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PROCEEDINGS OF SUDAN SYMPOSIUM AND WORKSHOP ON REMOTE SENSING

October 1980

Visiting International Scientist Program

Remote Sensing Institute · SDSU · USA

·VISP·

VOLUME 1

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PROCEEDINGS OF SUDAN SYMPOSIUM AND WORKSHOP ON REMOTE SENSING

October 1 - 11, 1979

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Remote Sensing Institute
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Brookings, South Dakota 57007
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July, 1980

ABSTRACT

These Proceedings contain papers presented at The Sudan Remote Sensing Symposium and Workshop held in Khartoum, Sudan, from 1st to 11th October, 1979. This Symposium and Workshop were organized and conducted jointly by the National Council for Research of the Democratic Republic of The Sudan (NCR), and the Visiting International Scientist Program (VISP) at the Remote Sensing Institute, South Dakota State University (RSI), Brookings, South Dakota.

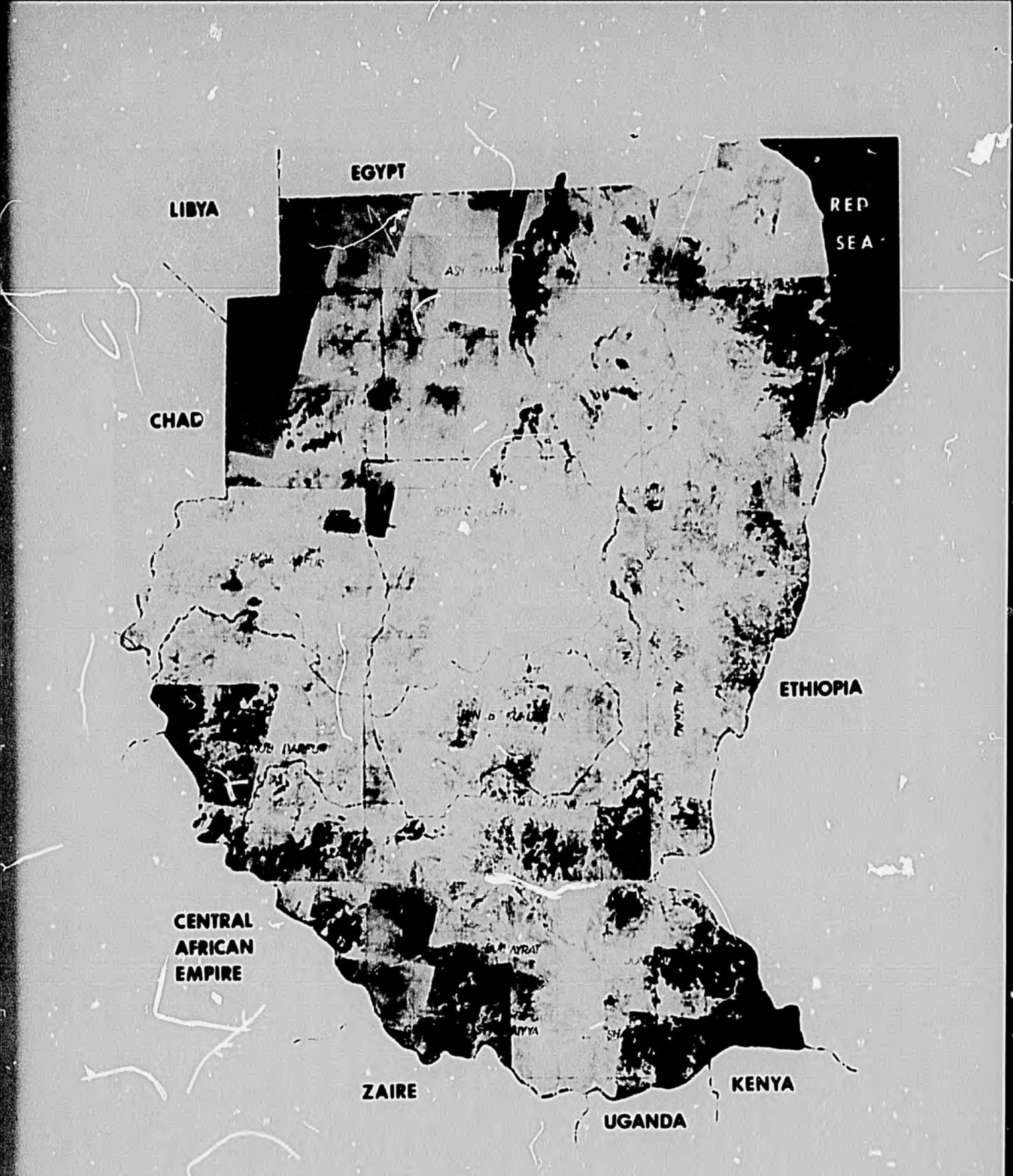
The Symposium and Workshop is part of a training program sponsored jointly by the government of the Democratic Republic of The Sudan and the Directorate of Science/Office of Science and Technology, United States Agency for International Development (AID) under contract no. AID/ta-C-1468.

Also included are the reports prepared by the Sudanese scientists during their training at RSI in Brookings.

It was realized that the new technology of remote sensing offers the Sudanese scientists engaged in natural resources development and management a promising tool in their endeavor for a fast study of the vast area of their country, contributing to the process of progress and development of The Sudan. The program was initiated to offer practical training on the applications of remote sensing for natural resources development and management. The Symposium and Workshop were planned to convey the technology to a wide sector of Sudanese scientists engaged in developing, managing or teaching natural resources.

The presentations dealt mainly with the principles and applications of remote sensing, together with studies carried out in The Sudan applying remote sensing techniques.

The Editors



Landsat Mosaic of Sudan, Prepared by Sudan Survey Department, 1979.

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Remote Sensing Symposium and Workshop

Oct. 1–11, 1978
Khartoum, Sudan

حلقة دراسية للاستشعار من البعد

انعقد صباح امس الاول بمجلس الابحاث العلميه والتقنية اجتماع اللجنه المشرفه على تحضير حلقة فى مجال الاستشعار من البعد .

وذكرت مصادرنا ان اللجنة توصلت الى اقرار البرنامج الذى اعده مجلس الابحاث العلمية لقيام حلقه تدريبية لاستخدام تكنولوجيا الاستشعار من البعد لدراسة الموارد الطبيعيه تستغرق اربعة اسابيع تبدأ من اول سبتمبر القادم .

يأتى هذه الحلقة التدريبية فى اطار استعدادات المجلس القومى للبحوث لانشاء مركز قومى للاستشعار من البعد . وصرح مصدر مسئول بمجلس الابحاث العلمية والتقنية التابع للمجلس القومى للبحوث انه فيما يتعلق باستخدام تكنولوجيا الاستشعار من البعد يقوم المجلس القومى للبحوث بالتعاون مع هيئة المساحة الامريكية بالاعداد لتنظيم هذه الحلقة التدريبية لاستخدام تكنولوجيا الاستشعار من البعد فى الفترة من ١ر٩ الى ٣٠ر٩ وعقد ١ر١٠ الى ١٤ر١٠ر١٩٧٩ على التوالى .

ويقوم بتنفيذ هذه البرامج معهد الاستشعار من البعد بجامعة داكوتا الجنوبية بالولايات المتحدة الامريكية ومعهد الدراسات البيئية بجامعة الخرطوم هذا وقد بعث المجلس القومى للبحوث الى المصالح والوزارات والهيئات ذات الصلة بترشيح من تراه مناسبا للاستفادة من هذه الحلقة الخاصة بعمل استخدامات تكنولوجيا الاستشعار من البعد هذا وكانت جامعة داكوتا الجنوبية بالولايات المتحدة الامريكية قد شاركت بتدريب بعض السودانيين فى هذا المجال سيسهمون فى تدريس حوالى ٢٥ دارسا من السودان بالاضافة الى بعض الدارسين الذين يمكن استقبالهم من بعض الاقطار المجاورة والناطقة باللغة الانجليزية ..

NATIONAL COUNCIL FOR RESEARCH (NCR)

Program for the Remote Sensing

Symposium and Workshop

(1st Oct. to 11th Oct. 1979)

SYMPOSIUM

Monday 1st October

9:30 a.m. Opening Session (10 minute talks)
Session Chairman: Sayed Abdel Rahman Ahmed El Agib

1 - "Welcome Address - NCR"
Professor Mohamed Osman Khidir, Secretary General NCR

2 - "Welcome Address - U.S. AID"
Mr. Harmon E. Kirby - Chargé D'Affaires - U.S.A. Embassy, Khartoum

3 - "General Sudan Training Summary & Welcome from RSI"
Dr. Donald G. Moore, Coordinator of International Activities - Remote Sensing Institute, South Dakota State University, Brookings, South Dakota

4 - "The Role of NCR in Adopting New Technologies"
Professor Mohamed Osman Khidir, Secretary General NCR

10:30 a.m. Refreshments and Poster Session

Tuesday 2nd October

9:30 a.m. General Session (20 minute talks & 10 minute discussion)
Session Chairman: Sayed Abdel Rahman Ahmed El Agib

5 - "Physical Basis of Remote Sensing"
Dr. Donald G. Moore, Coordinator of I.A. - RSI

6 - "The History of Remote Sensing"
Ms. Mary DeVries, Computer Scientist and Training Officer - RSI

7 - "Landsat Views The Sudan"
Mr. Amazis Samuel Andrawis, Research Geologist and Training Officer - RSI

8 - "How Do We Use Landsat and Remote Sensing"
Dr. Stanley Morain, Director of Technology Applications Center, New Mexico

11:00 - 11:30 a.m. Break and Poster Session

Session Chairman: Professor Mohamed Osman Khidir

9 - "Maps as Fair Measure to A Country's Knowledge"
Dr. Hassan Mohamed Hassan, Director General, Survey Department

10 - "Remote Sensing Activities and Future Plans in Sudan"
Dr. Salah M. El Rabaa, University of Khartoum; and Abbas Doka, Yousif Yagoub, Abdel Rahim Abdel Aziz

5:30 - 7:00 p.m. Poster Session

END OF SYMPOSIUM

WORKSHOP

Wednesday 3rd October

9:30 a.m. Specialized Technical Papers (30 minutes)
Session Chairmen: Dr. Ibrahim Hassan Mohamed, Amazis Samuel Andrawis

1 - "Landsat Program Specifications and Future Systems"
Ms. Mary DeVries, RSI

10:30 a.m. Break

11:00 a.m. 2nd Morning Session

2 - "Vegetation Mapping - Emphasis on Forestry in Southern Sudan"
Syd./ Yahia Bushara, Forest Administration

3 - "Interpretation Models for Using Landsat Data"
Dr. Donald G. Moore, Coordinator of I.A. - RSI

4 - "Landsat Uses in Monitoring Vegetation in Various Climatic Zones"
Dr. Stanley Morain, Director of Technology Applications Center, New Mexico

5 - "Land Use Mapping in Central Sudan"
Syd./ Yousif Yagoub, Soil Conservation and Land Use Administration

5:30 p.m. Afternoon Session

6 - "Method for Using Landsat Data in Regional Soil Mapping"
Dr. Donald G. Moore

7 - "Application of Remote Sensing in Soil Mapping in Central Sudan"
Syd./ Abbas Doka, Soil Survey Administration, Wad Medani

8 - "Landsat Interpretation Techniques Applied to Sudan"
Mr. Amazis S. Andrawis, Research Geologist and Training Officer, RSI

Thursday 4th October

9:30 a.m. Continued Specialized Technical Papers
Session Chairman: Dr. Ibrahim Hassan Mohamed

Morning Session

9 - "Radar Interpretation and Application in Resource Survey"
Dr. Stanley Morain

10:30 a.m. Break

11:00 a.m. Morning Session Continued

10 - "Image Enhancement Techniques and Geographic Information Systems"
Ms. Mary DeVries - RSI

11 - "Remote Sensing and Cartography in The Sudan"
Dr. Hassan Mohamed Hassan - Survey Department

12 - "The Use of Skylab Photography in Small Scale Mapping"
Dr. Ismat M. El Hassan - University of Khartoum

5:30 p.m. Afternoon Session

13 - "Geological and Hydrogeological Analysis by Remote Sensing"
Mr. A. S. Andrawis - RSI

14 - "Hydrogeological Interpretation Using Landsat Data in Difficult Areas"
Dr. S. M. El Rabaa - University of Khartoum

15 - "Geological Application of Landsat Data to Central Sudan"
Syd./ Shadul Ahmed Shadul - Geology Department

Saturday 6th October

9:30 a.m. Continued Specialized Technical Papers
Morning Session
Session Chairmen: Dr. Hassan Mohamed Hassan, Dr. Ibrahim Hassan Mohammed

16 - "Physical Basis of Monitoring Surface Water"
Dr. Donald G. Moore - RSI

17 - "Hydrogeological Application of Landsat Images in Central Sudan"
Syd./A/Rahim A/Aziz - Rural Water Corporation

10:30 a.m. Break

11:00 a.m. Morning Session Continued

18 - "Radar Applications"
Dr. Stanley Morain - Technology Applications Center

19 - "Satellite Observation of Desertification"
Dr. Donald G. Moore - RSI

20 - "Blowing Hazards in the Kordofan Province"
Syd. Yousif Yagoub

21 - "Mapping and Locating Sand Dunes in the Kordofan Province Using Landsat Data"
Syd. Abbas Doka

22 - "Application of Remote Sensing in Urban and Regional Planning"

"General Principles of Application"
Dr. Yagoub Abu Sinn, Geography Department, University of Khartoum
"Khartoum Example"
Dr. Yagoub Abdalla Mohamed, Geography Department, University of Khartoum

Sunday 7th to Tuesday 9th October

Practical Sessions: For participants only, to be subdivided into four groups:

1 - Soil Survey Group - Wad Medani

2 - Land Use and Vegetation Group

3 - Geology Group

4 - Water Resources and Survey Group

Wednesday 10th October

9:00 a.m. Field Trip

Thursday 11th October

10:00 a.m. Closing Session
Session Chairman: Dr. Ibrahim Hassan Mohamed

A - "Introductory Address"
Dr. Ibrahim Hassan Mohamed, NCR

B - "Farewell Address"
Dr. Donald G. Moore - RSI

C - Reports, Evaluation, and Recommendations from Representatives of the Four Groups:
C1 - Sayed/Yahia Bushara, Land Use and Vegetation Group
C2 - Sayed/Abbas Doka, Soil Survey Group
C3 - Sayed/Abdel Rahim Abdel Aziz, Water Resources and Survey Group
C4 - Sayed/Shadul Admed Shadul, Geology Group

D - "Closing Address"
Dr. Hassan Mohamed Hassan (on behalf of NCR)

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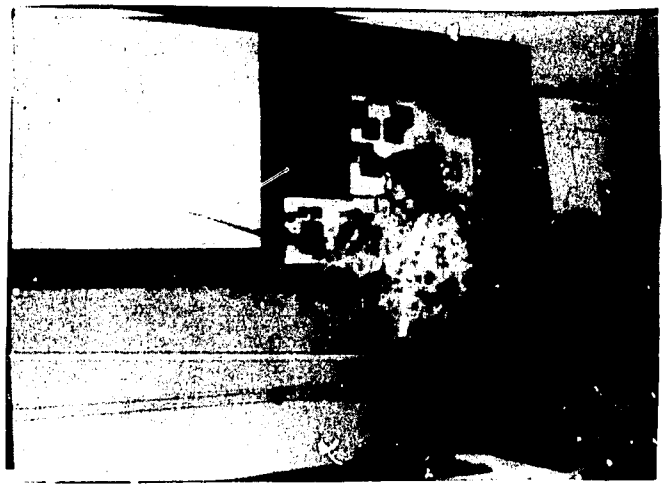
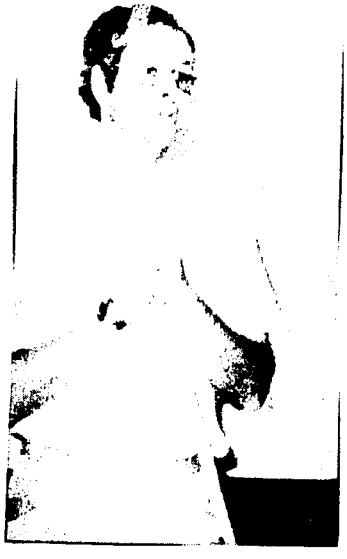
Date: 29/9/1979





INAUGURATION

By

Sayed/Abdel Rahman Ahmad El Agib*

In the name of God The Merciful, The Almighty; we open this seminar on remote sensing. I apologize for the absence of Sayed/Wadie Habashi, President of the National Council for Research, who has a previous commitment outside of Khartoum.

In this opening session we shall listen to welcome addresses from speakers representing the National Council for Research; The Remote Sensing Institute, South Dakota State University; U. S. Agency for International Development and the American Embassy.

Now, I call upon Professor Mohammed Osman Khidir, Secretary General of the National Council for Research, to give his welcome opening address on behalf of The National Council for Research.

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* Director, Council for Scientific and Technological Research; National Council for Research; Khartoum, Sudan.

WELCOME ADDRESS

by

Prof. Mohamed Osman Khidir*

Honorable guests and participants,

Ladies and Gentlemen,

It is my pleasure and privilege to greet you all, and to extend to our honorable guests, on behalf of the National Council for Research and on behalf of the Government of the Democratic Republic of the Sudan, a most hearty welcome to Khartoum.

I wish to seize this opportunity to thank the United States Agency for International Development for financing this workshop and to thank the staff of the Remote Sensing Institute of South Dakota State University for their participation in the long process of preparation for this workshop.

Aerospace technology, being a new field, has led to the coordination of efforts of scientists, and has imposed international cooperation to promote the development of this technology. The convening of this workshop at this time of universal recognition of the need for coordination in applying aerospace technology to solve some of the many problems that face the earth is indeed most fortunate.

* Secretary General, National Council for Research, Khartoum

The purpose of this gathering is to bring together experts in remote sensing technology and resource scientists as well as planners and decision makers to discuss the ways and means of applying this new technology to the identification of the natural resources potentials in the Sudan. We hope to achieve a practical exchange of information in order to establish a basis for further development and application of this promising technology.

In attempting to develop its natural resources, Sudan will always need a reliable, updated, continuous data base. Remotely sensed data have proved to be an effective aid in resource identification, classification and monitoring of a variety of earth resources, both renewable and non-renewable. When combined with conventional techniques of information collection and utilization, such data have greatly reduced the time and increased the accuracy of analyzing and inventorying resources, as the data collection period is short, the quantity of raw information is immense and the scope of the data is broad and repetitive.

In a country as vast as the Sudan, the use of remote sensing technology is perhaps the only economically feasible way of surveying our natural resources in several fields, e.g. agriculture, rangeland, forestry, land use, soils, surface and ground water resources, soil degradation, desert encroachment, geological surveys, etc.

The Sudan has taken serious steps in building its remote sensing capacity. The National Council for Research (NCR) is in the process of establishing a National Remote Sensing Center. Thus, we have started with the most basic part of the process, that is to prepare the human skills required. In fact, there are already some scientists and technicians who have been trained abroad.

The NCR, together with USAID, concerned Government Departments and the University of Khartoum have made the necessary preparations to make the participation of the Sudanese scientists more effective. Some participants have been given a preparatory course in the fundamentals of remote sensing techniques for a duration of one month so as to ensure better understanding and contribution.

Once more, our most hearty welcome and our best wishes for a happy and fruitful stay in The Sudan, and for a successful workshop.

WELCOME ADDRESS

Harmon E. Kirby*

Mr. Chairman, Professor Khidir, Ladies and Gentlemen, members of this workshop in remote sensing.

It gives me great professional and personal pleasure and satisfaction to be here today and to participate in the opening of what promises to be a very important workshop indeed. I say a personal pleasure and I might elaborate on that first. It was about seven or eight years ago that I was asked to participate in another workshop on remote sensing much like this one in New Dehli, India. At that time too, as is the case today, USAID was participating in the sponsorship of a seminar on remote sensing, and I found it most fascinating indeed.

Later on, when I returned to Washington for an assignment there, I had the opportunity to engage in a number of seminars at a local university on the subject of remote sensing. That increased my fascination for the subject. Although in all honesty I am probably the least qualified person technically here today, nonetheless, if you don't mind my saying so, I yield to no one in my interest in this very important technique and technology.

I said that it gives me great professional satisfaction to be here as well, on behalf of the U. S. Embassy in Khartoum and USAID-Sudan. We are particularly pleased that AID is helping to support this seminar.

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* Charge d'Affaires, U. S. Embassy, Khartoum

The world hears a great deal these days about the new global agenda, the new agenda that faces both the developed world and the LDC's alike. I think that we all recognize that two of the most important topics on that new global agenda are first, how to assure adequate resources for the economies of all our countries; and second, how the developed and developing worlds can cooperate to insure that needed advanced technology is transferred appropriately to the LDC's.

At this time, when the question of the availability of adequate resources for all nations is very much in doubt, it is particularly the developing countries which need very desperately the resources which will make their economies run better and which will enable their governments to insure the increasingly better life that all of their peoples are demanding of them.

The second item on the global agenda I mentioned is the transfer of sophisticated technology from the developed countries to the developing countries which are trying to find their place in the economic, social and political world order. It seems to me that this seminar that you are launching here today, and in which you will all be engaged over the next two weeks combines these two agenda items on this new global agenda in a very interesting way. First of all, as we all know, the great promise of remote sensing is that it will assist all nations on the globe, but particularly countries like The Sudan with, probably vast but untapped resources, to study and measure exactly what the country's resource base is.

It has become a cliche in the world to hear that The Sudan is doubtless rich in resources, but that because of lack of infra-structure it is

difficult to identify those resources and to develop a coherent and comprehensive plan for their appropriate exploitation. But to a very considerable degree it seems to me that is what remote sensing is all about. Here in The Sudan, remote sensing, via a satellite from outer space, will study where your mineral and other resources are, where the deposits are and their extent, and then will give some idea as to how these resources might be used for the betterment of the people of this great country.

Remote sensing can also tell us a great deal about the fertility of the soil, about rain patterns, water tables, and how the potentially arable land in this country might be better used to feed the people of The Sudan and of the Middle East and Africa. So, the remote sensing concept is directed quite explicitly toward the resource needs of The Sudan.

The second item I mentioned is the transfer of technology, and of course remote sensing is, as I have already suggested, one of the world's most exciting and sophisticated new technologies. Indeed this seminar is to a very considerable degree all about the question of transfer of this technology from the developed west -- where it has been refined, and particularly in the United States if you will -- to the use in a country like the Sudan.

It seems to me that this seminar itself suggests a useful model for approaching transfer of technology problems. It seems to me that this seminar suggests a sophisticated blend of the efforts of university sectors in the two countries, i.e., non-governmental institutions and their expertise, with the backing and support of the governments involved as well. Here we have, on the one hand, participating in this seminar and in its preparation the Government of Sudan working through the National Council for Research, and we have on the other the U. S. Government

participating through funding from USAID. Then, of course, the seminar is located here today at the University of Khartoum and many of the seminar participants come directly from the University, with others coming from the National Council for Research. And last but not least, we have the university from my own country, South Dakota State University, which has done so much seminal work in the remote sensing field and in particular in training people around the globe, including The Sudan, to use this technology.

So, again it seems to me that we are all approaching this question of the transfer and training in this particular technology in a very mature and sophisticated way. To summarize it again, we are blending both governments' efforts with those of university experts from the two countries, and this model might well prove adaptable elsewhere for the whole question of transfer of technology.

Mr. Chairman, I would like, if I may, to conclude where I began by telling you again how pleased I am at being asked on behalf of the U. S. Embassy in Khartoum and USAID-Sudan to participate in this extremely worthwhile seminar and to help get it launched in the proper direction. Given the eagerness and the interest that I have already seen manifested here this morning, I have no doubt that over the next 14 days your endeavors will be very useful and productive indeed.

I wish you well in your endeavors and look forward to hearing great things both about the seminar and about the uses to which this grand technology of remote sensing will be put in future on behalf of The Sudan and on behalf of other countries that need the technology so badly and can potentially use it to such great advantage. Thank you very much.

WELCOME ADDRESS

Donald Moore*

Distinguished guests and conference participants:

It has been the pleasure of the Visiting International Scientist Program (VISP) at the Remote Sensing Institute (RSI), South Daktoa State University, sponsored by the Directorate of Science/Office of Science and Technology, United States Agency for International Development, to work with the scientists and the administration of the Government of Sudan. The project entitled "Design and Implementation of a Training Program of Applied Technology in Remote Sensing for Sudan - Contract AID/ta-C-1468 - had the following as project objectives and guidelines.

Objectives:

* To provide administrative personnel with an understanding of the economic and technological feasibility of applying remote sensing technology to the resource and environmental problems of their country or region.

* To help scientists interested in applying remotely sensed data and aerospace technology design, implement, and administer programs concerned with the exploration, development, management, and conservation of their natural resources.

* To train scientists in laboratory and field techniques so they may carry out projects of special importance to their regions.

* To provide the administrative and technical training required to develop, implement, and maintain an operational remote sensing program.

---

* Head of Visiting International Scientist Program and Assistant Director, Remote Sensing Institute.

Guidelines:

* Stress application of remote sensing, emphasizing practical application rather than academics.

* Employ data from home regions.

* Prepare illustrative materials useful at home in seminars and workshops for sharing the participant's knowledge with concerned countrymen.

* Supply a base of satellite photographic and digital data, interpretation maps, appropriate statistics, and development potentials to the host country for immediate use.

* Provide experience in using equipment and interpretation techniques with varying levels of equipment sophistication and costs.

* Stress training to equip participants with skills to establish their own training program at home.

* Build liaison between visiting scientists and experts from around the world in the field of remote sensing.

Personnel from the Remote Sensing Institute have visited Sudan many times. As most of you know we collaborated with you and Egypt to conduct the resources inventory of over 160,000 km^2 in the jungle area in southern Sudan. You are always a most gracious host and we have always enjoyed working with your Administration and Scientific Staff.

We had the opportunity of working directly with nine of your top scientists during their tenure as Visiting Scientists at the Remote Sensing Institute.

Their initial training included lectures and demonstrations defining the technology and instrumentation of remote sensing. Practical image interpretation exercises in the laboratory and the field were conducted for experience in the interpretation methods useful for Landsat, SKYLAB, and aircraft images. A field trip through South Dakota, Colorado, and Nebraska provided visits to many state and federal action agencies who are using remote sensing in the United States.

Landsat and SKYLAB data of the various spectral wavelengths and available dates for Sudan were secured from the EROS Data Center, Sioux Falls, South Dakota, the world archive of Landsat data products. These transparencies, prints, and digital tapes were appropriately enhanced and formatted for use and evaluation by the Visiting Scientists. The remainder of their six-month visit included their study and evaluation of remote sensor data in their respective disciplines. Where feasible, resource maps were prepared. These preliminary maps were not solely based on remote sensing interpretation since all the Visiting Scientists were well experienced in the field and had excellent local knowledge of the area for which they were evaluating. These preliminary maps can be used very effectively as the first state of a multistage investigation for reconnaissance mapping. They are meant to provide a broad overview of the whole or a large region of Sudan and not to provide great detail for any one area. The original reports and maps describing their activities are available from the authors and will be published as a workshop proceedings. Many of the maps are displayed as posters during this workshop. A condensed version of the reports is generally provided in this workshop by the authors.

During the training period and my various visits to Sudan, help was provided for the conceptual development and initial planning of the Sudan Remote Sensing Center. I urge your serious evaluation of remote sensing as it applies to your specific needs in acquiring basic resource data and in monitoring changes in the Sudan landscape. This workshop has been designed to present example interpretation techniques and to evaluate and apply those techniques to Sudan. Through the nine scientists who have trained at RSI, the most careful and capable evaluation for their specific discipline

specialties has been completed. Please address questions on topics for which you have specific concern to them or the other available specialists.

As your remote sensing center develops, continue to use these experts to guide yourselves and your associates in appropriate techniques for the use of the data. They are now very competent training officers and will be of extreme value in advancing the techniques of remote sensing in Sudan.

Lastly, on behalf of the delegation from the United States, I extend my sincere appreciation for your excellent hospitality and friendship, and for arranging this workshop. The opportunity of visiting Sudan and of working with you is truly a pleasure.

THE ROLE OF THE NATIONAL COUNCIL FOR RESEARCH IN ADOPTING NEW TECHNOLOGIES

By

Prof. Mohamed Osman Khidir*

Article 18 of the Permanent Constitution of the Democratic Republic of the Sudan stipulates that "The State shall endeavour to develop and modernize the society through scientific planning and care for the promotion of skills, scientific research and academic and applied studies".

The National Council for Research (NCR) was established in 1970. Its act states that the main objectives of NCR are:

a) to encourage, organize and promote scientific research in its various aspects with a view to achieve the objects of the economic and social development within the framework of the policy of the State.

b) to formulate a comprehensive policy for scientific research and direct the plans, means and methods for the execution of such policy in such manner as to ensure efficient and effective utilization of the human and material resources available at the units and organs of scientific research.

In a less industrialized setting like that of The Sudan, as well as other developing countries, national institutes, like NCR, entrusted

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with the formulation of science policy are bound to find a formidable challenge in the adoption of new technologies. The success or failure of these national bodies may be open to debate, but the role and responsibilities of these bodies remain unquestionable. Such mandates arise, largely, from near total dependence of the public on governmental agencies as undisputed custodians of their welfare and interests.

The benefits accruing to society from new technologies touch in one way or another the lives of most people and often in an everlasting manner, whether these technologies are remote sensing, semiconductors, solid state microwave devices or higher yielding varieties of crop plants. It is, however, the management of the benefits and the drawbacks as well as the intrinsic features of these technologies that give impetus to the role of national bodies like NCR. Thus, the management of these technologies rests on NCR because of the interdisciplinary character of these technologies. In addition, these new technologies are often best adopted and transferred within the framework of international cooperation and managed on regional or global basis in order to give regional or international efforts an opportunity to supplement national endeavours, particularly when certain fields like oceanography only lend themselves to regional and international endeavours. The NCR is best suited to secure the necessary cross-national cooperation.

To fulfill its role as a government advisory body, promoter of research and development and public trustee of consumer welfare, the NCR must act as intermediary between potential clients and technology sources and be able to forge a three-way linkage between development efforts and old and new technologies. This task entails passing judgment and advising the government on a host of issues. These include: identification of the demand for the new technologies, location of potential users, determination

of the level at which these new technologies ought to be introduced and evaluation of the social, economic and environmental consequences of the introduction of the new technologies.

However, in order to fulfill its task in the adoption of new technologies, the NCR is trying very hard to build its infrastructure. One such infrastructure is the National Computer Centre; another is the National Remote Sensing Centre (which will be the theme of one of Dr. El Rabba's contributions to this workshop) and a third is the National Centre for Technology.

According to its bylaws, the National Centre for Technology shall assist in the transfer, adoption and development of technology. The establishment of this centre has been motivated by the ever-changing nature of technologies and the need to avail to the development efforts, on a constant basis, technologies that are not currently being applied to development either through transfer, adaptation and adoption or through evolution and promotion of indigenous technologies and innovations.

It is a fact that in the Sudan as well as in many developing countries, intellectuals, policy makers and technology importers often have very different perceptions of the technology that is appropriate to the country's needs. For the technology exporters to be involved in determining what is appropriate would, of course, be an unwarranted trespass on local autonomy. The National Centre for Technology should aim mainly at increasing our capacity to generate technology indigenously. It should also link and integrate the non-sectoral activities of science and technology in the sectoral planning (for agriculture, health, industry, etc.) so that attempts in generating technological progress can be intimately interwoven into the

fabric of development. This task involves several activities:

1) Advising on the choice of available technologies.

2) Building a reliable data acquisition system on available technologies and providing information on them to prospective users.

3) Designing a delivery system for the diffusion and popularization of technology.

4) Developing normative capabilities to assess incoming technologies and to secure legal protection for any technological inventions or innovations.

5) Organizing seminars and courses on new and advanced technologies.

To conclude, broadly speaking, development is concerned with two important goals: 1) satisfying the most basic needs; and 2) modernization. Of course, science and technology are an indispensable part of the development process. Yet, they are only two elements in a larger setting where political, social and economic traditions and values may be more fundamental factors affecting change.

THE HISTORY OF REMOTE SENSING

Mary DeVries*

Remote sensing can be defined as the use of electromagnetic energy to measure the physical properties of distant objects. The term "remote sensing" was coined by Evelyn Pruitt, formerly of the U. S. Office of Naval Research, when sensors were developed which made it possible to observe in regions of the electromagnetic spectrum which were beyond the range of human vision and photographic sensitivity.

Photography has played an important role in the development of remote sensing. The first photographs were reportedly taken by Daguerre and Niepce and reported on by the former in 1839. One of the earliest attempts at aerial photography was made in 1858 by Gaspard Felix Tournachon who took "bird's-eye" photographs of a French village from a captive balloon.

In 1860 James Black and Sam King ascended to an altitude of 630 m in a balloon and successfully photographed parts of the city of Boston. L. Cailetet of France, using an unmanned balloon equipped with a camera, devised a method of recording the height reached by the balloon by automatically superimposing the image of an aneroid barometer on each exposure.

In 1903 Julius Neubronner, a photography enthusiast, designed and patented a breast-mounted aerial camera for carrier pigeons. The camera weighed only 70 grams and took 38 mm square negatives. Exposures were made automatically at 30-second intervals by a built-in timing mechanism.

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Kites were also used as platforms for aerial photography. E. D. Archibald, an English meteorologist, is credited with making the first successful photographs from kites in 1882. G. R. Lawrence, an American kite photographer, was able to obtain a photograph of San Francisco on the day of the great earthquake and fire in 1906. A kite was used to hoist a gigantic camera to a height of 600 m above the city. The camera which Lawrence used weighed more than the Wright Brothers' airplane and pilot.

Although many excellent photographs were taken from balloons and kites, it was desirable to have a platform that was more navigable. The airplane provided such a platform and, appropriately, the first recorded photographs from an airplane were taken by Wilbur Wright in 1909 when he took motion pictures over Centocelli, Italy.

Color film became commercially available in 1935 and among its first users for aerial photography was George Goddard in 1937. Despite its early state of development during World War II, color film was used to a limited extent for purposes such as measuring the depths of underwater features in support of amphibious assault activities. An early form of color infrared film was developed for camouflage detection late in World War II but was not used operationally. The three-layer color infrared film used today results mainly from developments during the Korean War in the early 1950's.

The use of aerial photography for military purposes dates back to early World War I and completely changed the tactics of war. A vast amount of military information such as equipment, manpower and tactical movement could be obtained by periodic aerial photography missions.

Radar, an acronym for radio detection and ranging, is a technology whose principles have been known since 1889, but has only recently found its

place in the remote sensing realm. The term "radar" is commonly used to describe the broad class of electromagnetic sensing systems which operate in the microwave and longer wavelength regions. Initially radar was used for (as the name suggests) detection and ranging purposes only. Airborne image-forming radar is a relatively new development which is being extensively used and investigated for remote sensing purposes. Sidelooking airborne radar (SLAR) is perhaps the best known of the image-forming radar systems.

Contrary to popular beliefs, remote sensing by rocket is not new. Patents were issued as early as 1891 and 1907 for rocket-type devices for obtaining aerial photography. In 1946 space pictures were taken from V-2 rockets launched from White Sands Proving Ground. Systematic earth orbital observations began in 1960 with the launch of Tiros I, the first meteorological satellite. The Mercury and Gemini series of manned and unmanned space flights provided evidence that space photography was valuable for earth resources information, especially in the field of geology. This evidence contributed to the development of the NASA Earth Resources Technology Satellite (ERTS) system, later known as Landsat. This series of satellites to date has provided nearly one-half million scenes of data. The three manned SKYLAB missions (1972-1974) also provided thousands of photographs and other types of data of the earth's surface as part of the Earth Resources Experiment Package (EREP).

Along with the development of aerial platforms (from balloons to space stations) we have also witnessed the development of various types of sensors. Today's scientist can choose from an array of sensors including cameras (both panchromatic and multispectral), radar, and scanners.

Present plans call for the continuation of the Landsat series of earth resources satellites with new and improved sensors. A French satellite called SPOT (Système Probatoire d'Observation de la Terre) is planned for launch in 1984. The Space Shuttle, presently planned for launch in the early 1980's, will be a reusable manned aircraft/spacecraft which will be a platform for remote sensing operations and, in addition, will be capable of retrieving satellites from space for refurbishing and repair. These and other systems hold promise for a bright and exciting future for remote sensing.

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LANDSAT VIEWS THE SUDAN

by

Amazis Samuel Andrawis*

Since the launch of Landsat 1 on the 22nd of July 1972, many coverages for the whole area of The Sudan have been acquired. The map in Fig. 1 shows the approximate scene locations of Landsat imagery for The Sudan. Applying the path and row system, The Sudan is covered by paths from 182 to 193, and rows from 45 to 57. About 130 scenes cover the whole area of the country.

Landsat 2 and Landsat 3 are still orbiting around the world. Most of the coverage we have for The Sudan is that acquired by Landsat 1. To have additional data acquired for Sudan, a request must be made to NASA with rationale for the use of the data since the capacity of the recorders aboard Landsat is limited, and the demand for new imagery is high. One of the recent coverages is that taken in August 1978 for the Gezira area to study the effect of the flood. The results of this study are found elsewhere in these proceedings.

Landsat data can be obtained from the EROS Data Center at Sioux Falls, South Dakota, in a variety of forms. It can be obtained as a photographic product such as black and white negatives or diapositives of 9 inch or 2.25 inch size, as false color composite transparencies, or as black and white

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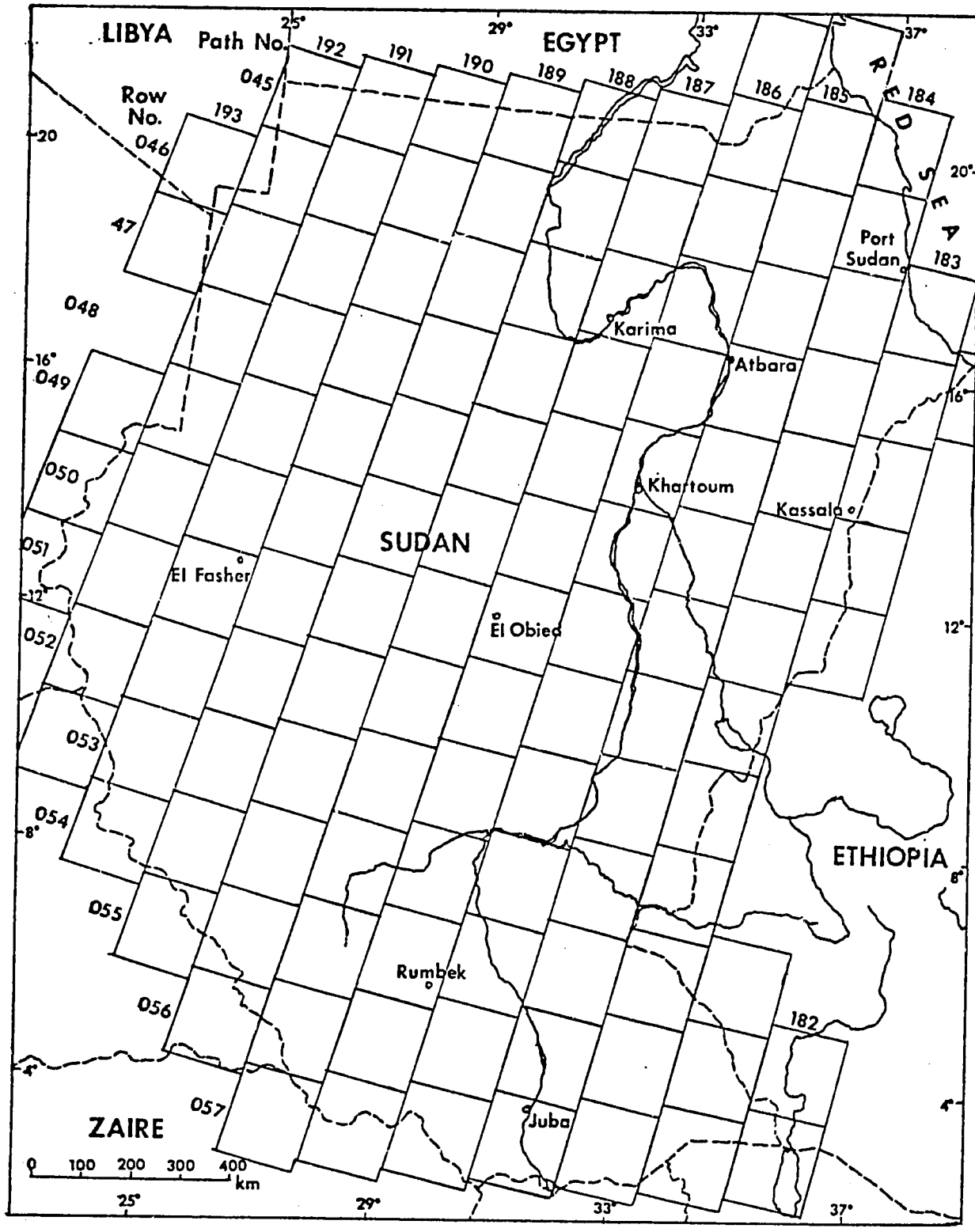

Figure 1. Path and row system for the location of Landsat coverage of the Sudan.

and color prints at various scales from 1:1,000,000 to 1:250,000. Also the data can be obtained in a digital form on a computer compatible tape (CCT). All these products, the use of each, advantages and methods of interpretation will be discussed during this workshop.

