, Imperata cylindrica and Pennisetum subangustum. The forbs include Echinochloa pyramidalis, Urena lobata and Hyptis ssp.

These narrow bands of riparian vegetation constitute a rich source of forest products and provide good year-round grazing land.

Unit FD

This is a transitional formation comprised of deciduous woodlands and dense semi-evergreen Guinean forests. It occurs on the low plateaus to the southeast of Ziguinchor, on slightly ferralitic clayey-sands to sandy-clays. The deciduous woodlands are the same as type F2 and are confined to the highest portions of the plateau where groundwater is too deep to influence the vegetation. The dense semi-evergreen forests occupy the lower parts of the plateau where the groundwater is shallow enough to be utilized by many of the woody species. The composition of this formation is quite heterogeneous, although it does not represent the climax vegetation. The characteristic trees are Daniellia oliveri, Khaya senegalensis, Ceiba pentandra, Detarium senegalensis, Erythrophlaeum guineense, Parinari excelsa and Cola cordifolia. The cover ranges from 60 to 80% and together with an understory of 20 to 40% shades the forest floor from direct sunlight. Lesser trees and shrubs include Elaeis guineensis (very common at the forest edge), Saba senegalensis, Combretum micranthum, Albizzia zygia, Voacanga africana and Gardenia sp.

The herbaceous understory is not as well developed as that of a savanna. Grasses include Andropogon tectorum and Beckeropsis uniseta, and the numerous forbs include Dioscorea prehensilis, Crotalaria glauca and Commelina sp.

This is one of the richest forest formations in the country in terms of its considerable economical value, particularly for a country which imports over three-fourths of the wood it needs for construction. Nevertheless, this formation should be protected from the unrestrained deforestation that the region has experienced in recent decades.

Unit LJ

This complex of palm groves and secondary forests occurs on the low plateaus to the south and west of Ziguinchor. The deciduous woodlands to the east have almost completely disappeared in this area and are replaced by a semi-evergreen, dense formation. The vegetation has been degraded over the centuries by fire (which still occurs, though is not widespread) and deforestation and is modified by the selective preservation of certain species, particularly Elaeis guineensis. This oil palm is no longer restricted to the periphery of valleys as it is to the east and dominates these low plateaus.

Tree associates that dominate these low plateaus are essentially those found in the dense forests of unit FD, with the scattered appearances of Borassus aethiopium. The shrub composition is also similar and includes such additional associates as Malacantha alnifolia, Uvaria chamae, Tetracera alnifolia, Cnestis ferruginea and Landolphia heudelotii. The herbaceous cover is quite dense and includes the grasses Cymbopogon giganteus, Pennisetum subangustum and such forbs as Abrus precatorius, Desmodium velutinum, Commelina sp. and Cissus sp.

This formation appears to have developed from abandoned fields, as indicated by the dense population of Elaeis guineensis and the relatively low density of large trees.

Fig. 5.49. Portion of a Landsat false-color composite over Basse Casamance. A number of vegetation and land use types are visible, including a) mangroves, b) upland agriculture, c) upland secondary forests with burned understories, d) an active bush fire in Guinea-Bissau, e) tannes, and f) a complex of secondary forests and palm groves, and dense evergreen forests. Date: Feb. 21, 1973.

Unit Dh

This unit is one of the few relics of the moist evergreen Guinean forest that once blanketed the Basse Casamance. It is currently protected, lying within the Parc National de Basse Casamance.

The upper story of this upland forest is dominated by a heterogeneous association of large trees, particularly Parinari excelsa, Erythrophlaeum guineense with Anthocleista ssp., Albizzia ssp. and Antiaris africana.

The shrub and smaller tree understory does not appear to be climax but rather is reverting slowly to its original state. It contains many species of Sudanian origin (Schneider and Sambou, 1982). Common species include Tetracera alnifolia, Saba senegalensis, Uvaria thomasii, Combretum micranthum, Anthostema senegalensis, Pavetta corymbosa and Cnestis ferruginea. The herbaceous cover is not well developed as a result of the low light conditions. Among the grasses are Andropogon auriculatus and Schizachyrium platyphyllum. Common forbs include Dioscorea hirtiflora and Abrus precatorius.

The high canopy averages 20 to 30 m and its overlapping crests form a cover of nearly 100%.

Unit I

This thicket colonizes the coastal dunes which have been deposited along the Atlantic in southern Casamance. The present thicket was likely once covered by a dense Guinean forest. The short, almost impenetrable, woody cover averages 2 to 4 m in height and is dominated by Malacantha alnifolia, Salacia senegalensis, Fagara leprieurii, Chrysobalanus orbicularis, Nauclea latifolia, Cnestis ferruginea, Landolphia heudelotii and other less common associates.

Although the present use of this formation is very limited, P. Giffard (1974) indicates that a reforestation effort may be promising given the high rainfall, the shallow water table and the favorable soil texture.

5.5 THE VEGETATION DEGRADATION MAP

The vegetation degradation map represents an integration of several sources of information, including the Map of Vegetation Cover, 1:500 000; the Land Use/Land Cover Map, 1:500 000 scale; field data collected by the vegetation survey team; maps of population and animal distribution; and climatic data. Vegetation degradation as it appears on the map is defined as the diminution or destruction of plant production and productivity within an ecosystem. It can be observed through reduced productivity of desirable plants, alterations in the vegetative biomass, and reductions in the diversity of the flora. Vegetation degradation, along with the degradation of soil, water and

animal resources, contributes to the process of desertification, by which the overall biological potential of the land is reduced, leading ultimately to desert-like conditions. The map shows relative occurrence of vegetation degradation due to three principle sources:

1) Degradation induced by climatic events. This source of vegetation degradation is related to the dry period experienced in Senegal since the early 1970's. Three levels of climate-induced degradation are shown: very severe (northern Senegal), severe (central Senegal) and moderate (southern Senegal). These broad classes were determined were completed by expressing the average annual rainfall of the dry period (1970-1984) as a percentage of the average annual rainfall of the predrought (1930-1969) period. Thus, in the northern third of Senegal, rainfall of the dry period amounted to less than 60% of the predrought average. Furthermore, analysis of rainfall data shows that the distribution of rainfall within a given season and year to year is highly erratic in the north, further inflicting stress on the vegetation. In central Senegal, post-1970 rainfall amounted to 60 to 70% of that of pre-1970. In the south, rainfall averaged over 70% of the predrought period. Rainfall in the south tended to be more evenly distributed spatially and temporally. The map boundaries between the classes of climate-related degradation are somewhat arbitrary, as they are based on percentage figures. They are meant only to give an indication of a transition in climatic severity.

2) Degradation induced by human activity. This category refers to all anthropogenic disturbances of the vegetation cover. The most direct impact of man on the vegetation includes the destruction or degradation of the cover through conversion of range and woodlands to dryland agriculture, exploitation of woodland resources for firewood and charcoal production, and the practice of rangeland burning. Indirect longer term impact includes shifts in settlement patterns, the development of new settlements and an increase in population density.

Three qualitative classes of man-induced vegetation degradation are used on the map: very severe, severe and moderate. In the "very severe" case, dramatic loss of vegetation cover occurs, which can almost always be observed on the Landsat imagery as increases in ground reflectance in the visible bands. "Severe" degradation is less noticeable on the imagery but is quite noticeable on the ground. Generally, vegetation cover loss is only partial. "Moderate" degradation is not directly visible on the Landsat imagery, though indicators, including the occurrence of bush fires may be present. Generally, the loss of vegetation cover is gradual, with a slow succession toward more open formations. Evidence of moderate degradation can be observed in the field.

3) Degradation induced by animal pressure. Animal-induced degradation generally results in range degradation through over-grazing and trampling of the understory. The level of animal impact on the cover is a function of several factors, including herd composition, herd size and type of pastoralism. Three classes of severity are shown on the map: very severe, severe, and moderate. The criteria used to define these classes are similar to those used under man-induced degradation.

Three gray levels (including white) are used on the map to display the climate-related degradation. Hachures (map patterns) are used to show varying degrees of man and/or animal-induced degradation. Various combinations of these three sources can occur in a given area, indicating the main causes of degradation and their relative intensities. The darker the map tone and pattern, the greater the stress on the vegetation cover.

Vegetation degradation was evaluated within the context of its land use. The open vegetation formation of a given agricultural area was not compared directly with the adjacent "natural" formations, but rather to conditions of other agricultural areas. Similarly, rangeland conditions were compared to other rangelands. For example, in cultivated areas where the vegetation cover and productivity is maintained through conservation techniques, degradation was considered minimal or absent. Man-induced degradation through encroachment of agriculture onto "natural" vegetation is shown only where it has occurred since 1972 when Landsat data first became available.

5.6 APPENDIX C: VEGETATION AND LAND USE

Previous Page Blank

APPENDIX C

Definition of Vegetation Types

The following vegetation types are defined according to the inter-African accord on the nomenclature of the types of vegetation of tropical Africa. Only those types found on the accompanying vegetation map of Senegal are included here. The definitions are based on those of J. Trochain (1957), R. Letouzey (1969) and T. Monod (1956).

A. Steppe (steppe): open herbaceous formations, ocassionally mixed with woody plants. Bush fires do not generally occur within this vegetation type. Perennial grasses are widely spaced and do not usually reach a height of 80 cm. Annuals are often abundant between the perennials.

B. Pseudo-steppe (pseudo-steppe): although this term was not adopted by the inter-African accord, it is used here to describe a formation that has the characteristics of a steppe, though the herbaceous cover is more or less continuous and less open than that of a steppe.

C. Shrub and/or tree pseudo-steppe (pseudo-steppe arbustive et/ou arborée): a pseudo-steppe with scattered shrubs and/or trees.

D. Herbaceous steppe (steppe herbacée): a steppe where trees and shrubs are totally or practically absent.

E. Savanna (savane): a herbaceous formation composed of a cover of tall grasses measuring at least 80 cm at the end of the growing season. Forbs of lesser heights occur among the grasses. This cover is generally burned each year; trees and/or shrubs are often scattered among the grass cover.

F. Shrub savanna (savane arbustive): a savanna with scattered shrubs.

G. Tree savanna (savane arborée): a savanna with scattered shrubs and trees.

H. Savanna-woodland (savane boisée): a savanna where trees and shrubs form a generally open cover.

I. Shrub woodland (savane boisée arbustive): a savanna woodland where shrubs dominate; trees are somewhat scarce (this term is also not defined in the inter-African accord).

J. Dry woodland (forêt claire): an open woodland with deciduous trees of small to medium size whose canopies join together.

K. Gallery forest (forêt galerie): a dense woodland formation found along watercourses in savanna, steppe or prairie environments.

L. Moist forest (forêt dense humide): a dense multistratum community consisting of a high stratum of large trees; the grass cover is generally absent, though when present, it is composed of broad-leafed species.

M. Secondary forest (forêt secondaire): a facies of degradation of the moist evergreen or semi-evergreen forest. This formation is a product of past human activity.

N. Palm grove (palmeraie): a generally open formation dominated by species of palm trees.

O. Thicket (fourré): a dense, shrub formation, evergreen or deciduous, usually impenetrable, often fragmented. The grass cover is either absent or discontinuous.

P. Mangrove (mangrove): a coastal evergreen forest formation colonised predominantly by species of mangroves.

Q. Swamp praries (prairie marécageuses): communities of halophytes on swamp and marsh soils.

In addition to the above vegetation formation definitions, the following physiognomic classes of percentage of cover based on the ICITV (1976) clasification were used to further define some of the formations:

Shrub pseudo-steppe Tree pseudo-steppe Shrub savanna Tree savanna	Woody cover between 2 and 20% (open formations: 2 to 5% and closed formations: 15 to 20%)
Savana woodland	Woody cover between 20 and 50% Dense savanna woodlands: 40 to 50%
Woodland	Woody cover between 50 and 80%
Moist forest	Woody cover above 80%

Finally, a height of 5 m was adopted to distinguish between shrubs and trees.

APPENDIX C

Example of Field Observation Sheet

The following field observation sheet is an example of the type of data collected on vegetaton and land use at a given observation site. Over 570 field observations were conducted throughout Senegal. The raw data sheets were furnished to USAID/Dakar and to the DAT.

Letter codes following species names indicate abundance classes: TC-very common (très commun); C-common (commun); P-present (présent); PC-uncommon (peu commun); R-rare (rare).

Previous Page Blank

Observation 470 Date 15 avril 84 Réditeurs G. TAPPAN; A. BOODIAN

Lieu 2 km N de Saraya

Sol argileux, assez profond

Géomorphologie plateau assez plat : roches granitiques

Occupation du sol domaine forestier

Formation savane boisée

Strate Herbacée

Hauteur 50-100 cm Couverture 0-20% Remarques passage de feu

Graminées:

Andropogon amplectans - C
Andropogon gayanus - C
Andropogon pseudapricus - C
Pennisetum subangustum - C

Non Graminées:

Tephrosia sp - P
Waltoria indica - P
Waltaria lanceolata - P
Borraria chaetocephala - P
Asparagus africanus - P
Dioscorea prehensilis - P
Lepidagathis anobrya - P

Strate Arbustive:

Hauteur 2-4 m Couverture 30-40 %

Remarques très hétérogène; assez dense

Bombax costatum - P
Vitellaria paradoxa - P
Gardenia sp - P
Diospyros mespiliformis - C
Ximenia americana - P
Lannea acida - P
Entada africana - P
Detarium microcarpum - C
Anogeissus leiocarpus - P
Strychnos spinosa - P
Piliostigma thonningii - P
Pterocarpus erinaceus - C
Hexalobus monopetalus - C
Hannona senegalensis - C
Acacia dudgeonii - C
Parkia biglobosa - P
Ostryodarris stuhlmanii - P
Combretum nigricans - P
Combretum glutinosum - P
Combretum micranthum - P
Hymenocardia acida - C
Securidaca longipedunculata - TC
Terminalia macroptera - P
Vitex madiensis - P
Afrormosia laxiflora - P

Strete Arborée:

Hauteur 8-10 m Couverture 20 %

Densité imp. Remarques

Pterocarpus erinaceus - C
Anogeissus leiocarpus - P
Vitellaria paradoxa - P
Terminalia macroptera - C
Cordylla pinnata - P
Bombax costatum - C
Acacia dugeonii - P
Lannea acida - P
Combretum glutinosum - P
Combretum nigricans - P
Parkia biglobosa - P
Afrormosia laxifolia - P
Dentarium microcarpum - P
Afzelia africana - P

5.7 BIBLIOGRAPHY

ABT Associates, Inc. (1984) Senegal agricultural sector policy analysis: Preliminary draft. Cambridge, MA. 105 p.

Adam, J.G. (1956) "La végétation de l'extrémité occidentale de l'Afrique: La pointe des Almadies aux environs de Dakar." Bull de l'IFAN, Sér. A. 18(3):685-702.

_____.(1959) "La flore des calcaires de Rufisque et Bargny." Bull. de l'IFAN, Sér. A. 21(4):1160-176.

_____. (1961) "Contribution à l'étude de la flore et de la végétation de l'Afrique occidental: La Basse Casamance; première partie." Bull. de l'IFAN, Sér. A. 33(4):911-33.

_____. (1961) "Elements pour l'établissement d'une carte des groupements végétaux de la presqu'île du Cap Vert." Bull. de l'IFAN, Ser. A. 23(2):399-405.

_____. (1962) "Contribution à l'étude de la flore de la végétation de l'Afrique occidentale: La Basse Casamance; deuxième partie." Bull. de l'IFAN, Sér. 1. 25:116-53.

_____. (1962) "Eléments pour l'étude des groupements végétaux de la presqu'île du Cap Vert (Dakar): La Série du massif de Ndiass." Bull. de l'IFAN, Sér. A. 24(1):154-67.

_____. (1965) "Généralités sur la flore et la végétation du Sénégal." Etudes Sénégalaises, CRDS-Sénégal. No. 9. Fas. 3. pp. 155-214.

_____. (1966) "Les pâturages naturels et post-culturaux du Sénégal." Bull. de l'IFAN, Sér. A. (2):450-537.

Arid Lands Information Center (1981) Environmental report on Senegal: Draft. Office of Arid Lands Studies, Univ. of Arizona, Tuscon. 105 p.

Auberville, A. (1949) La Casamance: Contribution à la paléohistoire des forêts de l'Afrique tropicale. Paris: Société d'éditeurs géographiques maritimes et coloniales. 99 p.