To obtain Landsat imagery for a certain area, a computer list of all the imagery available for that particular area must first be requested. The EROS Data Center supplies this list free of charge. It contains all information about the imagery of a particular area. One selects from the list the most suitable imagery for one's purpose, - i.e. the date of imaging, cloud cover percentage, the individual bands or a false color composite, the scale of the prints - and then sends the order for the images to the EROS Data Center.

We have a good coverage of Landsat imagery, and in different dates, for our project area in Kordofan province. All these images will be available at the National Council for Research for use by the various government agencies.

We will inspect some Landsat scenes for different parts of the country and illustrate how to identify different ground features. Detailed procedures for image interpretation will be discussed later in the specialized lectures.

Landsat scene no. 1109-07540, band 5 (Figure 2) shows the area between El Obeid and El Nahud towns. It was possible to differentiate between the sandy sheet, the Nubian sandstone, and the shallow basement complex rocks, overlain by a thin cover of clays and sandy clays. Although there is not much tonal difference among the three units, they

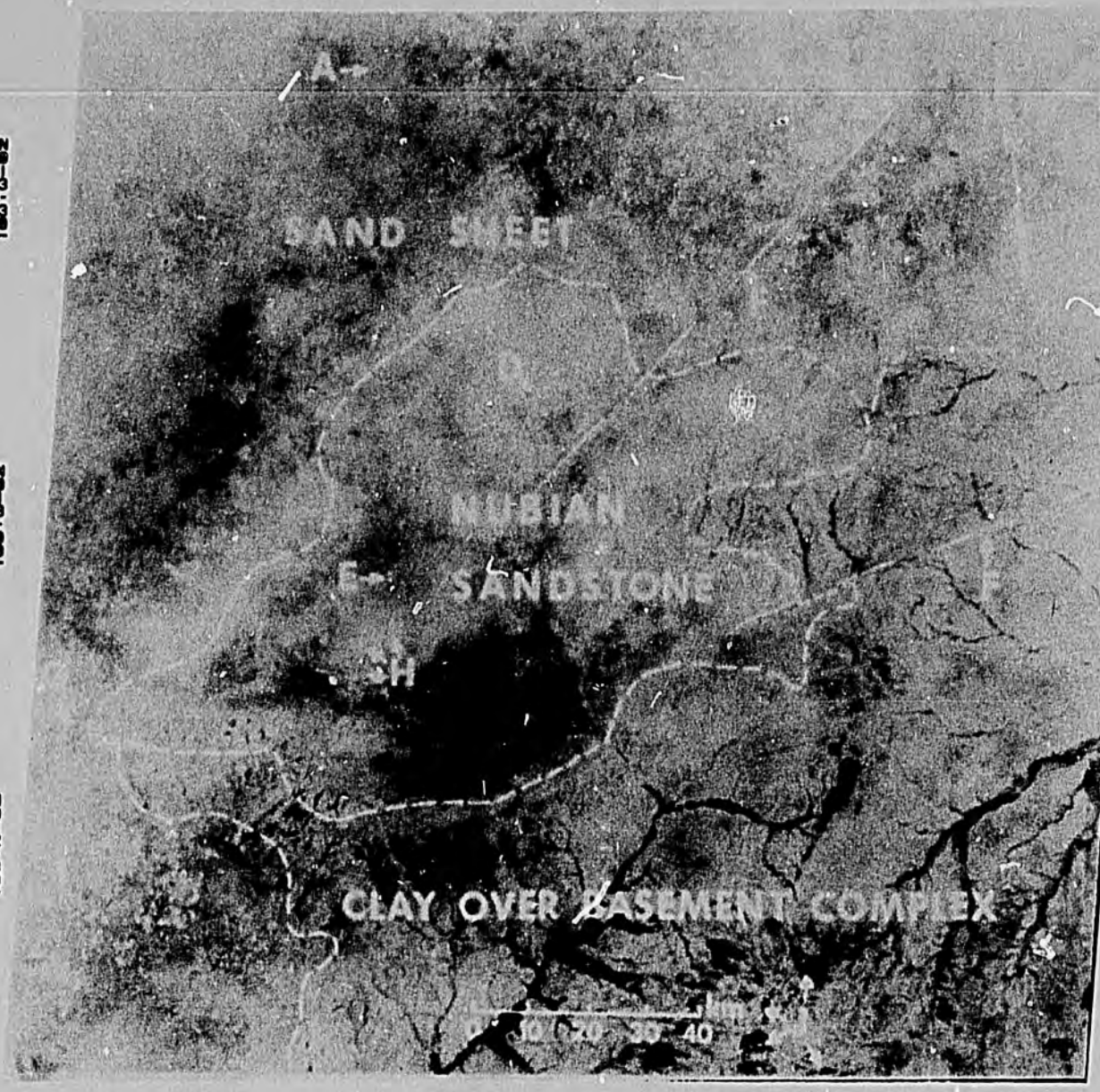

Figure 2: Landsat scene no. 1109-07540, band 5. A and E: areas of transverse E-W sand dunes, B & I: areas of small scattered fields of rainfed cultivation, C: El Obeid town, D: Khuwei village, F: fractures and faults, G: En Nahud town, H: villages with scattered cultivation around them, J: basement rock outcrops. The boundaries between the Nubian sandstone, the sand sheets, and the basement complex were clearly identified on the scene.

were easily identified through other criteria. The sand sheets are rough in texture due to small scattered cultivation practices where it is more clayey. Also, the sand sheets lack any drainage, since they are highly permeable. The Nubian sandstone is mostly covered by a layer of coarse sand and sandstone debris, occasionally ferrugenous, and clayey patches are scarce; thus, cultivation is very sparse and consequently the Nubian sandstone area has a smooth texture. Since the sandstone is moderately permeable, the drainage lines are few and ill-defined. The slopes of the southwestern edge of the Nubian sandstone have developed a deep and irregular type of drainage. The clays overlying the crystalline basement complex have a very low permeability and thus, a well developed and sharply defined drainage pattern.

Landsat scene no. 1213-07292, band 5 (Figure 3) shows an area in the Red Sea Hills between Mohammad Qol village and Port Sudan. Several ring structures are clearly visible. Some of the major linear features are marked, which are mostly faults of the African Rift System.

Landsat scene no. 2319-07281, band 5 (Figure 4) covers most of the Gezira and Managil agricultural schemes; El Guneid scheme can be seen at the NE corner of the scene. Wind-blown sand sheets and sand dunes are predominant west of the White Nile and are progressively invading the fertile cultivable land of the White Nile Valley. An old delta (probably pliocene) can be seen east of the White Nile. Its soil is unsuitable for cultivation. Bore holes drilled in this area show the occurrence of some gypsum beds. Wind-blown sands cover parts of the delta.

Landsat scene no. 2396-07561, band 5 (Figure 5) shows the area of

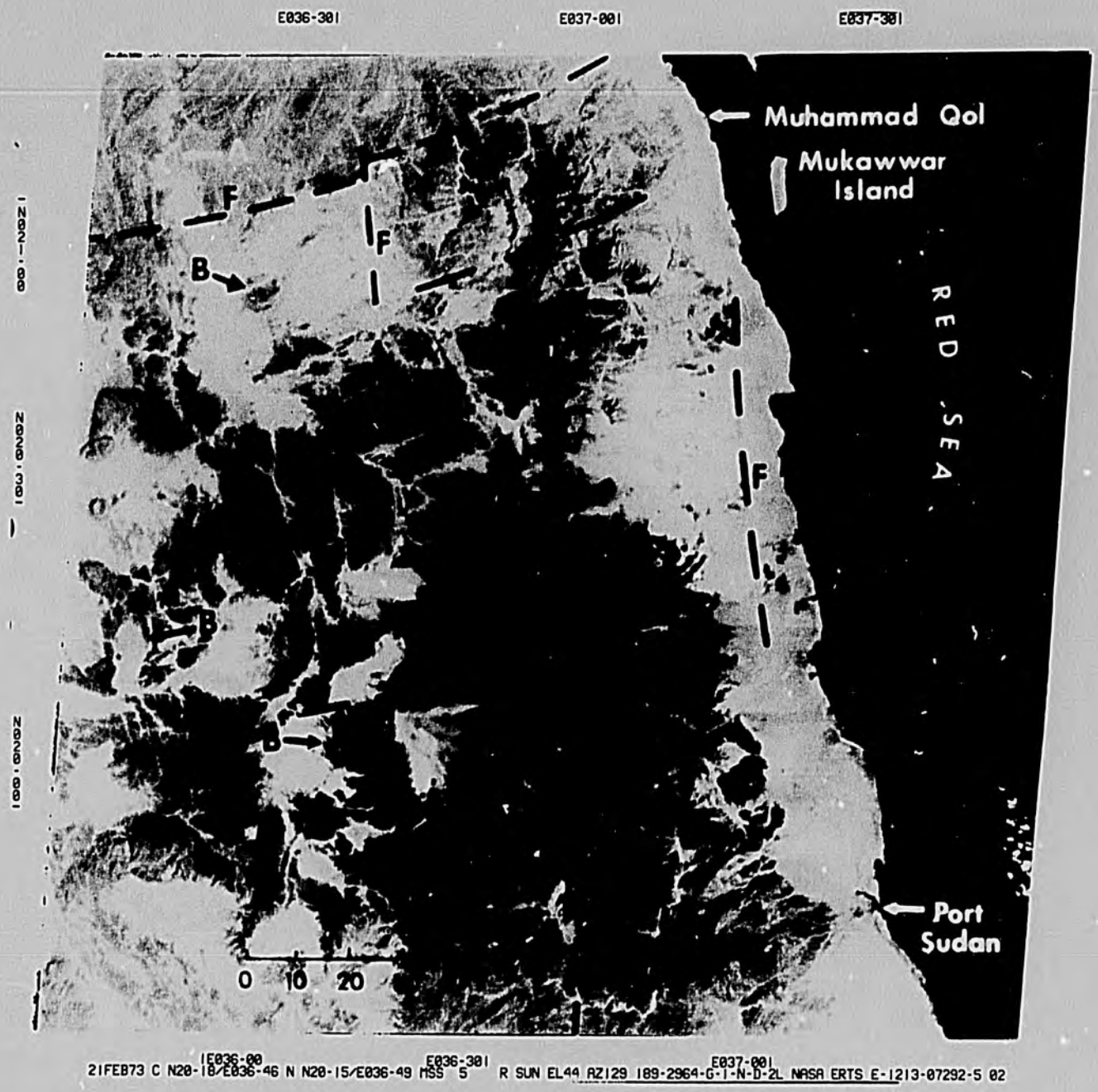

Figure 3: Landsat scene no. 1213-07292, band 5, for the Red Sea Hills area between Muhammad Qol and Port Sudan. "A" shows the location of Gebeit gold mine, "B" shows several ring structures, and "F", major fractures and faults.

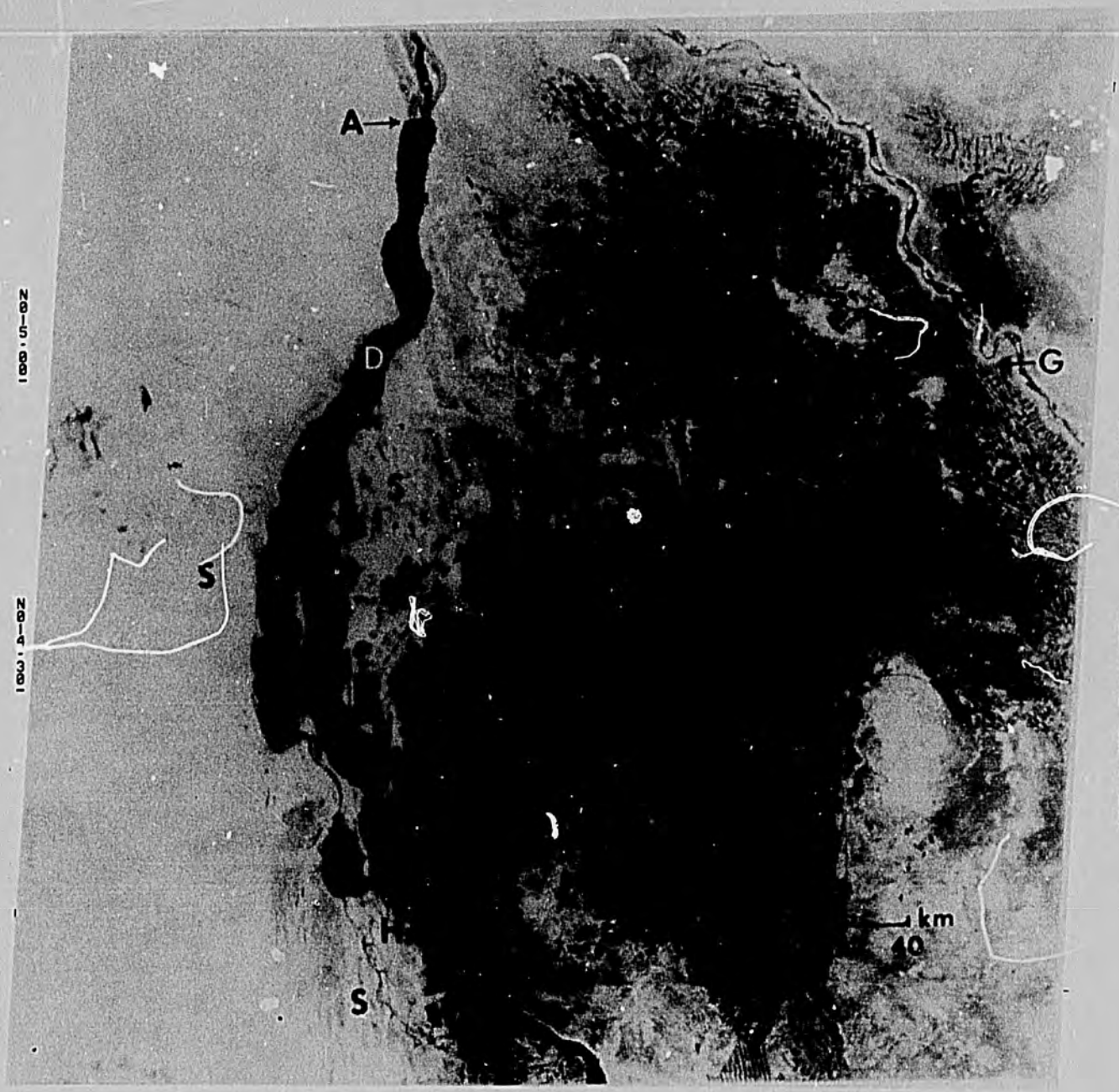

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Figure 4. Landsat scene no. 2319-07281, band 5. A: Jebel Aulia dam, B: Gezira agricultural scheme, C: El Guneid scheme, D: White Nile, E: Old delta (probably pliocene), F: Blue Nile, G: Wad Medani town, H: Ed Duweim town, J: El Managil agricultural scheme, S: wind blown sands and sand dunes.

Figure 5. Landsat scene no. 2396-07561, band 5. A: a ring structure, B: El Fasher town, C: Wadi El Ku, D: dykes outcrops, E: Jebel Marra crater with two lakes inside, F: basaltic lava flow, G: volcanic plugs and necks, H: striations caused by strips of wind blown sand.

Jebel Marra volcanic mass. The crater with the two Deriba lakes inside, the basaltic sheets, and the volcanic plugs are all clearly visible. The wind-blown sands produced the NE-SW striations in the eastern side of the scene.

Landsat scene no. 2319-07284, band 5 (Figure 6) includes the area of Khor Abu Habl alluvial fan west of the White Nile. This scene demonstrates the process of desertification; the wind-blown sands are moving southwards, covering the valuable agricultural lands. It can be seen on the image that the sands have covered the northern half of the alluvial fan, and have buried its tributaries. Tendelti town (marked E on the figure) lies on the northern buried channel. The longitudenal sand dunes in the area marked A and those in the SW corner, south of Khor Abu Habl, have different orientations, which is due to its being formed by winds from two different directions during different periods of time.

Landsat scene no. 2319-07275, band 5 (Figure 7) is for the Khartoum area. The crystalline basement rock outcrops of the Sabaloka area (marked "A" on the figure) are characterized by an abundance of linears, fractures, joints, and faults which are influencing the trend of the river channel. The Nubian sandstone outcrops (marked "B" on the figure) can be easily recognized by their flat-topped horizontal plateaus with well defined serrated edges. The Nubian sandstone outcrop of the Merkhiyat Hills (marked "C" on the figure) looks different in shape and darker in tone, as it is a different horizon in the Nubian series, with more ferrugenous material, firmly cemented and more resistant to weathering. The watershed line was accurately delineated by examining the drainage systems which are clear in the scene. An index map of the Landsat scenes acquired for the study area is shown in Figure 8.

Figure 6: Landsat scene no. 2319-07284, band 5. The area around A is covered by longitudenal sand dunes, B: the White Nile, C: marble outcrop, D: an area of small scattered fields of rainfed cultivation, E: Tendelti town, F: sandy area with villages seen as dark spots, G: Khor Abu Habl valley, H: Kosti town, J: Khor Abu Habl alluvial fan; the wind-blown sand invaded the northern part and blocked up the tributaries.

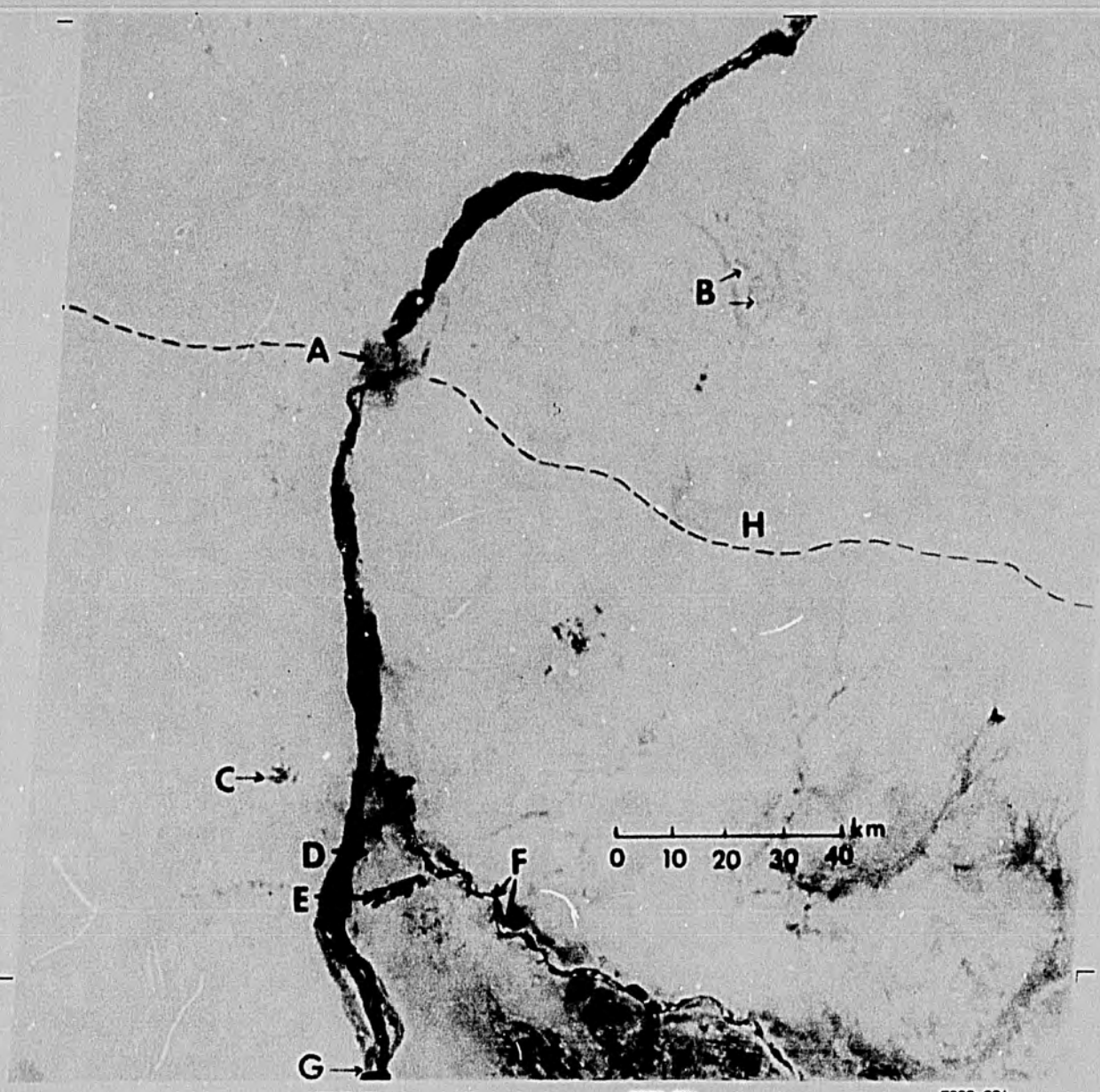

Figure 7. Landsat scene no. 2319-07275, band 5. A: Sabaloka complex outcrops, B: Nubian sandstone outcrops, C: Merkiyat Nubian sandstone outcrops, D: Khartoum town, E: green shelter belt, F: sand bars along the Blue Nile, G: Jebel Aulia dam on the White Nile, H: water shed.

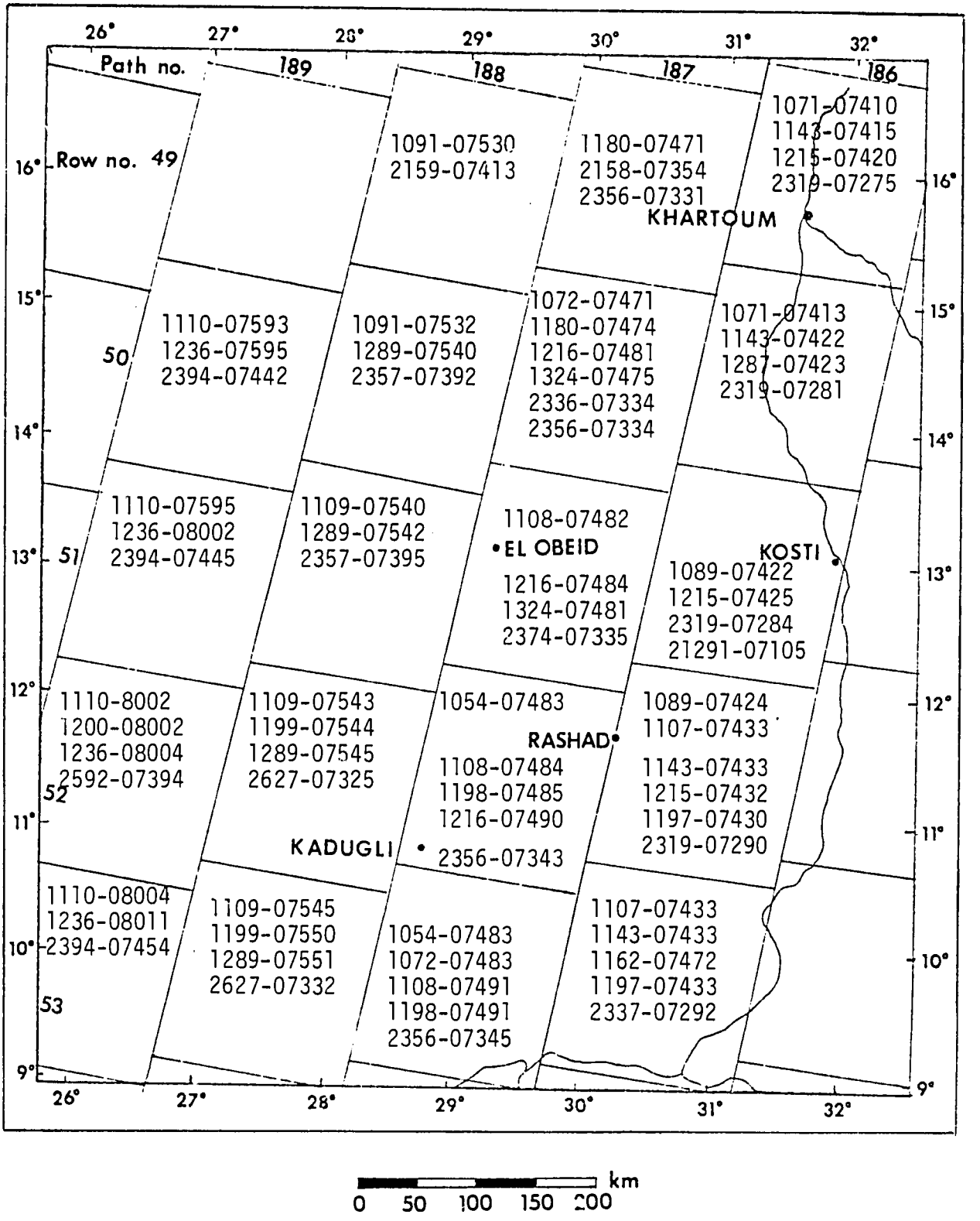

Fig. 8: Landsat index map for the study area.

USE OF RADAR FOR VEGETATION ANALYSIS

By

Dr. Stanley A. Morain*

INTRODUCTION

Radar imagery became a focus of interest for vegetation analysis in the mid 1960's, but is still the least well known of the present assortment of sensors. However, radar imaging systems are unique. First, they are active sensors transmitting a signal and receiving that portion reflected from the surface. Secondly, because they do not rely on solar illumination, ground coverage can be acquired when photographic and multispectral coverage cannot. Thirdly, as a consequence of their long wavelength, they can obtain imagery through thick cloud layers, and depending upon their specific wavelength, through many kinds of precipitating clouds. Finally, because they scan a range of viewing angles, they produce small scale imagery suitable for reconnaissance mapping. The sum of these attributes makes radar the best time independent sensor available.

Three kinds of vegetational information can be obtained from analysis of radar data: (1) geographic pattern; (2) gross structure and physiognomy; and (3) type identification. In all instances interpretations rely on converging evidence derived from principles of geography, biology and ecology; the interpreter's understanding of the principles of radar reflection from vegetation as well as his experience with the local environment; and inference. Detection, followed by delineation and categorization, are

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the fundamental steps in most remote sensing projects. How these steps are carried out and the lines of reasoning used to interpret images are described in the examples of this section.

PREVIOUS WORK

Single frequency radar has been evaluated in several studies for its contribution to physiognomic mapping (Morain and Simonett, 1965; Howard and Sapp, 1970; Hardy et. al., 1971; Daus and Lauer, 1971). The role of radar has been further discussed as a tool for mapping phenological changes (Morain, 1974) and for its contribution in mapping floristic and ecologic categories (Morain and [illegible]es and Senger, 1974).

In a more quantitative sense, densitometric data have been used to assist identification. Simonett, et. al. (1967), Schwartz and Caspall (1968), Haralick, et. al. (1970), and Morain and Coiner (1970) all used image density measures as a means of classifying field crops. This approach has not been systematically explored for natural classes, however.

Beyond these analytical and philosophical endeavors there has been virtually no attempt to develop interpretation keys. Both Hoffman (1960) and Simpson (1966) discussed the question of radar interpretation keys, but to date none have been constructed that have general utility. Morain and Coiner (1970), Hardy, et. al. (1971), and Coiner and Morain (1971) have produced prototype keys for crop and forest type identification. For a general review of the interpretive state-of-art in all these topic areas the reader should refer to the Manual of Remote Sensing (1976, Vol. II, Chapters 17 and 22).

INTERPRETIVE KEYS

Image interpretation keys for vegetation, crops and general land use vary according to the nature of those phenomena and their appearance on imagery. In crop discrimination, for example, keys developed from K-band imagery have not employed image texture because this parameter does not appear to aid interpretation. X-band imagery, however, does contain textural information, and in all frequencies studies for forest typing, texture is a major clue.

The use of keys to aid vegetation interpretation from radar was first attempted by Morain and Coiner (1970) using fine resolution X-band imagery. Field information was compared to image appearances to qualitatively determine the range of variation within and between fields. Then, for each crop in several different growth stages, work sheets were prepared to illustrate the variation. The work sheets constituted the base for constructing the dichotomous key shown in Table 1.

Other kinds of keys can also be constructed using radar imagery as a base (Coiner and Morain, 1971). Collateral, error, associate, and matrix keys are but a few of these, and they all have special purposes in vegetation analysis. The matrix key (Table 2) is particularly useful for identifying and delineating forest types.

INTERPRETATION OF IMAGE TONE AND TEXTURE

Basically, there are three sensor/terrain interactions influencing the strength of signal reflection from vegetation (manifested as image

TABLE 1

PROBABILITY* KEY FOR CROP TYPES AT GARDEN CITY, KANSAS

for

OCTOBER

(Derived from Radar Imagery)

A. Field has a moderately high to high return (light grey to white on radar positive) (with respect to HH)

- B. Field has a homogeneous** tone (with reference to HH)
  - C. Field displays a shift in tone from HH (lighter) to HV (darker)
    - D. Amount of tone shift is relatively unpronounced
      - E. HV tone is homogeneous ---------- sugar beets; or wheat > 3"
      - EE. HV tone is not homogeneous ---------- fallow
    - DD. Amount of tone shift is relatively pronounced
  - CC. Field does not display a tone shift HH (lighter) to HV (darker)
    - F. Field displays a tone shift from HH (darker) to HV (lighter)
      - G. Field has evident lineations ---------- cut alfalfa
      - GG. Field does not have evident lineations
    - FF. Fields does not display a tone shift from HH (darker) to HV (lighter)
- BB. Field does not have a homogeneous tone

AA. Field does not have a moderately high to high return

- H. Field has medium low to moderate return (medium dark to medium light on radar positive)
  - I. Field has a homogeneous tone (with reference to HH)
    - J. Field has lineations parallel to long axis of field
      - K. Tone shift is evident from HH (dark) to HV (light) -------- maturing alfalfa (flood irrigated)
      - KK. Tone shift is not evident
    - JJ. Field does not have lineations
      - L. Field displays medium coarse texture (particularly on HV image) ---- grain sorghum (rows ⊥ flight line)
      - LL. Field has no obvious image "texture"
        - M. Field has a moderate tone shift (HH to HV) -------- alfalfa > 12"
        - MM. Field has an unpronounced tone shift ---------- wheat > 3"
  - II. Field does not have a homogeneous tone
    - N. Cultivation pattern is observable (particularly on HV image) --- emergent wheat
    - NN. Cultivation pattern is not observable
      - O. Boundary shadowing is observable ---------- mature corn
      - OO. Boundary shadowing is not observable
- HH. Field does not have moderately low to moderately high return
  - P. Field has very low return (very dark grey to nearly black on radar positive)
    - Q. Field has a homogeneous appearance ---------- recently tilled
    - QQ. Field does not have a homogeneous appearance
  - PP. Field does not have very low return

*This key is experimental. It is based on only one look-direction (and for a narrow range of incidence angles) for one flight during October 1969 - almost at the end of the growing season for that year. It is a probability key in the sense that only the most likely, economically important crops are indicated for any given spot in the listing. To use it the interpreter must make a series of yes/no decisions until a logical end point is reached. For example, the first decision relates to image tone: does the field have a high or moderately high return (A) or does it not have such a return (AA)? If the answer is AA, then for subsequent decisions, that portion of the key above AA can be ignored, and the interpreter's attention focused on material listed below AA. The second decision would then be whether or not the field had a medium low or moderate return (HV vs. HH in the key). The process continues in this fashion until no further choices can be made. Notice that, if the location PP is reached, an error in judgment has been made. When this happens the entire process must be repeated. Similar reasoning applies to points BB, DD, GG, FF, KK, OO, and QQ, though future revisions of the key may provide information at these locations.

**"Homogeneous" refers to the uniformity of return intensity within the boundaries of a given field, i.e., there is no evident mottling of tone.

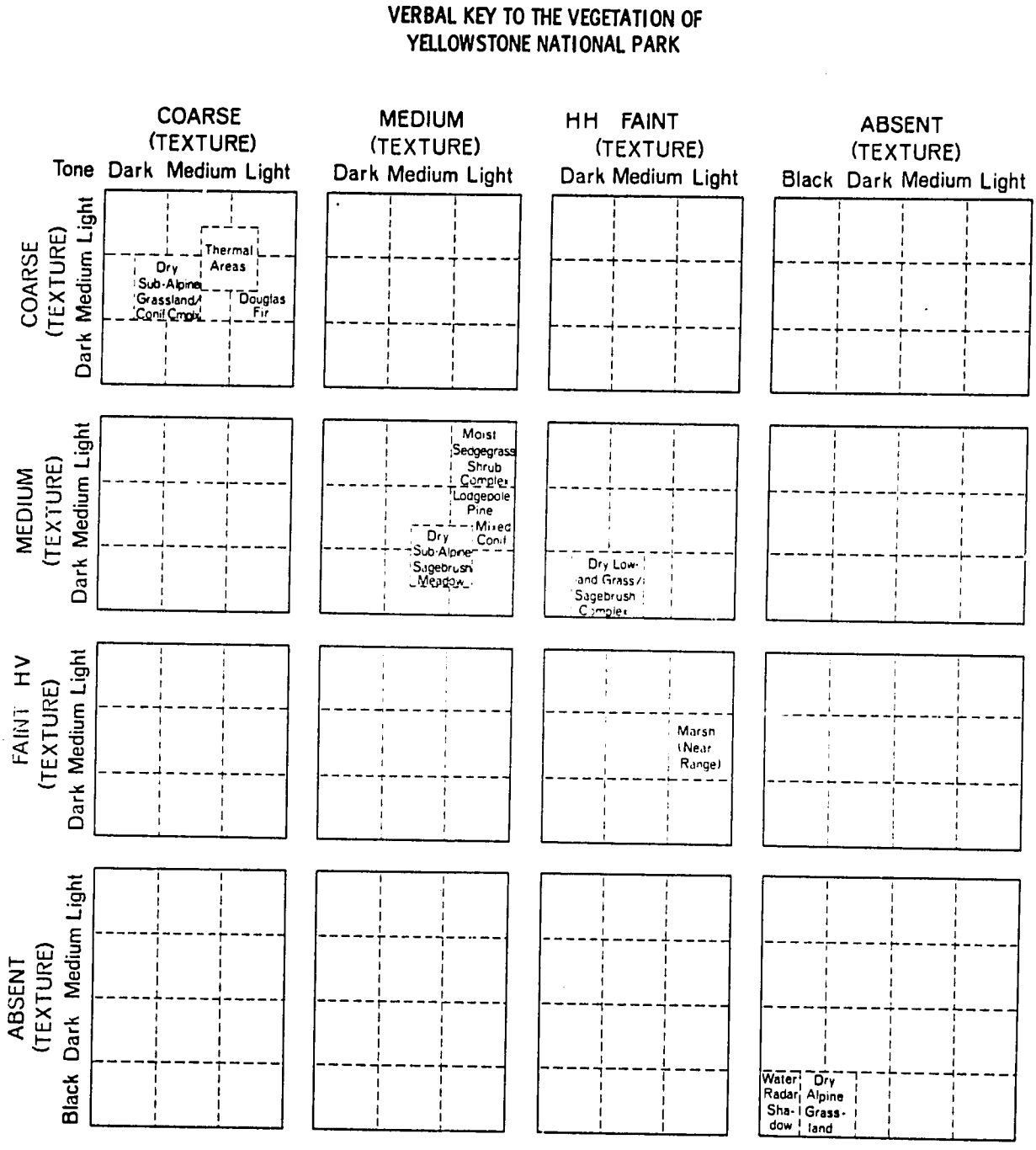

Table 2. Matrix key for identifying natural vegetation using 2-polarization K-band imagery. HH tone and texture form the "X-axis"; HV tone and texture form the "Y-axis." The intersections of these attributes define the location of vegetation types within the matrix.

tone). These can be divided into those factors associated with micro roughness and macroscale roughness. For vegetation analysis all three are significant. At the finest scale of reference (microroughness) grey tone is a function of the wavelength or frequency of the system being used and the viewing angle. Just as there are different amounts of blue, green, and red reflectance associated with vegetational phenomena (be they ecotypes, species, or whole communities) in the visible part of the spectrum, there are also different radar reflectances depending upon system frequency. Similarly, just as different types of vegetation have variable reflectances depending upon solar elevation and azimuth, and viewing angle; they also have different radar backscatter properties as a function of angle of illumination (incidence). The terrain properties that determine observed tones are leaf size, leaf area, leaf/twig ratio, percentage of ground cover, and total scene moisture.

Mesoscale roughness is the "gross roughness envelope" and is directly related to image texture. Consider a large parachute cloth dropped over a vegetative surface: this results in smoothing the high frequency roughness. In a forest, there would be large peaks and nulls resulting from the height variability between tree crowns and the open ground or understory cover; whereas, a shrub or grassland type would have considerably less amplitude. Consider now their appearance on the image. For the grass or shrub types there is little spatial variation in the envelope, so the resolution cells might be almost identical in grey tone. In the case of the forest where there is a possibility for substantial spatial variation, some cells might have stronger average returns than adjacent cells. If the peaks and nulls in the envelope are sufficiently large, the result would be areas of high reflection juxtaposed with areas of low reflection on the image, thereby

imparting terrain texture. The greater the variability in the envelope, the coarser the texture. Mature forests display coarser textures than young, even-aged stands. As the amplitudes in the envelope diminish (grass and shrub types) texture likewise diminishes.

System frequency and resolution most influence mesoscale roughness. Frequency is important because the longer the wavelength, the greater must be the amplitudes comprising the envelope. System resolution is important because in envelopes of high roughness the finer the resolution, the more prominent the texture. Since this is an averaging phenomenon the finer the resolution, the greater the variability in average signals over a rough envelope. On envelopes of low amplitude resolution is less important because the average grey tone is very nearly identical regardless of the area over which the signals were averaged (slope variations not considered). The terrain parameters that influence mesoscale roughness are associated with plant community structures (height, spacing of plants, etc.).