Audru, J. et IEMVT-LNERV (1966) Etude de pâturages naturels et des problèmes dans le delta. Etude Agrostologique No. 15. Deux tomes.

Avenard, J.M. et al. (1971) Le Milieu naturel de la Côte d'Ivoire. Mém. ORSTOM, No. 50. 391 p. et cartes.

Berhaut, J. (1967) Flore du Sénégal, deuxième édition. Paris: Le Livre Africain. 485 p.

Bertrand, R. (1972) "Morphopédologie et orientations culturales des Régions Soudaniennes du Sine Saloum (Sénégal)." Agronomie tropicale. 27(11):1115-190.

Bertrand, R. et Valenza, J. (1979) Evaluation des possibilités agricoles, pastorales et forestières des milieux naturels du Sénégal Oriental (carte au 1:500 000e). GERDAT-IRAT-IEMVT. Nimes-Courbassac: Impression Delta Productions.

Bille, J., et al. (1972) "Recherches écologiques sur une savane sahélienne du Ferlo septentrional (Sénégal)." La Terre et la Vie, Mém. 1-7. 26:325-472.

Boudet, G. (1970) Pâturages naturels de Haute et Moyenne Casamance. Etude agrostologique No. 27. 239 pp. et 1 carte au 1:200 000e.

_____. (1980) Systèmes de production d'élevage au Sénégal: Etude du couvert herbacé. IEMVT. 48 p.

Bourliere, F. (1978) La Savane sahélienne du Fété-Olé. Problèmes d'écologie: structures et fonctionnement des écosystèmes terrestres. Paris: Masson.

Braudeau, E. Join, P., et Le Brusq, J.Y. (1982) Etude pédologique des forêts classées du centre-est du Sénégal. ORSTOM, Dakar. 69 p.

Campredon, R., et al. (1982) "Essai de cartographie géologique automatisée dans un secteur sahélien: Influences des facteurs pédologiques et phytosociologiques." Bull. Soc. Géo. 24(1):9-12.

Chauvel, A. (1967) Notice explicative carte pédologique du Sénégal au 1:200 000e: feuilles Kédougou et Kéniéba-Kossanto. ORSTOM, Dakar. 155 p.

Clos-Arceduc, M. (1956) "Etude sur photographies aériennes d'une formation végétale sahélienne: La brousse tigrée." Bull. de l'IFAN, Sér. A. 28(3):677-84.

Collinson, A. (1977) Introduction to world vegetation. London: George Allen and Unwin. 201 p.

CTFT (1975) Mise en valeur des forêts de Basse et Moyenne Casamance: Inventaire forestier. Projet DP/SEN/71/522-1/FO. Nogent-sur-Marne. 94 p.

CTFT-SCET INTERNATIONAL (n.d.) Plan de développement forestier: Phase 1: Diagnostic. Dir. des Eaux et Forêsts Min. du Dév. Rural. 12 Tomes.

Dalsted, K., ed., et al. (1982) Resource inventory of southwestern Mauritania. Remote Sensing Institute, Brookings, SD SDSU-RSI-82-03. 334 p.

DAT, PNUD, DTCD (1984) Schéma national d'aménagement du territoire, version préliminaire. SEN 82.016.

Diallo, A. et De Wispelaere, G. (1968) Etude agrostologique No. 23. 173 p.

Diallo, A., et al. (1968) Pâturages naturels du Ferlo-Sud. Etude agrostologique No. 13. IEMVT-LNERV. 180 p. et 1 carte au 1:200 000e.

Dunsmore, J.R., et al. (1976) The agricultural development of The Gambia: An agricultural, environmental and socioeconomic analysis. Land Resource Division, Land Resources Study No. 22. Ministry of Overseas Development, Tolworth Tower, Sarbiton, Surrey, England. 450 p. and 4 maps.

DuPuy, A. et Verschuren, J. (1982) "Note d'Introduction biologique sur le parc national du delta Saloum." Mém. de l'IFAN. No. 92. pp. 67-92.

FAO-CTFT (1975) Mis en valeur de la Basse Casamance (République du Sénégal): Inventaire forestier. 296 p.

Fotius, G. et Valenza J. (n.d.) Etude des pâturages naturels du Ferlo Oriental (République du Sénégal). AGROST. No. 13. 180 p.

Freeman, P.H. (1982) Land regeneration and agricultural intensification in Senegal's Groundnut Basin. USAID, Dakar. 29 p.

Giffard, P. (1974) L'Arbre dans le paysage sénégalais. Dakar. 431 p.

Hagen, R.T. (1982) Remote sensing applications to forestry in West Africa. CRTO, Ouagadougou. 10 p.

IEMVT-ISRA (1977) Etude des pâturages naturels du Ferlo Boundou. Lab. Nat. d'Elevage et Recherch. Vét. Dakar-Hann. 119 p.

IFAN (1982) Rechreches scientifiques dans les parcs nationaux du Sénégal. Mém. No. 92. Dakar. 364 p.

_____. (n.d.) Senegal-Gambie: Carte d'utilisation des sols au 1:000 000e. Dept. de Géographie.

IGN (1969) République du Sénégal: Carte routière et touristique au 1:500 000. Paris.

_____. (1977) Atlas national du Sénégal. Paris. 147 p.

_____. (1980) Sénégal: Carte au 1:1 000 000e. Paris.

_____. (n.d.) Cartes de l'Afrique de l'Ouest à 1:200 000e. Feuilles des séries ND-28, ND-29 et NE-28. Paris.

ISRA-LNERV (1980) Processus de dégradations. 65 p.

Jeffreys, M.D.W. (1951) "Feux de brousse." Bull. de l'IFAN. 13(3):628-709.

Joint Operations graphic (ground) series 1501. (1966) Sheets ND-28, ND-29 and NE-29. 1:250 000 scale. Army Map Service, Washington, DC.

Keay, R.W.J. (1959) "Derived savanna--derived from what?" Bull. de l'IFAN, Sér. A. 21(2):428-38.

Khassoum, D. (1983) Edute du tapis végétal d'un ecosystème sahélien: Estimations des potentialitiés et analyse des processus de dégradations. ISRA-LNERV. 65 p.

Küchner, A.W. (1967) Vegetation mapping. New York: Ronald Press. 472 p.

Letouzey, R. (1969) Manuel de botanique forestière: Afrique tropicale. CTFT, Marne.

Lillesand, T. and Kiefer, R. (1979) Remote sensing and image interpretation. New York: John Wiley & Sons. 612 p.

MAB technical notes. (1975) The Sahel: Ecological approaches to land use. Paris: Unesco Press. 99 p.

Maignen, R. (1965) Notice explicative: Carte pédologique du Sénégal au 1:000 000e. ORSTOM, Dakar-Hann.

Marius, C. (1977) Notice explicative de la carte pédologique au 1:50 000e; Iles du Saloum. ORSTOM, Dakar. 47 p.

Michel, P., Naegele, A. et Toupet, C. (1969) "Contribution à l'étude biologique du Sénégal septentrional: Le Milieu naturel." Bull. de l'IFAN, Sér. A. 31(3):756-839.

Michel, P. (1973) Les Bassins des fleuves Sénégal et Gambie: Etude géomorphologique. Mém. ORSTOM, No. 63. Tomes I et II.

Monod, T. et Schnell, R. (1952) Melanges botaniques. Mém. de l'IFAN, No. 18. Dakar. 334 p.

_____. (1963) "Après Yangambi (1956): Notes de phytogéographie africaine." Bull. de l'IFAN, Sér. A. 2:594-619.

Mosnier, M. (1967) Etudes des pâturages naturels de Gallayel. Etude agrostologique. A6. 18. IEMVT-LNERV.

Nelson, H.D. et al. (1973) Area handbook for Senegal. US Govt. Printing Office, Washington, DC. 410 p.

Ndiaye, H.G: (1980) "Etude physiographique de la Casamance d'après les images Landsat." Comptes-rendus du séminaire de télédétection. 31 mars au 10 avril. Vol. 2. SERST/USAID. pp. 291-340.

Ndaye, P. (1980) "Végétation et faune." Atlas jeune Afrique du Sénégal. pp. 18- 19.

ORSTOM (1980) L'Arbre en Afrique tropicale: La fonction et le signe. Sér. Sci. humaines. Tome 17. Nos. 3 et 4. 320 p.

Pélissier, P., et al. (1980) Atlas du Sénégal. Paris: Editions Jeune Afrique. 72 p.

Pias, J. (1970) La Végétation du Tchad. T. and D. de l'ORSTOM. No. 6. Paris. 47 p. et cartes.

Poupon, H. (1980) Structure et dynamique de la strate ligneuse d'une steppe sahélienne au nord du Sénégal. T. et D. de l'ORSTOM. No. 115. Paris. 351 p. et cartes.

Reining, P. (1978) Handboook on deserfication indicators. American Association for the Advancement of Science, Washington, DC. 141 p.

Roberty, G. (1962) Carte de la végétation tropical occidental à 1:1 000 000e.

Sall, M. (1980) "Le Sénégal vu de Landsat." Comptes-rendus du séminaire de télédétection: 31 mars au 10 avril. Vol. 2. SERST/USAID. pp. 341-78.

_____. (1985) Projet fixation des dunes: Rapport préliminair. USAID-Eaux et Forêts-Dépt. de Géographie. 13 p.

Schneider, A. and Sambou, K. (1982) "Prospection botanique dans les parcs nationaux du Niokolo-Koba et de Basse Casamance." Recherches Scientifiques dans les parcs nationaux du Sénégal. Mém. de l'IFAN. No. 92. pp. 101-22.

Seck, O., éd. (1977) Atlas pour l'aménagement du territoire. Dakar-Abidjan: Les Nouvelles Editions Africaines. 159 p.

Shimwell, D. (1972) The description and classification of vegetation. Univ. of Washington Press. 322 p.

Stancioff, A., Tappan, G. and Staljanssens, M. (1985) Final report of the mapping and remote sensing project. Remote Sensing Institute, Brookings, SD. SDSU-RSI-85-04. 70 p

Terrible, M. (1975) Atlas de Haute-Volta: Essai d'evaluation de la végétation ligneuse. Centre Voltaique de la Recherch. Sci. Bobo-Dioubasso: Imprimarie de la Savane. 69 p.

Trochain, J. (1940) Contribution à l'étude de la végétation du Sénégal. Mém. de l'IFAN, Paris. 433 p.

_____. (1957) "Accord interafricain sur la définition des types de végétation de l'Afrique tropicale. Bull. Inst. Et. Centrafri., Nouv. Sér. pp. 55-93.

Valenza, J. et Diallo, A.K. (1972) Etude des pâturages naturels du nord Sénégal. Etude agrostologique. No. 34. IEMVT-LNERV. 311 p. et 3 cartes au 1:200 000e.

Valenza, J. (1977) Etude des pâturages naturels du Ferlo Boundou. Etude agrostologique. No. 50. IEMVT-LNERV. 119 p. et une carte au 1:200 000e.

Vanpraet, C.L. (1980) Système mondial de surveillance continue de l'environnement: Projet pilote sur la surveillance continue de la couverture forestière tropicale, Togo; Cartographie du couvert végétal et etude de ses modifications. Organisation des Nations Unis pour l'Alimentation et l'Agriculture. UN 32/6.1102-75-005. Rome. 117 p.

van Sleen, L.A., Sall, M. et Ndiaye, H.G. (1980) Comptes-rendus du séminaire de télédétection. Remote Sensing Institute, Brookings, SD. SL3U-RSI-80-04. Vols. I and II. 560 p.

Villiers, A. (1957) "Aperçu sommaire sur le peuplement des niayes de la presqu'île du Cap Vert (Sénégal)." Bull. de l'IFAN, Sér. A. 19(1):333-45.

Walter, H. (1979) Vegetation of the earth. New York: Springer Verlag, New York. 276 p.

Weber, A.W. and Major, J.T. (1984) Report and recommendation on soil conservation and regeneration in the Groundnut Basin of Senegal (draft). International Institute for Environment and Development. 30 p.

de Wispelaere, G. (1981) Systèmes de production d'élevage au Sénégal: Etude et cartographie de la végétation par télédéction. ISRA-LNERV-ACC. 51 p.

Zante, P. (1984) Etude de reconnaissance des sols aux aptitudes forestières: Projet Louga. ORSTOM, Dakar-Hann. 38 p.

Zonneveld, I.S. (1974) "On abstract and concrete boundaries: arrranging and classification." Tatsachen und Probleme der Grenzen in der Vegetation. Verlag Von J. Cramer. 41 p.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

CHAPTER VI: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction..... 637
6.2 Summary and Conclusions of the Hydrogeological Mapping of Senegal..... 638
6.2.1 Summary of the Hydrogeologic Mapping..... 638
6.2.2 Conclusions Drawn from the Hydrogeologic Mapping Effort..... 638
6.2.2.1 Conclusions Based on Geologic Mapping..... 638
6.2.2.2 Conclusions Based on Hydrologic Mapping..... 639
6.3 Summary and Conclusions of the Soils Mapping of Senegal..... 639
6.3.1 Summary of the Soils Mapping..... 639
6.3.2 Conclusions Drawn from the Soils Mapping Effort..... 640
6.3.3 Recommendations Based on the Soils Mapping Effort..... 641
6.4 Summary and Conclusions of the Vegetation Mapping of Senegal. 641
6.4.1 Summary of the Vegetation Mapping..... 641
6.4.2 Observations and Conclusions Drawn from the Vegetation Effort..... 642
6.4.2.1 The Senegal River Valley..... 643
6.4.2.2 The Northern Coast..... 643
6.4.2.3 The Dakar Region..... 644
6.4.2.4 The West-Central Agricultural Environment..... 644
6.4.2.5 The Pastoral Domain..... 645
6.4.2.6 The Eastern Transition Zone..... 647
6.4.2.7 The Region of the Shield..... 647
6.4.2.8 The Casamance..... 648
6.5 Recommendations..... 649
6.5.1 Recommendations Based on the Hydrogeologic Work of the Project..... 650
6.5.1.1 Geologic..... 650
6.5.1.2 Hydrologic..... 651
6.5.2 Recommendations Based on the Soils Work of the Project..... 652
6.5.3 Recommendations Based on the Vegetation Work of the Project..... 653
6.6 References..... 655

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This report represents the efforts of the Remote Sensing Institute and its Senegalese government counterparts at the Direction de l'Aménagement du Territoire in concert with other Senegalese Institutions, agencies, and individuals to fulfill the requirements of a bilateral agreement requiring that baseline resource maps of Senegal be prepared using remote sensing techniques, that this technology be transferred to the greatest number of Senegalese possible and that in so doing the project initiate a pilot institution building effort.

What was the basis for initiating such a project? It has been known for at least ten years that remote sensing techniques can assist in the evaluation of natural resources (Paul and Marscarenhas, 1981). The droughts of the 1970's had generated much concern about the status of the Senegalese environment. It was the hope of the drafters of the project document that this project would supply badly needed information and answer some important questions on the resources of Senegal: Has the drought affected the water table and hydrologic resources? What are the soils types of Senegal? What are the land use patterns? What soils are most capable of sustaining crops? What is the effect of cultivation on the soils of Senegal? What are the erosional limitations on agriculture? What degradation has occurred or is occurring in the vegetal cover of Senegal? Is the forested environment of the southern third of Senegal undergoing climatic or human stress? What are the mineral and fossil energy resources of Senegal?

It has been the aim of this project to focus on natural resource questions and attempt to find answers through the use of the now well established approach: the integrated remote sensing survey. We are convinced that the foregoing report and the attached maps significantly contribute to the search for answers to many of the questions asked.

This section will summarize our work, describe our conclusions and provide some recommendations which we feel may be useful in the development of Senegal and the improvement of the living standard of its people.

6.2 SUMMARY AND CONCLUSIONS OF THE HYDROGEOLOGICAL MAPPING OF SENEGAL

6.2.1 Summary of Hydrogeologic Mapping

1. Production of a new 1:500,000 polychrome map of the geology and surface hydrology of Senegal.

2. Production of a hydrologic map of Senegal at a scale of 1:500,000 showing the location of certain hydrologic features and indicating their potential.

3. Production of a tectonic map of Senegal at a scale of 1:1,000,000 showing the major structural, orogenic and metallogenic belts of Senegal.