Macroscale roughness is a complex image tone arising out of a combination of micro and mesoscale roughness superimposed on sloping terrain. The influence of slope on image tone has been thoroughly discussed by Lewis and Waite (1973) and MacDonald and Waite (1970). As far as radar interpretation is concerned, the most important aspect of macroscale roughness on vegetation has to do with its use for ecological surrogates.

To illustrate the above ideas a pine/fir forest in Oregon is considered. The imagery shown in Figure 1 is K-band. Basically there are three types of vegetation shown on the image. These three have different micro and mesoscale properties which can be interpreted in terms of grey tone and texture. In addition, there is sufficient variation in slope that complications are in an otherwise straight forward interpretation of grey tone.

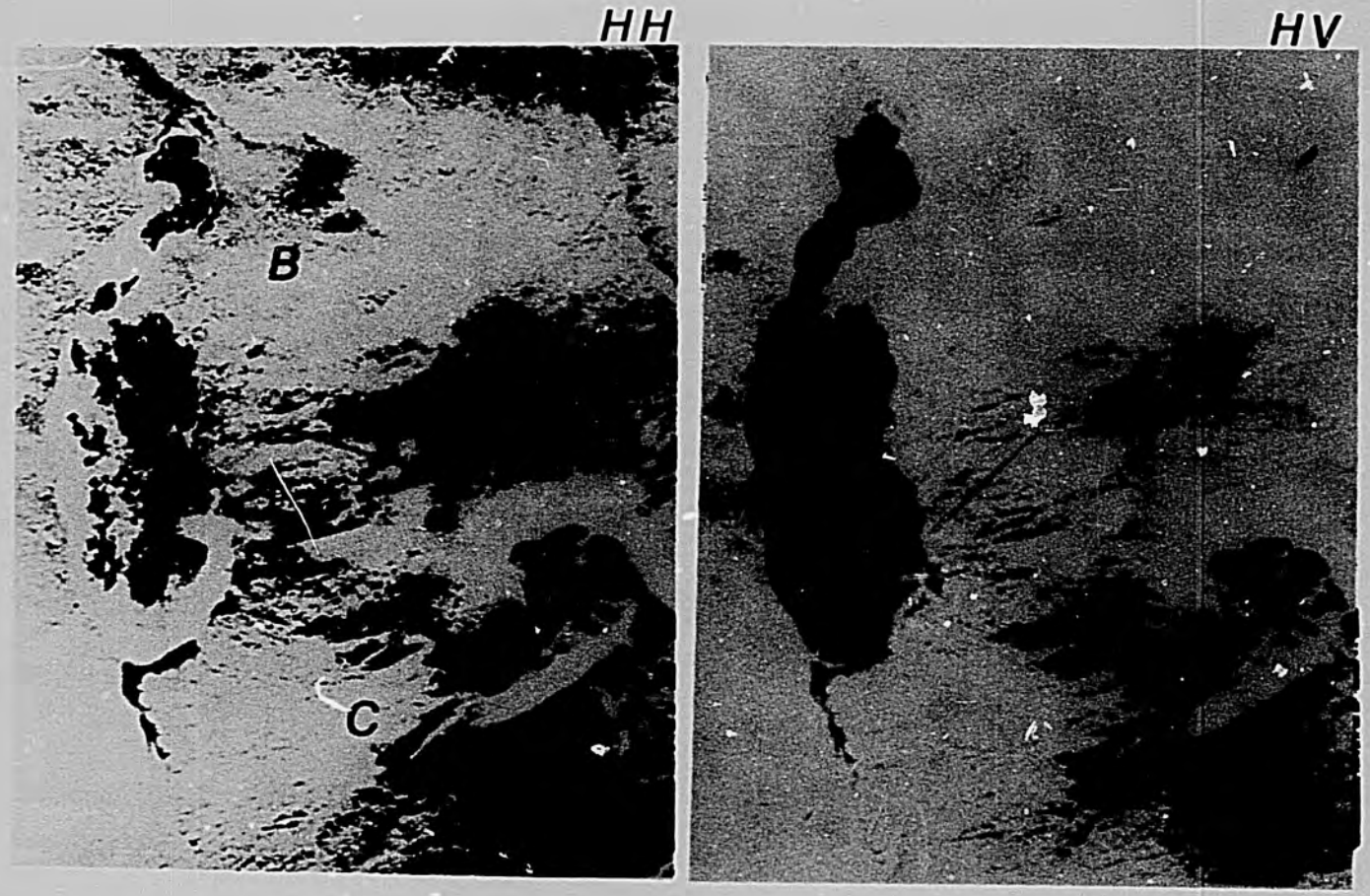

Figure 1. K-band HH image of forest types (tones and textures) near Lake-o-the-Woods, Oregon. A = white fir; B = ponderosa pine; C = chaparral shrub; D = ambiguities arising from terrain slope effects. In natural vegetation microscale roughness accounts most for image tone; mesoscale roughness (gross roughness envelope) accounts most for image texture; and macroscale roughness accounts most for the appearance of terrain features.

The area marked A is a white fir forest; that labeled B is a ponderosa pine forest; C indicates chaparral shrub; and D represents areas of ambiguity arising from slope influences.

The fir forest has a decidedly darker tone than either of the other types (both on the HH and HV image--effects of polarization are discussed in the next section). Moreover, if one compares the mesoscale roughness of the pine forest with the fir type, there is a subjective notion of less texture associated with the fir. The implication is that the gross roughness envelope for fir has less amplitude than that for pine at this resolution and frequency. Relative to the other types it would appear that fir forest is neither a good surface scatterer (HH polarization) nor a good volume scatterer (HV polarization), since this type is dark grey on both images.[1]

The interpretation for ponderosa pine forest has been discussed in Estes and Senger (1974, pp. 154-158). For present purposes it is discussed in relation to the surrounding vegetation types. In this example the basic tone of ponderosa pine and chaparral shrub communities is about equal. This suggests that these two types have nearly the same surface roughness and volume scattering properties. The only distinguishing features between the types is their differing textures. The gross roughness envelope of the pine forest is significantly rougher than that for the chaparral

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[1]For this analysis we assume that differences in moisture between vegetation types are negligible. The imagery was obtained in the fall of 1976 after a rather dry summer. In addition, the moisture in all these types may be effectively masked from the radar signal by physiological adaptations such as sclerophylly in chaparral. The reasons behind the darker tone of fir forest are not immediately clear. Part of the explanation may be related to the vertical orientation of the short needles. With such dense, vertically oriented needles, surface scatter may be signficantly reduced relative to the surrounding vegetation tyeps leading to a relatively darker tone on the HH image.

community. This difference can be seen in the accompanying ground photographs. For the pine forest, texture has the appearance of light and dark grey speckle, whereas the chaparral type has decidedly less spatial variation in tone. The relatively brighter tone of pine forest in comparison to fir may arise from the more random orientation of needles which are assumed to be the basic scattering elements at the microscale.

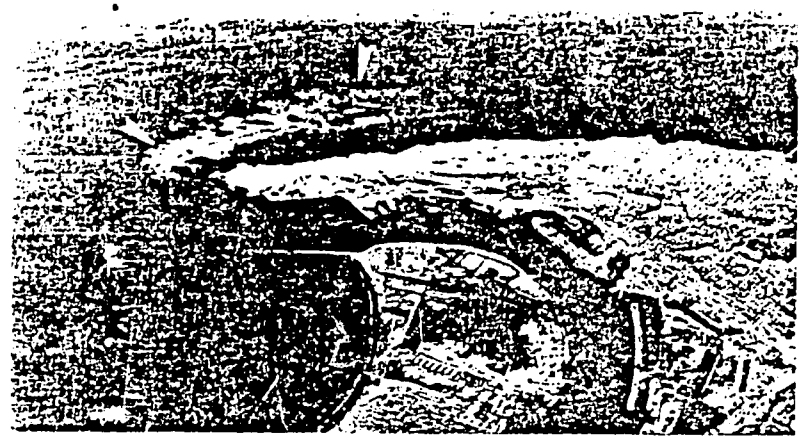
Differentiation of the chaparral community is made possible by its relatively unique radar backscatter properties. The greater variability in orientation and size of leaves on the individual shrubs leads to relatively high surface scattering and hence to a bright tone on the imagery. In contrast to the other types, however, the envelope is much smoother than for the forest types; hence, there is less image texture associated with the chaparral. Both of these properties (relatively smooth envelope and greater variability in leaf orientation) are illustrated in the photos in Figure 5. A third and important property of the chaparral community is the rather high contribution of volume scattering as evidenced by the relatively high reflectances shown on the HV image (not shown here). In most all respects there appears to be little difference in the reflectance of pine forest and chaparral, except in their textural renditions. Nevertheless, this important property is sufficient for the visual separation of these two types.

There are some areas in this example that cannot be interpreted with any degree of assurance. These are the areas marked D and are ambiguous because of slope effects; some facing away from and others toward the receiver. On slopes where the basic grey tone has been influenced by slope but where it can neither be described as radar shadow or blooming, one must rely on ecological surrogates to make the interpretation.

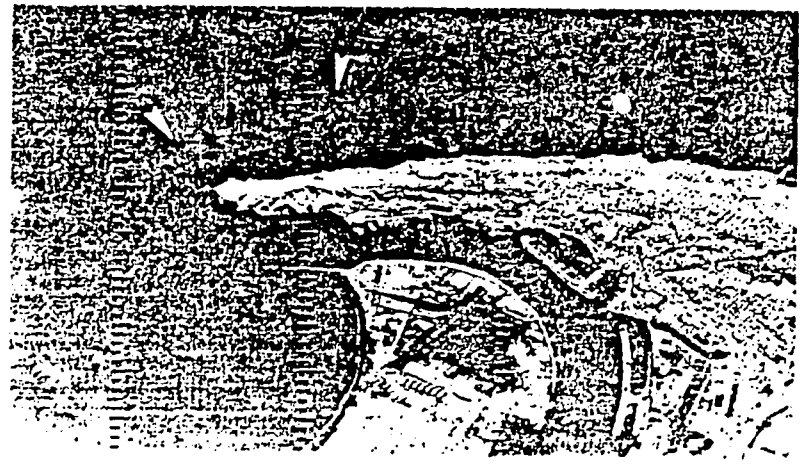
EFFECTS OF POLARIZATION ON TONE AND TEXTURE

Given two polarizations (HH and HV) the HH will be dominated by reflectances arising from surface scattering. The brightness on the radar positive image (tone) will be due foremost to surface scattering of the impinging signal. In general, this is referred to as surface roughness, where "roughness" is defined in terms of wavelength. Return on the HV image, in contrast, is primarily a function of "volume" scattering. By "volume" we mean to imply that signals are able to penetrate to some depth within the imaged scene. Independent of wavelength the ability of radar signals to penetrate depends on polarization with the cross polarized component (HV) containing most of the information on volume scattering. Therefore, the brighter the return on HV imagery, all other factors being equal, the greater the contribution from volume scattering and, by implication, the more heterogeneous the imaged material. For homogeneous media there should be little difference between HH and HV reflectances, whereas for heterogeneous media there should be some contribution to the HV signal.

A couple of examples will suffice to illustrate the above points. Figure 2 is a K-band, two polarization (HH and HV) radar image of the Point Loma Kelp bed off San Diego. A low-altitude oblique photo and a ship-board photo is also included to better illustrate the aspect of kelp in the water. On the HH image the configuration of the kelp bed is clearly detectable. The bright returns for the kelp area indicate a high amount of surface scattering of the impinging signals. The reason for the more or less continuous coverage of the kelp bed area is attributed to the rather coarse system resolution (about 15 meters) and the averaging techniques



HH Polarization



HV Polarization

Figure 2. K-band HH and HV images of Point Loma kelp bed. In HH images arrows point to bright reflectance from floats and stipes. Intricate detail of the kelp bed is visible because of the very low amount of volume scattering possible in aquatic environments.

employed in converting the reflected signals to imagery. By comparison on the HV image, which was obtained simultaneously, the kelp bed is much less distinct--only a "ghost" of the kelp bed is actually visible. This illustrates that there is, indeed, a slight contribution of surface scattering to the HV signal but the important point is that there is almost no volume scattering associated with the kelp. Radar signals cannot penetrate water, therefore there can be no signal penetration and no contribution from volume scattering. The result is that there is almost no HV signal returned. To appreciate this the nature of kelp beds is considered.

The long stipes of kelp are attached to the ocean floor and are lifted into a vertical position by numerous pear-shaped floats. Each of the pear-shaped floats is attached to a frond or leaf. These fronds float to the surface but never emerge above the water surface; they are always covered by a thin film of water. Consequently, the only portion of the kelp that actually protrudes above the water, and is therefore the primary contributor to the returned radar signal, are the pear-shaped floats and small sections of the stipes. These are the elements that contribute most to the radar reflectance. It has been argued by some that there is a contribution to reflectance from the fronds, but this is clearly impossible due to the specular reflecting properties of water at low antenna depression angles.

It is possible to increase the comparative reflectances between HH and HV polarizations by amplifying the receiver gain; and therefore possible to saturate the terrestrial portion of the HV image in order to enhance the relative brightness of the kelp bed. Although these kinds of shifts in receiver gain are feasible, they can seriously affect the interpretation because they are not usually calibrated or recorded. In Figure 2

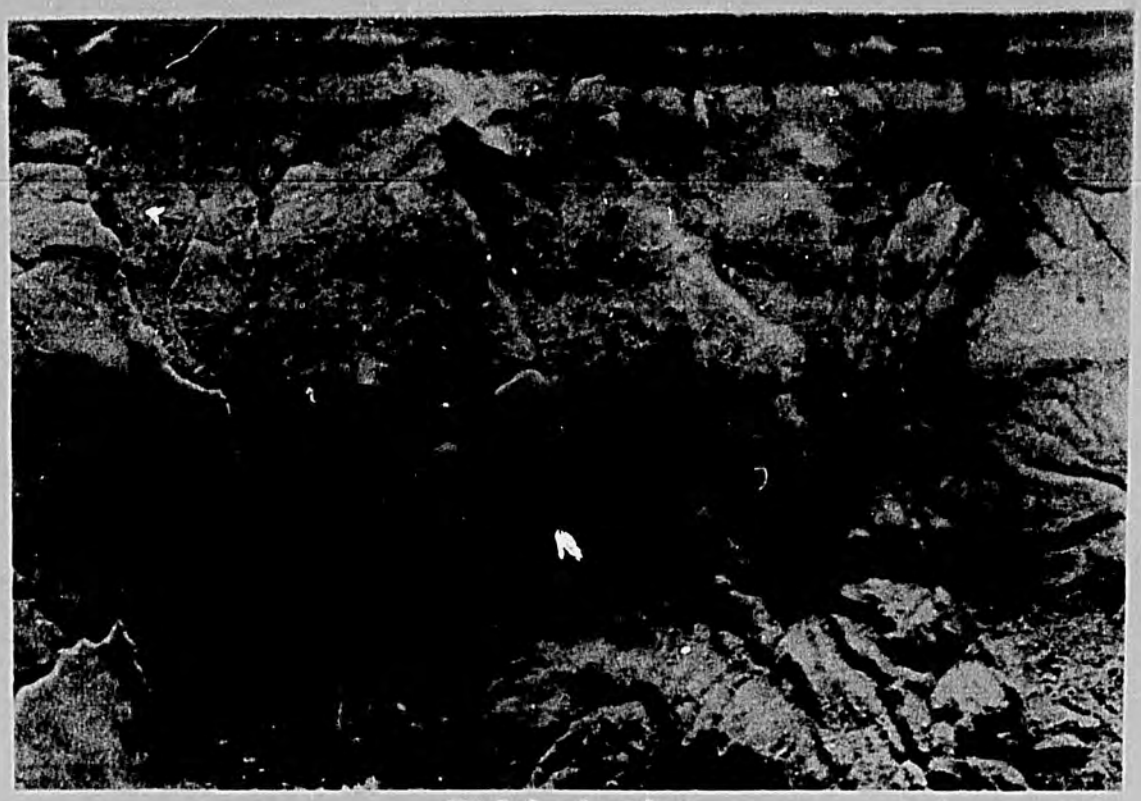
there was no apparent difference in the receiver gain for the two polarizations as evidenced by the similarity of their grey scale ranges for the land area.

Figure 3, a pine forest in Oregon, is included to illustrate the appearance of the area on the oblique panchromatic photograph obtained simultaneously with the HH and HV images (Figure 4). To aid in the interpretation typical views of the dominant vegetation types (ponderosa pine and sagebrush/basalt) are provided (Figure 5). Details of the area and an analysis using a variety of remote sensor data have been given by Cochran, et. al. (1969) and Morain and Simonett (1965). Neither of these papers, however, discussed in specific terms why the HH and HV images are different.

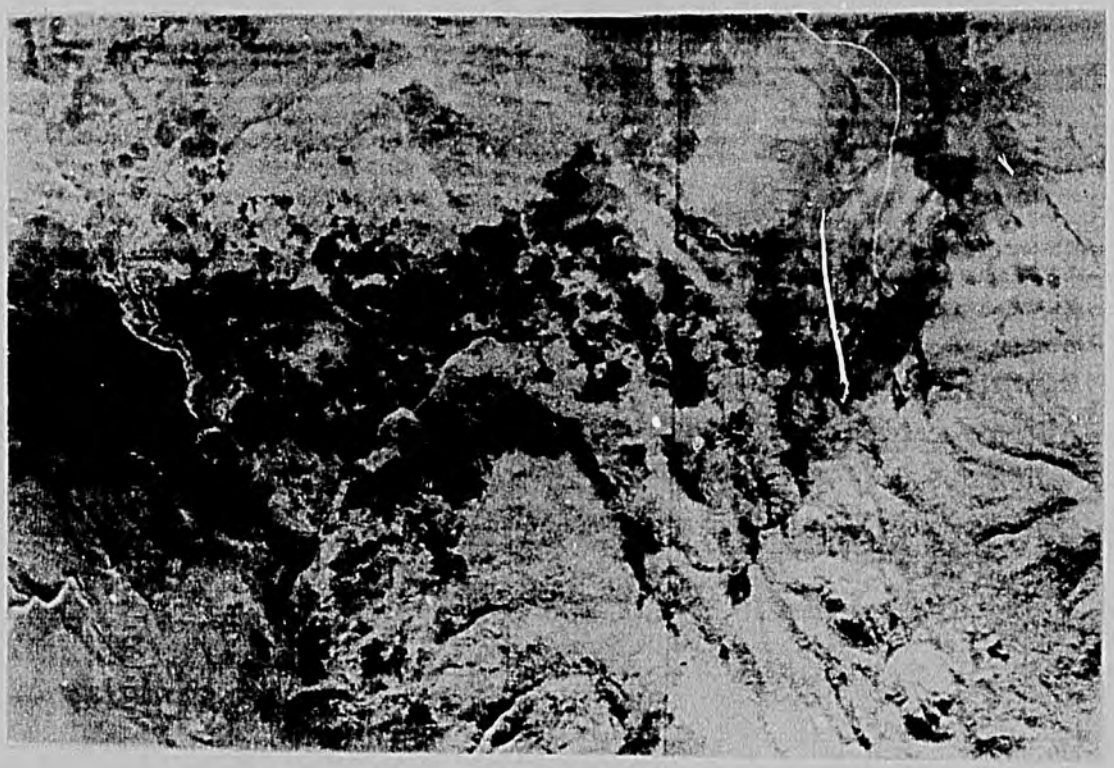
On the HH image there is no observable difference between the pine forest and the sagebrush in terms of their average grey tone. By carefully examining the HH image one can, nevertheless, begin to regionalize and segregate the forest from the non-forest. This is in part possible because of the different image textures. The implication from the observation of tone (without texture) is that both of these vegetation types are equally rough in terms of surface scattering. There are, however, significant differences in their mesoscale roughnesses.

If one compares the HV pattern to the HH pattern, the following observation is made. On the HV image the relatively bright tone of the forested region compared to the non-forested indicates that there is a significant contribution of volume scattering from the forest. Stated another way, the forest is a better volume scatterer than the non-forest, at least in this environment. Notice also that there is relatively little difference between the two polarizations for the sagebrush type. Although

Figure 3. Low altitude aerial oblique photograph near Horsefly Mountain, Oregon. Area represented is shown in Figure 4 in the upper right quadrant.



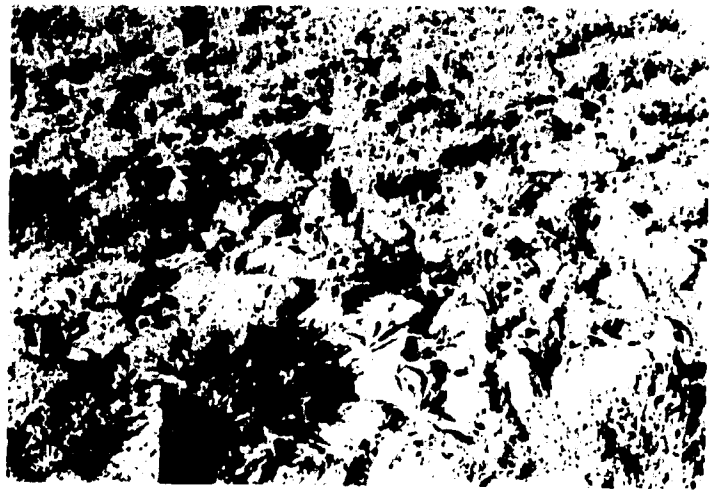
HH Polarization



HV Polarization

Figure 4. K-band HH and HV images of Horsefly Mountain, Oregon. Interpretation of the two main vegetation types is given in the text.

Ponderosa Pine



Basalt/Sagebrush

Figure 5. Typical ground views of Ponderosa Pine and sagebrush with basalt. See text for discussion.

discrimination is aided by this difference, the radar imagery merely shows that the forest category is a better volume scatterer. In another environment it could well be that the non-forest category as shown here would be better volume scatterer than some third category. The lesson is that radar interpretation is environment dependent and only relative statements can be made with regard to a given radar image or set of polarizations.

SUMMARY

These few examples by no means exhaust the considerations necessary to completely interpret vegetation from radar imagery. They are intended as an introduction to the lines of reasoning that can be employed to extract at least preliminary information and to explain the appearance of selected types on imagery. There is still need to consider the relative effects of moisture, depression angle, and frequency on radar reflectance.

As long as radar systems remain single frequency, we can expect to view the landscape in virtual monotone, just as if we tried to image through a narrow optical filter. In the case of radar we have reached a point where basic parametric research is absolutely essential, if we expect radar imagery to be used for identifying vegetational phenomena. In the meantime we should continue to develop non-identification (mapping) types of applications.

In the future, structural and physiognomic mapping from radar may be feasible, but will depend on the availability of finer resolution sensors, development of interpreter experience regarding the meaning of tone and texture, and exploitation of radar penetration potential. Research has

only begun to explore the contents and techniques of interpreting radar imagery. The traditional approaches cited reflect the novelty of the imagery and our inexperience using this exotic sensor.

MAPS AS FAIR MEASURE TO A COUNTRY'S KNOWLEDGE

By

Dr. Hassan Mohammed Hassan*

The national development of maps is the desire which necessity or curiosity imposes on mankind to explore the earth's surface (and for that matter, other planets), to move from one part to the other, or to better know any particular part on the path of experiences and enquiry.

Historically the Egyptians were the earliest recorders of examples of cartographic representations. To the Babylonians is attributed the high distinction of having originated the division of the ecliptic into twelve signs and later 360 degrees. The division of the day into 24 hours was the outcome of their sexagesimal system of numeration. These were adopted by the Greeks later in their geographical and astronomical studies. To the Arabs during the middle ages is attributed the discovery of the mariner compass.

When Columbus set out to discover the eastern shores of India, he didn't expect to find any land in the space occupied by the American continent due to an error in Ptolemy's maps.

On the other hand, the history of thematic maps does not go as far back as the astronomical and travel maps. The geological maps, for example, were first known in 1815.

It is in maps of greater or lesser antiquity that it is possible to trace with the greatest economy of effort the growth and spread of towns

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*Director General, Survey Department, Khartoum

and their decline, the growth of agriculture, industry of great states, the survival or development of lines of communication, varying types of roads, canals and railways. Erosion has caused both lands and towns to disappear and on the other hand reclamation of land and silting up has considerably altered coast lines and created new places. Rivers have changed their courses and the boundaries of countries have been altered at various dates. All these may be most advantageously examined on maps of one type or the other.

Maps and nationality are like weave and woof. Most countries in their prime development and civilization publish maps that show their culture in every branch of knowledge. It goes without doubt that the more advanced and complete the mapping of a country is, the more developed the country is or will be.

It can be seen on the attached table that the highly developed countries of Europe are almost completely covered with maps of different scales. It is also seen that the underdeveloped countries of Africa and Asia are bare of reasonable coverage of maps. As seen from the table, the Sudan maps exist only at 1:100,000 and smaller scale and at even 1:100,000 the coverage is less than 25%. Peru has only scanty coverage at 1:200,000 of less than 25%.

The relation between map coverage and the state development is not only an academic relationship but it is actually the practical relationship between the knowledge of the availability of resources and its exploration. All inventories of natural resources must be based on maps that indicate their extent and geographical location. Thus, maps are not only a fair measure to a country's knowledge but also are the basis of the country's development.

TABLE 1

OFFICIAL MAP SERIES

1:253,440 AND LARGER SCALES

PERCENTAGE COVER: 1%-25%, 25%-50%, 50%-100%

EUROPE

Albania			1:50,000	1:100,000	
Austria		1:25,000	1:50,000		1:200,000
			1:75,000		
Belgium	1:10,000	1:25,000	1:50,000	1:100,000	1:200,000
	1:15,000	1:40,000			
	1:20,000				
British Isles	1:10,560	1:25,000	1:63,360	1:126,720	(1:250,000
					(1:253,440
Bulgaria		1:25,000	1:50,000	1:100,000	
		1:40,000			
Czechoslavakia		1:250,000	1:75,000		1:200,000
Denmark	1:20,000	1:25,000	1:50,000	1:100,000	1:200,000
		1:40,000		1:150,000	
Estonia	1:20,000		1:50,000		1:200,000
Finland	1:20,000		1:50,000	1:100,000	1:200,000
France	1:20,000	1:25,000	1:50,000	1:100,000	1:200,000
			1:80,000		1:250,000
Germany		1:25,000	1:50,000	1:100,000	1:200,000
Greece	1:20,000		1:50,000	1:100,000	1:200,000
Holland		1:25,000	1:50,000	1:100,000	1:200,000
					1:250,000
Hungary		1:25,000	1:75,000		1:200,000
Iceland			1:50,000	1:100,000	1:250,000
Italy		1:25,000	1:50,000	1:100,000	1:200,000
Latvia		1:25,000	1:50,000		1:200,000
			1:75,000		
Lithuania		1:25,000		1:100,000	
Luxembourg	1:20,000		1:50,000		
Malta	1:2,500	1:25,000			
Norway		1:25,000	1:50,000	1:100,000	1:200,000
					1:250,000
Poland		1:25,000		1:100,000	
Portugal			1:50,000	1:100,000	1:200,000
Romania	1:20,000		1:50,000	1:100,000	1:200,000
Spain			1:50,000	1:100,000	1:200,000
				1:100,000	
Spitzbergen				1:100,000	
Sweden			1:50,000	1:100,000	1:250,000
Switzerland		1:25,000	1:50,000	1:100,000	
U.S.S.R.		1:25,000	1:50,000	1:100,000	1:200,000
Yugoslavia		1:25,000	1:50,000	1:100,000	

OFFICIAL MAP SERIES (Contd.)

AFRICA

Algeria		1:50,000	1:100,000	1:200,000
Angola			1:100,000	1:250,000
Basutoland		1:50,000		
Bechuanaland			1:125,000	
Congo	1:25,000	1:50,000	1:100,000	1:200,000
Egypt	1:25,000	1:50,000	1:100,000	1:250,000
Eritrea	1:25,000	1:50,000	1:100,000	
Ethiopia		1:50,000	1:100,000	
French Equatorial Africa		1:50,000	1:100,000	1:200,000
French West Africa		1:50,000	1:100,000	1:200,000
Gambia		1:50,000	1:125,000	
Ghana		1:50,000	1:125,000	1:250,000
		1:62,500		
Ifni		1:50,000		
Kenya		1:50,000	1:100,000	1:250,000
			1:125,000	
Liberia			1:125,000	
Libya		1:50,000	1:100,000	
Malagassi Republic			1:100,000	
Mauritius	1:25,000			
Moçambique				1:250,000
Morocco				
(Former French)		1:50,000	1:100,000	1:200,000
(Former Spanish)		1:50,000	1:100,000	1:200,000
Nigeria	1:25,000	1:50,000	1:100,000	1:250,000
		1:62,500	1:125,000	
Rhodesia, Zambia and Malawi		1:50,000	1:100,000	1:250,000
Sierra Leone 1:10,000		1:50,000		
		1:62,500		
Somaliland (British)	1:25,000	1:50,000	1:125,000	
Somaliland (French)			1:100,000	1:200,000
Somaliland (Italian)		1:50,000		1:200,000
South West Africa			1:100,000	
Sudan			1:100,000	1:250,000
Swaziland		1:50,000		
Swaziland		1:50,000	1:100,000	1:250,000
Tanzania			1:125,000	
		1:50,000	1:100,000	1:200,000
Tunisia		1:50,000	1:100,000	1:200,000
Uganda		1:50,000	1:100,000	1:250,000
Republic of South Africa	1:25,000	1:50,000	1:100,000	1:250,000

ANTARCTICA

Antarctica	1:25,000	1:50,000	1:100,000	1:200,000
				1:250,000

OFFICIAL MAP SERIES (Contd.)

ASIA

Aden				1:100,000	1:250,000
Borneo (British Territories			1:50,000		
Burma			1:63,360	1:126,720	1:253,440
Ceylon			1:63,360		1:253,440
China			1:50,000	1:100,000	
Cyprus	1:10,000	1:31,680			
India		1:25,000	1:50,000 1:63,360	1:126,720	1:253,440
Indochina (Former)					
Cambodia				1:100,000	
Laos				1:100,000	
Viet Minh		1:25,000		1:100,000	
Viet Nam		1:25,000		1:100,000	
Indonesia		1:25,000	1:50,000	1:100,000	
Israel	1:20,000		1:50,000	1:100,000	1:250,000
Japan		1:25,000	1:50,000		1:200,000
Jordan				1:100,000	1:250,000
Korea		1:25,000	1:50,000		1:200,000
Lebanon			1:50,000	1:100,000	1:200,000
Malaya		1:25,000	1:63,360		
New Guinea (British)		1:25,000	1:63,360		1:250,000 1:253,440
New Guinea (Dutch)				1:100,000	1:250,000
Pakistan			1:63,360	1:126,720	1:253,440
Philippine Islands		1:25,000	1:50,000	1:100,000	1:250,000
Siam			1:50,000	1:100,000	1:200,000
Syria			1:50,000	1:100,000	1:200,000
Turkey		1:25,000	1:50,000		1:200,000
U.S.S.R.			1:50,000	1:100,000	1:200,000

OFFICIAL MAP SERIES (Contd.)

AMERICA

Alaska			1:63,360		1:250,000
Argentina		1:25,000	1:50,000	1:100,000	1:250,000
Bolivia					1:250,000
Brazil		1:25,000	1:50,000	1:100,000	1:250,000
British Honduras			1:50,000		
Canada			1:50,000	1:126,720	(1:250,000
			1:63,360		(1:253,400
Chile		1:25,000		1:100,000	1:250,000
Columbia		1:25,000		1:100,000	
Costa Rica		1:25,000	1:50,000		
Dominican Republic			1:50,000	1:100,000	
Ecuador		1:25,000			
Falkland Islands			1:50,000		
Greenland					1:250,000
Guatemala			1:50,000		1:250,000
Guiana (British)			1:50,000		
Guiana (French			1:50,000	1:100,000	1:200,000
Guiana (Dutch)				1:100,000	1:200,000
Hawaii	1:24,000		1:62,500		1:250,000
Jamaica			1:50,000		1:250,000
Mexico		1:25,000		1:100,000	
Nicaragua				1:150,000	
Panama	1:20,000	1:25,000			1:250,000
Paraguay			1:50,000		
Peru					1:200,000
Puerto Rico	1:20,000	1:30,000			
Salvador			1:50,000		1:200,000
United States	1:24,000	1:31,680	1:62,500	1:125,000	1:250,000
		1:48,000			
Uruguay			1:50,000		
Venezuela		1:25,000		1:100,000	1:250,000

AUSTRALASIA

Australia		1:25,000	1:50,000	1:100,000	1:250,000
			1:63,360		1:253,440
Fiji Islands			1:50,000		
New Zealand		1:25,000	1:63,360		1:250,000
					1:253,440

REMOTE SENSING ACTIVITIES AND FUTURE PLANS IN SUDAN

S. M. El Rabaa*

When one talks about remote sensing in any country, he usually gives some idea about the components of that country, such as its physiography and climate. Thus, I will do likewise for The Sudan. The Sudan is the largest country in Africa. Its area is over 2,500,000 square kilometers. This country has diverse climatic and natural regions starting from the sandy desert in the north with almost zero precipitation to tropical steppe in the far south. The Sudan has great development potential. International agencies often call The Sudan "the bread basket of the future for Africa and the Middle East". They have good reasons to say this. We have exploited only very few of our resources, whether renewable or non-renewable. One has to look at our real demands. I am not going to say how we are going to solve a problem like this or the problems of development. We have an opportunity to discuss the problem during this workshop, the theme of which is "how to use a promising new technology in solving some of our problems".

The demand of data for wise planning for resource development is something that everybody agrees upon. These data include either geographic or economic and institutional data. One can see that remote sensing, of which you have a fairly good idea about its use, is a suitable technique to solve the problem of resource surveys for our vast region.

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Indeed, Sudan started to adopt this new technology a long time ago. The year the National Council for Research was developed in 1970 was also very glamorous for aerospace technology. At that time, in 1969 man reached the moon, and within the next year specimens from the moon had been displayed all over the world and everyone was struck by this new technology. One of the very first functions of the National Council for Research was displaying moon rocks in The Sudan.

Later, The Sudan was the only country that made a proposal to NASA in 1970 to include coverage of some parts of the country in NASA's program. By 1971 Sudan had been selected as one of three countries among the developing countries of Africa to start a pilot project using Landsat data. Now anyone can make use of the data available from the common mission of Landsat.

By 1972, when the first products from Landsat became available, the Ministry of Agriculture in Sudan, through the Canadian AID and FAO, started to plan the first project using Landsat imagery.

So, in this connection, The Sudan is one of the very few developing countries which has been selected for all the good reasons as a country where experiments of application of remote sensing using Landsat imagery were made. From that time, we started to have considerable activity in this field. Much was bilateral activity between one department and another. Some departments managed to build small remote sensing capabilities through regional or foreign international aid.

During the period from 1973 to 1974 the agriculture project was being executed. Since then, we started to have some specialists in a number of disciplines with different levels of training on remote sensing applications.

It is well known that The Sudan has applied aerial photography a long time ago, long before most African countries. In the fifties, The Sudan had some of the best personnel and the best instrumentation in that field in Africa, and a good percentage of the country was covered by aerial photographs. Many of the scholars went to aerial photography courses and training.

We ended up with many good experts on aerial photography. At the same time we noticed that many departments started to establish sections for aerial photo-interpretation such as the Geological Survey Department, the Forestry Department, and the Soil Survey Department. So by the time remote sensing became glamorous and was found to be a useful tool that could be applied in Sudan, we were really in quite good shape except we needed the training on the use of data acquired by Landsat satellites.

This is ample economic justification for applying remote sensing in our resource surveys. Taking into consideration the size of the country and the type of information needed for resource development, one might go in to detailed work to identify and map the resource component, and such detailed work would be very expensive. We do not know the outcome of planning such a detailed survey. If it does not give any positive results, it would be a lost expense that a poor country may not be able to afford.

At the same time the reconnaissance type of work often done in a developing country is the type of work that may miss potential resources because one did not go into any detail. Landsat imagery provides us with a new scale. Although the most common product of Landsat imagery is photographic products at a scale of 1:1 million or 1:1/2 million, it can still be enlarged to the scale of 1:1/4 million. The type of information in the Landsat image is a different type of information which requires that our idea about "small scale" should be changed.

Previously, anything above 1:60,000 scale was called "small scale". Nowadays, Landsat imagery commonly produced at the half million scale should be called very small scale because at this scale one integrates a lot of data. Vegetation is used to choose a geologic feature or drainage may be used to choose a soil property. This complex interaction and the use of integrated criteria may result in getting information from the Landsat image which is much beyond the scale that you often work with, say 1:1/2 million.

Now we have found a new scale that covers a large area and yet yields more information than we used to get from what we previously called "small scale", whether it was small scale photography or our usual type of quarter million scale mapping. What is obtained from the Landsat image might be called "comprehensive reconnaissance." What is really obtained is more than would normally be expected from the scale at which one is working. This is one way of getting data which does not involve much money and does not deal only with the

generality. So, with less money one goes beyond the very general type of reconnaissance. This is particularly useful for planning any further detailed work without missing any potential area.

In a country like Sudan which is 2 1/2 million square kilometers in area and has a very bad communications situation, remote sensing technology is ideal and there is really no need for further justification for developing this technology in Sudan.

In regard to the institutional aspect, the most basic part of building a remote sensing capability is training the people of the country on the use of this technology. The beauty of this technique is that it enables updating of data. It's the only technique that provides for continuous monitoring of the earth's surface every 9 or 19 days. A certain area can be seen next season, next year, or after several years. For this reason there is a need for local capabilities to be always available for continuous monitoring of the changes that takes place and to make full use of the technique.

A good mosaic was made last year for the Sudd region. Next year it might be useful to see what changes have occurred. The same might be repeated the year after. There are a lot of dynamic type of problems that need Sudanese capabilities to monitor. For this reason emphasis must be placed on the development of human skills, which is an essential part of such techniques.

I would like to state very sincerely that we are very fortunate to be associated with the Remote Sensing Institute of South Dakota State University. I myself have been there to experience their

training. Six Sudanese scientists in six different disciplines were trained at the Remote Sensing Institute. Now, those six scientists are training others as you see in this workshop.

Therefore, a plan for training the people was the basis for fulfilling the institutional requirements. Some other aspects of the institutional requirements which must be considered are the type of setup and where it should be located. I will delay discussing these points for a while until I show you how our own specialists who have been trained at the Remote Sensing Institute look at remote sensing and, very briefly, the type of information they can obtain.

Mr. Chairman, if you permit, I would like to introduce Abbas Doka, Yousif Yagoub and Abdel Rahim Abdel Aziz. They are examples of the people who were trained in South Dakota and will give us an idea about their training and the work they did in their respective disciplines.

Abbas Doka M. Ali*

I will give a very short review of my project which demonstrates the application and the value of remote sensing technology in monitoring natural resources, especially soil resources in central Sudan. During the workshop I will speak in detail about the methods we applied, the results which we came to, and the products which we obtainted.

From the visual interpretation of the Landsat imagery and the compilation of all the data obtained we ended up with a soil map showing the different soil associations and another map for the different landscapes of central Sudan. The soil map was interpreted for different land uses for traditional and rain-fed agriculture, showing the potentiality of these soils in that part of the country.

The technique proved to be useful. Moreover, it enables us to show the decision-makers where the regions with good potentials are, to concentrate in their developing strategy for the country. For example, we show them, through certain maps, the suitability of the various soils for different crops. We show them the areas of soils with low potential for the time being. Later on, with more money and further studies and treatment, these poor soils can be developed.

A report comprising all this information in the form of maps, diagrams, and tables constituted the final product of my study concerning the soils in central Sudan.