4. Production of a water and mineral resources potential map at a scale of 1:1,000,000 showing the locations of the major mineral, fossil fuel as well as water resources of Senegal and the areas deemed to have potential for these resources.

5. Training of over 100 individuals in the basic use of remote sensing for geology and hydrologic resources and the training of one individual on a long-term basis in the detailed application of remote sensing techniques to geohydrologic investigations.

6. Increased the level of knowledge of remote sensing of a large community of Senegalese who now make up a pool of talent available for the planning, conducting and evaluating of natural resources by means of remote sensing and thus provide a basis for institution building.

6.2.2 Conclusions Drawn from the Hydrogeologic Mapping Effort

6.2.2.1 Conclusions Based on Geologic Mapping

Based on the geologic mapping and Landsat interpretation, we conclude the following:

- The Saraya granite is of metasedimentary origin as is the associated uranium mineralization.

- The Mako Series is an allochtonous sequence and represents one of many such imbricate overthrust segments in Senegal Oriental.

- Potential exists for gold in the Proterozoic banded iron deposits and jasperoid rocks of Senegal Oriental.

- Potential exists for chrome in the Mako Series.

-Potential exists for lignite and bituminous coal in the Tiel-Tambacounda axis, in particular in areas related to post-Paleozoic plutonic emplacement.

-Potential exists for biogenic concentrations of base metals in the Ségou-Madina Kouta Series.

-Potential exists for hydrothermal resources, base metals and silver in Birrimian calcareous rocks intruded by younger monzonitic granites in the Bandafassi-Ibel area.

-Potential exists for petroleum and gas in Paleozoic traps in the Tiel-Tambacounda axis and the Ross Bethio-Tivaouane area.

-Potential exists for geothermal energy sources in the cratonally active post-Mesozoic regions.

-Potential exists for porphyry-type deposits in the Youkounkoun Series.

6.2.2.2 Conclusions Based on Hydrologic Mapping

Based on hydrologic data, we conclude the following:

-Potential exists for new sources of water from Neogene fossil river sediments.

-The pre-Senegal River drainage system was an east to west system across the Ferlo and Groundnut Basin to the Fossé de Kayar.

-In portions of the Senegalese basin, the Maestrichtian aquifer is structurally discontinuous and therefore unlikely to be susceptible to salinization, except locally.

-The collection of and comparison of well data shows only a slight worsening of the hydrologic balance in Senegal.

-The water supply of Senegal is adequate, but is poorly understood, inadequately explored and improperly exploited.

6.3 SUMMARY AND CONCLUSIONS OF THE SOILS MAPPING OF SENEGAL

6.3.1 Summary of the Soils Mapping

1. Production of a new 1:500,000 polychrome map of the physiography, soils and soils associations of Senegal. This is the first soils map of Senegal at this scale.

2. Production of a land capability map at a scale of 1:500,000 summarizing the soil characteristics, their limitations and relationships to other environmental factors. This is the first

map providing data for potential land use on a national basis.

3. Production of a 1:1,000,000 soil degradation map of Senegal showing areas undergoing erosion and/or ecological stress due to wind, water, human, animal as well as chemical degradation.

4. Training of over 100 individuals in the application of basic remote sensing techniques to soils mapping.

5. Increased the level of knowledge of Senegalese scientists in the use of remote sensing, thus creating a pool of talent which will be available for future remote sensing projects in Senegal.

6.3.2 Conclusions Drawn from the Soils Mapping Effort

Suitabilities for the various formations defined in the legend may be summarized as follows:

-Coastal formations are generally best suited to protective reforestation; grazing possibilities are rather limited, and cultivation is limited by such factors as salinity and flooding.

-Alluvial formations offer minor forestry possibilities; the quality of rangeland and agricultural land varies to a large extent.

-Eolian formations also offer minor forestry potential; grazing potential is often fair to good, and the agricultural potential often real, though it depends on the possibility of irrigation.

-The Cap Vert has an urban vocation that extends over all of the recent volcanic formations and even the hinterland.

-The "Continental Terminal" sandstone formations offer a generally low forestry potential, and the Casamance is actually the only really favorable area. Agricultural and grazing suitabilities are also highly variable.

-Forestry suitabilities on marno-calcareous Paleocene are quite variable; grazing potential is moderate and agricultural suitability is most often quite low.

-The Ndiass Massif on Maestrichtian sandstone offers low potential in general, except for cultivation in the valley bottoms.

-In the Senegal Oriental region, forestry potential is generally low except on granite and micrograined igneous bedrock. Rather variable, rangeland suitabilities as most often fair to good on sedimentary or metamorphic bedrock. Agricultural potential is restricted to a few favorable locations.

6.3.3 Recommendations Based on the Soils Mapping Effort

1. Agricultural potential is thus rather confined to the Groundnut Basin, parts of the hydrographic system and the coastal formations, the Casamance and a few other favorable sites. Areas of conditional potential are often quite favorable in the northern Ferlo; Ferlo Boundou and Senegal Oriental offer the least favorable conditions.

2. The deep wells drilled in the Ferlo actually have a negative impact on soils by concentraing the herds which subsequently trample areas around the watering holes. The major problem is the sociological value of herds, which results in an excessive demand on grazing lands.

3. Only Casamance forests may be considered for wood production schemes, which should still be conservative. The planting of, such allochthonous, fast-growing species, as Gmelina arborea, which was seen in some areas, is not advisable since it is known strongly influence soil evolution.

4. The need for firewood is a problem to be solved by a woodlot policy adapted to the structure of the local communities. It is actually possible to combine shrub and forest crops in a more environmentally balanced way by creating a bocage structure, which is known to have a beneficial impact on ecology and soil conservation. The Senegalese must be taught to consider tree plantations as part of their agricultural system. This attitude is vital, especially for the Groundnut Basin, which is very much degraded by overcultivation.

5. Wind or water erosion susceptibility is generally high to very high throughout the country, and most soils are very fragile despite their location. Moreover, soil is generally deficient in phosphorus and potassium, making fertilizer indispensable. The soils with the highest chemical fertility are often those with the poorest physical properties, which makes cultivation difficult (e.g. vertic soils, brown utrophic soils, regosols on basic rocks, etc.). They are also limited in extent.

6. The irrigation technique best suited for the northern part of the country is sprinkler irrigation because of the rather light textures of the soils. This method, however, requires rather important investments and technology.

6.4 SUMMARY AND CONCLUSIONS OF THE VEGETATION MAPPING OF SENEGAL

6.4.1 Summary of the Vegetation and Land Use Mapping

1. Production of a 1:500,000 scale color map of the vegetation cover of Senegal (4 map sheets plus one legend sheet). The map was

compiled from multitemporal interpretations of Landsat imagery, acquired between 1972 and 1981, from aerial surveys (1983 to 1985), extensive field surveys (1982 to 1985), and available documents. Both physiognomic and floristic information is shown on the map. Descriptions of each map unit are provided in this report.

2. Production of a land use/land cover map of Senegal, 1:500,000 scale, black and white, in 4 map sheets plus a legend sheet. The map shows areas primarily used for forestry, grazing, agriculture, and nonutilized lands, with numerous subdivisions within each category. The map was also compiled from Landsat, aerial surveys, field surveys and available documents.

3. Production of a Map of Vegetation Degradation of Senegal, 1:1,000,000 scale, black and white. This map shows the general causes of vegetation degradation and the degree of severity attributed to each. The map integrates numerous sources of spatial data including Landsat imagery, aerial surveys, field surveys, the above vegetation and land use maps, climatic data, soils maps, and other available documents.

4. This project provided numerous Senegalese scientists and administrators with valuable exposure to the use of multistage remote sensing for vegetation and land use surveys. This was accomplished through on-the-job training and through several seminars on remote sensing.

6.4.2 Conclusion Drawn from the Vegetation Mapping Effort

The principal contribution of this vegetation and land use survey of Senegal lies mainly in the maps, which provide an up-to-date, nation-wide inventory of these highly dynamic, fragile surface resources. Every attempt was made to exploit the information-rich and indispensable satellite imagery at our disposal and to integrate existing documents with our extensive field observations to produce detailed, yet readable maps. Thus, the thrust of this effort was directed at conducting a systematic, rapid inventory of the various vegetation and land use types, including their geographic distributions, a qualitative description of their composition and an indication of their condition. Given the large area of study, the limited time and manpower allocated to the field survey (a total of 3 months in the field to map approximately 200,000 km^2), the diversity of cover types encountered and the relatively small scale of the final maps, the focus was placed on data collection and systematic inventory rather than on data analysis. As a result, observations on such phenomena as the inter-relationships between vegetation, soil, climate, animals and man and the successional positions of the various vegetation communities and their changes over time are largely lacking. The map user is encouraged to use these baseline resource maps and accompanying information as:

-an inventory of the vegetation, land use and land cover of Senegal, showing the areal distribution of the various cover types in the landscape.

-a tool for analyzing the natural environment and the relations between it and the vegetation and land use types.

-a means of assessing development potential on a countrywide basis.

-a means of planning future action with regard to an optimal, integrated land use plan.

In the course of conducting the vegetation and land use/land cover inventory, a number of general observations were made, many of which derive directly from the Landsat imagery (and were verified on the ground). These points have been grouped by the eco-geographic environments defined in section 5.4. They are summarized as follows:

6.4.2.1 The Senegal River Valley

-Increasing reflectance values in the visible bands on Landsat imagery between 1972 and 1981 indicate that the riverine *Acacia nilotica* woodlands (unit F4) are undergoing severe stress. Several dates of imagery taken during or shortly after the rainy season show little evidence that the flooding within the Senegal River Valley, a necessity for the survival of these woodlands, has occurred. Ground observations confirm a high mortality rate. These woodlands are degrading in many areas to a shrub and tree steppe.

-The swamp prairies within the Parc du Djoudj have been decreasing in extent--also a result of the low water levels of the Senegal River. This decrease has severely degraded the wildlife habitat and caused a reduction in the wintering bird population.

-Drought and low river levels have severely curtailed subsistence farming within the valley.

-Irrigated perimeters appear to be the only promising means of ensuring any reliable crop production. A dramatic increase in irrigated perimeters (particularly rice) have been noted on the Landsat imagery. Most of these areas, located between Podor and Bakel, were too small to map at the 1:500,000 scale.

6.4.2.2 The Northern Coast

-Many of the older and even some of the recent coastal reforestation efforts are degraded (loss of woody cover, high mortality) as a result of human pressure.

-As they advance downward, large expanses of active dunes threaten to engulf the *niayes*.

-The loss of vegetation cover and re-activation of sands surrounding many of the villages on the semi-fixed coastal dunes have occurred. This results largely from a combination of severe grazing pressure and the cutting of trees for fuel. The circumference of degradation around these settlements has been expanding in recent years.

-Incursion of sea water and drought have led to a high rate of mortality among the hydrophytes of the interdunal depressions, or niayes. The hardest hit species are those of Guinean affinity, particularly Elaeis guineensis.

-Aerial overflights indicated that there has been a significant reduction in market-gardening within the niayes as evidenced by the large number of abandoned fields. Reduced rainfall and increased salinity appear to be the main causes.

6.4.2.3 The Dakar Region

-The vegetation cover types of the Dakar Region exhibit severe degradation from three main causes: severe drought, overgrazing, and severe pressure from an increasing population.

-Dramatic increases in urban expansion (Pikine, Cambarene, suburbs of Dakar) are evident on the satellite imagery and on aerial photographs; there is evidence of significant loss of woody cover over much of the rangelands and croplands adjacent to the urban areas.

6.4.2.4 The West-Central Agricultural Environment

-No evidence of the original, natural vegetation cover was found in the interpretation of the Landsat imagery, or on aerial photography taken by the Project from 1983 to 1984. A few relic species of the once extensive Sudanian woodland that covered this region were found, but nowhere does the woody cover reflect its original structure.

-Areas of extreme degradation, most noticeable through the near total loss of the tree stratum (corresponding to high reflectance values on the Landsat visible bands), are evident, particularly to the north of a line between Mekhé and Darou Mousti. These areas lie in contrast to denser formations (mainly Acacia albida) in some areas of the Thiès Region.

-Comparisons of 1978 aerial photographs to aerial photographs acquired by the Project from 1983 to 1984 indicate a significant reduction in the extent of fallow fields. The agricultural pressure appears to be intensifying, accompanied by a loss of herbaceous and woody cover associated with fallow fields. More land is thus exposed to eolian erosion during the long, dry season.

-Analysis of Landsat imagery, aerial photographs and field data indicate a reduction in the cultivation of groundnuts and a

corresponding increase in millet/sorghum cultivation. This change is particularly evident in the 1982 to 1985 period. Although technically feasible, no attempt has been made to date to quantify crop area and crop by administrative unit through analysis of Landsat data.

-There appears to be insufficient use of crop residue, particularly on fields planted in groundnuts. This lack is evident from the air and on the satellite imagery by the high reflectance of the exposed, sandy dior soils.

-Although no in-depth analysis was made, considerable variation in crop condition from one area to another (biomass levels, health and vigor) was observed on wet season Landsat imagery. Further study is needed to relate these variations to actual ground conditions.

-The northern Groundnut Basin in particular has been severely affected by drought in the last fifteen years, making it a high risk area for dryland agriculture. Although some agricultural expansion has occurred on to the Pastoral Zone since the initial Landsat coverage of the area in 1972, the rate of expansion is declining.

-Large expanses of abandoned fields where cultivation has been discontinued due to increasing soil infertility are evident from the Landsat imagery. These areas are concentrated to the east of Kaolack (refer to unit V11).

-Expansion of the Groundnut Basin into the Department de Kaffrine continues at a rapid rate. Areas of cropland are even encroaching upon the edges of the forest and rangeland preserves, particularly the Réserve Sylvo-Pastorale de Déali, the R.S.P. de Doli, the R.S.P. du Sine Saloum, the Forêt de Bandia, the F. de Paté, the F. de Malem Niani, and others. This encroachment is very conspicuous on multitemporal comparisons of Landsat imagery.

-Degradation and mortality in the mangrove communities of the Sine Saloum River complex are increasing. To the north and east of Foundiougne, these communities have nearly disappeared, while to the south, along the Saloum River, the communities are under considerable stress from increasing soil salinity. Along the Diombos River, the vegetation appears relatively free of stress.

6.4.2.5 The Pastoral Domain

-The vegetation within the Pastoral Domain, particularly in the northern Ferlo, has been the most severely affected by the dry period of the last 15 years. Rainfall in the northern third of Senegal since 1970 has averaged less than 60% of the 1930 to 1969 mean.

-Drought, combined with overgrazing, has led to a pronounced reduction in woody vegetation cover, particularly on upland landscapes of the sandy Ferlo. In contrast, the vegetation within depressions has

remained relatively dense, thus increasing the occurrence of the striped pattern of the Sahelian bush.

-Drought, combined with overgrazing and woodcutting, has radically modified the floristic composition of the vegetation communities. When the herbaceous cover fails to provide adequate forage for livestock, as is often the case, ruminants focus on the woody species. As a result, the more palatable species (Acacia seyal, Commiphora africana, Acacia senegal, etc.) decrease in number while such less palatable and more drought-resistant species as Boscia senegalensis and Calotropis procera increase in density.

-High mortality rates were observed for some species, particularly Sclerocarya birrea. This phenomenon is mainly drought induced. Furthermore, very few young individuals of Sclerocarya birrea and several other species were found, indicating a shift in composition toward a more xeric community.

-Nearly all of the watering holes of the Pastoral Domain stand out on the Landsat imagery in the form of light patches surrounding one or several black dots. The light areas, ranging in radius from 3 to 10 km, correspond to highly degraded and denuded landscapes surrounding the water holes and scattered human settlements. Drought, overgrazing and trampling of the herbaceous cover are the primary causes of this phenomenon. With the disappearance of the grass cover, grazing is diverted to on the woody species until most or all of the vegetation disappears. The already serious situation is compounded by a loss of soil to wind and water erosion and an increase in runoff.

-Particularly noticeable from the air is the staggering amount of rangeland lost to termite mounds. A preliminary examination of 1984 aerial photographs of the Pastoral Domain indicate that termite mounds (both active and defunct) cover up to 50% of the soil surface.

-The emergence and development of the herbaceous stratum is highly dependent upon the distribution (spatial and temporal) and quantity of rainfall. This dependence is quite evident on Landsat wet season imagery. Green-up of the herbaceous cover corresponds well to areas having recently received significant rainfall.