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Abdel Rahim A/Aziz*

During our six-month training course at the Remote Sensing Institute, South Dakota State University, we started by getting acquainted with the different techniques of applying remote sensing in the different fields. My field is water resources on which I concentrated during my studies. Besides having lectures, practicing the techniques, and going on some field trips, we started on a project to study an area in central Sudan.

The area we studied lies between latitudes 12° and 17° north and extends from the White Nile to the east to longitude 28° 15' to the west.

I made up broad objectives for my study. The first objective was to find out if Landsat can serve as a field and base map. At the present time we do not have reliable topographic maps. Such maps are very important for those people working in rural areas for water resources. The only available maps are quarter million topographic sheets which were drawn in the thirties and before. Therefore, it is time to start correcting and updating maps of water resources. The second objective was desertification and was prompted by the interest of the Committee of Desert Encroachment to study the areas affected by desert encroachment.

The first objective was fulfilled by studying Landsat imagery of 1972. Because the main concern of the study was water resources, I concentrated on the selection of the imageries acquired after the

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rainy season because during the rainy season the region is mostly cloudy and difficult to interpret. Right after the rainy season, the cloud cover is much less, the drainage system is clearly seen, and the depressions are filled with water.

To satisfy the second objective I intended to interpret imageries of 1976 and then to compare the imageries of 1972 with those of 1976 in order to study the effect of desertification on the area and to quantify water resources in terms of the past and current water losses.

I started by using different bands for my interpretation. The area of our study comprises 342,000 square kilometers. Except for the small water courses with inappreciable flow (locally known as "Rigeilat"), the entire drainage system was delineated and the whole area was divided into four basins.

By delineating these 4 basins, I was able to identify easily the water courses and the tributaries feeding each of them. This is especially important since we, the people from Rural Water Corporation, face a lot of difficulties due to the meandering of water courses. I might state that we have many structures which we erected some years ago and due to the diversion of the courses are now left without water.

So, by interpreting Landsat imageries, one can easily update the drainage map and can easily check the water courses and their trend of meandering before installing any structure for water storage or for the control of the meandering stream.

On Landsat imageries we can easily differentiate between clear and turbid water; however, we still need a device by which we can quantify the sediments suspended in water.

Yousif Yagoub*

One of the objectives of my study at the Remote Sensing Institute, South Dakota State University, was to use Landsat data for determining the land use patterns in central Sudan. Actually it is fortunate that in land use mapping there is not a single classification system that could be applied at all times and in different conditions. For example, one can always map man's activities on the earth's surface and call it a land use map, provided that it gives meaningful information.

The area for which we conducted this survey was in central Sudan where the main activities are shifting cultivation in the form of small crops ranging in area from an acre to a few acres. The other activity is the nomadic movement of cattle over the area.

Another objective was the evaluation of the visual interpretation of Landsat imageries for monitoring land use, as well as signs of desertification in the area. For our study we used black and white prints and color composites at a scale of 1:500,000. During our interpretation we were confronted with some difficulties which I will mention later during the workshop.

Generally, our study resulted in two classification levels. The first classification level comprised those classes which are distinctly seen on the imagery because of their high contrast in relation to their surroundings. This includes, for example, the reserve forests, the dwelling centers, and the mechanized crop production schemes in

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Southern Kordofan. Other land use practices were actually not clearly defined on the imagery, but because of our background information about the area we were able to recognize and delineate them. The major geographic units were easy to delineate, such as the major river systems in the area, the clay plains, the sand dunes, and the sand sheets. We could interpret the land uses in these different physiographic units because of our previous knowledge of their relationship.

Someone may ask about the significance of this kind of map. Actually, there is not a single up-to-date map or adequate information about the land use of that area. We consider the map which we produced to be a base for making a land use map which will help to delineate or to select sample areas for more studies. These maps which we prepared from Landsat data are very useful for regional planning.

The other factor which we also considered is the cost and the time involved. In one month we mapped an area of 194,400 square kilometers, which is covered by six Landsat scenes. A Landsat image costs about U.S. $25.00. If this cost is compared to the enormous cost of aerial photography you can actually realize the importance of using Landsat data for such studies.

Salah M. El Rabaa

The presentations of the three preceding speakers, are an example of the results that can be obtained even with a simple and a short period of training. Indeed, the training process is still going on, on a department-individual basis; but we all have one aim, which is to develop the remote sensing capabilities in Sudan.

Concerning the institutional setup, we are fortunate to have the National Council for Research (NCR) in charge of the remote sensing activities in The Sudan. Prof. Mohammed Osman Khidir talked to you about the role of the NCR in this manner. Indeed the role of NCR solved a lot of problems. We have one institution (the NCR) in charge, and thus can coordinate and make policy. This is very important, particularly when dealing with matters that need coordination.

The whole intent of the activity plan is to establish a place in which all remote sensing scientists, technicians and those associated with remote sensing, or just simply resource surveyors, can come together and work together. One of the most significant applications of remote sensing data is the integrated study of those data. That makes them superior to most other methods of surveying since it does not serve one discipline, but many different disciplines. To fulfill the institutional condition it is necessary to have a center to look after these activities, simply because it is a coordinating, policy making, and training committee in which almost all relevant government departments and educational institutions are well represented. The chairman of the committee is the secretary general of the NCR.

The setup we are proposing is that the NCR, under the umbrella of the National Committee, coordinates the work of foreign, regional and international agencies, and also coordinates with the government and semi-government departments. Proposals can be sent to the national committee by departments, and aid can be offered to those government departments through the National Committee.

The National Center consists of three components: a service component, a training component, and a research component. The National Center will train people for the government and coordinate with the government by having government personnel work for the center on different projects. The National Center will work closely with the Survey Department as it is the department that acquires data, especially aerial data. Thus, there are a lot of complementary technical services that the National Center and the Survey Department will share.

The NCR has several different agencies, some of which will work closely with the National Center. One of these is the National Computer Center (when established). The National Center will start with simple, though effective, interpretation and data analysis procedures but should be capable in the future to use the computer. By that time we hope that the NCR will have the National Computer Center already in operation.

The NCR has already established a documentation center. One job of the National Center is to disseminate information and data to users. This can be done through the documentation center or sometimes directly.

The National Center was given the responsibility of information dissemination in order to solve a lot of traditional problems. When these remote sensing activities started there was a lot of bilateral work between departments and other agencies and no one knew what the other was doing. It was not unusual to find four or five experts coming from abroad doing very similar studies in connection with different departments or even with individuals. The coordination activities of the National Committee have eliminated this duplication.

The director of the National Remote Sensing Center is the secretary of the National Committee. Thus, there will be a very strong link between the National Committee and the National Remote Sensing Center. The director is the chairman of the executive body for the Remote Sensing Center itself. The center consists of what we call "Chief Investigators" or "Main Researchers" who will cover relevant disciplines such as soil, hydrology, geology, cartography, land use, and agronomy. Thus, the chief investigators will cover the disciplines that use the technology. Some government departments may have little remote sensing capability themselves, but this capability will be enhanced by their coordinator working with the chief investigators.

The chief investigator is a discipline-oriented person. If he is a soils man, I would call him "the permanent ambassador" of the soils department at the Remote Sensing Center. If he is in land use, I would call him "the permanent ambassador" of the land use department. Thus we escape the problem that often arises in this situation concerning who should be doing what. The director of the

Remote Sensing Center will be a U.N. project manager for the for the first few years until it is completely turned over to the government.

The Remote Sensing Center can be justified by looking at some problems which exist in this country. If we consider monitoring of desertification it will justify by itself a remote sensing center. If we realize that there will be tremendous environmental changes after the establishment of the Jonglei canal and that it will need continuous monitoring, that is reason enough. If you look at the state of our regional maps for the whole or parts of the country at this time - the soil map, ecology map, geological map, etc. - they are so simple and are really outdated. The cost of updating or making a new soil map or ecologic map for The Sudan is almost the same as the cost of establishing this Remote Sensing Center. Again, having a Center and National Committee requires a lot of foreign, regional and international cooperation. Without this central agency, the coordination and cooperation with those foreign bodies will be really ineffective.

THE LANDSAT SYSTEM AND OTHER EARTH RESOURCES SATELLITES

Mary DeVries*

The Landsat Satellites

The Landsat series of earth resources satellites (Figure 1) has been providing valuable data for both the researcher and operational user since July 23, 1972, when the first of the series was launched. Although a life-expectancy of one year was originally projected, this satellite (Landsat-1) remained operative until January 6, 1978.

Two additional satellites (Landsat-2 and Landsat-3) were launched January 22, 1975, and March 5, 1978, respectively. Both satellites are presently operative, although Landsat-2 was deactivated for a period of time (November 5, 1979 to May 4, 1980) because of attitude control problems. Landsat-3 experienced a high occurrence of line-start anomalies between January and June, 1980 and is presently being used conservatively to prolong its lifetime.

The satellites are in orbit 920 km above the earth's surface. They encircle the earth every 103 minutes, or 14 times per day, and pass over the equator at approximately 9:30 each morning. The entire globe, except the poles, is covered every 18 days. In general, when two satellites are in operation their orbits are staggered by nine days.

Landsat Sensors

Two types of sensors are included in each of the Landsat satellites. The first of these is the Return Beam Vidicon (RBV) system. This camera system was originally included because of its geometric accuracy. The RBV systems aboard Landsat-1 and 2 consist of three cameras, each

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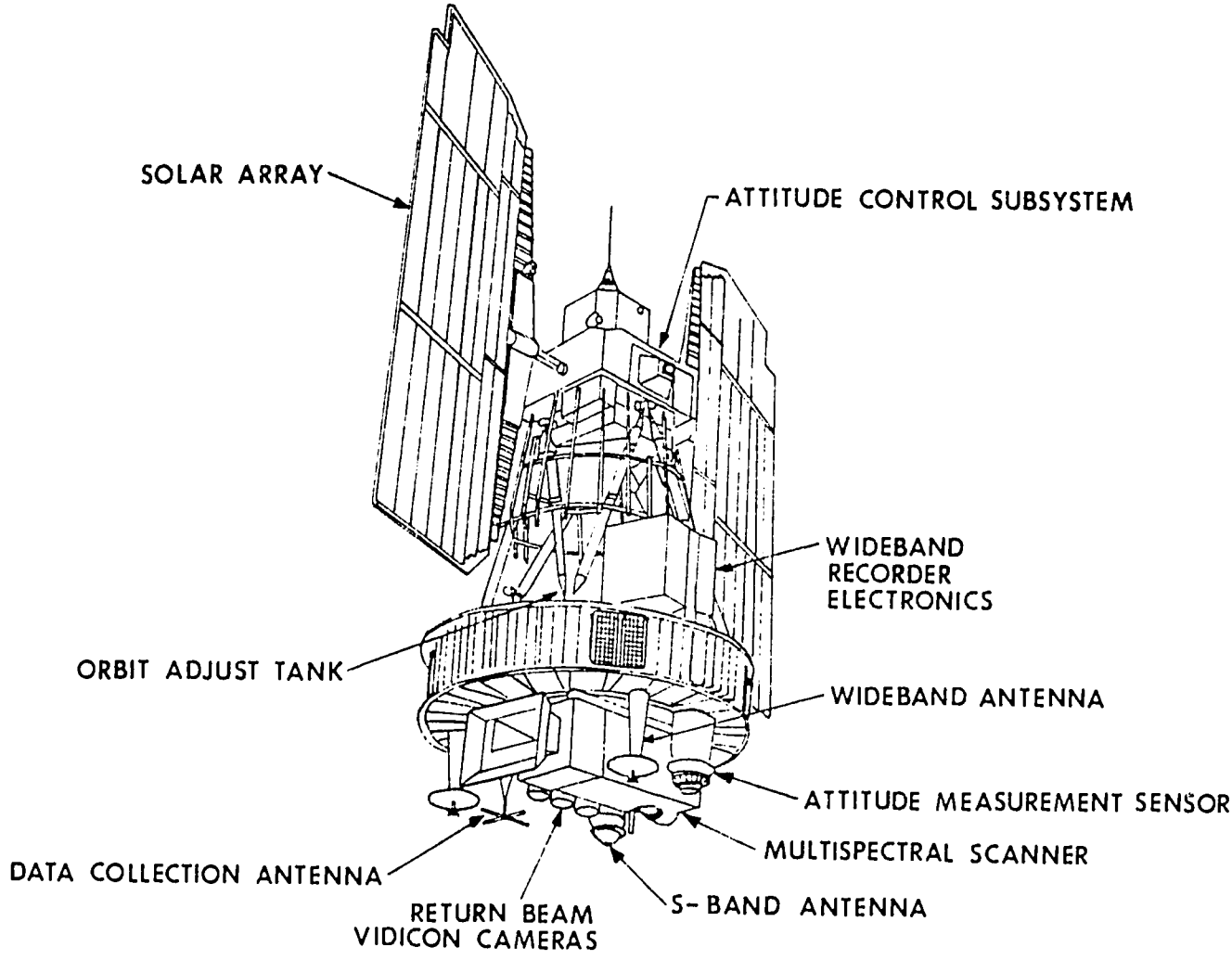


Figure 1: The general configuration of Landsat - 1, 2 and 3. From NASA Landsat Data Users Handbook.

imaging an area of 185 x 185 km per scene. The first camera, RBV 1, samples the 0.475 to 0.575 μm region of the electromagnetic spectrum. RBV 2 and RBV 3 sample in the 0.580 to 0.680 μm and 0.690 to 0.830 μm regions respectively (Figure 2). Unfortunately, the RBV sensors on both Landsat-1 and 2 were shut down soon after launch because of the power drain they imposed on the system.

The RBV system aboard Landsat-3 differs from that aboard Landsat-1 and 2 in that it is a two camera system, each sampling in the 0.505 to 0.750 μm region (Figure 2). Each RBV scene images an area 98 x 98 km. Thus, four scenes are required to cover the same area as that covered in a scene from Landsat-1 and 2, but the spatial resolution is improved by a factor of two.

The second sensor system aboard the Landsat satellites is the Multispectral Scanner (MSS) system. This scanner system, which utilizes a rotating mirror to reflect the incident electromagnetic waves to the optical sensors, was chosen for its radiometric accuracy. Four regions of the visible and near infrared portions of the electromagnetic spectrum are sampled by the MSS system aboard each of the satellites. The first MSS sensor, MSS 4, samples in the 0.5 to 0.6 μm (green) region. MSS 5 samples the 0.6 to 0.7 μm (red) region and MSS 6 and 7 sample in the 0.7 to 0.8 μm (near infrared) and 0.8 to 1.1 μm (near infrared) regions respectively. A fifth sensor, MSS 8, which samples in the 10.4 to 12.6 μm (thermal infrared) region is included on Landsat-3 (Figure 2). An area of 185 x 185 km is imaged for each MSS scene. The spatial resolution of MSS 4, 5, 6, and 7 is 79 m while that of MSS 8 is reduced to 237 m.

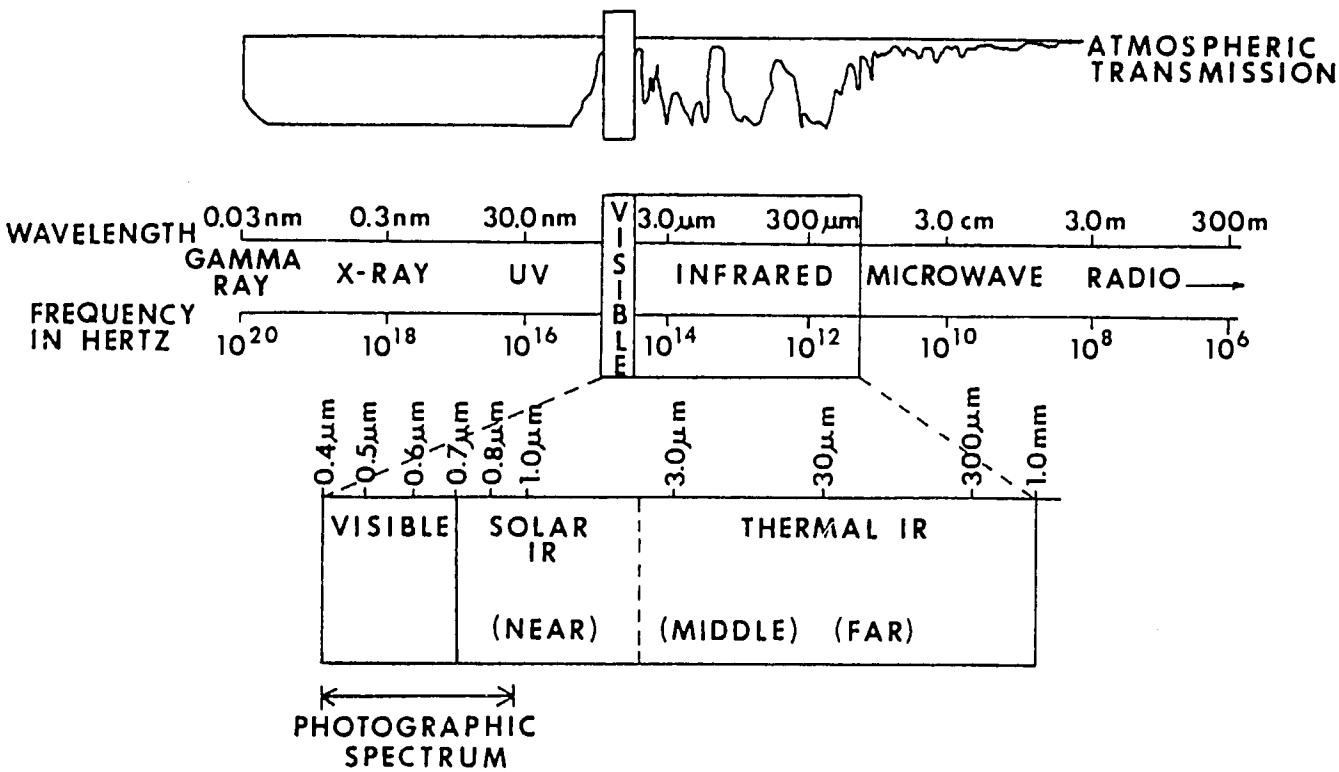


Figure 2. The visible and infrared portions of the electromagnetic spectrum. After Taranik, 1978.

Landsat Receiving Stations

Landsat data are transmitted directly to the receiving station when the satellite is within the line of sight for that station. If the satellite is not within the transmitting range, the data are recorded on onboard tape recorders for transmittal later when the satellite comes into range. At the present time, only the Landsat-3 onboard recorders are operational, however.

Presently there are operational receiving stations in the United States (Maryland, California and Alaska), Canada, Brazil, India, Iran, Italy, Japan, Sweden, Argentina and Australia. Landsat receiving stations are planned for China, Thailand, Upper Volta and Zaire (Figure 3).

A diversity of Landsat products is available from the various stations. In addition to maintaining a data base of U.S. Landsat data, the EROS Data Center (the U.S. Department of the Interior data archival and dissemination center located near Sioux Falls, South Dakota) also maintains information on non-U.S. Landsat data holdings. Users wishing to purchase data which were received at non-U.S. stations should, however, order from that station (or agency) directly. Users should be aware of the fact that data formats may vary from station to station.

Landsat Data Flow

The transmission of Landsat data to one of the three U.S. receiving stations is the initial step in the complex series of steps which results in the generation of master reproducible data products. A simplification

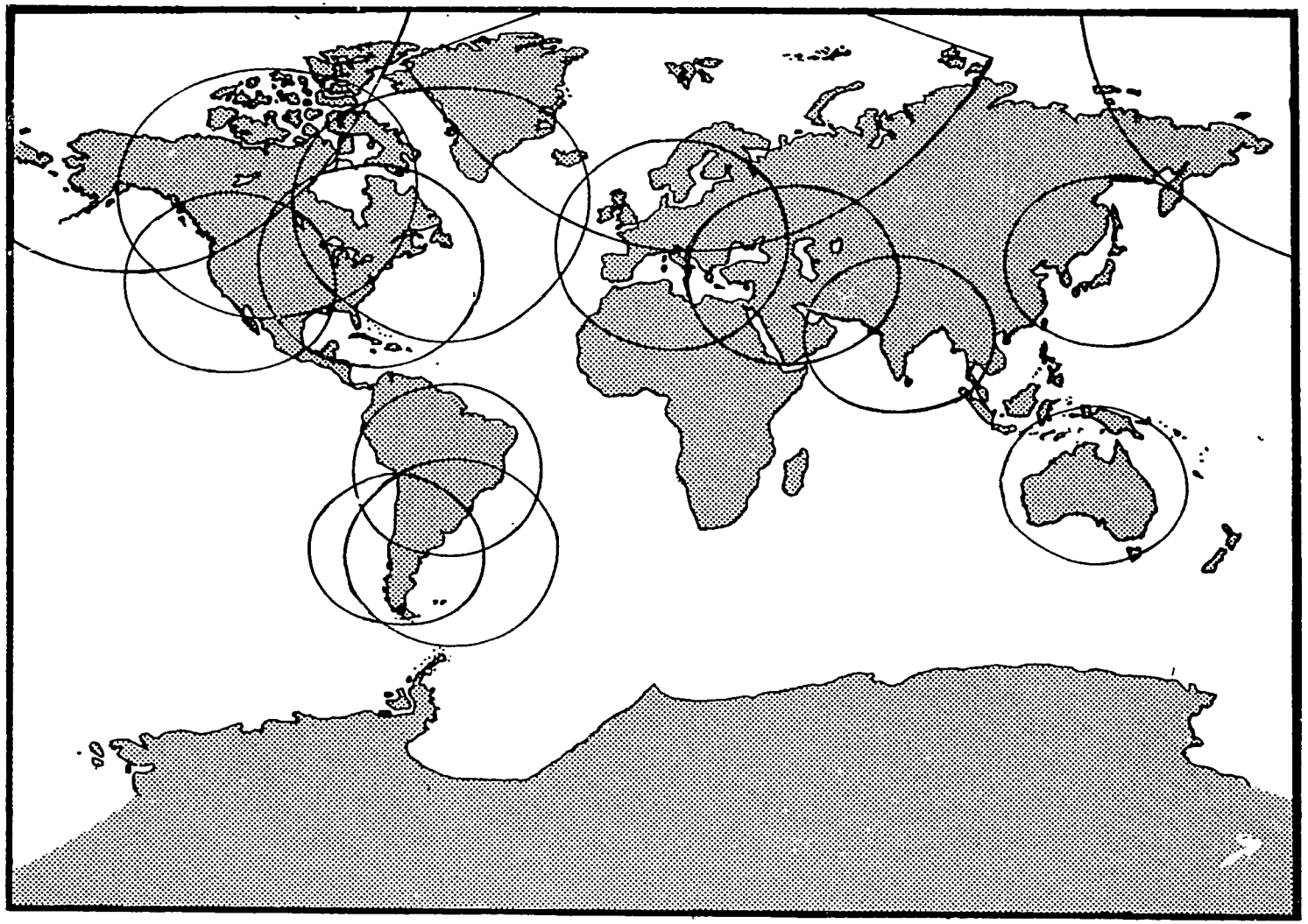


Figure 3: Approximate receiving ranges of worldwide Landsat ground stations. From "Landsat Data Users Notes", May, 1979.

of the present process for the generation of standard Landsat MSS data products is shown in Figure 4.

Data acquisition takes place when the Operations Control Center at NASA/Goddard commands the MSS to acquire data over selected areas. These data are transmitted immediately if the satellite is within transmitting range of one of the three U.S. stations, or are recorded and transmitted later if not within the transmitting range. The station receives the data via tracking antennas and records it on wideband video tape (WBVT). A commercial domestic communications satellite system (Domsat) is used to transmit the data in the WBVT format from the Alaska and California stations to NASA/Goddard.

At NASA/Goddard the WBVT data are pre-processed to a digital form and output to a high density tape (HDT). The pre-processed digital data are then input to the Master Data Processor (MDP) for radiometric and geometric corrections. The MDP also creates the annotation data which will appear on each image when reproduced.

The data on the HDT which is generated by the MDP are transmitted to the EROS Data Center (EDC) via Domsat. The digital data microwave transmissions are received by an antenna at EDC and re-recorded on HDT The data are now ready for processing by the EDC Digital Image Processing System (EDIPS).

A micro-processor, which is part of EDIPS, is used to generate a histogram of pixel values for each scene from the HDT data. This histogram calculates the total number of pixels occurring at each of the 128 intensity levels for each MSS band of the scene. Algorithms

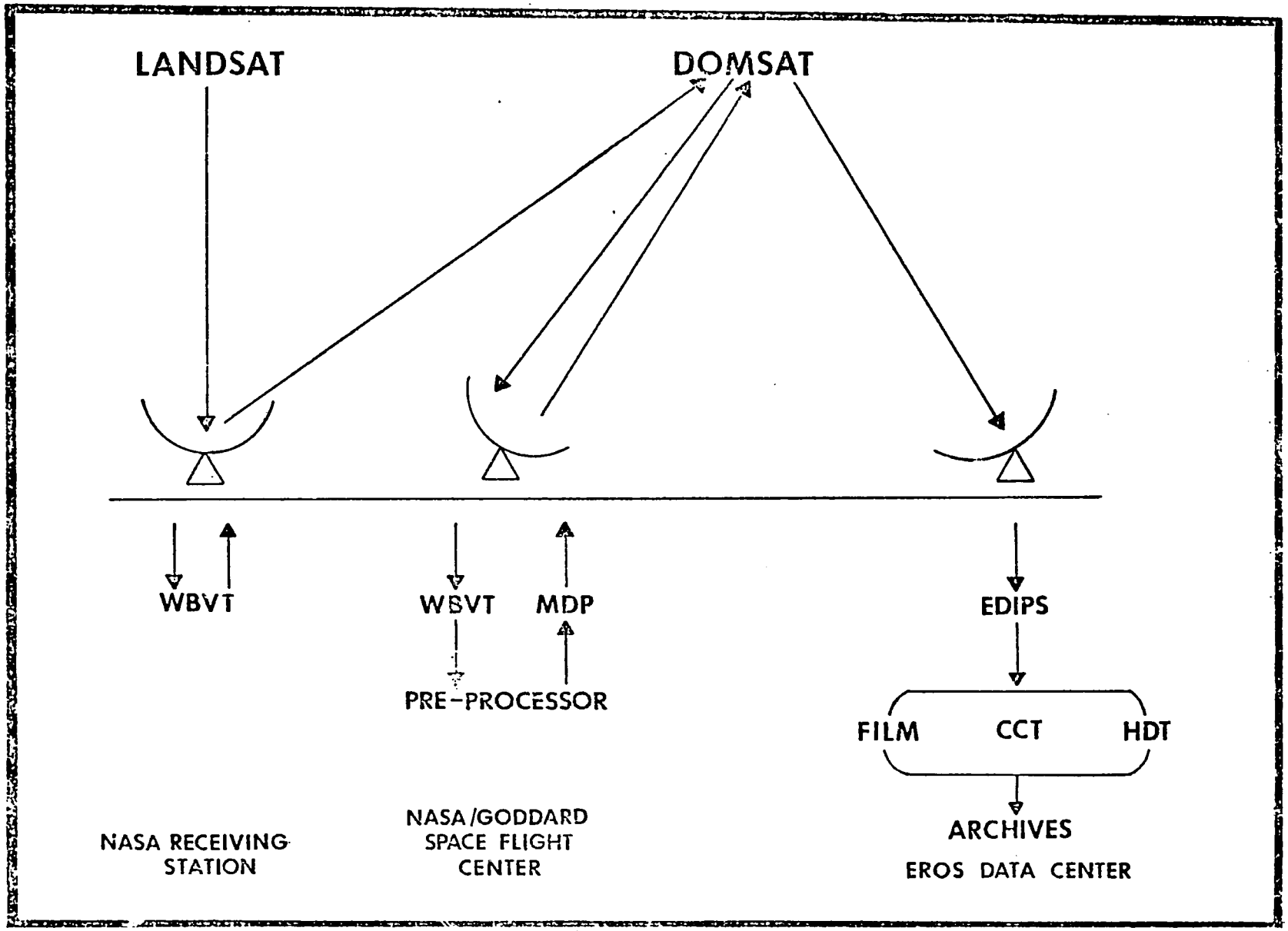


Figure 4. The flow of Landsat from initial acquisition to production of master reproducible products. After "Landsat Data Users Notes", September, 1979.

for haze removal and for the mapping of image grey levels to preassigned film density levels using a logarithmic lookup table are also applied by EDIPS. The digital data are then formatted for input to an on-line laser beam recorder which produces the film version of the Landsat data. Magnetic tape recorders are also on-line in EDIPS for creating computer compatible tapes (CCTs).

The EDIPS-produced film and the fully processed HDTs received from NASA/Goddard are maintained at EDC for product generation and dissemination. CCTs are produced upon user demand from the HDTs.

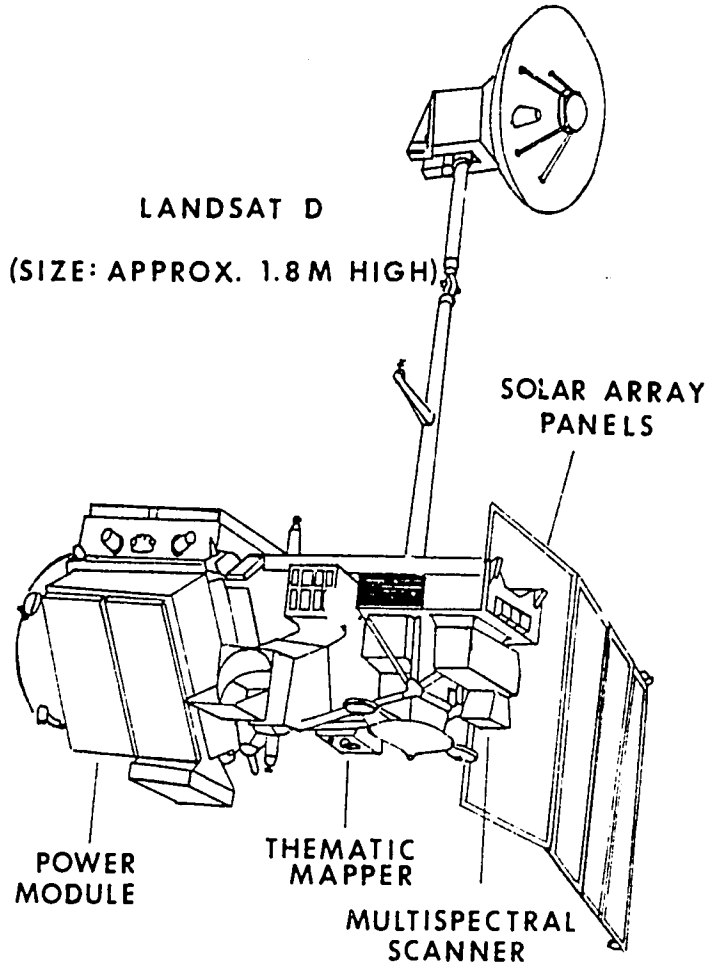
If no major problems are encountered at any point, a throughput time of 12 days can be expected for the total process from acquisition to archival for standard products. The throughput time will vary greatly if nonstandard products are involved.

Landsat-D

The next satellite in the Landsat series is Landsat-D, which will be known as Landsat-4 after successful launch (Figure 5). It is presently scheduled for launch in late 1981. However, it may be launched sooner with a modified sensor package if both Landsat-2 and 3 cease operations.

Landsat-D will have a nominal orbital altitude of 705 km and a descending equatorial crossing at about 9:30 to 10:00 a.m. It will maintain a 16-day cycle of repetitive coverage.

Two sensor systems are scheduled to be aboard Landsat-D, each of which will cover a ground area of 185 x 170 km per scene. The first of the sensor systems is the MSS system, which will be similar to that



SPECTRAL COVERAGE OF THEMATIC MAPPER

BAND	MICROMETERS
1	0.45 - 0.52
2	0.52 - 0.60
3	0 63 - 0.69
4	0.76 - 0.90
5	1.55 - 1.75
6	10.4 - 12.5
7	2.08 - 2.35

'igure 5. Landsat D schematic and spectral coverage of the thematic mapper. After "Landsat Data Users Notes", July, 1979.

aboard Landsat-3. The second system is a seven-band sensor called the thematic mapper (TM) which will have an instantaneous field of view (IFOV) of 30 meters in contrast to the 80 meter MSS IFOV. The TM spectral coverage is shown in Figure 5.

The Landsat-D MSS data will be relayed to NASA/Goddard via the new Tracking and Data Relay Satellite System (TDRSS). This system, which is scheduled to be operational in 1982, will consist of two geosynchronous communication satellites and an Earth station and will be used by all of the NASA orbiting satellites. Landsat-D data will be relayed to one of the geosynchronous communication satellites and then to a single ground station at White Sands, New Mexico. From there the data will be retransmitted via Domsat to NASA/Goddard. The MSS data will be radiometrically corrected at NASA/Goddard and relayed to EDC via Domsat. At EDC the data will be geometrically corrected and further processed for archival and dissemination. Final plans for the processing of TM data are not firm at this time.

Other Earth Resources Satellites

While the Landsat series of satellites is perhaps the best known of the earth resources satellites, several others exist or are in the planning stage. Among these are HCMM, Magsat, SPOT, MRS, Stereosat, Mapsat and the Space Shuttle.

The Heat Capacity Mapping Mission (HCMM) satellite was launched in 1978 for the purpose of establishing the utility of thermal infrared remote sensor-derived temperature measurements of the Earth's surface

taken within a 12-hour interval at times when surface temperature variation is at maximum. These day/night temperature differences are used for the determination of thermal inertia, i.e. the property of material to resist temperature changes as incident energy varies over a daily cycle.

The HCMM spacecraft orbit is sun-synchronous with a 620 km orbital altitude and a nominal ascending equatorial crossing time of 2:00 p.m. The sensor aboard the spacecraft is the Heat Capacity Mapping Radiometer (HCMR) with a visible (0.55 to 1.1 μm) channel and a thermal infrared channel (10.5 to 12.5 μm). The resolution of the visible channel is 0.5 km and the resolution of the thermal channel is 0.6 km. The swath width is 716 km.

A magnetic field-sensing satellite called Magsat was launched into low-altitude polar orbit by NASA on October 30, 1979, for the purpose of gathering information about regional anomalies in the Earth's magnetic field. Magsat provides both scalar and vector measurements on a broad scale on a repetitive basis. The principal sensors aboard Magsat are a Cesium-vapor total field magnetometer and a three-axis fluxgate magnetometer. To reduce the effect of the spacecraft's own magnetic field, the sensors are located at the end of a 6.1-meter extendable boom.

The French government is presently planning to launch a new satellite in 1984 called le Système Probatoire d'Observation de la Terre (SPOT) or, translated literally, the Earth Observation Test System. Its proposed first mission will be to collect image data for land use investigations. On this mission, SPOT will carry two identical, scanning-type, High Resolution Visible instruments operating in the visible and near infrared

portions of the spectrum. The swath width will be 60 km and the resolution will be 20 m or 10 m, depending on whether the sensors are operating in the multispectral or panchromatic mode. A pointable mirror will make it possible to obtain stereoscopic image pairs. The 822-km altitude orbit will be near-polar and sun-synchronous with a descending equatorial crossing at 10:30 a.m. and a 26-day repetitive cycle.

The Multispectral Resources Sampler (MRS) satellite is being planned by NASA to utilize linear array technology. This technology involves the use of an array of fiber optics which are aligned across the satellite's ground track and "pushed" along the satellite's path. The MRS is basically designed as a research instrument to provide higher temporal, spatial and spectral resolution. It will thus facilitate research in a variety of application areas. The MRS is presently awaiting funding for the multilinear array.

Another future satellite which will utilize this new linear array technology is Stereosat. Stereosat is being designed to provide world-wide stereoscopic coverage using a single-instrument system equipped with three high-resolution, line-scanning cameras. Two of these cameras would be pointed fore and aft at equal angles from the third vertical-pointing camera. The three dimensional stereoscopic imagery is useful for determining the earth's structural forms for applications such as petroleum exploration and geologic mapping. The orthographic data obtained by the vertical camera could be correlated with Landsat-D thematic mapper data. A sun-synchronous, 705-km altitude orbit with a 9:30 a.m. descending node is currently proposed along with a swath width of 61.4 km, a 48-day repetitive cycle and 15 m resolution.

Mapsat, a mapping satellite which is presently in the conceptual design stage, would be capable of acquiring stereo multispectral Earth images using solid-state technology to minimize the use of moving parts. The Mapsat sensor would operate in three spectral bands which are nearly coincident with Landsat bands 4, 5, and 7 and would have a spatial resolution as great as 10 m. The difference between Mapsat and other imaging systems being proposed, such as MRS, is the manner in which the sensors are pointed. The Mapsat sensor would be in a fixed convergent stereoscopic system whereas the MRS sensor would have been pointed mechanically.

The Space Shuttle, which is expected to be operational in the early 1980's, will be a reusable manned aircraft/spacecraft which will be capable of a large variety of missions. Before each launch a mission payload is installed in the payload bay of the Shuttle. Each mission, which will typically last from seven to 30 days, will involve a diverse array of instrumentation. Among the Shuttle missions will be those with earth resources objectives. In addition, present plans call for Landsat-D and follow-on earth resources satellites to be retrievable by the Shuttle. This will reduce costs as well as allow for repairs to be made in case of malfunction.

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VEGETATION MAPPING - EMPHASIS ON FORESTRY IN SOUTHERN SUDAN

By

Yahia I. Bushara*

This presentation will deal with vegetation mapping with special emphasis on a particular experience in mapping the vegetation of the "Sudd" region of the southern Sudan. Before describing how the vegetation was mapped, I will begin with the application of remote sensing in crop inventory, forestry, agricultural crops, or any parameter of the land surface relating to vegetation which may be measured.

Nowadays everything is getting very expensive, and man-power is the most expensive element. Referring to time; if you wish to engage specialized officials in a survey, they will be very costly for the time spent on accomplishing the task. Likewise, every assessment that is to be made by man with the aid of instruments applying new technologies, the more time spent on doing the job, the more expense you have to pay.

Vegetation mapping is pursued for various reasons. For instance, we may make a vegetation map of a certain part of a country for ecological reasons to see what kind of vegetation and plant associations are present. We may wish to assess certain parameters of interest to us concerning the vegetation. For instance, we may wish to assess the sorghum crop for a certain year or the timber crop in a particular tract of forest. We have various parameters which we use to assess them. Referring to forest inventory, the conventional method is to have a map of the tract. Take a sample according to intensity

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and according to the area that is specified. Eventually, one knows the parameters to be assessed and then applies the appropriate statistical sampling method and goes into the field, collects the data, processes it, and comes up with the final assessment. This conventional method is very lengthy and in under-developed countries like Sudan, it is very time consuming and therefore very expensive due to the lack of ramification of roads, if any roads exist at all, so accessibility is very difficult.

Remote sensing is helping in this sense. If we have aerial photographs of the tract, the matter simplifies and in a mosaic of the tract, you have the whole area to be looked at, and the individual photographs can be studied under the stereoscope. This enables you to divide broadly the area into similar or different regions and to stratify the area. At the same time one can locate the sample sites on the aerial photographs in much less time than the conventional method of ground reconnaissance. Aerial photographs, if they are taken together with ground reconnaissance, are less costly procedure than pure ground reconnaissance.

Aerial photography is still not inexpensive. If you cover 50% or even 30% of the area by aerial photography, you have an enormous quantity of aerial photographs to deal with and the office time spent on the interpretation and the revision of information from these will be rather long. The longer the time spent on any one job the more costly it will be.