-The quality (floristic composition) of a given rangeland can vary from year to year as a result of a complex set of ecological variables. Therefore, observations taken within one or two years must not be construed to represent absolutes.

-An estimated 20% of the rangelands of the Pastoral Domain are burned each dry season, despite on-going governmental programs to reduce the occurrence of grass fires. In the Ferlo, some fires are contained by fire breaks. Fires not only destroy valuable dry season forage but also expose the soil to wind erosion.

6.4.2.6 The Eastern Transition Zone

-Human- and animal-related degradation of the vegetation cover dominates over climate-related degradation.

-Although agriculture occupies less than 20% of the land in the western portion of this zone, and less than 5% in the eastern portion, multitemporal analysis of the Landsat imagery indicates that it is expanding rapidly. Systematic deforestation of the upland savanna-woodlands (units B5 and Bd9) can be easily monitored from Landsat imagery. The vegetation and land use maps show the extent of agriculture versus natural vegetation as it appeared in 1981, the date of the most recent Landsat coverage at our disposal.

-Livestock-related degradation of the vegetation cover has become acute in the 1980's for herds which traditionally remain in the north Ferlo have migrated into this area in search of better forage. The localized degradation around waterholes and settlements is not quite as severe as it is in the north Ferlo. Nevertheless, most of the valley settlements are surrounded by areas of degraded cover with radius extending from 0.5 to 3 km. Much of the deforestation here is associated with clearing for cultivation rather than overgrazing.

-Though the results are not evident on the imagery, the logging of trees for construction and charcoal making threatens the existence of the upland savanna-woodlands. Logging has altered the heterogeneity of the floristic composition, leaving behind the less "useful" trees at the expense of species like Bombax costatum and Pterocarpus erinaceus.

-Bush fires are much more widespread in this zone than to the north. An estimated 60 to 70% of the land is burned each year (based on interpretations from Landsat data). These fires are started by cultivators, herders and hunters. The effect of fire on the vegetation physiognomy and composition is considerable. Fire-resistant woody species survive, while others perish. Perennials are better adapted for resistance than annuals. The woody cover is reduced in density by annual fires, thus favoring the development of savanna formations.

6.4.2.7 The Region of the Shield

-The vegetation resources of this region have remained relatively untouched when compared with the rest of the country. The woody cover has been largely unexploited due to the remoteness of the region, the low population density and the very low level of infrastructural development.

-With human and animal pressure on the vegetation resource at a minimum (with the exception of the Kédougou and Salemata areas) and a less severe drought situation, the greatest loss of the woodland resource

is caused by fire. Analysis of the Landsat imagery indicates that over 80% of this region is burned each year. Little effort has been made to limit the occurrence of bush fires. The situation is complicated, however. If fires do not occur regularly, excessive amounts of combustible material collect and may cause severe damage to shrubs and trees when ignited than if more regular, lower fuel fires were to occur. Further study is needed.

-Varying in structure and composition, the vegetation cover is strongly correlated with the physiography and soils. Because of the small mapping scale and limited field data, vegetation communities were aggregated into a mosaic of types. The vegetation of the lateritic plateaus, ironpans (bowé) and gentle slopes were mapped as a single unit, while the vegetation of the valley slopes and talwegs were grouped into another unit. Further investigation is needed to describe the map units of southeastern Senegal.

6.4.2.8 The Casamance

The vegetation of the Casamance is undoubtedly the richest of Senegal, offering the greatest potential in terms of forest resources. Yet, through the course of the present mapping effort, it has become apparent that these resources are rapidly disappearing. Multitemporal analysis of the Landsat imagery over the Casamance indicates that drastic changes in the land cover are occurring, including:

-In the Haute and Moyenne Casamance, rainfed cropland increased by 30 to 50% between 1972 and 1979.

-Upland woodlands of the Haute and Moyenne Casamance have suffered a 10 to 15% loss in area to agricultural encroachment during the same years.

-Upland woodlands and secondary forests of the Basse Casamance suffered a 15 to 20% loss in area between 1973 and 1979. Field observations indicate that this encroachment of agricultural lands onto the natural vegetation formations is continuing in the 1980's.

-In Basse Casamance rainfed cropland increased 15% between 1973 and 1979. This figure is lower than that of Haute and Moyenne Casamance as the potential for expansion is more limited due to the extensive estuary formations. Furthermore, rainfed agriculture was already very extensive in 1973; it already exceeded the area covered by forest formations by approximately 15%, and more than doubled that level by 1979.

-Increasing soil salinity and human activity have caused a significant decrease in mangrove cover, amounting to between 5 and 10%. This decrease is particularly acute in the Bignona and Ziguinchor areas. Also noted was a corresponding areal increase in the tannes and mudflats of the Casamance estuaries.

-The distribution of bush fires within the upland savanna-woodlands and woodlands of the Casamance is as widespread as it is in the Region of the Shield (Senegal Oriental). Over 80% of the uplands are burned each year. Unlike the Ferlo, few attempts have been made to control bush fires. While their impact on both the woody and herbaceous vegetation is considerable, further study is needed to determine the best plan of action with regard to fire control.

-The primary causes of vegetation degradation in the Casamance are human-related. The semi-deciduous and deciduous forests that once blanketed the Casamance are being reduced to upland remnants through widespread deforestation in favor of rice, groundnut, cotton and manioc cultivation.

-Drought effects on the upland vegetation of the Casamance have been relatively moderate. The areas which have suffered the most adverse effects are the lowland and estuary vegetation formations. Among them are the mangrove formations, whose high mortality rates have been aggrevated by improper drainage procedures which have lead to severe soil acidification.

-Since 1970 the traditional swamp rice cultivation has also suffered from the lower rainfall levels. The rains have not been sufficient to leach the accumulation of surface salts, and a significant decrease in swamp rice is apparent on the imagery. This increasing salinity explains in part the dramatic expansion of upland agriculture at the expense of the natural forest cover. More detailed analysis of Landsat imagery and aerial photography is needed to determine the rates of decrease in swamp rice cultivation and the rates of increase in of upland agriculture.

-Not only has the forest and woodland cover been shrinking at an unprecedented rate, but it has also been floristically degraded by logging and fire. The resulting shift from dense formations to more open formations could be quantified through multitemporal analysis of aerial photographs.

6.5 RECOMMENDATIONS

The very large amount of new data provided by this survey will require much more than a rapid analysis before conclusions can be drawn and a set of comprehensive recommendations made. Furthermore, because the data is subject to change due to its dynamic nature, some of its value will be lost before the necessary analyses are made, numerous conclusions drawn, correct decisions made and some action taken. Although we do present a number of recommendations, our task and that of the Senegalese planner would be simplified if the data previously published and that which we have gathered here were to be assembled in a format permitting its analysis in a more rapid, precise, quantitative and statistical way. Such an approach would permit future projects and analysis to be incorporated more efficiently and analyzed more

effectively and rapidly, thus reducing the possibility of repetition and error. It is therefore our first recommendation that the materials presented in this report, those previously collected and future data be integrated into a Geographic Information System (GIS). Such a system has been shown to be a rapid, efficient and comprehensive means of analyzing large amounts of illustrative, descriptive and statistical data in many parts of the world, including Senegal (Cisse, 1984).

What other specific recommendations can we safely make on the basis of our work and in conjunction with recommendations previously made in the Schéma national d'aménagement du territoire (1984)? It was stated earlier that most of our work consisted of collecting data either in the field or from Landsat interpretation. Furthermore, the presentation of these data in the maps appended to this report was a time consuming effort. Because such cartographic work is not usually undertaken by those who have already served as data collectors and in various other capacities, the time left was insufficient for the authors to analyze and integrate the data and produce a set of comprehensive recommendations. With this caveat plainly stated, we feel we can present a limited number of recommendations or rather suggestions formulated on the basis of our limited experiences and conclusions.

6.5.1 Recommendations Based on the Geologic and Hydrologic Work of the Project

6.5.1.1 Geologic Recommendations

A. Practical or immediate recommendations

1. Test the gold potential of the sedimentary series most closely associated with the jaspers and banded iron ores of Senegal Oriental.

2. Test the chrome bearing potential of the Mako ultrabasic sequence.

3. Test the potential for lignite on the eastern flank of the Oldou Débokol gravity anomaly.

4. Search for accumulations of stromatolites and associated, biogenically enriched base metal deposits in the Ségou-Madina Kouta Series.