Landsat imagery is a step higher. You can view an enormous area in just one frame, 185 x 185 kilometers. It offers a better look at the whole area and an overall idea about the whole tract. For this purpose, the view from Landsat is better than from stereo-pairs of aerial photographs or from a mosaic, because the mosaic will be enormously large and it may have to be

dissected into parts. Ground reconnaissance becomes very accurate as one can go on doing the ground check according to the specified preliminary interpretation.

Aerial photography is a next step because on it trees can be viewed in three dimensions. The height of the trees can be measured, the percentage coverage of the crowns can be determined, and in some cases even the diameter of the trees can be measured. There are various criteria by which one can actually do measurements using the air photos. This is of course accurate enough for most uses but not as accurate as actually going into the field, felling the tree, and measuring its height, diameter and assessing it.

On Landsat imagery one can see all of the tract or a great part of it in one or a few scenes. It is not possible to see as much of the details as may enable you to conduct certain kinds of measurements. For instance, it is not possible to define a single tree on an image nor to measure its height. All you can see are similar areas represented on the imagery by their tone, and from this we assess our parameters on the basis of the area. So the area is very essential to assess the amount of yield that may be obtained from a certain crop to say it is so much in units per hectare. That is not sufficient unless the area is known which is occupied by that cover type. So in the inventory, knowing the area is very important and fundamental in the assessment of the parameters. Aerial photographs are helpful in area assessment. Also, satellite images are helpful in the assessment of the areas of the various cover types, providing we are able to interpret the imagery and delineate the areas of the various cover types. So, to assess the areas of the various cover types, as in the case of forest inventory, the area can be stratified and samples taken from each cover types. Aerial photographs

for sample areas can be obtained for each cover type instead of photographing the whole area since the various cover types are delineated. From the aerial photographs one may come down to a smaller area and take ground samples. Then you can relate the measurements back to the area and will thus be able to come out with an assessment of the parameters whatever they may be, crop yield, timber volume, fuel wood volume, or pasture carrying capacity.

This is a brief discussion of the use of remote sensing in the assessment of parameters with reference to vegetation. Remote sensing offers a great reduction in time and labor in assessing parameters. This new tool is cost effective, and that is what we are after; to reduce the cost of all the operations so that our return is higher.

A practical experience of vegetation mapping using Landsat data was conducted in Southern Sudan, namely, the area of the Jonglei Canal Project. When this matter was introduced several years ago, various information was needed about the area as it existed at that time. Needed was information about the geology, the soils, drainage, vegetation and all other aspects. This experience which will be discussed is only one part of the total survey, that of vegetation mapping. The material used in mapping the Jonglei Canal area, whose location map is shown in Figure (1), are large scale, 1:250,000 topographic maps, and a Landsat mosaic of the area, (Figure (2)), at the scale of 1:1,000,000 in black and white. The material available was this mosaic, and also 1:500,000 scale, black and white enlargements of the same frames used in the mosaic. There were also 1:1,000,000 color composite prints for the different seasons of wet and dry. A field trip was made through the area, going by road from Malakal to Juba. Also, reconnaissance flights at a low altitude in a small aircraft for a few transects were made covering

Figure 1. General location of the study area.

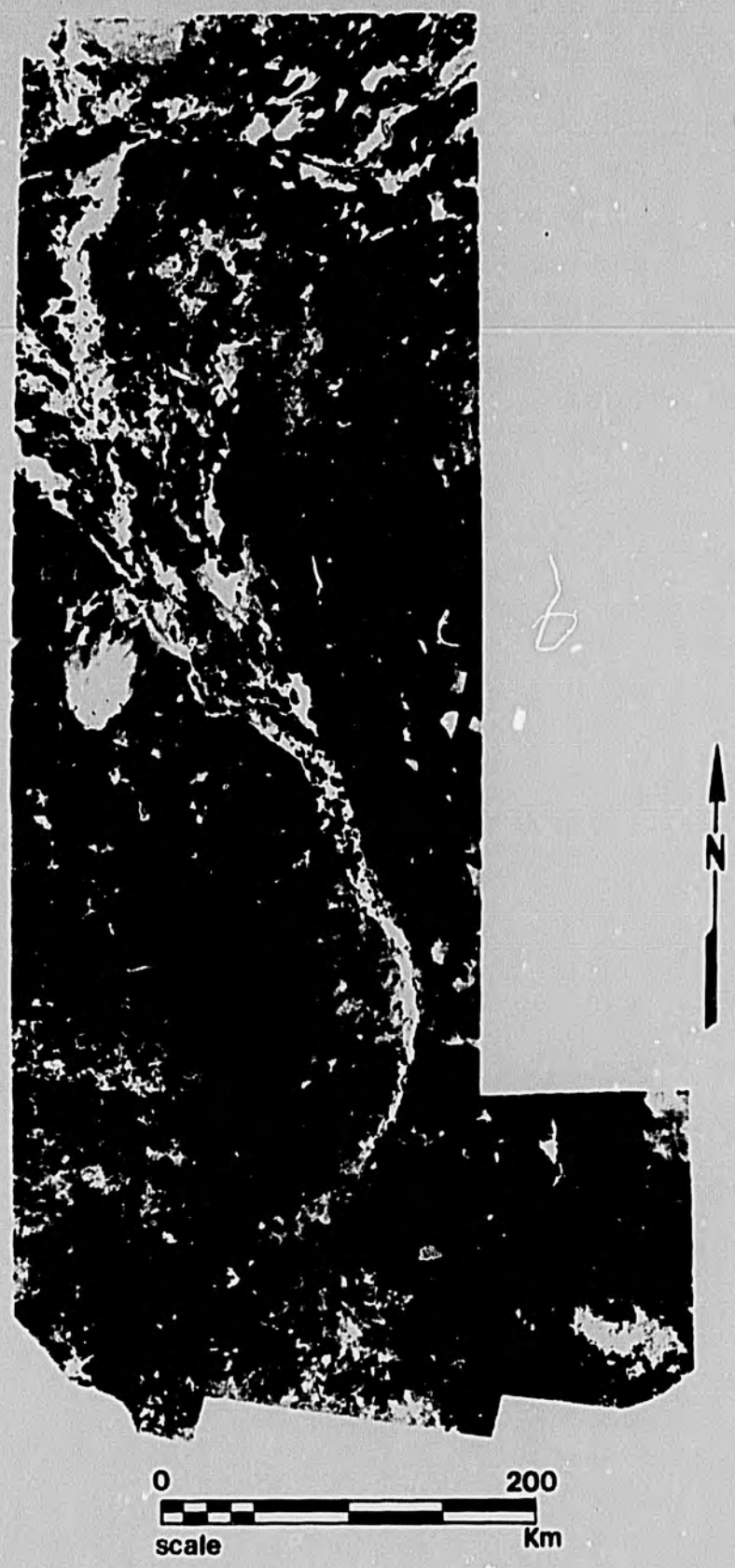

Figure 2: Landsat Mosaic, band 7 of Jonglei Canal Area.

the area, making visual observations of the ground surface. So, this is a kind of multistage study using Landsat imagery, air reconnaissance, and ground survey. There were no aerial photographs available.

A fair knowledge of the vegetation was essential in the interpretation, as the interpreter knows what expectations are there. The use of the infrared band (band 7) together with the other bands of the multispectral scanner was very useful for the study of each vegetation unit by comparing the different signatures it gives on each band. Band 4 lies within the visible green portion in the electromagnetic spectrum, band 5 in the visible red, while bands 6 and 7 are in the near infrared portion. It is known that green vegetation gives very high reflectance in the infrared portion of the spectrum so that if you have a band 7 image you expect vegetation to register as very bright in comparison with other features on the surface of the earth. If you have a color composite the green vegetation will be registered in band 7 which is printed in red, so vegetation will appear in various shades of red in contrast to other surface features around it.

Making use of the ground reconnaissance and aerial reconnaissance does require an experienced interpreter; a preliminary map was prepared and then a final vegetation map was produced. Due to its size it is not presented in this paper.

All dense green vegetation as registered by band 7 of the scanner will register very bright. The course of Bahr El Jebel from Juba down to Malakal, and the White Nile down to Kosti, is mostly covered with floating water hyacinth so what we see is not the water surface itself but the plants that are floating on the water surface. In the swamp area, known as the "Sudd region", we find floating islands of all kinds of hydrophytic plants or

weeds like papyrus and Umm Tuba covering the whole surface of the water. So, it was very easy on this map to delineate the hydrophytic areas or areas with water covered by floating plants. The black spots within the white areas are the open waters not covered by green plants. Water appears very dark in band 7 because it does not reflect the infrared radiation but absorbs it so it appears dark. If this were a color composite the same interpretation can be made but with different colors.

In Figure (2) the texture is sort of p[illegible]d or rough in the clayey soil (flood plains). The lateritic soil has a different type of vegetation. Grass gives us a smooth image texture and the black spots are burnings. This was in November and the white areas are unburned areas. The "Imatong Mountains" are very densely covered with green vegetation and grasses and show white. The "Kinetti River" which expends itself before it reaches "Bahr El Jebel" into a swampy area and shows as a white line due to the vegetation near and in the channel. It is very much covered by water hyacinths so you can even delineate the boundaries of the swampy area in this part.

This resulting map is a preliminary map because not all the material was available and not much time was available for office interpretation. Moreover, the ground and air reconnaissance were rather limited. But still, you can see that a considerable amount of information was extracted from this mosaic which was compiled from thirteen Landsat imageries. Through careful interpretation we were able to guess approximately what was there on the ground within a period of about three weeks.

In about three weeks we came out with an approximate map for an enormous area. This would not have been possible if we were to use the conventional methods of ground reconnaissance, as in some places you may not even be able

to get access due to the swampy nature of the Sudd region. If we were to use aerial photographs, it would have taken a longer time, and we would have had to spend a lot more money for the photos and for more office and laboratory work to produce such a map.

IMAGE INTERPRETATION MODELS FOR LANDSAT DATA INFORMATION EXTRACTION

Donald Moore*

ABSTRACT

The Landsat image provides an interpreter a two-dimensional spatial display representing the land surface. Differences in land surfaces are presented on the image in the form of image tones, textures, and patterns. Landsat also offers a new dimension of temporal or time changes. Due to the satellite altitude of sensing, in contrast to aircraft altitudes for which we are accustomed, the scales and resolutions of the data are considerably different. However, the same interpretation procedures apply to either aircraft or satellite images for extracting information. The interpretation of images is based upon the ability of an interpreter to recognize image features for which he correlates the image feature to known land surface characteristics. This paper illustrates models for interpretation that can be used by the interpreter to understand the data provided in an image (or images) for extracting useful information.

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INTRODUCTION

The interpreter must relate image features of tone, texture, and pattern to conceptualized landscape models for delineating and describing the mapping units. He does this by his field experience and knowledge of landscapes to develop concepts, i.e. if certain areas should be bright or dark in tone; that cultural practices associated with agriculture yield a rough image texture versus the smooth image texture for surface water; or that a well integrated drainage pattern indicates permeable surficial materials versus poorly integrated or no drainage for other material characteristics. The experienced image interpreter has excellent knowledge of the relationship of landscape to large-scale pancromatic photography but if he has no experience with the multidate, multispectral, small-scale Landsat image he must redefine his interpretation models. Often the interpreter does not fully utilize the "multi" of Landsat because too much information is available and he has difficulty in assimilating all the information into a model for interpretation. This paper provides brief examples of simple interpretation models and rationale for their use for the glacial landscape of eastern South Dakota. The models are site specific and transferability is limited as differences in climate, vegetation, cultural practices, and the many variables occurring spatially affect the resultant reflectance as captured by Landsat. However, the beginning stages of any survey relies upon models such as the following to be generated and used when selecting appropriate imagery and when interpreting the data.

SPECTRAL INTERPRETATION

A simple model based upon spectral data from Landsat can be applied to surface water. Two features of surface water are normally observed in Landsat; that of its identification, location, and area measurement, and

secondly, that of turbidity by mineral or biologic materials. The basic physics of light penetration in water yields information to establish an interpretation model: Figure 1 illustrates the anticipated depth of penetration of the sun's energy for the various Landsat spectra. The maximum penetration of light energy in pure water occurs in MSS 4 decreasing through bands MSS 5, 6, and 7.

Examples of photographic images in Figure 2 illustrate the same concept. The white reflecting bottom of the swimming pool can be observed through the water in the shorter, "red", spectral region and can not in the longer, "infrared", region. Note the visibility of lines on the bottom of the pool in Figure 2a.

If absorbing, reflecting, and/or scattering substances are dissolved or suspended in the water, their spectral properties will influence the scene reflectance. This property, in addition to the depth penetration of various wavebands, provides a method of multi-spectral interpretation using the Landsat data. To locate surface water bodies, the MSS-7 infrared spectral region will define the boundaries due to the high scene contrast between water and the surrounding landscape. If substances that reflect and scatter the incoming radiation are present in the water body, which would yield tonal contrasts between "clear" water and "natural or turbid" water, the substances would have to be on the surface or very near the surface of the water to be observed in the infrared bands. Whereas, the red and green bands could reveal differences at greater depths. For clear water, the greatest potential depth penetration of the light energy in the spectral regions available for the Landsat data would be in the MSS-4 images. Therefore, the greatest potential for bathymetric mapping would occur in MSS 4 or 5. A comparison of different water bodies in the same scene may then lead to a ranking of those which are more turbid than others. Multidate

observations may indicate to the biologist or other interpreter reasons for the turbidity differences.

The interpreter can use these general relationships on data as presented in Figure 3. The Landsat data can be interpreted for an initial stratification of lakes for subsequent detailed ground-based sampling. Using this procedure, a sampling program can hopefully be developed to include the widest variation in lake characteristics. A group of lakes (Figure 3) in the northern portion of the "Prairie Coteau" in eastern South Dakota is used for the example.

Note that for MSS 7, the lakes appear uniform in film density. If surface area is not used in the stratification, then proceed to MSS 6. Lake #1 appears different than #2 → 11 and should be set in a separate class. In MSS 5, lakes #2, 3, and 5 appear different than #4, 6, 7. 8, 9, 10, and 11. Proceeding to MSS 4, and first comparing #2, 3, and 5, note that #2 and 3 appear separable from #5. Next in comparing #4, 6, 7, 8, 9, 10, and 11, the film density exhibits a contrast between lakes #4 and 11 versus #6, 7, 8, 9, and 10. The stratification is summarized in Table I.

In summary, for a stratification based only on reflectance differences in the Landsat spectral regions, five separable lake classes were developed using only a visual analysis technique. If a ground-based sampling program were developed to study five lakes, which hopefully would include large differences in lake characteristics, this procedure would be helpful for selecting lakes with widely differing physical and chemical qualities. One lake from each of the classes should be selected. The same screening procedure could be used to locate sampling points in turbidity plumes, river

Table I. Lake stratification based on reflectance as recorded on the Landsat multi-spectral data presented in Fig. 3.

Spectral Band	Lakes Classified into Separable Classes*				
MSS 7	Class A				
	1,2,3,4,5,6,7,8,9,10,11 (no stratification)				
MSS 6	Class A1	Class A2			
	#1	#2,3,4,5,6,7,8,9,10,11			
MSS 5	Class A1	Class A2a		Class A2b	
	#1	#2,3,5		#4,6,7,8,9,10,11	
MSS 4	Class A1	Class A2a1	Class A2a2	Class A2b1	Class A2b2
	#1	#2,3	#5	#4,11	#6,7,8,9,10
	Final Classification				
Resultant Strati-fication	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
	#1	#2,3	#5	#4,11	#6,7,8,9,10

* Numbers denote specific lakes as identified in Fig. 3.

discharges, etc. The interpreter, unless very familiar with the area, does not know exactly what is causing the difference but he does know that differences exist and he can design his sampling program accordingly.

Emergent vegetation in the shallow prairie potholes can be easily identified using a multi-spectral interpretation. Prints of MSS bands 5 and 7 are shown in Figure 4. The emergent vegetation (lakes 1 and 2) is as highly reflective in the MSS-7 band as the surrounding landscape; whereas, in band 5 the vegetation appears similar to the water. Therefore, viewing the two spectral regions identifies both open water and potholes which are filled with emergent vegetation. Merging the reflectance anomalies of vegetation with those of water are therefore required. As we increase the complexity of the landscape, the models become more complex.

LANDSCAPE ANALYSIS MODELS

A model has been developed and applied for locating shallow glacial aquifers in Eastern South Dakota. Specific cropping patterns are prevalent for the different types of geologic materialsrepresented in eastern South Dakota. Experience indicates that only rarely can aquifers be delineated by Landsat interpretation solely on the basis of landform recognition in this area. This is because the topography of eastern South Dakota is flat and the land is under heavy cultivation. The newcomer to this area is usually amazed at the flat countryside which is covered by a patchwork of fields. Aquifer identification must be made, therefore, by recognition of land-use features associated with aquifers. A typical landscape model of the region is shown in Figure 5. The outwash terrace and alluvium are the features to map for aquifer location.

About 50% of the land surface of eastern South Dakota is pasture while the remaining 50% is cultivated and is roughly divided equally among alfalfa, corn, and small grain. Morainal areas tend to have high percentages of grain and low percentages of alfalfa; whereas, terraces and flood plains have high percentages of pasture and alfalfa and low percentages of corn and grains. One reason is that flood plains are normally wet in the spring and hence early row crops are not planted because tillage operations and planting are difficult in regions of wet soils. Deep-rooted phreatophytes, such as alfalfa, are well-adapted to this environment. They require no early spring tillage or harvesting and can beneficially use water from the shallow water tables. Remote sensing identification of aquifers underlying major valleys is possible by observing these and other land-use patterns associated with the flood plains. A spectral model for the landscape in Figure 5 must be generated reflecting major seasonal reflectance variations for the various landforms. This model is presented in Figure 6.

Flood plains are (2) used for rangeland in boggy (high water table) areas, or (b) are planted to crops including corn and alfalfa. In the spring they generally have low infrared reflectance where plowed, moderate reflectance where they are rangeland, or high reflectance where they are planted in alfalfa. In the fall, flood plains generally have moderately high reflectance. They are most easily recognized by their irregular, elongaged patterns and by the irregularity of field patterns on the immediately adjacent uplands.

Outwash terraces (e.g. those with >1 m (3.3 ft.) of loess cover which stores water) are plowed in the spring and have very low infrared reflectance. In the fall they have high reflectance. However, these terraces are evident

only with considerable scrutiny, and are difficult to distinguish from other geologic features such as a ground moraine.

The spectral analysis which permits delineation of flood plains and their associated outwash aquifers from areas of till involves many factors. In general the aquifers have:

(1) Lower infrared reflectance in late spring imagery. This is caused by the cultural practice of plowing more of the flood plain in the late spring exposing the consistent dark-colored "A" horizon which has a high organic matter content.

(2) Elongated outline, caused by the orientation of the valley; dendritic tributaries may be present.

(3) Small elongated down-valley patterns within the valley, caused by tree-covered channels, oxbows, and abandoned channels.

(4) No knob and kettle topography such as found in end or stagnation moraines.

(5) Meandering streams visible within the larger valleys.

(6) Serrated pattern along the edge of the valley, caused by stream meanders.

The spectral model for aquifer identification is especially required when selecting appropriate dates of Landsat imagery for analysis. Figure 7 is a September Landsat coverage and has relatively uniform land cover over all the landforms. These data have little value for aquifer identification. Figure 8 shows the same area in May when differential land cover allows interpretation of landforms which provides the key to location of outwash aquifers. Compare the spectral information to the cross-sectional and plan views of Figure 5. Recent alluvium (A), terraces, (B), slopes, (C), and

upland morainal deposits (D), are all easily intepreted from the May Landsat data. The aquifers underlie A and B. Figure 9 illustrates the resulting aquifer interpretation for the "Prairie Coteau" and region to the south when this model is applied.

CONCLUSIONS

Landsat data provide a valuable tool when used by an experienced interpreter who understands the landscape in question. Many data users make the early mistake of acquiring Landsat in spectral regions and during a season where the interpretation is difficult since little scene contrast is available for interpretation. If appropriate data were available optimizing contrasts the interpreter would then consider Landsat as a valuable asset. The time required to order and receive data while in the survey phases does not allow mistakes in ordering the wrong data. A model must be developed, the data ordered responding to model predictions for a spectral assessment of scene features in question, and the data ordered accordingly. Any data reorders take more time than is normally available.

The models are site specific and must be developed for the region in question. Often in regional surveys, various models must be developed to reflect climatic and landscape changes within the region. The radiance measured by Landsat is a function of the reflectance at the land surface. If vegetation occurs on the surface, Landsat depicts the vegetation. Likewise, if weathered geologic deposits occur at the surface, the reflectance is from that weathered surface and not from the hard rocks underlying. Therefore, the interpreter must utilize his knowledge of Landsat and of the landscapes in question to use seasonality and multispectral to his advantage rather than as a disadvantage. This can only be accomplished through modeling.

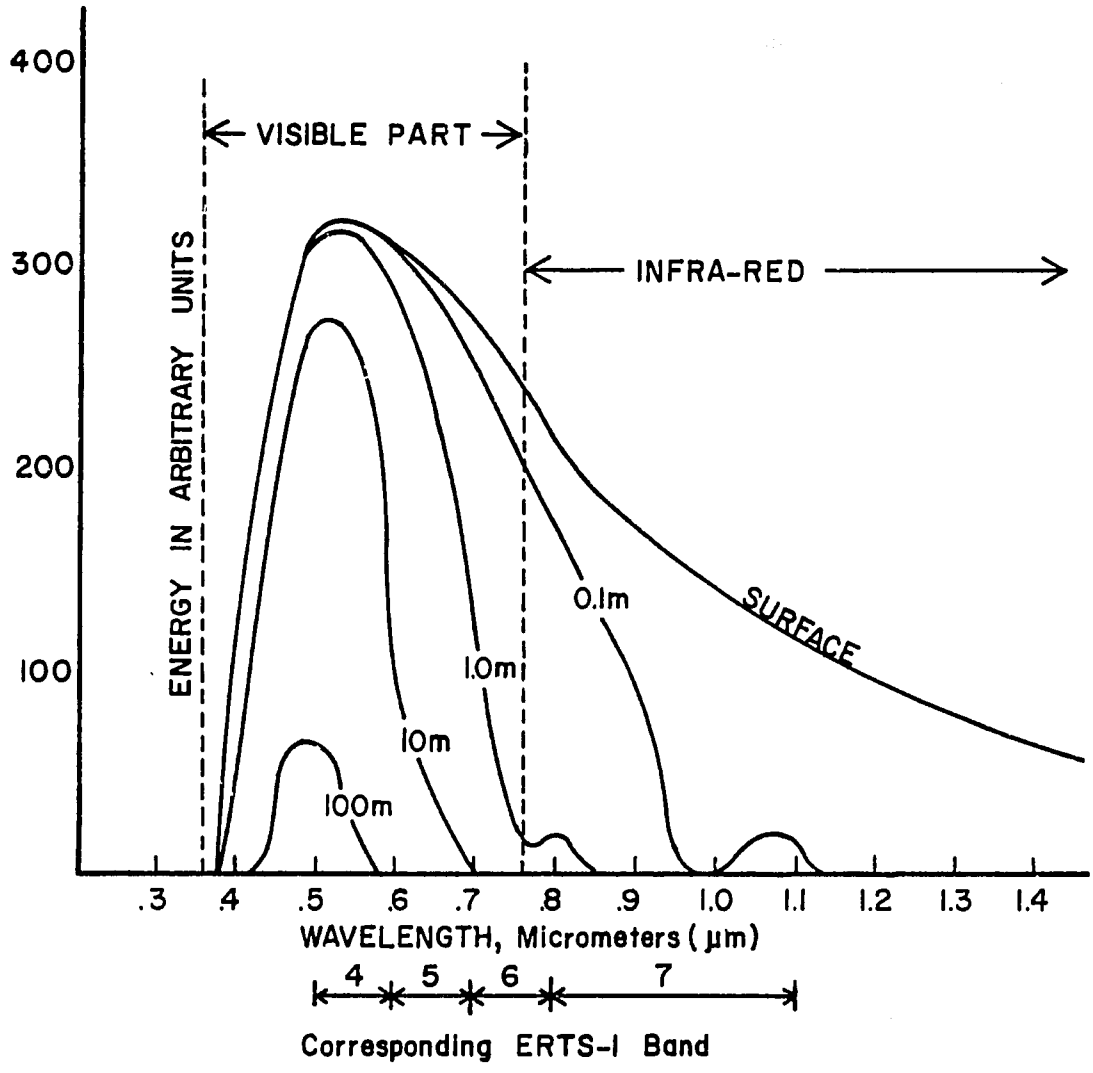
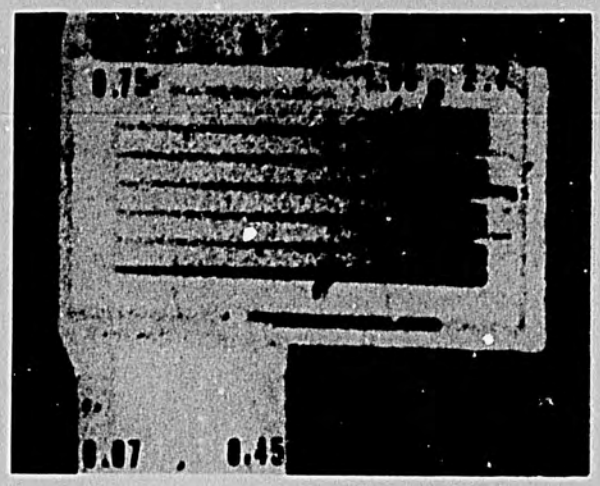
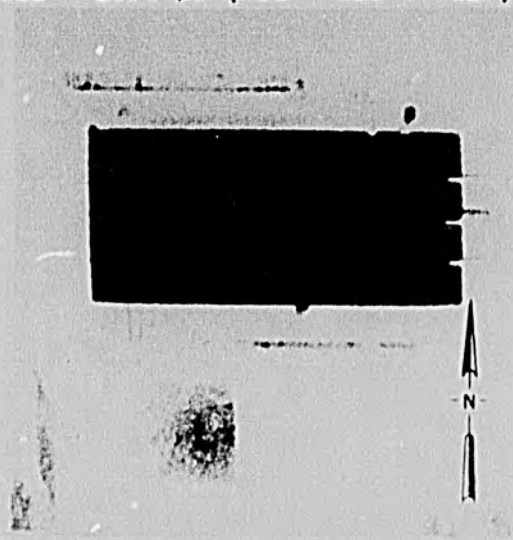


Fig. 1 - Energy spectra of sun and sky radiation reaching various depths in pure water. (after Sverdrup, H.V., M.W. Johnson, and R.H. Fleming. 1942. The Oceans: Their Physics, Chemistry, and General Biology. Prentice Hall, New York. p. 105).



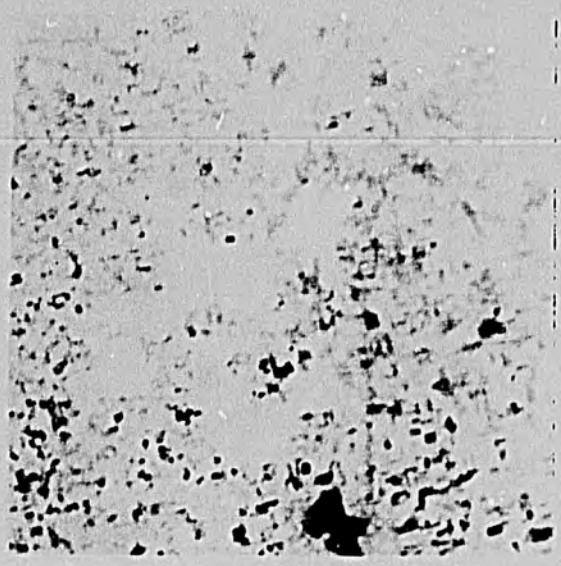
a) Black and white Kodak 8403 TRI-X film filtered in the 0.59 → 0.71 μm (red - #25 filter) region.



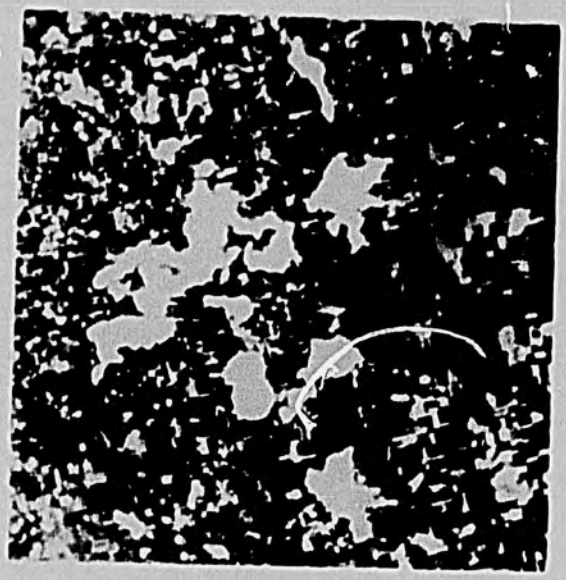
b) Black and white infrared Kodak 2424 film filtered in the 0.68 → 0.90 μm (infrared - #89B filter) region.

Fig. 2 - Photographic imagery illustrating reflectance contrasts associated with depth differences of clear water contained in swimming pools. Depths are in meters. Refer to Figure 1 to determine the optimum wave band for depth penetration in pure water.

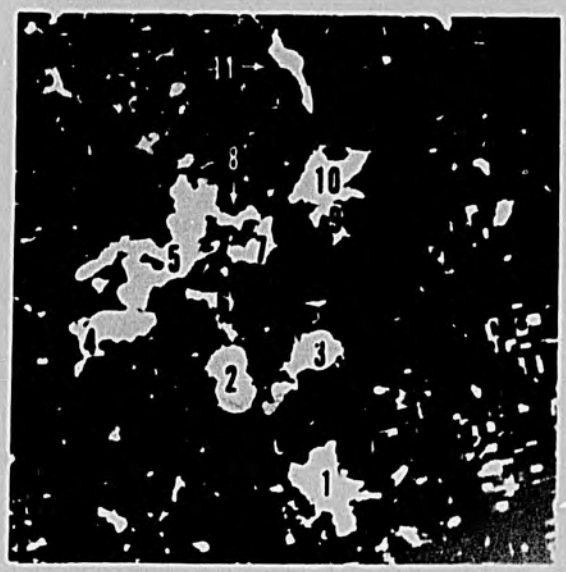
Band 4. 0.5 to 0.6 μm



Band 5. 0.6 to 0.7 μm

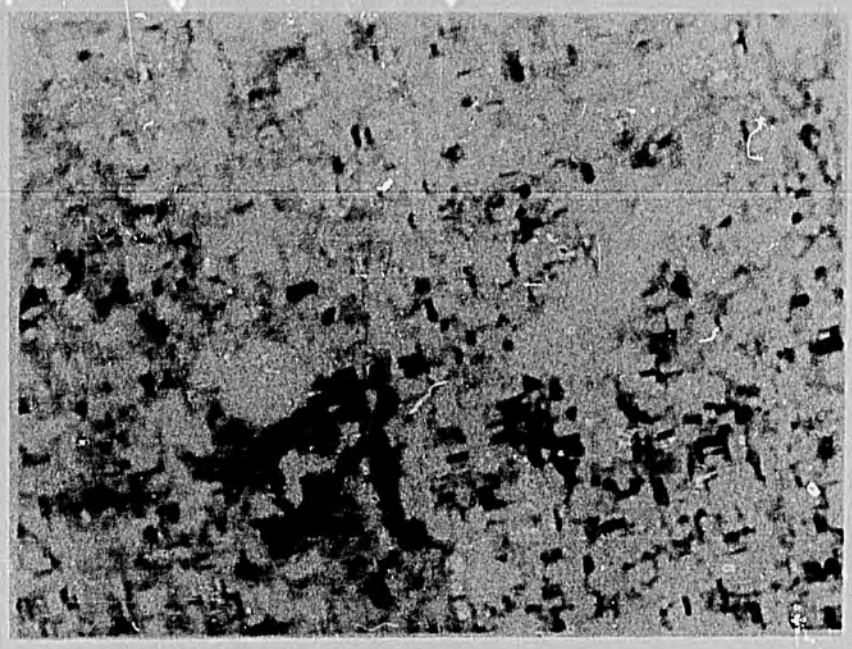


Band 6. 0.7 to 0.8 μm

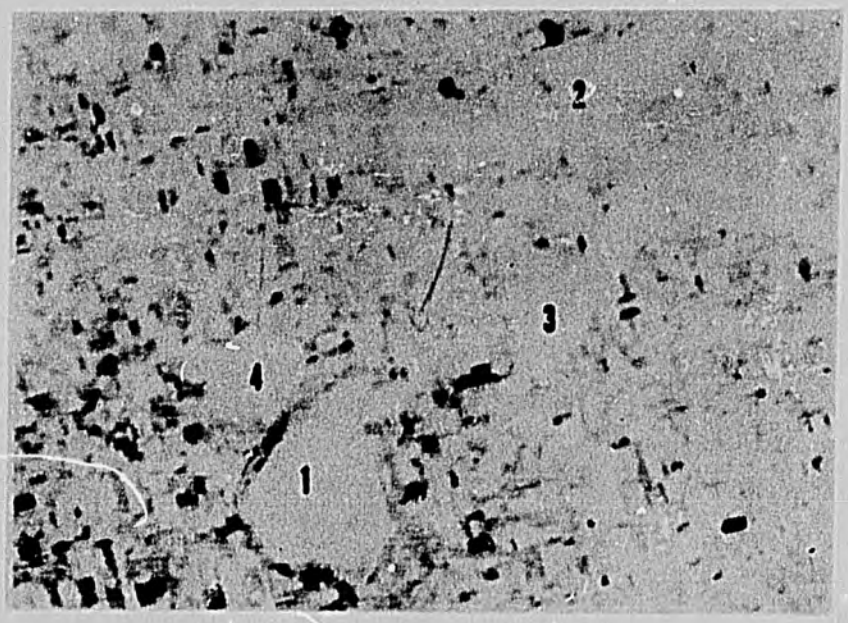


Band 7. 0.8 to 1.1 μm

Fig. 3 - Multi-spectral Landsat, MSS negative prints of lakes on the Prairie Coteau, Northeastern South Dakota on September 21, 1972. Approximate scale 1:500,000 -- Image ID # 1060-16485.



Band 7



Band 5

Fig. 4 - Bands 5 and 7 Landsat data illustrating the separation of open-water potholes versus those containing emergent vegetation. Potholes 1 and 2 are not easily identified in band 7 and are filled with emergent vegetation; whereas, potholes 3 and 4 are essentially open-water lakes. Negative prints of September 21, 1972, data. Approximate scale 1:250,000 --- Image ID # 1060-16494.

Typical Landscape Model of Eastern South Dakota

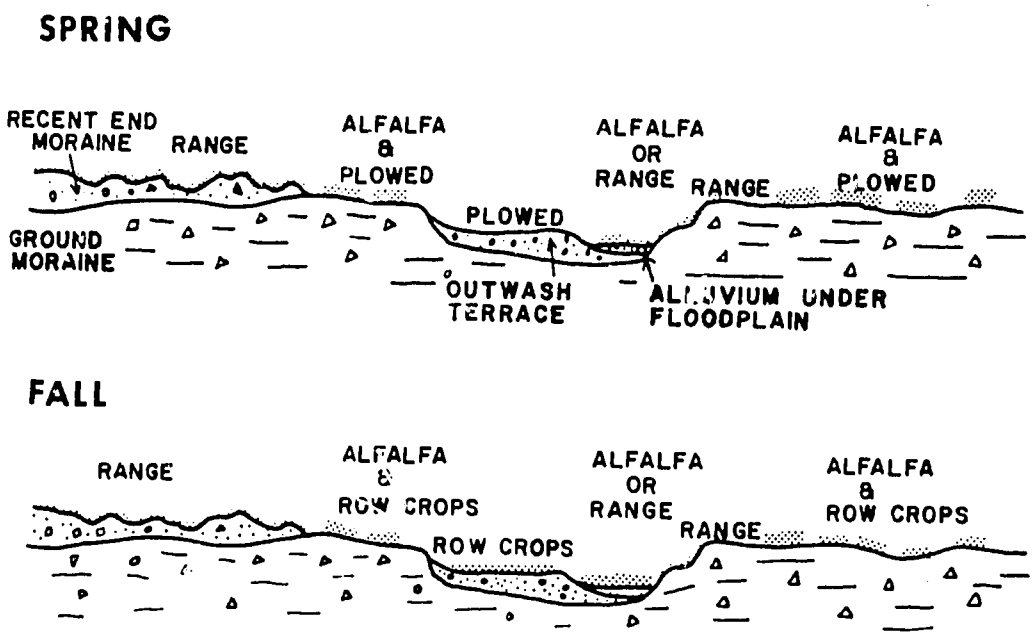


Fig. 5 - Idealized sketch showing geology and land forms on the Prairie Coteau in Eastern South Dakota. The cross section has a vertical exaggeration of about 20x.

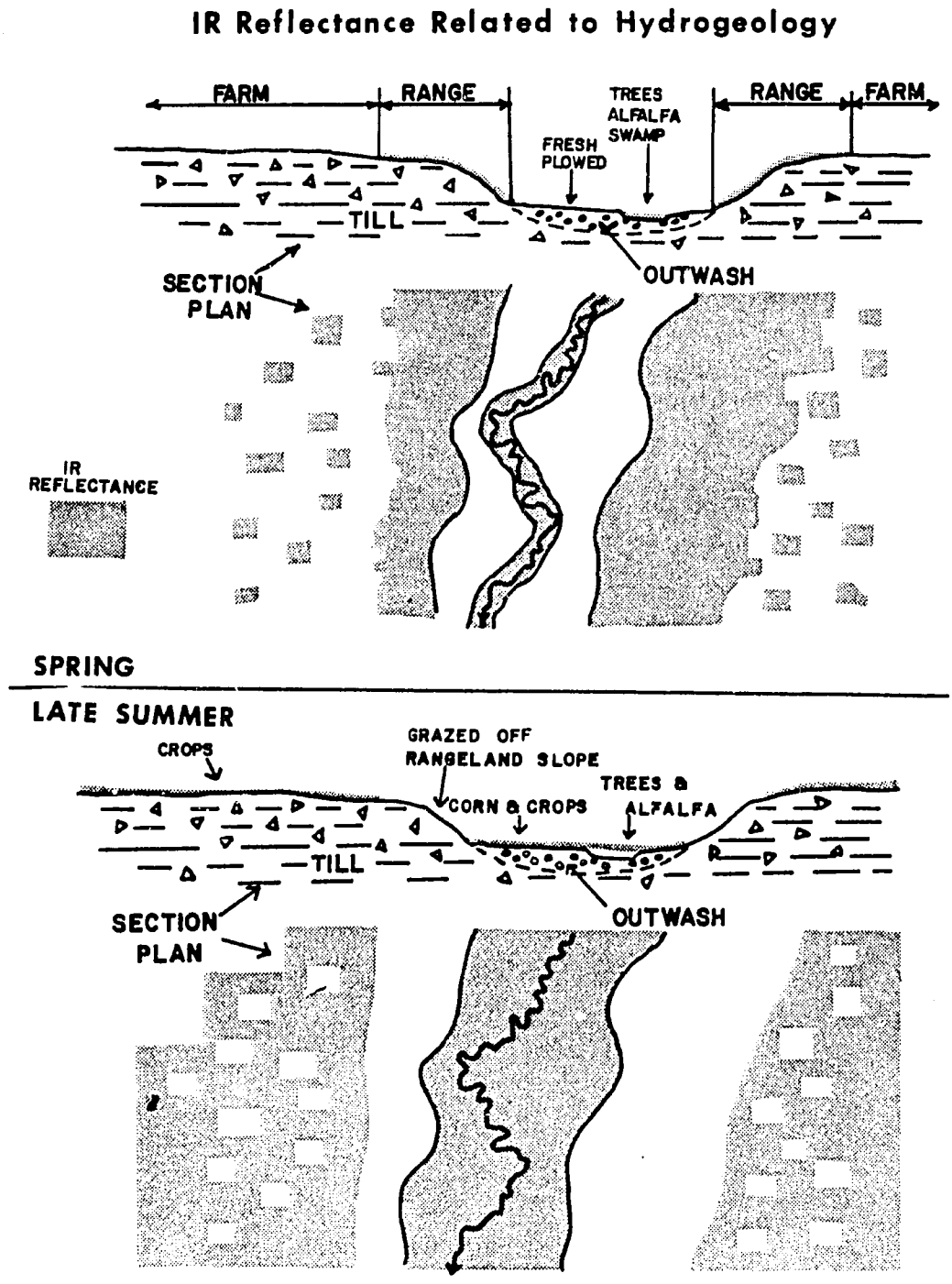


Fig.6 . Schematic cross section and plan views showing the theoretical infrared reflectance and patterns associated with aquifers.