5. Search for hydrothermal base metal concentrations in the calcareous sequences of the Dialé and Daléma series when they are intruded by calc-alkaline, post-orogenic granites.

6. Review the oil and gas potential of Senegal and formulate a new approach (legal and financial) for the development of Senegalese hydrocarbon resources.

7. Remap the Precambrian and Paleozoic region of Senegal Oriental at a scale of 1:50,000 or 1:100,000 to resolve numerous stratigraphic, structural and metallogenic problems which now negatively affect long-term mineral development.

8. Through research, attempt to find ways to more effectively and less expensively use Senegalese phosphates in Senegal.

B. Less immediate recommendations

9. Establish the potential of the Kakadian granitized series for massive sulfides.

10. Investigate the potential for geothermal resources in the Senegal Basin where positive gravity anomalies occur which may represent Mesozoic or more recent intrusive hot spots occur.

11. Investigate the potential for oil and gas in the thicker Paleozoic sections of Senegal represented by negative gravity anomalies.

12. Re-evaluate the gravity and magnetic data and improve the tectonic map and the understanding of the tectonic and metallogenic history of Senegal (research project).

13. Investigate the make up and depth of the material represented by the north-south trending, 50 to 60 milligal positive gravity anomaly which bisects eastern Senegal (research project).

6.5.1.2 Hydrologic Recommendations

A. Practical recommendations for immediate action

1. Investigate the potential of fossil rivers as interpreted from Landsat data, especially in towns or villages located on these features.

2. Halt shallow well drilling from the estuary and the river bed of the Sine Saloum to 10 km inland to slow the rate of saline infiltration.

3. Drill a few deep wells to the Maestrichtian aquifer in the above zone to meet the needs of the local populations.

4. Proceed with a carefully planned campaign to investigate the potential of the Maestrichtian aquifer.

5. Require, if possible, villages and towns (particularly in the Groundnut Basin) to provide the Direction de l'Hydraulique with information on the wells in their areas. Provide simple forms and instructions through the agricultural extension service for

the organized collection and evaluation of this data.

6. Support the study of the Paleocene and Eocene aquifers of western Senegal to establish their potential.

7. Study the potential use of the Maestrichtian aquifer for limited irrigation purposes for the development of vegetable and fruit gardens in the Groundnut Basin.

8. Through the extension services, educate villages to more regularly clean (deepen) conventional wells.

9. Support the development of inexpensive, light weight material to be used as liners in conventional wells. Such an effort could increase the production of wells, extend their life, make them easier and safer to clean, and decrease the potential for accidents during well digging. It is proposed that such liners be made of plastic and produced in 3-piece, 2 m sections, with notched extremities for a tight fit. The sections should be made to fit the 2 m diameter conventional wells, and, when needed, perforations should be added to permit the entry of water. The advantage of plastic over concrete is that it is light weight and transportable. Moreover, it could be emplaced in existing wells and permit the exploitation of more than one water bearing layer in the same well.

10. Review deep wells in the Ferlo to ascertain their effect on the ecosystem of the Ferlo. The decision to drill more wells, and so provide more water for more cattle, should be based on such a study. An alternate solution might be considered if such additional water usage were found to place too great a burden on the Maestrichtian aquifer. This solution would provide for the pumping of the Senegal River waters into the Ferlo system west of Kanel, thus creating a green belt (see 3.10.6 for further explanation) and alleviating the demands on the deep Maestrichtian aquifer.

11. Assist villages in digging second or third wells where, as demonstrated in our survey, the recent drought has depleted or strained the existing wells.

6.5.2 Recommendations Based on the Soils Work of the Project

The suggestions or recommendations related to soil use are detailed under the description of each soil unit. Furthermore, the Land Capability map is in a sense the summary document for the soils mapping effort. This map represents an integration of the soil characterizations and descriptions that pertain to use. The hierarchical gradation of each unit and the restricting factors that limit each unit define its potential and therefore its recommended use.

Three additional suggestions might be considered. In citing the works consulted, it was noted that certain areas of Senegal have excellent and numerous soil descriptions, whereas others have received much less attention. Furthermore, because of recent environmental degradation due to the lack of rainfall or overcultivation, several areas need to be studied in further detail. It is therefore recommended that the Groundnut Basin in particular and areas comprising the Nouvelle Terres be considered for additional soils mapping at a scale of 1:50,000 or 1:100,000. It would be worthwhile to analyze the soils of Senegal, especially in the two previously mentioned regions to establish their fertilizer requirements. Finally, additional field work should attempt to evaluate the effects of cropping patterns on the soils of the central and western portions of Senegal.

6.5.3 Recommendations Based on the Vegetation and Land Use/ Land Cover Work of the Project

Without an in-depth evaluation of the considerable spatial data collected on vegetatioon and land use, it would be premature to make specific recommendations on the optimum management of these dynamic surface resources. Some general recommendations include:

1. More emphasis should be placed on multitemporal monitoring of the dynamic surface resources of vegetation and land use, taking advantage of the repeated Landsat coverage over Senegal. This will enable resource specialists to closely monitor such problems as the locations and rates of deforestation, the effects of bush fire on the vegetation cover, mortality rates of the riverine woodlands along the Senegal River, mortality of the mangrove communities, effects of waterholes on Sahelian rangelands, etc. This monitoring should be the first step in reversing the effects of degradation and overexploitation.

2. The nearly threefold increase in the spatial resolution of Landsat data, offered by the new Thematic Mapper should be utilized to improve crop statistics and as an aid in predicting crop yields. Although crop identification and crop condition estimation were not performed under this study, experience gained from Landsat interpretations and detailed ground data collection indicate that identification and differentiation between groundnuts, millet/sorghum, and fallow fields is possible, but such efforts are limited by the spatial resolution (80 m) of the Landsat MSS system. The new Thematic Mapper system, however, offers great potential in overcoming this difficulty, and could revolutionize the method of collecting agricultural statistics.

3. More attention must be given to the effects of bush fires on the rangelands and woodlands. Reduction in the frequency of bush fires, particularly in the southern half of Senegal where fire-control measures are presently limited, may help solve the critical shortage of firewood. By limiting the occurrence of fire,

a natural thickening of the woody strata would occur over time. Under proper management, some of the woodland areas could be thinned out by selected tree felling and collection of firewood. The firewood could then be transported to distribution centers in areas experiencing severe shortages (the Grondnut Basin, the Fleuve Region). This procedure would also alleviate some of the pressure on the degraded tree cover in the north and west.

4. More protection of the forêts classées and réserves sylvo-pastorales is needed. It is quite apparent from the Landsat imagery that agricultural expansion has encroached upon these "protected" areas. Major problem areas can already be identified on the vegetation and land use maps; however, further analysis of recent Landsat imagery and aerial photography is needed to pinpoint these areas.

5. Among the most degraded landscapes in terms of soils and vegetation cover are those in the vicinities of water holes. They appear as circular blemishes on the Landsat imagery, indicating severe loss of cover. Regulations regarding their use with a goal of minimizing soil and vegetation degradation should be implemented, particularly since the present trend is leading to permanent degradation. The periodic closure of water holes may solution. This would require us watering holes in rotation. Other possibilities include controlling the access to the waterholes through fences which would allow certain areas around the water holes to regenerate. Access could be gained through temporary corridors which could be shifted from one year to the next.

6. There is an urgent need for research and experimentation on methods for reducing the overexploitation of the woody cover and to encourage natural regeneration. While this study did not focus on solutions to the problem, the on-going large scale removal of the vegetation cover through agricultural expansion, overgrazing, tree cutting and fires was evident not only from the field surveys, but also quite visible on the Landsat imagery.

7. The users of the results of this mapping survey should also consult the extensive literature on the forest, rangeland, and land cover resources of Senegal. There are numerous, valuable studies on such subjects as rangeland productivity, various uses of herbaceous and woody species, results of reforestation efforts, etc. An integration of the spatial information gathered during the present effort with findings from other studies should lead to the drafting and implementation of an optimum, integrated plan for land use and development.

6.6 REFERENCES

DAT, PNUD, DTCP (1984) Schéma national d'aménagement du territoire, version préliminaire. SEN.82.016.

Paul, C. and Mascarenhas, A. (1981) Remote sensing in development. Science 214(4517):139-45.