Fig. 7 - A fall Landsat false-color composite of MSS 4, 5, and 7 on September 1978. Note the vegetation masks the hydrogeologic features. Compare with Figure 8. (Original in color)

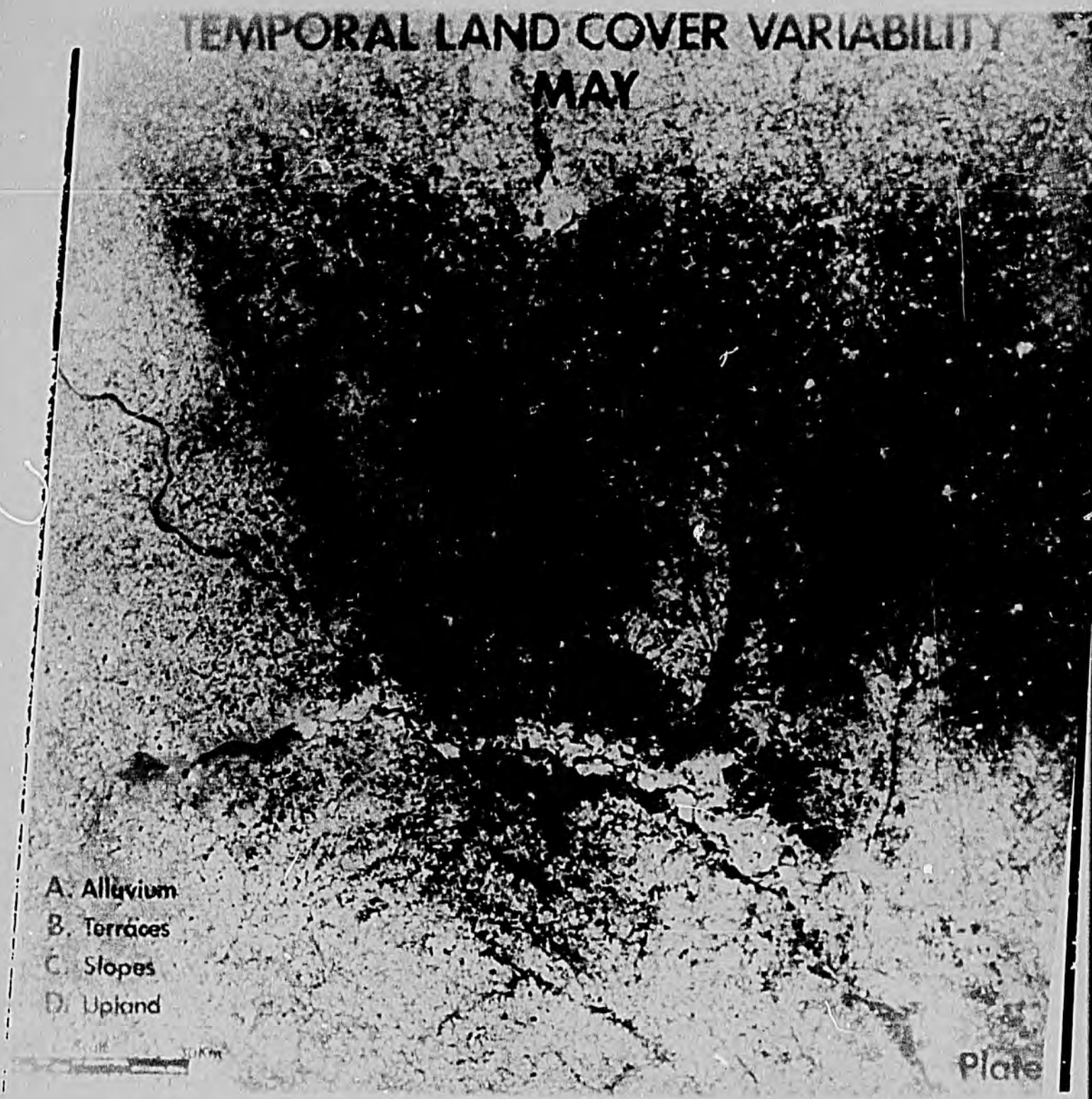


Fig. 8 - A spring Landsat color composite of May 13, 1978 of the same area as that presented in Fig. 7. The areas ondicated at A and B in the image are those to be identified. (Original in color)

Fig. 9. Interpretation of potential aquifer locations based upon application of the interpretation model to spring and fall Landsat data. Interpreted aquifer delineations (noted in black) are on a negative print MSS 7 image background including the Prairie Coteau and regions to the south.

RADAR USES FOR NATURAL RESOURCES INVENTORIES IN ARID ZONES

Stanley A. Morain*

ABSTRACT

Although it is believed that imaging radar systems will serve an ancillary role to photography in remote sensing of desert environments, the scope of their usefulness should be closely reviewed. Normally the atmosphere over arid lands is cloud free and contains little moisture, hence photographic sensing in both the visible and infrared spectral regions is greatly enhanced. Spectacular photographs obtained by Gemini and Apollo spacecraft over the Sahara, the southwest United States and Australia testify to the potential of photography in acquiring resource data from these localities. Degradations result, however, from high albedos, which reduce contrast ratios; dust and haze, which reduce contrast and scatter short wavelength signals; color ambiguity, which confounds the task of terrain identifications; and earth-sun relations, which influence the quality of data received. Moreover, one should note that most arid lands are poorly known, remote, only partially photographed from aircraft altitudes, and very sparsely mapped. Under these circumstances radar, employed simultaneously in space, might prove highly useful in landform inventories and studies of broad vegetational distributions. Other critical information pertaining to soil moisture variations, saline and mildly saline situations and certain geologic structures may be obtained.

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Lastly, the superiority of imaging radar to record continuous broad swaths of terrain should facilitate resource inventories by providing a preliminary, though non-metric, mapping base.

INTRODUCTION

Remote sensing of Earth's natural environments has progressed rapidly in the past decade. In 1972 the first earth resources satellite (LANDSAT) carrying scanner and camera systems was placed into polar orbit. Their primary task was to record and monitor both physical and cultural terrain features to provide data for thematic maps and land use inventories. Also in '72 the first microwave experiments from space were performed on Skylab I. Although the prime effort in Skylab was directed at sea-state and radiometric temperature determinations, tasks were designed for terrain investigations as well. Both active and passive microwave sensors were on-board but their ground resolutions were so gross (ca. 10 km/side of the resolution cell) that detailed terrain applications were not possible. Eventually it is hoped that fine resolution imaging radars will be added to satellites for resource inventories from space.

It has been argued that imaging radars will serve an ancillary role to photography in sensing dry environments (Simonett, et al., 1969a). Normally the atmosphere over arid lands is cloud free and contains little moisture; hence the number of hours available annually for conventional and infrared photography is much higher than would normally be experienced in either the humid low latitudes or in high latitudes. Spectacular photographs obtained by Gemini and Apollo spacecraft over the Middle East, Australia and the southwestern United States testify to the potential of photography for

Fig. 1 Enlargement of portion of a space photograph taken by the crew of the Apollo 6.

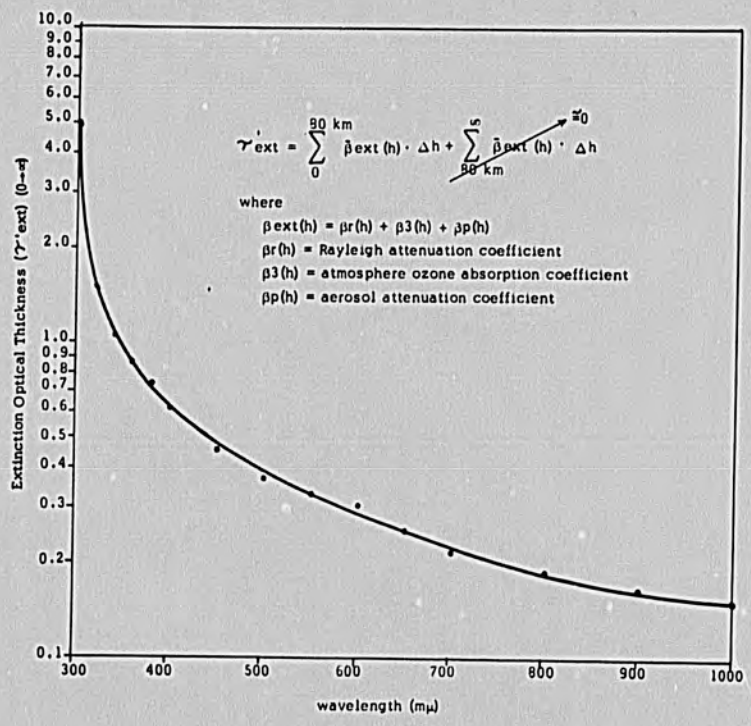

Fig. 2 Theoretical trend of extinction optical thickness for a clear standard atmosphere (after Elterman 1964). Actual attenuation is a function of local instantaneous dust, aerosol, ozone and haze conditions so the "standard atmosphere" is never achieved in nature. Thus the above curve illustrates the best possible conditions ever available for spacecraft photography.

acquiring resource data from these regions (OSSA, 1970). Figure 1 is an enlargement of portion of an Apollo 6 photograph of the Tucson area taken with a hand-held Hasselblad camera in April 1968 from a height of 217 km. Aside from minor red saturation related to time (about 7:45 a.m.) and film type, the image is of very high quality. Data losses can occur, however, through the combined effects of high albedos with dust and aerosol concentrations in the atmosphere. These phenomena tend to reduce image contrast and scatter short wavelength signals (Figure 2). In addition there are film and terrain related color ambiguities which confound the job of terrain identification (Artsybashev, 1962; Simonett, et al., 1969b). Considering that the arid lands of the world constitute almost 36% of the land area, are poorly known, remote, sparsely mapped, and largely unphotographed from aircraft altitudes, it is important to investigate sensors which are independent of solar illumination and most weather conditions.

The following account outlines the basic principles behind radar imaging by reviewing the system and terrain parameters effecting data output; then proceeds to give examples of arid land studies conducted by the author and others from the Remote Sensing Laboratory, Center for Research at Kansas University.

RADAR SYSTEMS

For terrain sensing the basic radar equation (1) states that the power returned (P_r) to the receiver from any scattering element is a function of the transmitted power (P_0), the gain of the antenna (G), the wavelength of the

$$P_r = \frac{\sigma G^2 P_0 \lambda^2 [f(\Theta\ \phi)]^4}{(4\ \pi)^3 R^4} \qquad (1)$$

transmitted energy (λ), the backscattering coefficient (σ) for that element, some function of the "look" angle (θ) and the beam width (ϕ), and the distance (R) to the target. In this equation each of the sensor parameters can be precisely controlled so that the only terrain variable is . For areas which are large and homogeneous in relation to the wavelength of the system being used, the backscatter equation can be rewritten in terms of a backscattering cross-section defined as σ^o, a dimensionless ratio which incorporates beam width (ϕ) and pulse length (λ) into an areal average. It is this value, σ^o, that is central to radargrammitrists as the best terrain descriptor in the active microwave region.

Parameters which affect the magnitude of σ^o can be divided conveniently into those which influence the dielectric properties of the terrain, such as moisture and salt content; and those pertaining to system and terrain geometry. Our knowledge of the contribution of complex dielectric to backscatter from terrain is scanty and as a consequence geometric properties usually become the main issue in interpretation. It is likely that, as systems become more refined, and as the reflectivity/conductivity properties for various entities become known, the ability to separate dielectric influences from roughness influences in the environment will be enhanced. For the present it is generally true that the larger the dielectric constant, the larger will be σ^o. Most natural solids have constants less than eight. However, at K-band frequencies (see appendix A) Moore (1969) has calculated that water approaches 30. For this reason we should expect moisture to be a predominant influence on radar return from the ground.

Typical geometry for a side-looking airborne radar (SLAR) system is whown in Figure 3 as it might have appeared over Tucson, Arizona (compare

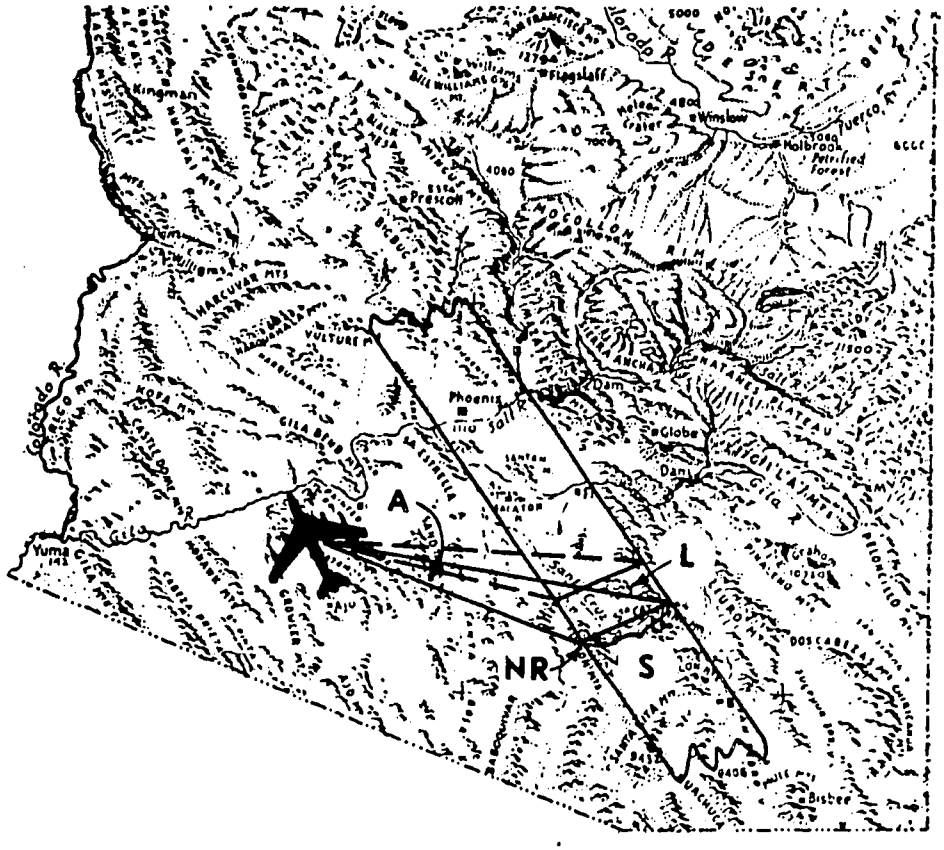

Fig. 3 Geometry of a typical SLAR system. A= range of viewing angles with the near range (NR) closest to the aircraft. S= swath width--a joint function of A and aircraft altitude. L= shadowing on slopes facing away from aircraft and illustrates importance of "look" direction.

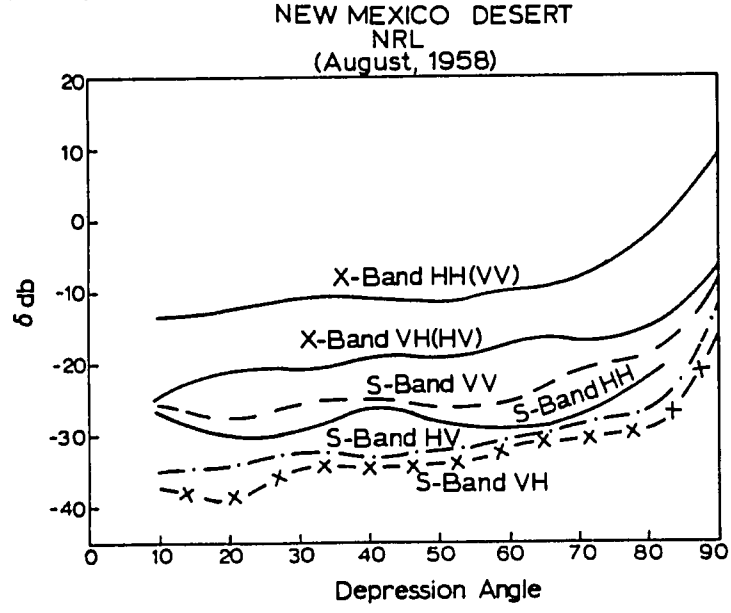

Fig. 4 Backscatter return from a scene in the New Mexico desert for two frequencies and four polarizations.

Figure 5). For a fixed cell size σ^o has angular dependencies which are a function of the roughness, volume scattering and resonances determined by object geometry. "Smooth" surfaces (those which have scattering facets less than ca. $\lambda/10$ apart) are characterized by specular-like reflection; that is, at all incidence angles other than 0° they reflect signals away from the receiver and appear as dark grey or black on the resulting imagery. In optics an approximate analogy would be to shine a flashlight onto a mirror in a darkened room. If the light is aimed directly into the mirror (zero incidence) an intense bright spot will appear; at all other angles the return will be much diminished. "Rougher" surfaces (those with scattering facets between $\lambda/2$ and 2λ apart) behave more nearly as isotropic scatterers; consequently they have a nearly constant return as incidence angle is increased. Carrying through with the analogy, it would be as if the observer shined the flashlight onto a projector screen instead of a mirror. Differences in arising through variations in polarization are not well documented, but in theory rougher surfaces have greater depolarizing potential. At small σ^o angles of incidence depolarization will be least (MacDonald and Waiter, 1970).

In Figure 4 backscatter curves taken from unpublished NRL data are presented for a portion of the New Mexico desert. Two frequencies (X- and S-band) and four polarizations (HH, HV, VV, VH) are compared over a 90 degree sweep of viewing angles (θ). For the X-band frequency with a wavelength between 2.8 and 4.8 cm the like-polarized components (HH and VV) are indistinguishable, as are the cross-polarized returns (HV and VH). The difference between the cross and like terms however is about 10 db. Theoretically this suggests that different terrain information could be obtained by imaging in the two modes. In this particular case, however, the trend of the two curves

is so similar that little new information is obtained by comparing them. At the S-band frequency (7.7 to ca 19 cm), on the other hand, non-linear differences occur between all four polarizations and these probably pertain to ground properties. Since S-band is a lower frequency than X-band, one would expect better surface penetration, and this may be the the explanation surrounding differences displayed in Figure 4. In addition, by increasing the wavelength, surface roughness properties change accordingly. By linking imaging radars that employ widely separated frequencies it may be possible in the arid zones to delimit hardpan, shallow stone lines, sand depths, or a host of other surface and near subsurface phenomena. For these kinds of studies the absence of moisture in the environment is a definite advantage.

A final but critical parameter of interest to radar users is resolution. The average resolution of data contained in this report is 50 feet. Much finer data can be obtained by converting from so-called "brute force" to "synthetic aperture" systems. In optical terms this is equivalent to increasing the focal length of the camera. The overwhelming advantage for radar is that, even from space altitudes, fine resolution can be maintained. Thus by narrowing the swath width in a synthetic aperture system, data of finer resolution than that presented here are anticipated from space. Moreover, since orbiting platforms are more stable than aircraft, image distortions and other degradations caused by air turbulence should be reduced.

ARID ZONE APPLICATIONS

Initially, space oriented resource inventories will focus on such broad-scale topics as soil, vegetation, geology (geomorphology), drainage and hydrology (including irrigation) and agriculture. As thematic maps and other

land use information become available for these interests, more comprehensive management and development schemes can be implemented. It is therefore important to appreciate the role radar data might play in some of these initial surveys. The following sections deal specifically with soil, vegetation and hydrologic mapping capabilities.

Soil Mapping

Several investigators have reported on the scope for soil studies using radar data as a base. Simonett (1968) was able to distinguish four soil associations in Woods County, Oklahoma near the dry/subhumid boundary. These were largely restricted to uncultivated areas such as badlands, salt plains, floodplains and terraces. On adjacent cultivated land soil texture patterns were masked by complex crop geometries and variable moisture patterns. Barr (1969) found that regional engineering soil types could be identified by inference combined with recognition of repetitive patterns. In his study areas it appeared that brute force systems yielded higher quality data than synthetic aperture radar, but given the present state-of-the-art in these type systems this is not surprising. Since there was little penetration at the wavelengths used by Barr, the reflecting surface was found invariably to be the first surface intercepted by the signals. In desert regions that surface is usually a combination or rock or bare soil and desert shrub. The low density of plants per unit area together with a wide range of soil textures over short distances, leads one to suspect that significant soil information might be derived from the radar frequencies.

Figure 5 is a reproduction at original scale of Ka-band imagery λ = .8-,9 cm obtained over Tucson in November, 1965. The valley region is devoted largely to irrigated agriculture and, as Simonett found, the soil

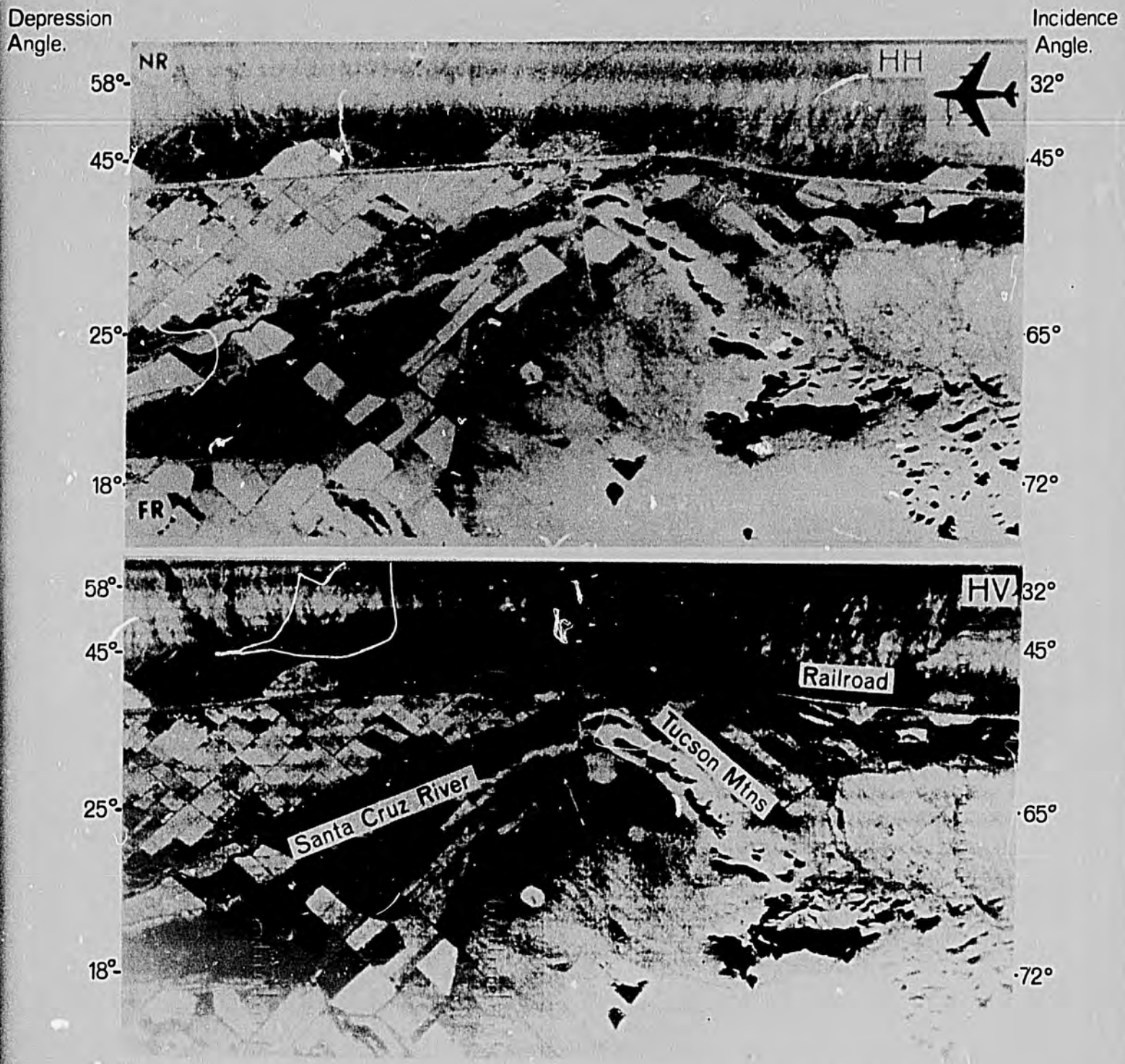

Fig. 5 K-band radar imagery near Tucson, Arizona. Note soil patterns revealed on alluvial fans surrounding Tucson Mtns. and on slopes north of railroad line. Pattern in valley is partly obscured by agriculture.

pattern is mostly obscured. Large areas on the alluvial fans and smaller areas along the valley (particularly adjacent to the Santa Cruz River) reveal a pattern closely resembling that mapped by the USDA Soil Survey (Young, et al., 1931). Vegetation throughout the uncultivated area consists of creosote bush (Larrea divaricata), scattered mesquite (Prosopis juliflora) and burroweed (Haplopappus tenuisectus). It is improbable, therefore, that the patterns on the imagery are due to definable plant communities. In Figure 6a boundaries have been delineated from the radar by combining information from the like (HH) and cross (HV) terms. Once delineated, the areas could be categorized through reference to the preexisting soil survey map compiled in 1931. A complete set of texture types including broken and stony land, coarse textured pebbly and sandy soils, silt loams, loams and clay loams resulted from this categorization. Highest returns on Figure 5 are observed for the stony and pebbly soils especially those in the near and medium radar range; that is, at lower incidence angles. These surfaces are apparently behaving as isotropic scatterers, perhaps because of the angularity of the sand grains comprising the surface and the comparability of their size to that of the transmitted wavelength. Generally, as texture becomes finer, radar return diminishes: loams, clays, and clay loams image as medium to cark gray tones, while silt loams image almost black. The apparent anomally of silt loams imaging darker than clay loams in what is otherwise a consistent trend may be explained by the fact that, in this area, the Gila silt loam characteristically melts together to form a smooth surface reflecting the bulk of radar signals away from the receiver.

The patterns on Figure 6a can be compared with a simplified version of the USDA soil map illustrated in Figure 6b. The major difference between

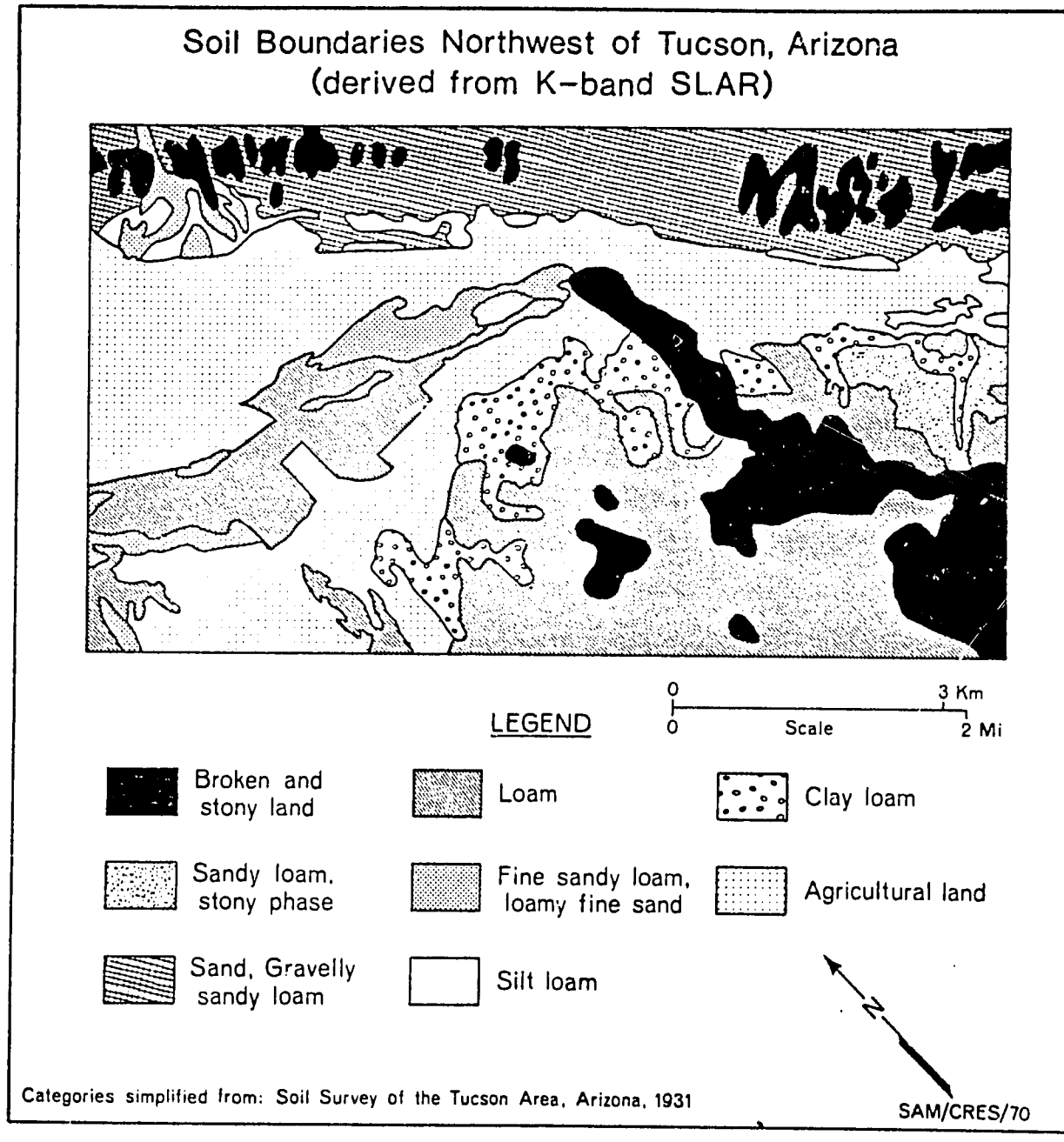
Soil Boundaries Northwest of Tucson, Arizona
(derived from K-band SLAR)
LEGEND
0
3 Km
0
Scale
2 Mi
Broken and stony land
Loam
Clay loam
Sandy loam, stony phase
Fine sandy loam, loamy fine sand
Agricultural land
Sand, Gravelly sandy loam
Silt loam
N
Categories simplified from: Soil Survey of the Tucson Area, Arizona, 1931
SAM/CRES/70

Figure 6A.

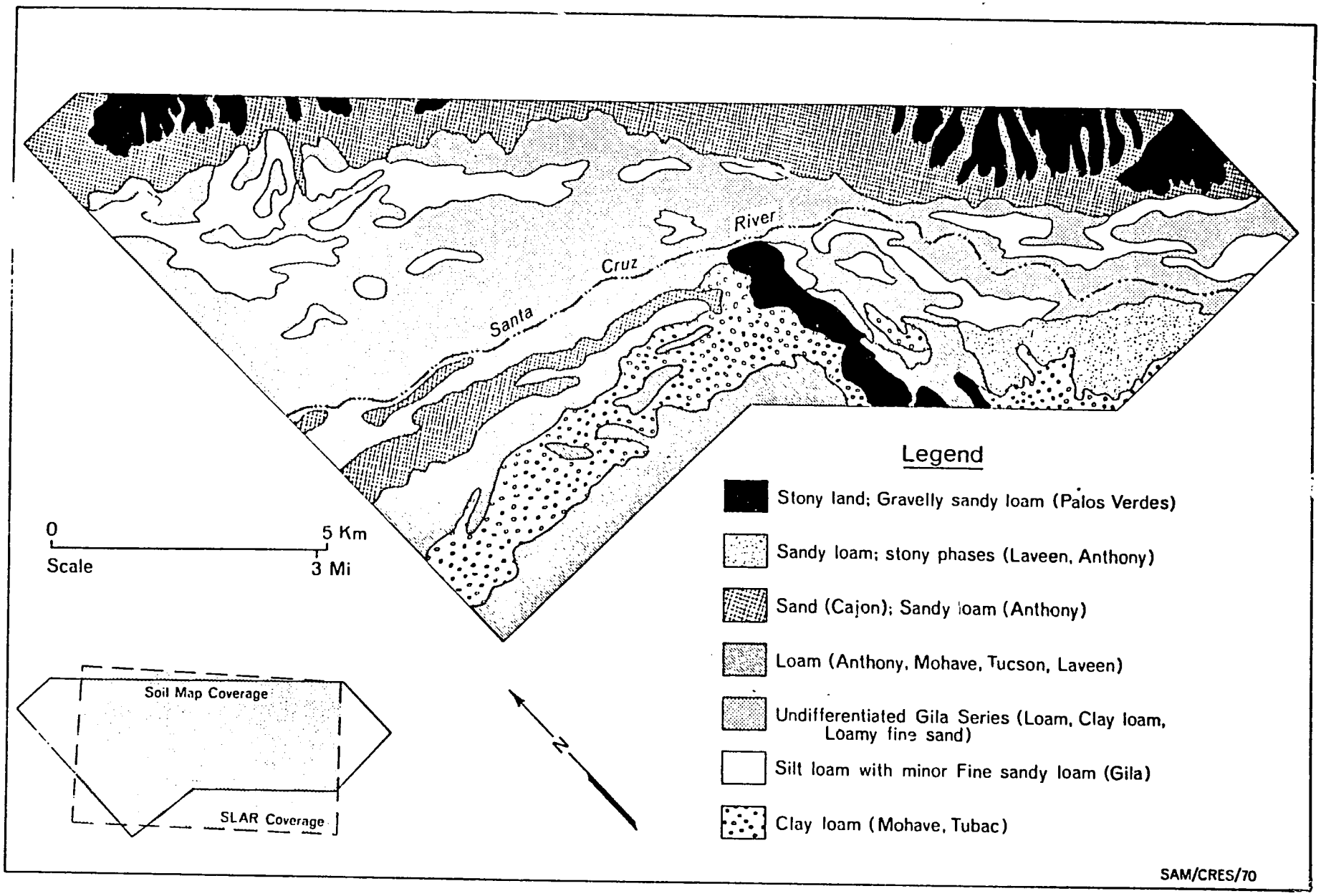
Santa
Cruz
River
0
5 Km
Scale
3 Mi
Soil Map Coverage
SLAR Coverage
N
Legend
Stony land; Gravelly sandy loam (Palos Verdes)
Sandy loam; stony phases (Laveen, Anthony)
Sand (Cajon); Sandy loam (Anthony)
Loam (Anthony, Mohave, Tucson, Laveen)
Undifferentiated Gila Series (Loam, Clay loam, Loamy fine sand)
Silt loam with minor Fine sandy loam (Gila)
Clay loam (Mohave, Tubac)
SAM/CRES/70

Figure 6B.

them is that the cultivated area has expanded since 1931. Most of the expansion has involved soils of the Gila series. The overall correspondence in pattern is striking and suggests that interpreters knowledgeable about local soil-vegetation-topography relationships could produce reconnaissance or semi-detailed soil maps from radar. Much research still needs to be done, however, to define σ^0 for various soil textures and conditions, as well as moisture contents, at specified frequencies and viewing angles.

Consistency of radar backscatter is, of course, an important issue in mapping any terrain phenomena. It is encouraging, therefore, that exactly the same texture/backscatter trend has been observed and mapped near Tule Mtn. in the Trans-Pecos of southwest Texas. In this locality broken and stony land was separable on the basis of terrain texture and drainage patterns. Very gravelly loam representing the Reeves series imaged in medium grey tones, and, as texture became finer in the Ector and Rio Grande series, backscatter intensity diminished.

Vegetation Mapping

Vegetation patterns have been observed on radar imagery from a wide variety of environments. In only a few cases however have desert communities been identified directly rather than as a surrogate related to soils or topography (Morain and Simonett, 1966). The reason, primarily, is that desert communities are gnerally low and sparse. Consequently, their backscattering cross-sections are complicated by "noise" from lithology, soil surfaces, moisture contents, and possibly by salinity patterns. This is precisely the kind of problem confronting interpretation of coarse resolution color space photography. For this and other reasons it is widely agreed that unambiguous identification of area-extensive terrain categories can seldom be achieved

by a single sensor without the aid of local surrogates, perhaps not even then. Given a basic pattern such as that in Figure 6a local interpreters could make sound judgments regarding the distribution of plant communities.

Figure 7a,b shows two aspects of the desert vegetation in Escalante Valley, southwestern Utah. The region is largely characterized by great basin sage (Artemisia tridentata) but in lower lying and more saline localities shadscale scrub (Artiplex confertifolia) becomes the dominant type. In moister, less saline situations a variety of grasses form the association and on the upper slopes of the alluvial fans, juniper woodlands occur. The sagebrush type is uniformly low but has a variable density. In more open areas a sandy (pebbly) surface is often exposed to radar signals, but in denser stands there may be relatively little return contributed by soil--especially at higher incidence angles where objects protruding from a flat surface intercept most of the impinging signal.

From the radar imagery it is possible to delimit the shadscale scrub community, the larger localities of grass, and, by inference, the area dominated by sagebrush (Figure 7c). Juniper woodlands cannot be confidently located due to their association with rough topography. Preliminary field investigations have confirmed that plant cover more than soil differences influence the radar return from this area, though a more detailed examination might show equal dependence. Unquestionably the soil and vegetation patterns are highly correlated. Figure 7c suggests that the most important influences on backscatter from desert terrain are height and density of vegetation and soil texture. If so, significant differences in image texture, tone and polarization should be observable in places such as central Australia where huge areas are dominated by mulga scrub (Acacia aneura), spinifex plains (Triodia spp.) or mixtures of the two. The bluebush deserts of South Australia

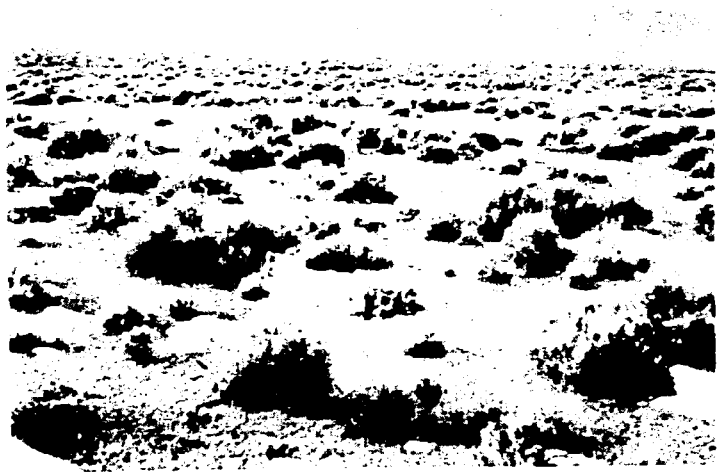

Figure 7a

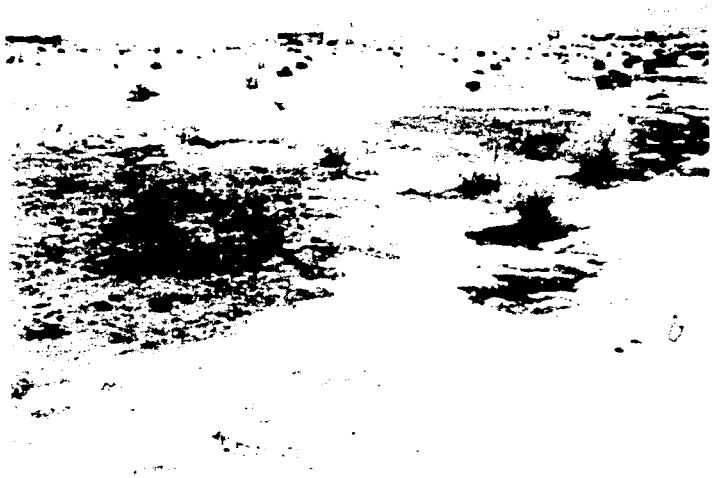

Figure 7b

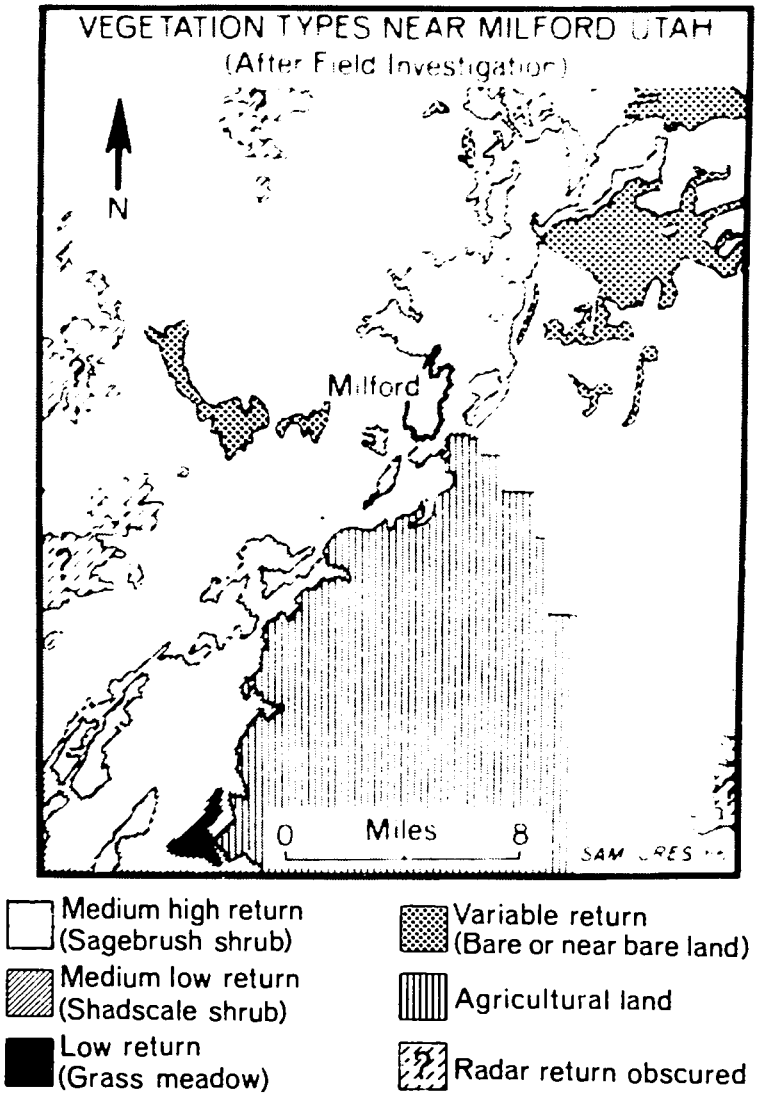

Figure 7c

consisting mainly of Kochia should be analogous to the great basin sage of North America.

As a second example of mapping potential for vegetation, Figure 8 shows a high altitude area north of Flagstaff, Arizona. Within the region three vegetational zones are known to exist; pine forest (mainly Pinus ponderosa); grassland; and juniper woodlands. From the preceeding discussion one would expect to find clear cut boundaries attending such grossly different height and density phenomena, at least at higher incidence angles. Inspection shows that this is indeed the case. The variations are so great in fact that image textures as well as tones can be delineated and categorized. For areas of pine forest (see Figure 9a) a definite "popcorn" texture is observed on the original imagery. Since both polarizations display nearly the same tone and texture, it appears that ponderosa forests have little depolarizing potential. "Texture" is a complex combination of phase relationships between trees of varying height and resonances associated with needle spacing. Phase may be particularly important in mature stands where scattering facets facing the receiver are added in time phase (giving a bright spot on the imagery) and those facing away from the receiver are subtracted (giving a dark spot).

On enlarged versions of the cross and like polarized components, intricate patterns of tone and texture can be recognized, then categorized according to known ecological relationships and image appearance. Figure 9a demonstrates the capacity for mapping not only the broad structural groups, but several subgroups as well. Although the cross polarized image is not shown in Figure 8, the addition of this information permits a few boundaries only marginally distinguishable on the HH to become clear. The technique is analogous in photography to adding a different film-filter combination.

Fig. 8 K-band like polarized imagery of the Kendrick-Humphreys Peak area, Arizona. Tones and textures represent broad plant communities.

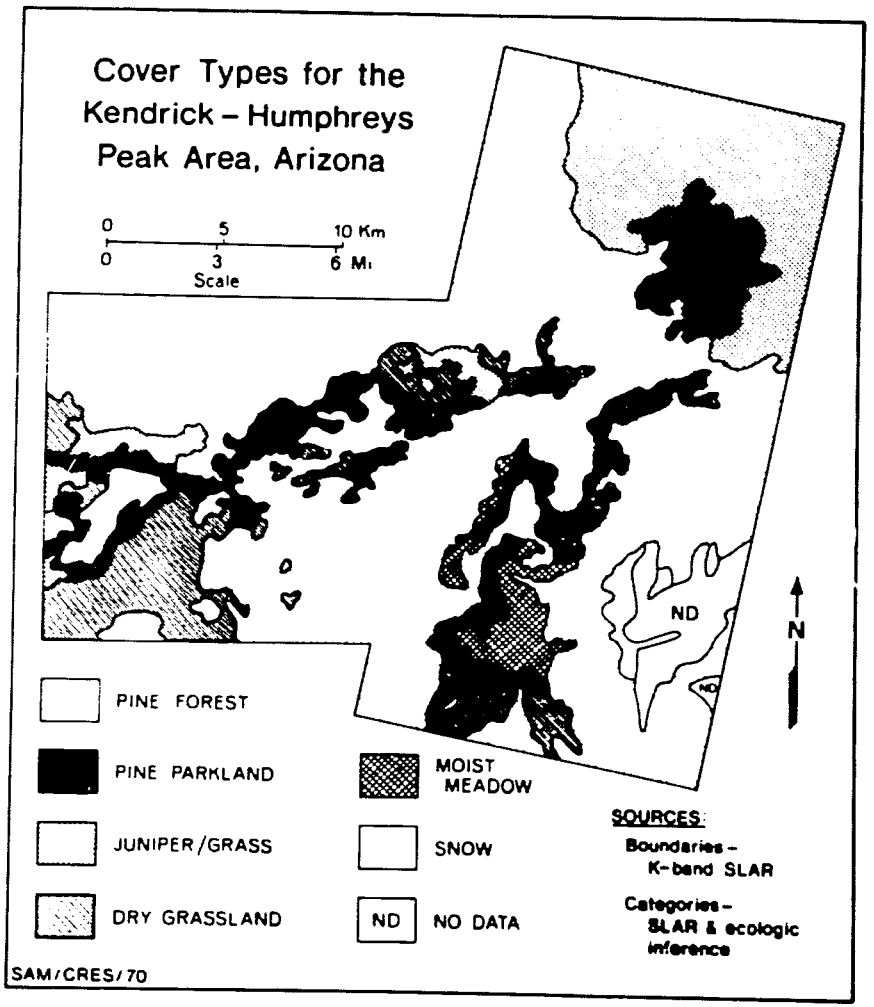

Figure 9a

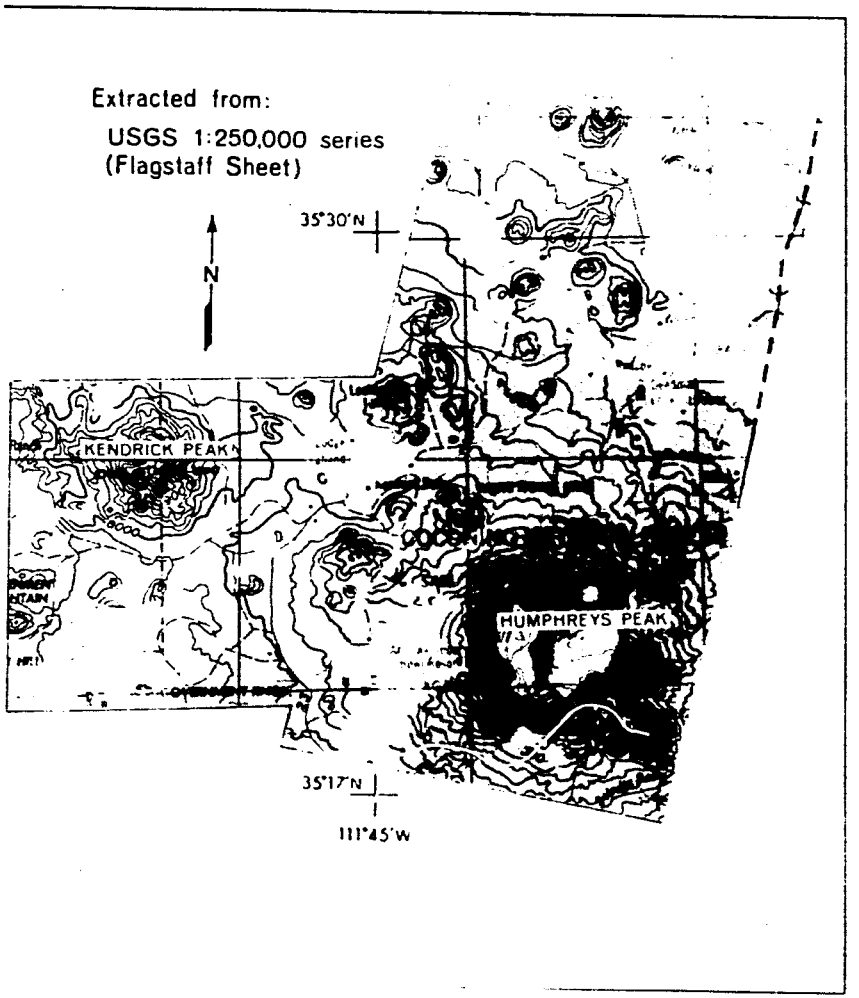

Figure 9b

Presumably, if the full complement of polarizations and viewing directions were available, highly reliable delineations could be made. The reasons why some plant communities depolarize signals more than others are not fully known. Some preliminary statements can be found in Morain (1967) and Morain and Coiner (1970).

Detection of Moisture Related Phenomena

By definition moisture is the most precious resource in desert areas. Any information pertaining to it would be valuable input into problem solving and development schemes. It has already been demonstrated that radar imagery can serve an important function in drainage basin analysis (McCoy, 1967) and two important conditions particularly favor its use in desert environments: 1) the relative absence of vegetation, which, if dense enough, can obscure surface configuration and drainage details, and 2) the enhancement of terrain features arising from radar highlighting and shadowing. Using enlarged imagery McCoy has shown that data for stream length, stream order and basin size comparable to that calculable from 1:24,000 topographic maps can be derived. These data are not presently extractable from space photography because of inadequate ground resolution. Even without this limitation the similarity of albedos between desert washes and surrounding countryside would hinder their extraction. Figure 10 illustrates the potential for radar drainage studies in a highly complex region around Tule Mtn., Texas.

Aside from drainage studies, radar sensors have been shown by MacDonald and Waiter (1970) to be sensitive to gross soil moisture variations when viewed in the near radar range. Extending their results, it may be possible to identify moisture regions in the desert immediately following rainfall. The addition of moisture to fine textured soils, which, when dry, image in dark tones, should increase their backscattering cross section. In contrast,

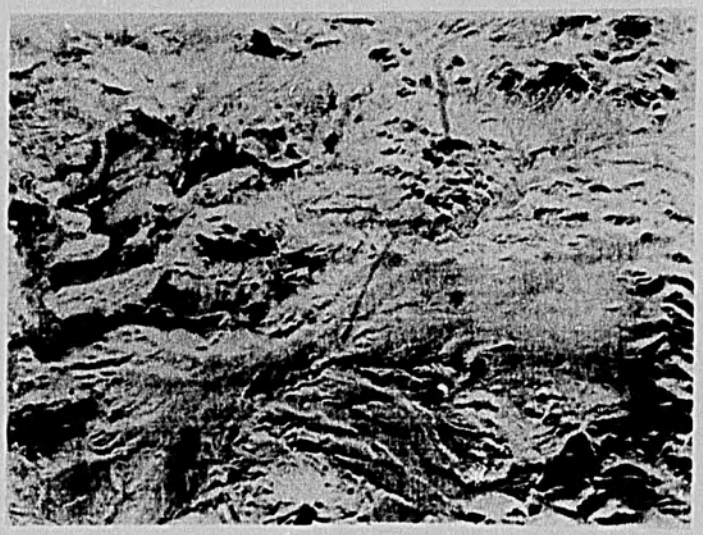

Fig. 10: K-band like polarized imagery of the Tule Mtn. area, SW Texas. Note the drainage detail.

coarser textured soils having rapid internal drainage and faster drying rates (and which already approach isotropic backscattering characteristics) may show only minor changes with additional moisture. By monitoring the time required for various σ^{o} to return to typical dry values, subtle patterns of moisture persistence in the landscape might be detected. Examination of imagery obtained over the Trans-Pecos during a mild storm in November 1965 appears to lend support to this hypothesis.

Another interesting possibility involving tandem radar systems operating in widely separated frequences (or for a single system with a sweep frequency like that being developed at Kansas) might be in mapping atmospheric rainfall patterns and comparing them to simultaneously obtained ground moisture patterns. The first task would employ a high frequency system sensitive to rainfall while the second would use a lower frequency able to penetrate rainfall rate of a known amount.

CONCLUSIONS

The versatility of radar sensors and their demonstrated ability to supply data for selected mapping problems warrants their consideration for inventory programs of arid zones. Among their advantages are: 1) independence from solar elevation which, for passive photographic sensors, severely influences reflectance properties of terrain phenomena; 2) independence from haze, dust and other attenuating materials in the atmosphere; 3) the ability to maintain fine resolution even from space altitudes by electronically controlling the length of the antenna; 4) the ability to image continuous swaths of terrain to obtain a preliminary mapping base--albeit non-metric; 5) the

potential with long wavelength systems for conducting studies of hardpan and other near subsurface phenomena; 6) the sensitivity of medium and fine resolution systems to structural differences in vegetation, and 7) their sensitivity to terrain moisture conditions.

Further research must follow to ascertain the relationships of σ^{o} to frequency, polarization, complex dielectrics, and incidence angle. Our limited investigations indicate that low angles are best for detecting differences in soil texture and moisture, while higher angles are more sensitive to vegetation height and density. It is not anticipated that radar sensors, either SLAR or spaceborne, will replace photography as a primary data source, but the unique contributions of active microwave sensing for resource inventories in deserts should be vigorously pursued. Perhaps radar will prove to be more valuable than at first suspected and will fulfill a supplementary rather than merely ancillary role to photography.

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APPENDIX A

Radar Band	Frequency Range GHz	Wavelength Range (cm)
P	.2 - .4	133.3 - 76.9
L	.4 - 1.5	76.9 - 19.3
S	1.5 - 3.9	19.3 - 7.69
C	3.9 - 6.2	7.69 - 4.84
X	6.2 - 10.4	4.84 - 2.75
K (General Designation)	10.9 - 36.0	2.75 - 0.83
Ku Approx.	12.5 - 18.0	
K Approx.	18.0 - 26.5	
Ka Approx.	26.5 - 40.0	
Q	36.0 - 46.0	0.83 - 0.65
V	46.0 - 56.0	0.65 - 0.54

EVALUATION OF LANDSAT DATA FOR DISASTER ASSESSMENT AND PLANNING SUDAN FLOOD 1978*

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A. DOKA

SOIL SURVEY ADMINISTRATION, WAD MEDANI, SUDAN

ABSTRACT

The use of Landsat data in reconnaissance disaster assessment was evaluated for the 1978 Gezira Flood of Sudan. The authors concluded that Landsat data are beneficial fora rapid assessment of large-area flood damage if high quality, cloud-free data are available in a timely manner. They are best used in stratifying zones of varying levels of apparent damage. After quantification of various themes of damage by ground or low-flight aircraft observation, the Landsat interpretation provides a data base to extend the point observations into a map. The mapping units are measured to quantify the assessment.

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INTRODUCTION

Heavy rains fell on parts of the Sudan in July 1978 resulting in widespread floods. The Gezira agricultural scheme in central Sudan was heavily damaged. This irrigated agricultral scheme lies between the Blue Nile and White Nile, forming a triangle with Khartoum at the apex, and Kosti and Sennar at the base (Fig. 1). It covers an area of about one-million hectares in the vast flat clayplain between the two rivers. The Gezira agricultural scheme is Sudan's economic backbone, since cotton, the nation's major foreign currency earner, is grown there.

The Gezira province received 370 mm of rain in two days, two and a half times its 150 mm average annual precipitation. The flat terrain and low permeability of the heavy clay soil, together with the irrigation water already brought to the fields just before the rains, created an environment very prone to flood damage. The malfunctioning of the limited surface drainage system helped cause the water to remain ponded on the soil for a long period of time after the rains had ceased (Gezira Board Annual Report 1978-1979).

According to preliminary reports, about 500,000 people were affected; 150,000 became homeless. One hundred villages were completely destroyed, and 220 villages were badly damaged. A low-altitude aerial photograph of a flooded village in central Gezira Scheme is shown in Fig. 2. As most of the houses were built of clay, they collapsed easily when soaked by the flood (Fig. 3). About 600,000 hectares of crops, mainly cotton, were flooded. Large portions of the irrigation canals were destroyed and thousands of tons of fertilizers and pesticides already applied to the soil were washed away. Several thousand head of livestock were drowned (verbal communication with P. F. Krumpe, and news releases in Sudanese newspapers).

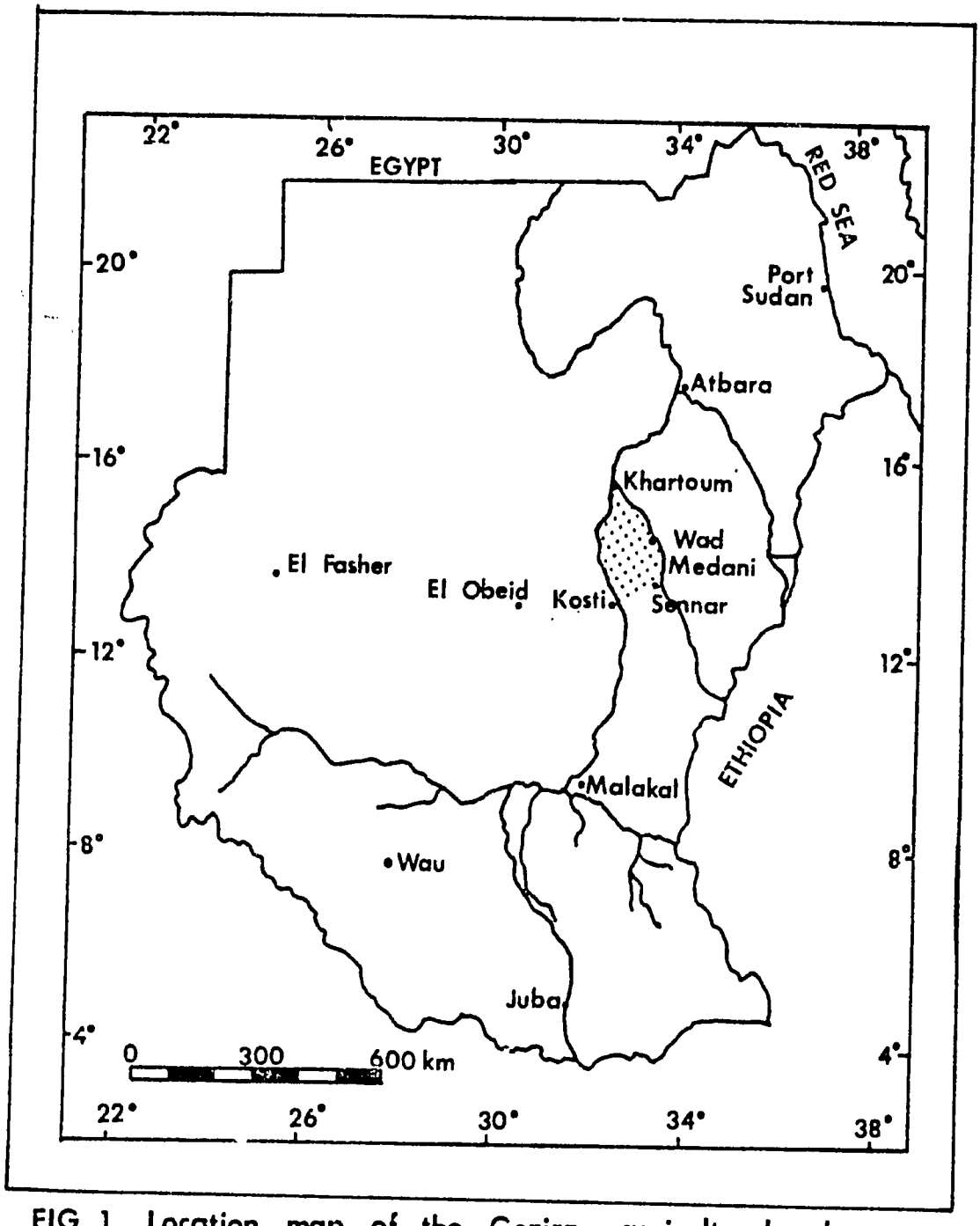


FIG. 1 Location map of the Gezira agricultural scheme (dotted area).

Figure 2. A flooded village in central Gezira scheme.

Figure 3. Since most houses are built of clay, they collapsed easily in the flood.

It was reported that the areas most affected by the flood were the northwestern parts of the agricultural scheme known as the "Managil Extension". The general slope of the scheme trends towards the northwest to the Managil Extension.

The whole Gezira area was inaccesible for several weeks after the flood. Most of the roads in the area are not paved and become impassable when wet. This situation resulted in the lack of timely data concerning the flood.

In response to the Sudan Government's appeal for international help, the Office of U. S. Foreign Disaster Assistance (OFDA) participated in the efforts of relief and rehabilitation for the disaster stricken area. Meanwhile, OFDA decided to use the Sudan flood as an example to study the applicability of Landsat data in assessing flood damage.

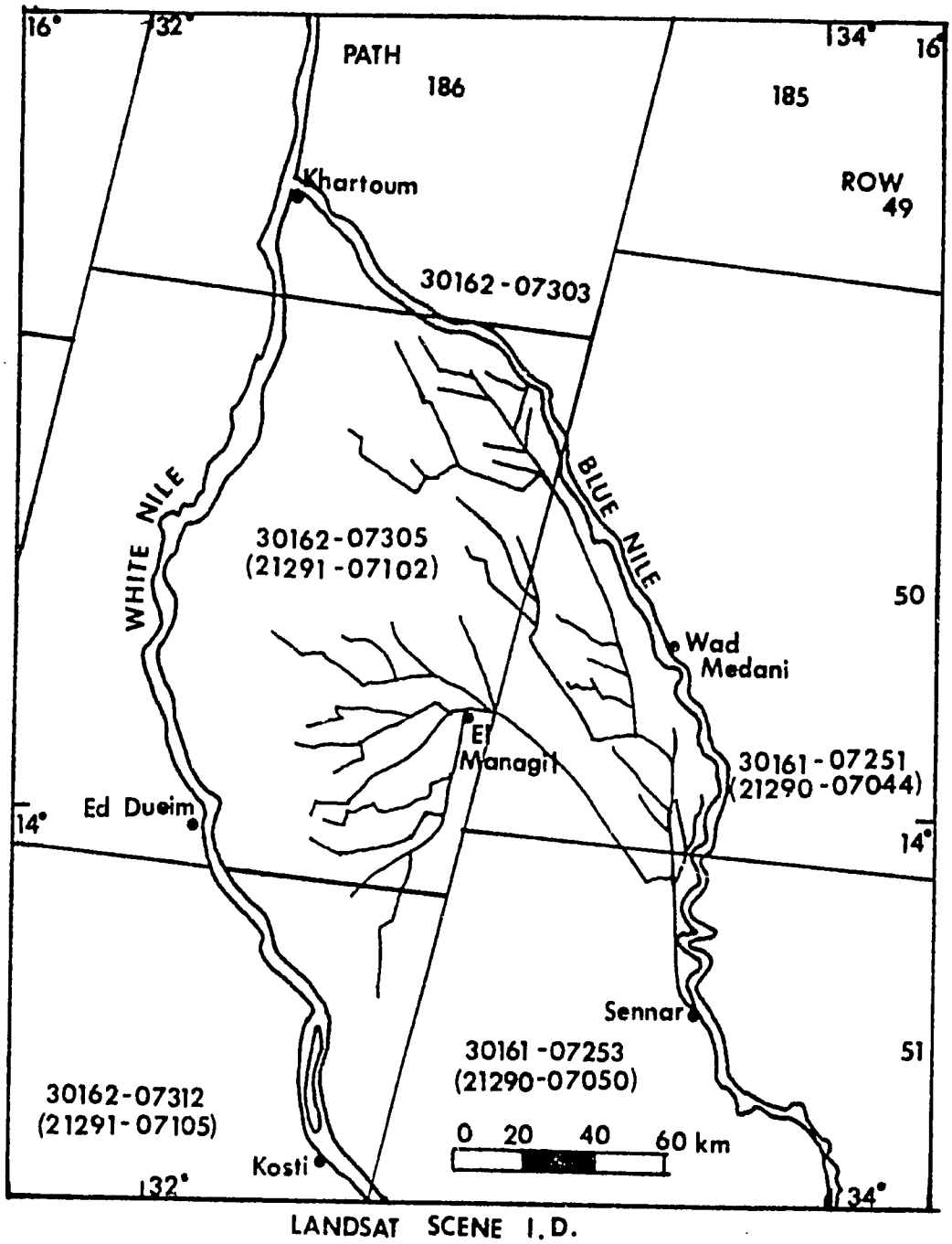
Several studies have been published on the applicability of Landsat data for flood disaster assessment. The work of Myers and Waltz 1972, Benson and Waltz 1973, Deutsch et al 1973, Moore and Rusche 1974, Deutsch and Ruggles 1978, and Thillaigovindarajan 1978, offered the authors good guidelines in this study.

OBJECTIVES

The objective of this study was to evaluate Landsat data for flood disaster assessment for the Gezira or a similar flood.

AVAILABLE DATA

Two post-flood Landsat coverages were obtained (Fig. 4). The first was on the 4th and 5th of August 1978 and the second was on the



LANDSAT SCENE I.D.

( )-4&5 AUGUST 78

OTHERS-13&14 AUGUST 78

FIG.4 Index map of Landsat coverage.

13th and 14th of August 1978. The first had considerable cloud cover. The second had only a slight cloud cover. Both coverages were utilized in this study.

Ground information concerning damage caused by the flood was generally not available. Neither the Sudan Gezira Board's annual report for 1978-1979 nor the records of the Sudan Gezira Board and the Ministry of Irrigation contained the type of information that could be used in this study. This was partially due to the inaccessibility of the whole region for several weeks after the flood. Several maps for the area were obtained from the Sudan Survey Department which were helpful for delineating village locations, roads, topography, and irrigation canals.

The information collected by interviews from officals of the Gezira Board and other offices, as well as from local people within the flooded area, was of a generalized nature and was not the result of a documented survey.

INTERPRETATION

Landsat data for the scenes shown in the index map (Figure 4) were obtained in the form of photographic negatives and diapositives in the four bands, as well as computer compatible tapes (CCT's) for scenes 30162-07303 and 30161-07251. Prints in the four bands as well as false color composites were studied and compared.

The final interpretation and compilation of results was made on an overlay on a false color composite mosaic for the study area at

a scale of 1:250,000, using August 13 and 14 images.

On the false color composite, surface water and saturated clays were identified by different shades of bluish colors ranging from dark blue to pale bluish white. The surface water occurred in cultivation benches, formed ponds in low lying areas, and accumulated along the sides of breached irrigation canals. It was possible to identify breaches indirectly through the accumlated water along the side of the canal. The breaches were caused either by the flood or by man in an attempt to drain water through the irrigation canals; however they brought in more water than they drained (verbal communication with Gezira Board officials).

Through visual interpretation and guided by the apparent remaining flood water on the surface and the areas of saturated soil, the whole area was classified into three categories.

(1) Highly damaged

(2) Moderately damaged

(3) Slightly damaged

The total area of each of the three damage levels was determined from the map (Fig. 5) reduced from a 1:250,000 original map. From existing maps, villages in the area were plotted on an overlay, superimposed over the map of damaged areas, and the number of villages in each of the three damage categories was determined. By multiplying the number of villages in each category by the average population per village, the approximate number of people affected was obtained (Table 1).

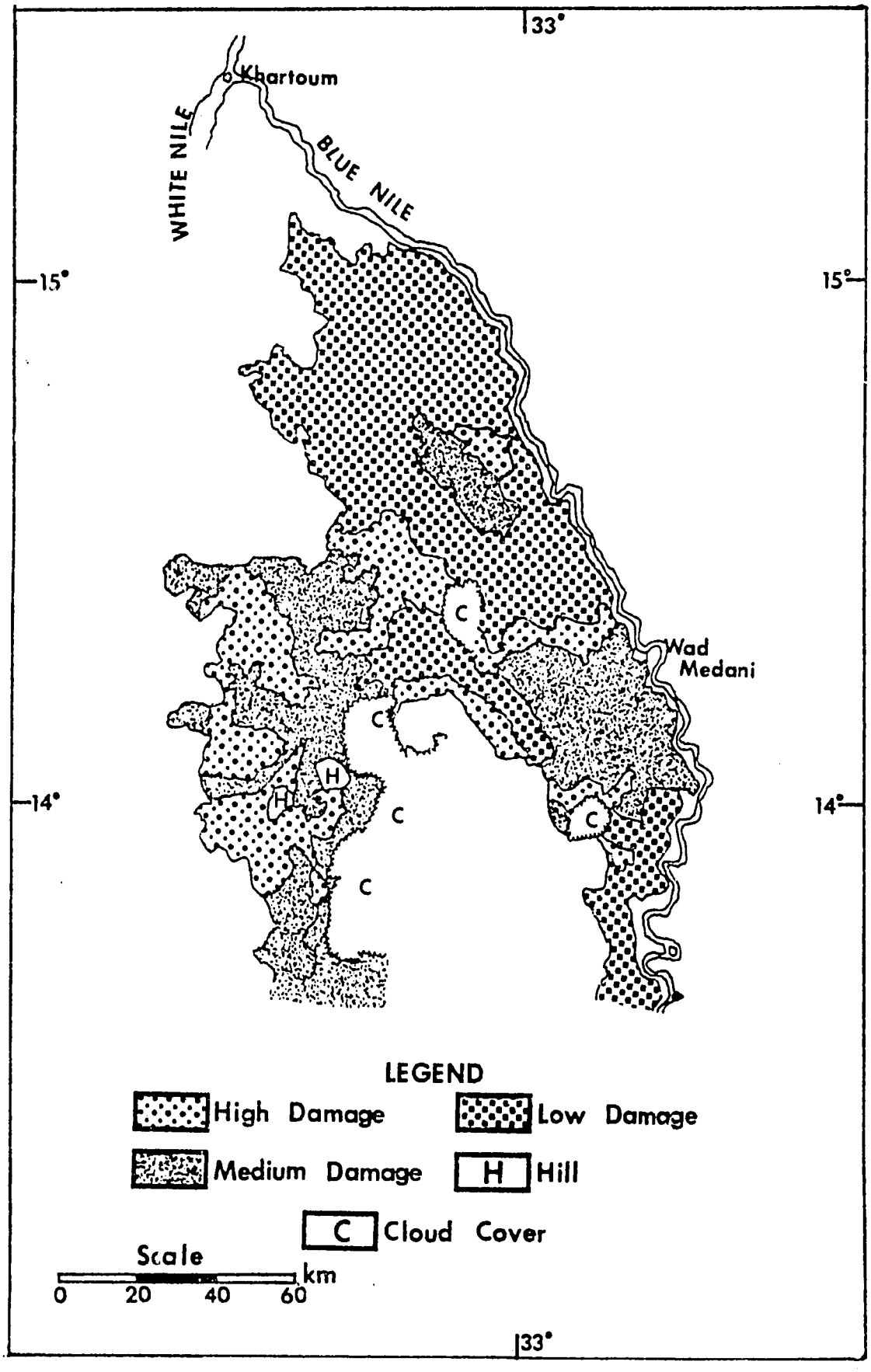


FIG. 5 Classification map of damaged areas.
(Map reduced from a 1:250,000 original.)

TABLE 1: EXTENT OF FLOOD DAMAGE AS DERIVED FROM INTERPRETATION

Extent of Damage[1]	Agricultural[2] Area in Hectares	Number of[3] Villages Affected	Number of People Affected
High damage	235,730	133	115,311
Moderate damage	574,200	214	186,538
Slight damage	517,430	184	159,528

1- The three damage levels shown are estimates derived from the apparent remaining surface waters and saturated soil identified in the Landsat scenes.

2- Some agricultural areas included did not belong to the Gezira agricultural scheme.

3- The numbers indicated for villages affected were based on villages plotted on maps published by the Sudan Survey Department.

RESULTS

A damage estimate map is shown in Fig. 5. The southeastern part of the area, south of Wad Medani,developed a number of turbid water pools due to its irregular topography (Fig. 6). The rest of the irrigation scheme area is generally flat with a gentle slope towards the northwest. Flood waters accumulated in the cultivation benches, with the depth decreasing from the northwestern bank towards the southeast, followed by a zone of saturated soil (Fig. 7). A low-altitude aerial view of the flooded cultivation benches is shown in Fig. 8.

A temporal composite according to procedures by Deutsch et al 1973 and Deutsch and Ruggles 1978 for the area west of Wad Madani was prepared by superimposing an August 4th Band 7 positive scene printed in cyan and an August 13th Band 7 positive scene printed in magenta. On the resulting composite we found that:

(1) Areas covered by water on both dates were dark violet to blue.

(2) Areas covered by water on August 4 and saturated soil on August 13 were magenta to red.

(3) Areas of saturated soil on August 4 and water on August 13 were blue.

(4) Areas of saturated soil on both dates were blue to magenta.

The composite showed a slight diminishing of flood water surface area between August 4 and August 13. A tracing of the temporal composite is shown in Figure 9 showing the different areas mentioned above, marked with the same corresponding number.

It was difficult to conduct a meaningful classification using digital analysis due to the wide range of conditions ranging from wet

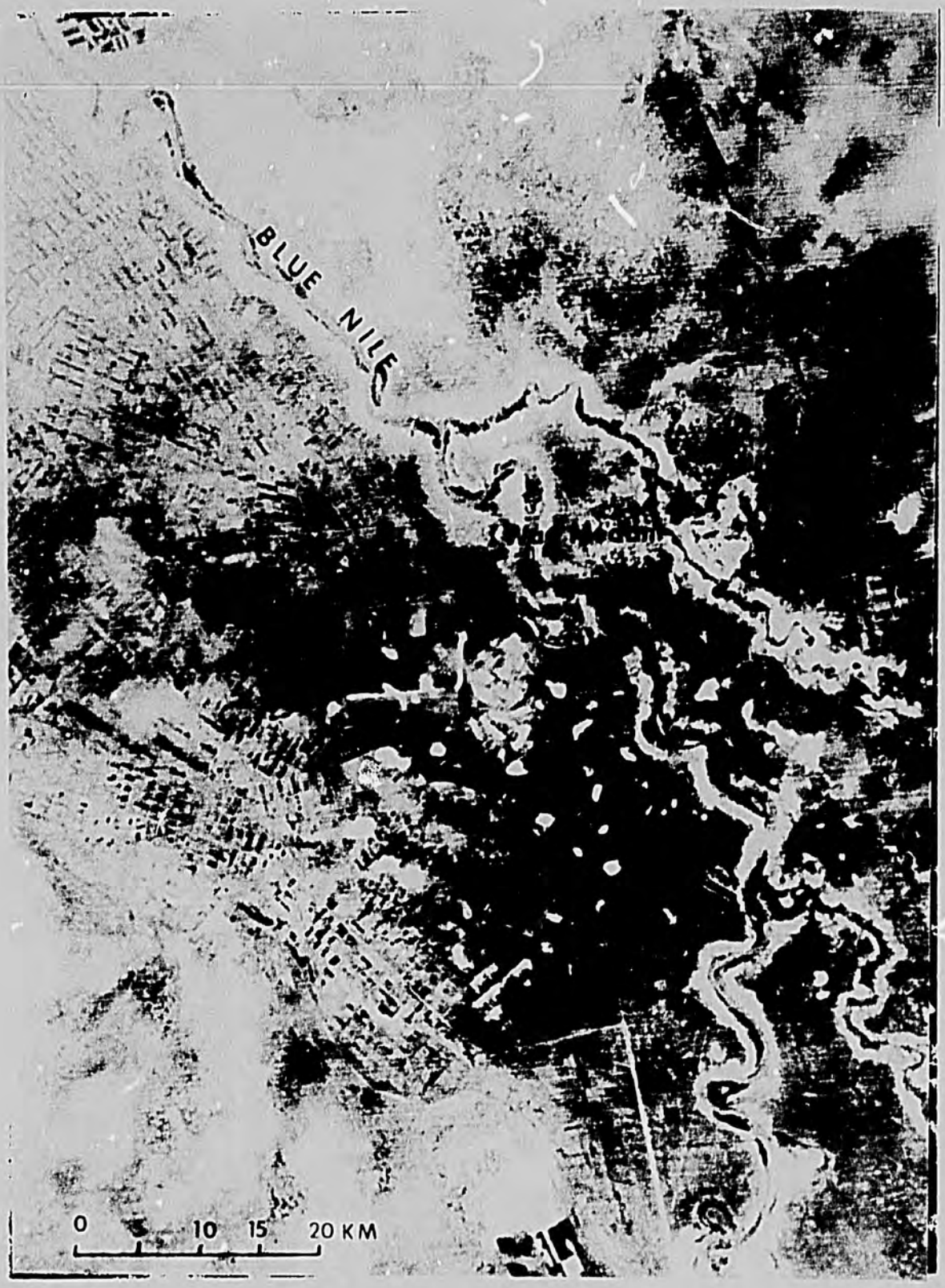


Figure 5. A portion of B & W Landsat scene no. 21290-07044 dated Aug. 4, 1978, band 5, scale 1:500,000 for the southeastern part of the Gezira scheme. Ponded surface water with high turbidity and/or saturated clays appear in light tones with distinct boundaries.

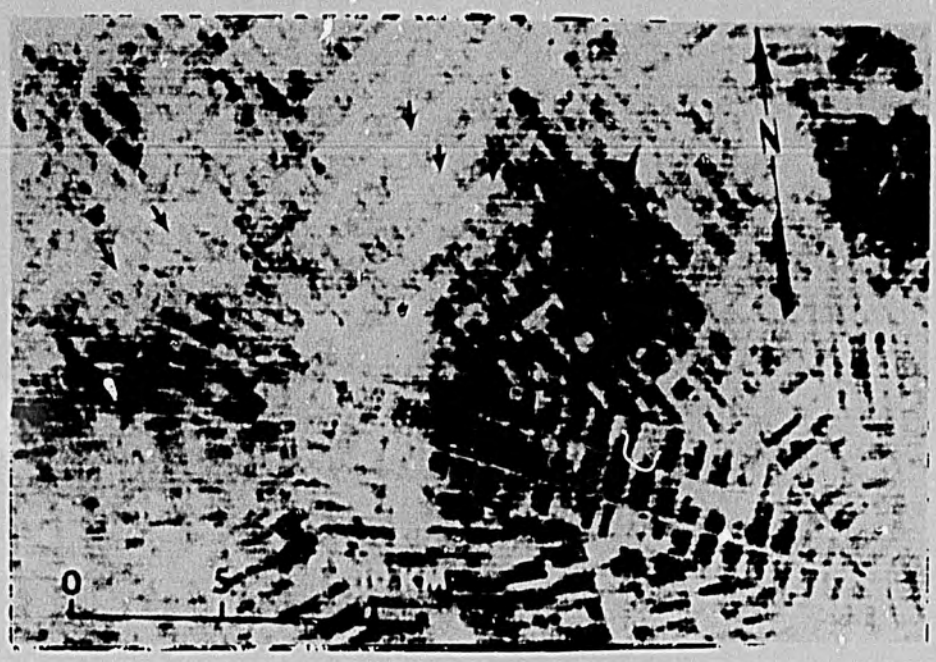


Figure 7: A portion of Landsat scene, band 5, scale 1:250,000 for central Gezira scheme showing flooded cultivation benches (shown by arrows).

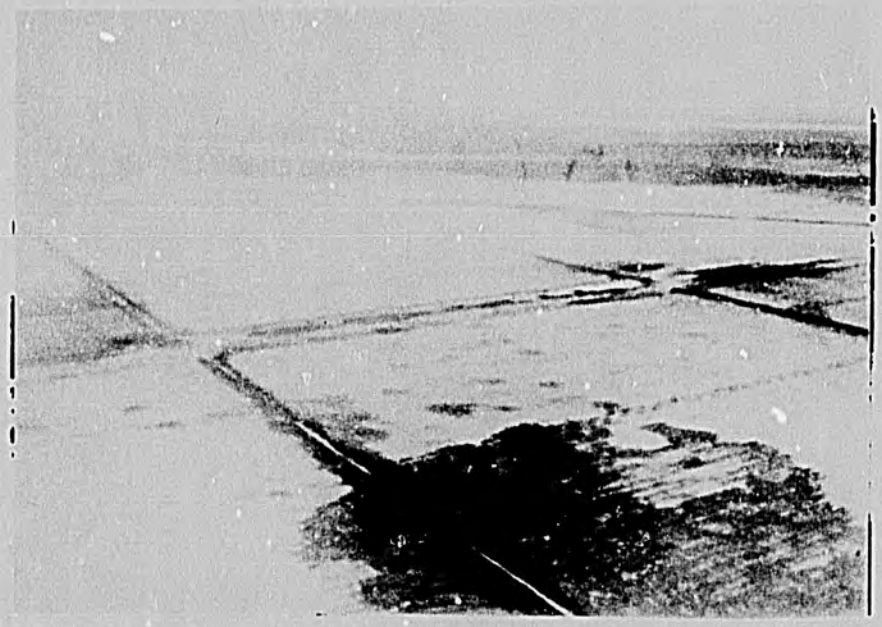


Figure 8: Low altitude aerial view of flooded cultivation benches.

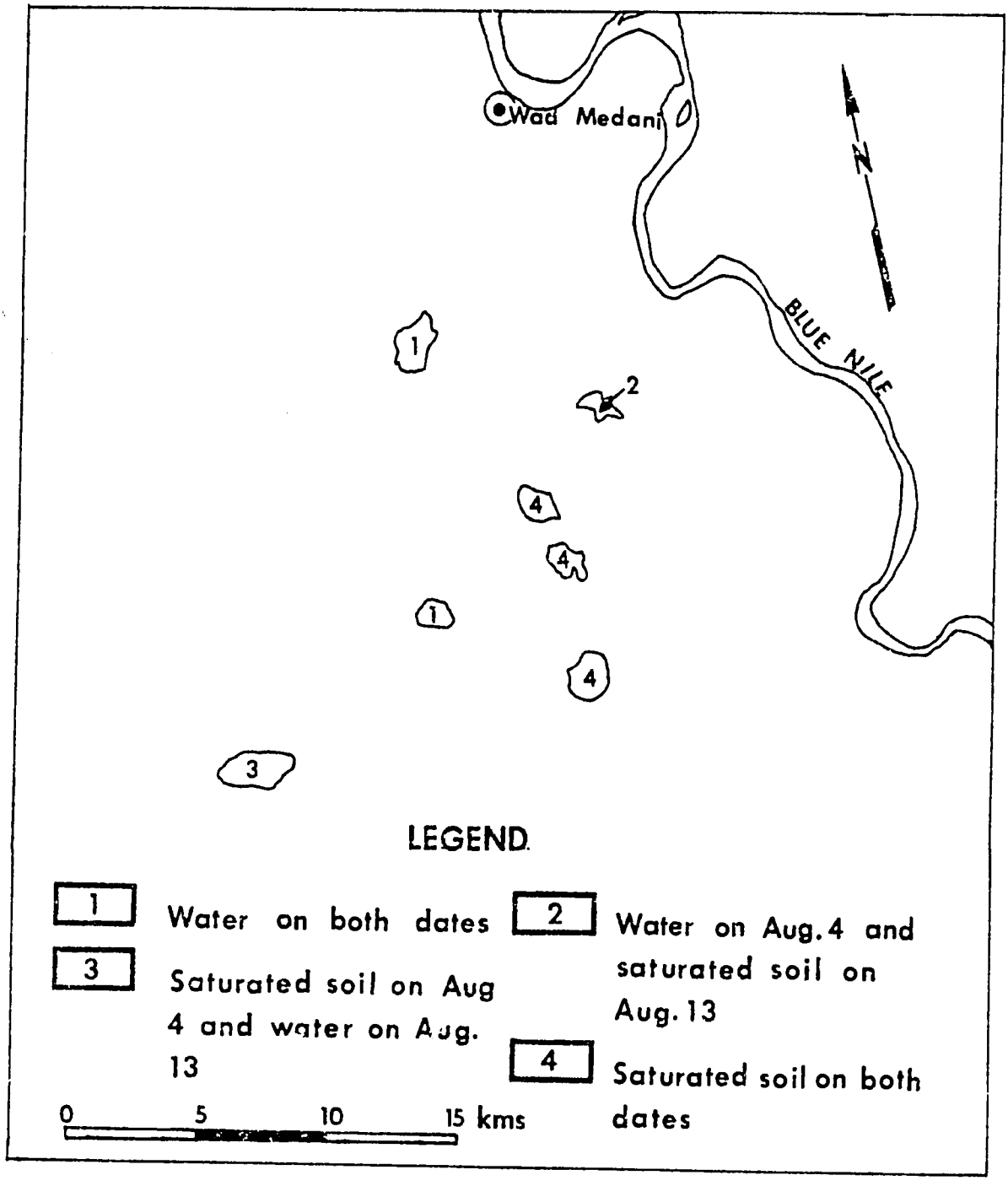


Fig. 9: Tracing of the temporal composite for the area south of Wad Medani for Aug. 4th and Aug. 13th 1978.

soil to completely flooded areas, together with a variety of crops in different stages of growth emerging from the water, or lying on the saturated soil.

CONCLUSIONS

Landsat data are a useful tool in the assessment of damage caused by floods. The data provide a fast, but approximate picture of the degree of flood damage, and the limits of the areas affected. More accurate results can be obtained if the study is supported by proper ground data collection for sample areas in the flooded region. The value of Landsat data for flood studies is increased if the following conditions are fulfilled:

A. Cloud-free coverage is obtained during the peak of the flood, or immediately after.

B. Data are processed and delivered to the investigators within a few days of acquisition.

C. Ground data are collected simultaneously with Landsat coverage or very close to it.

D. Pre-flood Landsat data are available for the region, or otherwise during the same season in the previous year.

E. Damage assessment is conducted using historic, demographic, topographic, and other available data.

The use of Landsat is appropriate to stratify the region in question into "apparent damage" levels. The stratification can be used to extend

the limited ground samples to make large area estimates.

ACKNOWLEDGEMENTS

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LAND USE MAPPING IN CENTRAL SUDAN

Yousif Yagoub*

ABSTRACT

An area in central Kordofan province was studied. The objective was to evaluate the use of Landsat data for mapping land use and monitoring desertification.

Imagery of the post rainy season, around November, was the best for the purpose. It showed enough contrast among crop lands, pasture, and regions affected by desertification. By visual interpretation, and aided by existing information, it was possible to obtain a preliminary land use and land potential map of the region. It was also possible to identify areas affected by desertification associated with blowing sands, land misuse, and overgrazing. The recognition clue was the high reflectivity of both bare lands and wind blown sands, combined with their patterns as dunes.

Several maps were constructed showing the degree of suitability of land for each of the traditional crops of the region.

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USE OF LANDSAT IMAGERY FOR DETERMINING SOIL POTENTIAL: EXAMPLE FOR JONGLEI PROJECT, SUDAN

A. A. Klingebiel

INTRODUCTION

It is essential to have an inventory of the soil, water and related resources of a country if the potentials for producing food and fiber are to be known. Before plans can be made for producing more food and fiber, it is necessary to know where this can be done, what kinds of limitations may be encountered, and the prospects of successfully and economically overcoming the limitations. Production can be increased by finding new lands not now used or by improving the management of those areas now in use.

Soil scientists are knowledgeable about those soil properties that influence plant growth. They have studied the relationship of soil texture, soil depth, soil permeability, soil wetness, soil slope, and the chemical and biological properties to the kind and amount of plants that can be grown. By identifying and locating the different kinds of soil (there are thousands of different kinds of soil in the world) on a map, a soil scientist can make specific recommendations about the potential of the different soils for various uses.

Techniques and methods have been developed through the use of Landsat imagery whereby an evaluation can be made of the soil potential for producing food and fiber for individual countries or for broad areas within countries.

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This involves the use of all applicable resource data as it relates to the soil potential. To carry out such a project efficiently and effectively it is necessary to complete specific tasks in an orderly manner as set forth in this text.

The methods and procedures that were developed by Klingebiel and Myers (1974 and 1975) to evaluate soil resources were designed to locate those areas that have good, fair, and poor soil potential to produce food and fiber. The information was designed for use in regional and national planning. The following is a brief summary of the steps followed in developing soil potential maps in The Sudan and in other countries.

1. Obtain Landsat imagery for both "wet" and "dry" seasons.

2. Prepare overlays on clear plastic of existing resource maps (soils, geology, topography, climate, vegetation, land use, infrastructure, etc.) at the map scale to be used.

3. Prepare photo interpretation keys to interpret tonal differences observed on the imagery.

4. Synthesize (presently) available data and maps and prepare a first draft soil map for use in aerial reconnaissance and field studies.

5. Compile yield and related data by kinds of soil (and/or by location) for making soil interpretations.

6. Develop criteria and assumptions to use in making soil interpretations.

7. Use a small aircraft to fly at low altitudes over the entire area to observe, record and relate tonal differences on imagery to actual aerial observations.

8. Reconnaissance ground check by car and on foot to describe dominant soils and observe soil behavior under different uses and management.

9. Reconstruct the preliminary soil map (prepared in the office) using information obtained in aerial and ground reconnaissance.

10. Describe mapping units and major components of units.

11. Record in tabular form selected soil properties for each of the major soil components, including factors which limit their use.

12. Prepare a table of yield estimates for selected crops under defined levels of management for major kinds of soil.

13. Prepare interpretive maps from soil maps and interpretations.

14. Prepare recommendations regarding actions needed to achieve soil potential.

RESOURCE INFORMATION AND MAPS

Imagery

The first step in the preparation of a resource inventory of a country is to order the most recent and best quality Landsat imagery available. A great deal of information is available on this subject so an "in depth" presentation will not be made here. It is important to know that imagery at 1:1,000,000 and 1:500,000 scale are generally best for soil surveys of entire countries or large areas within countries. Images at this scale have good resolution and are easy to handle in the field. In addition, many other resource maps are made at this scale. It is important to remember that Landsat imagery at larger scales (1:250,000 and 1:125,000) have no more detail than the 1:1,000,000 scale imagery. There is only more paper

and usually the features on these larger scale images are not as clear as on the smaller scale images. Also the interpretations that can be made are the same for both scales.

More accurate interpretations can be made if both black and white (bands 4, 5, 7) and false color composite imagery is obtained. In addition, it is best to get two sets of the false color composite imagery - one of the dry season and one of the wet season (or one for the growing season and one for the dormant season). Color transparencies at 1:1,000,000 scale are especially good when used with a light table.

When a large quantity of imagery is to be used, it is best to consult with someone knowledgeable about satellite imagery before making purchases. Satellite imagery at a scale of 1:1,000,000 should always be purchased regardless of the other scales needed. This scale of imagery can be used directly with navigation maps at the same scale.

Navigation Charts

It is important to have a map at the same scale as the Landsat imagery that shows topography as well as cultural features such as roads and towns. The Defense Mapping Agency, Aerospace Center, St. Louis Air Force Station, St. Louis, Missouri 63118, USA, makes such maps at 1:1,000,000, 1:5,000,000 and 1:9,000,000 scales. The 1:1,000,000 scale map is ideal to use as a base for preparing clear plastic overlays of landscape and cultural features to be used with Landsat imagery. These maps are among the most accurate available in the world and no project should be completed without using them as one of the resource maps.

Other Resource Maps

Copies of soil maps, geology maps, vegetative maps, land use maps and other maps that may be useful in interpreting the Landsat imagery should be obtained. These maps should be reduced or enlarged to the scale of the imagery. Important data from these maps should then be traced on clear plastic and overlayed on the imagery to help interpret the meaning of the different tonal patterns observed on the imagery. Some tonal differences on the imagery cannot be explained with the resource maps and must be checked on the ground. Of course all resource inventory maps prepared from Landsat imagery must be checked on the ground for accuracy with the interpretations altered where necessary.

Climatic and Hydrologic Data

Climatic data should be obtained that will be representative of all major soil or landform areas of the country. Monthly averages for precipitation and temperature are essential. Other related data such as evapotranspiration, frequency of flooding, etc. are very useful. A isohyetal map can be prepared on clear plastic and overlayed on the imagery to help make soil interpretations.

Agricultural Experiment Station Data

Agricultural Experiment Stations or other research and survey organizations should be located on the imagery. Data obtained from these stations should include the following: (1) soil map of the area, (2) kinds of crops grown, (3) yields obtained under different levels of management, (4) response to use of fertilizers, soil drainage, irrigation, cropping sequences or other management practices, and (5) evidence of erosion and experiences

with practices to reduce erosion. If these stations are not available, the same kind of data should be obtained from the better farmers in the area. These data will be used later in the study when the soil interpretations will be developed.

PREPARATION OF FIRST DRAFT OF SOIL MAP

Mosaic of Study Area

A mosaic is now made of the study area using the best color imagery at 1:1,000,000 scale. Clear plastic should be placed over the imagery so that lines can be drawn without marking up the imagery. A special pen called "Sharpie", made by Sanfords in the USA, is especially adapted for use on clear plastic. A second set of these same images should be available for use as individual maps in the field and in the aircraft.

Photo Interpretation Keys

A careful study of the imagery will show different image tones, textures, and patterns. Photo interpretation keys need to be prepared for use in synthesizing the basic resource data and in interpreting the differences observed on the imagery. The task is to relate color tones, tonal characteristics and geometric patterns to specific and consistent differences on the ground. Landforms, vegetation, drainage patterns, geology, and soil color are all clues used to relate the differences observed on the imagery. These observations are recorded to help make interpretations from the imagery.

By placing some of the plastic overlays prepared earlier from soil, geology, vegetation, topography and land use maps over the imagery it will be possible to identify the reasons for some of the differences observed.

Just being able to separate on the map major differences in topography, soil wetness, salinity or different kinds of vegetation is a first step in preparing a first draft of a soil map. As many different kinds of delineations on the map as can be observed should be made, labeling those areas having identical tonal color and patterns with the same symbol. Delineations should be large to enough to be labeled with a symbol. The multidate observations will aid in recognition of various surface features.

Classification of Map Units

A standard soil classification should be adapted (FAO, Soil Taxonomy - USA, French) for use as a basis for the delineations shown on the soil map. Phases of some segment or segments of a classification system (order, suborder, great group, subgroup, family, association of series) should be used. Phases important to the use and management of soils such as soil depth, texture, coarse fragments, slope, soil reaction, permeability, wetness, and flooding are all important enough to delineate.

Each different symbol that appears on the map is called a mapping unit. The composition of mapping units at this scale (1:1,000,000 and 1:500,000 or 1:250,000) commonly have more than one kind of soil in them. Each of the components of a mapping unit (where more than one kind of soil is in a unit) needs to be described and an estimate made of the percent of that soil in the map unit. The mapping unit itself is given a symbol and a name. Criteria need to be established setting forth the limitations of the various classes of the soil properties that are used to describe the mapping units and components of units. This applies specifically to such items as soil depth, permeability, soil reaction, soil drainage, soil texture and coarse fragments, soil wetness and flooding. Criteria and limitations for these

phase classes can be found in the old USDA Soil Survey Manual, in the New Soil Taxonomy, and in the report prepared by the Remote Sensing Institute, South Dakota State University in 1978 entitled "Soil Resources of Southern Sudan and Potential for Agricultural Development". Table 1 from that report shows how selected soil properties for components of mapping units can be recorded.

PREPARING A FIRST DRAFT OF THE INTERPRETATIONS OF SOILS

After the mapping units and their components have been described, soil interpretations are made showing their potential for various uses. These interpretations are based on the estimated soil properties set forth in Table 1, on data from the Agricultural Experiment Stations, on farmer experiences and on the climatic data applicable to the different soil areas. Criteria and limitations of the various rating classes used in evaluating the soil potential for various uses also need to be developed. Examples of the kind of ratings and evaluations that can be made may be found in the Remote Sensing Institute report referred to earlier and in FAO Soils Bulletins 22 and 32. An example of the kind of interpretive table that can be prepared is shown in Table 2.

Soil interpretations are made by kinds of soil within limited climatic zones. By knowing the kind of soil, a set of soil properties are assigned to that soil (Table 1). By knowing these properties, predictions of soil behavior can be made by experienced soil scientists. Soil behavior is directly related to properties such as soil wetness, flooding, droughty soils and hazards of erosion, etc. Soil depth controls the rooting depth of plants. Actual experiences that have been recorded or observed on specific kinds of

TABLE 1: Selected Soil Properties for Sedimentary Clay Soils (Estimated)*

Map Unit Symbol	Component of Unit	Area Ha	Area %	Soil Slope %	Soil Depth Class	Soil Texture A	Soil Texture B	Coarse Fragments	Permeability Class	Soil Drainage Class	Soil Wetness	Flooding	Avail. Water Cap.	Soil Reaction pH A	Soil Reaction pH B	Soil Reaction Sodic A	Soil Reaction Sodic B	Relative Productivity	Native Vegetation	Reference Materials (1)
I A	#1 (4)		80	0-1-	VD	C	C	0	VS	P-SP	3	2	3	7.8	> 8.4	1	2	P	Tall Grass	P1-F1,1,21
	#2 (4)		20	0-2	VD	C	C	0	VS	P-SP	3	2	3	7.5	7.8	1	1	P	Tall Grass	P3,5-F1,16
I B	#1 (4)		100	0-2	VD	C	C	0	VS	SP-P	3	2	3	7.5	7.5	1	1	P	Grass-Trees	P2-F1,3
I C	#1 (4)		70	0-2	VD	SiC	C	0	S	SP	3	2	2	6.8	7.8	1	1	F	Tall Grass	P6-F2,3,4
	#2 (4)		30	0-2	VD	C	C	0	VS	SP-P	4	4	3	7.8	> 8.4	1	2	P	Tall Grass	P1-F1,1,21
I D	#1 (4)		60	0-2	VD	L	CL	0	M-VS (2)	MW-SP	2-3	2	2	7.2	7.6	1	1	F	Trees-Grass	P8-F4,21
	#2 (4)		40	0-1	VD	C	C	0	VS	P-VP	4	4	3	7.4	- 7.8	1	1	P	Grass-Trees	P7-F4,23
I E	#1		100	0-1	VD	C	C	0	VS	P-VP	4	4	3	7.8	> 8.4	1	2	P-VP	Tall Grass	O-Imagery Topo. Maps
I F	#1		35	0-2	VD	L	SiC	0	M-VS (2)	MW-SP	2-3	3	2	7.2	7.6	1	1	F	Grass-Trees	F2,6
	#2		65	0-1	VD	C	C	0	S-VS	P-VP	4	4	3	7.4	- 7.8	1	1	P	Tall Grass	F2,7,8
I G	#1		40	0-1	VD	SiC	C	0	S-VS	SP-P	2-3	2-3	2	6.8	- 7.5	0	1	F-P	Grass-Trees	F2,12,13
	#2		60	0-3	D-MD	L	C (3)	0	M-VS (3)	W-MW	2	2	2	6.0	- 7.0	0	1	F	Trees-Grass	F2,19
I H	#1		50	0-1	VD	C	C	0	VS	P	4	4	3	7.8	> 8.4	1	- 2	P	Tall Grass	F3,17-F4,18a
	#2		50	0-2	VD	C	C	0	VS	P	4	4	3	7.5	7.8	1	- 1	P	Tall Grass	
I I	#1		80	0-2	VD	C	C	0	VS	VP	4	4	3			3	3	P-VP	Tall Grass	F3,19
	#2		20	0-2	VD	CL	C	0	S-VS	P-VP	3	3	3			1	2	P	Tall Grass	F3,19

(1) P - refers to profile descriptions (ground crew); F - refers to flight notes from aircraft; O - refers to other references

(2) Very slow permeability at 70-85 cm from surface

(3) Laterite common

(4) Soil properties measured or evaluated in field

* A portion of Table 15, page 79, "Soil Resources os Southern Sudan and Potential for Agricultural Development", Report SDSU-RSI-78-11 to Permanent Joint Technical Commission for Nile Waters, Khartoum, Sudan 1978.

Table 2: Soil Potential for Sedimentary Clay Soils

Map Unit Symbol	Component of Unit	Area		Work-ability	Seeding Establish.	Potential Mechan-ization	Erosion Hazard	Potential Suitability For Use (1)					Reference Materials (2)
								Rainfed Agriculture			Irrigated Agriculture		
		Ha	%					Low Level Mgt.	High Level Mgt.	Major Soil Limitations	High Level Mgt.	Major Soil Limitations	
I A	#1		80	3	4	3	1	SC	S3	wavc	(S2) (3)	av	P1-F1,1,21
	#2		20	3	4	3	1	SC	S3	wvc	(S2)	av	P3,5-F1,16
I B	#1			3	4	2	1	S3	S3	vc	(S2)	tv	P2-F1,3
I C	#1		70	2	3	2	1	S3	S2	vc	(S2)	tv	P6-F2,3,4
	#2		30	3	4	3	1	SC	S3	wiavc	(S2)	iav	P1-F1,1,21
I D	#1		60	1	1	1	1	S3	S2	fp	S2	tp	P8-F4,21
	#2		40	3	4	3	1	SC	S3	wiv	--	--	P7-F4,23
I E	#1		100	3	4	3	1	N1	N1	wiv	--	--	O-Imagery Topo. Map
I F	#1		35	2	2	1	1	S3	S2	fp	(S2)	tp	F2,6
	#2		65	3	4	3	1	SC	S3	wiv	(S2)	iv	F2,7,8
I G	#1		40	3	3	2	1	S3	S2-3	w	(S2)	tp	F2,12,13
	#2		60	1	1	1	1	S3	S2	f	S3	tp	F2,19
I H	#1		50	3	4	3	1	SC	S3	wiav	(S2)	iav-	F3,1[illegible]-F4,18a
	#2		50	3	4	3	1	SC	S3	wiv	(S2)	iav	
I I	#1		80	3	4	3	0	N1	N1	wiav	--	--	F3,19
	#2		20	2	3	2	0	SC	S3	wav	--	--	F3,19

(1) Ratings apply to a majority of the area for the component of the map unit

(2) P - refers to profile descriptions (ground crew); F - refers to flight notes from aircraft; O - refers to other references

(3) Ratings in () are for paddy rice

*From Table 16, page 84, "Soil Resources of Southern Sudan and Potential for Agricultural Development". Report SDSU-RSI-78-11 to Permanent Joint Technical Commission for Nile Waters, Khartoum, Sudan, 1978.

soil within a set of climatic conditions can be projected to other soils having similar soil properties and climatic conditions. The advantage of a soil map is that it provides the vehicle for showing the location and extent of these different soils.

Soil interpretations that are made from the resource data listed earlier are based entirely on the soil properties and their relation to climate. Economic factors such as roads, distance from markets, and availability of water for irrigation (except in desert areas where no known water is available) are not a part of the criteria used in determining potential. Climate, however, is a very important factor. Economic factors are considered along with the physical factors as a first step in the planning stage. This second step is essential before construction plans or the decision to develop an area is made. A feasibility study to determine the economic success of the project must be made. The interpretive maps and data show those areas where the soil potential for a particular use is good, fair or poor. The interpretive data help to pinpoint the areas that need further study.

FIELD PROCEDURES

Aerial Reconnaissance

The preparation of the first draft map and interpretations has now been completed. It is now time to check the work by low altitude flights over the area for identification of broad landscape features and for checking on the ground for validating the properties of soils and observing the kind and amount of plant growth.

Field studies and reconnaissance aircraft flights are essential parts of the satellite interpretation procedure, the classification of soils and the establishment of photo interpretation keys. Preferably the aircraft flights should precede the ground check, since observations provide a general comprehension of many features that comprise the final product and also dictate many of the ground check points that require attention on the field study trip.

Prior to making the aerial reconnaissance, a navigation chart (map) for the study area at 1:1,000,000 scale is placed on a firm backing and covered with clear plastic. After a careful study of the imagery, a decision is made regarding the areas to be observed from the aircraft. Straight lines are then placed on the clear overlay over the navigational chart starting at the airport and going to areas that can be identified easily from the air and that go over the areas to be viewed. The careful preparation of these flight lines is essential so that the pilot and the observers know where they are at all times. Observations are meaningless if you do not know where you are. The same kind of plastic overlay with flight lines is placed over the imagery.

A small aircraft, flying at an altitude of about 1,000 meters above the ground surface and at a speed of about 120 nautical miles per hour, provides a very suitable platform for the purpose. False-color infrared Landsat imagery at 1:500,000 scale is ideal for making both the aerial and ground study; however, most people prefer the 1:1,000,000 scale imagery for the aerial survey because it is the scale of the navigation charts used to locate roads, streams, towns and other cultural features. The two maps are often used simultaneously during the aerial flights. Photographs are taken

from the aircraft (35 mm) to show the relationship of the landscape with the other features observed on the imagery. Color-infrared film is used as well as high speed color film. Pictures are keyed by number to specific areas on the imagery.

Notes from observations made from the aircraft regarding vegetation, landscape features, land use and kinds of soil are recorded by numbers beginning with one. The location of the observation is identified by number on the plastic overlay that is over the imagery in the same order as it is recorded in the notes recorded. At the end of the flight the data recorded can be studied and boundaries on the map adjusted to coincide with the new observations made.

Ground Check

A subsequent ground check is an essential part of the photo interpretation procedure. This consists of traversing the area so that representative soils within each delineation can be studied. The dominant soils are classified and observations made of the vegetation, terrain, and other features important in the use and management of the soil. Soil interpretation and photo interpretation techniques are integrated to determine the most useful utilization of land resources.

In completing the ground check, it is important to ground inspect representative areas of each of the major map units. Due to the time constraint and the kinds of data that can be obtained from small-scale maps (called 4th order in the USA system of classification), the major portion of time should be spent in those areas having the greatest potential and little time in the poor soil and climatic areas.

It is important in this phase of the work to locate and study any agricultural experiment station data that may be available for the study area. By correlating soils and climate to plant growth and management, predictions can be made and data projected to other areas having similar soils and climate. The same is true for information that is obtained from people that live or work in the area.

Because of the nature of the survey, emphasis is placed on a broad overview of landscape features and on composition of the map units in terms of percentage of area having good, fair, or poor potential for a particular use. The time spent on making the map and the detail of the mapping will depend on the effort to be expended. The more time spent on field checks the more reliable will be the results. As stated earlier, the main task to be accomplished at these smaller scales is to determine the location and extent of the areas within the study area that have good, fair, and poor potential for a specific use. The followup studies that should come after this study should be concentrated in those areas that have good potential for use. More detailed evaluations can be made on larger scale maps to show more specifically the kind and degree of soil limitation for use. These more detailed studies will also give a more specific answer to the amount of the different kinds of soil in the area.

COMPLETION OF STUDY

Soil Map

The product of the aerial observations and field studies is a final soil map resulting from synthesizing the background material with all of

the observations and data obtained in the air and on the ground. Final descriptions of each map unit are prepared and soil properties and soil interpretation tables are completed to conform with the mapping units shown on the final soil map.

Final adjustments are made in the soil boundaries to conform with observations made from field checks. A soil legend is prepared for the map that portrays two levels of generalization. The first commonly refers to broad landscape, geologic or soil features. At the first or broadest level not more than six to eight different kinds of units are shown. Under each of these broad units the more detailed mapping units are shown. There are many examples available to show how a legend should be prepared. The USA Soil Taxonomy, and the RSI report on Soil Resources of Southern Sudan are sources of information on legends.

Soil descriptions of mapping units and components of mapping units need to be corrected and updated based on the field checking. The table of selected soil properties (Table 1) needs to be corrected for the final report.

Interpretations

Interpretation maps are produced from the final soil map. Predictions can be made about the soil potential for range use, land capability, erosion hazard, soil wetness, soil depth, soil slope, suitability for irrigation, suitability for growing specific kinds of crops and many other uses. With these interpretive maps, decision makers can weight the alternatives for using the soils in different ways.

The value and use of this study is dependent largely on this last section that deals with making predictions about the potential of the various

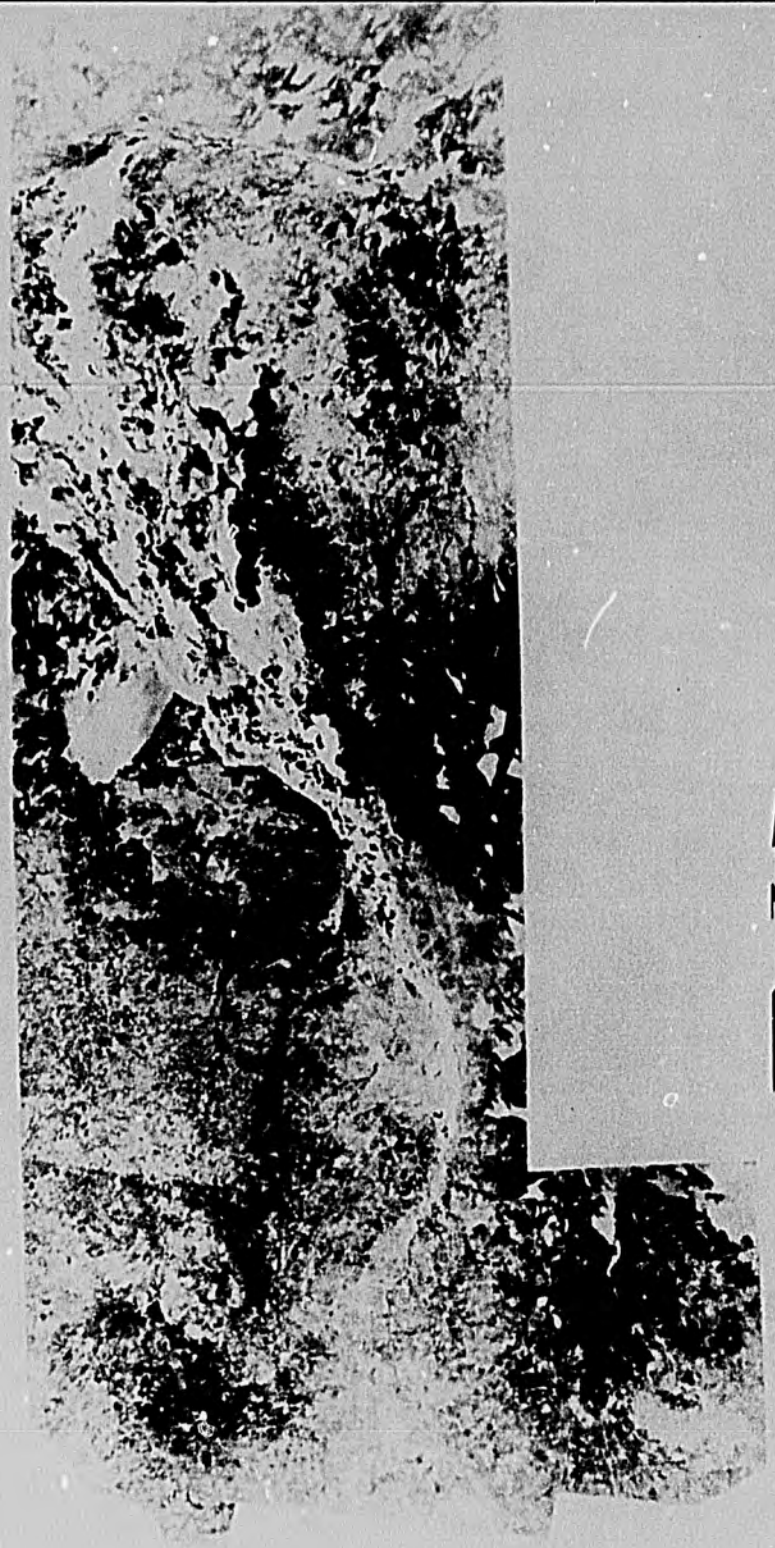
soils for specific uses. Using the basic soils map, the estimated soils property table (Table 1), the interpretations table (Table 2) and the criteria developed for making soil interpretations (RSI report for Southern Sudan), interpretive maps can be prepared similar to those on the following pages.

By knowing the kind of soil, their properties, their location in the landscape, and the climate, it is possible to make hundreds of different kinds of interpretations. Specific interpretations such as yields for specific crops under defined levels of management to general suitability for farming, forestry or range can be made. To do this, however, it is essential to obtain "hard data" or experiences by kinds of soil within the study area or from areas that have similar soil and climate conditions.

The soil maps with accompanying interpretations are intended to give a broad picture of the potential soil resources of a region or country. They can be used to provide a guide for more detailed study of those areas that have good or fair potential for development. If specific works of improvement such as drainage or irrigation are planned more detailed soil studies are needed. These soil maps will focus the efforts for future development on those areas that have the greatest potential for development and improvement. They will also pinpoint the kinds of soil limitations that need to be overcome if the area is to be developed or improved. Please see attached example interpretations for the Jonglei area of Southern Sudan.

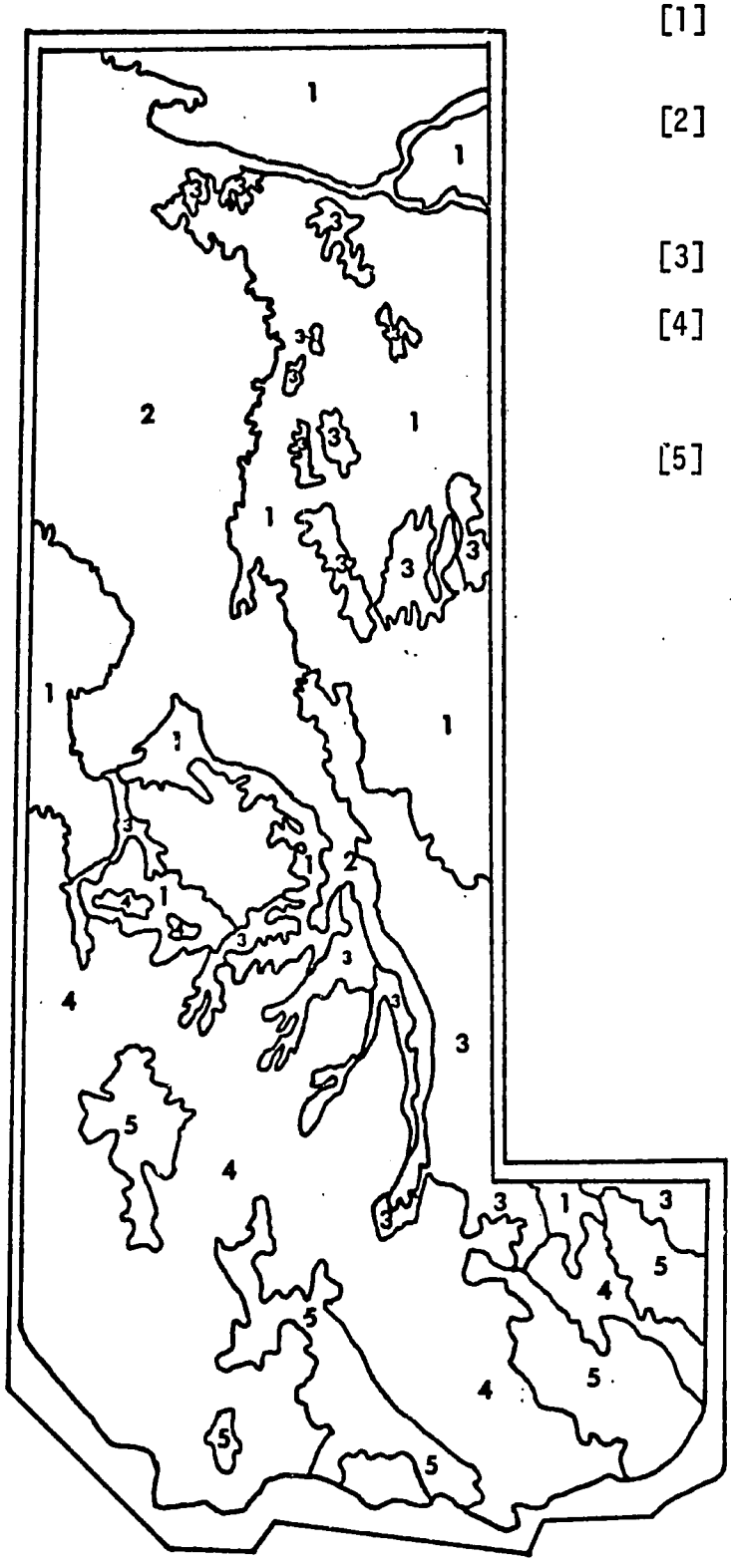
The data obtained from these kinds of studies will provide decision makers with more reliable information about the soil potential of a region or country to produce food and fiber. The method described here can be employed at a reasonable cost and completed for an area in a relatively short time. These methods have been used successfully in several countries.

The following figures are interpretations made using mosaic (Figure 1) of 167,474 km^2 of the Southern Sudan. This "dry-season" mosaic is prepared from 14 different Landsat scenes which are photographically tone-matched for easier tonal analysis from scene to scene. The original was in color. Mosaics for both wet season and dry season were prepared. Procedures as described in this paper were followed for the survey resulting in the generalized interpretive map in Figure 2. (Original scale was 1:500,000). Various facets of the landscape or soils map can be displayed such as Figure 3 (Map of Soil Slopes) or Figure 4 (Map of Soil Wetness During the Growing Season). Interpretive maps of soil potentials and limitations for rainfed agriculture can be presented as in Figures 5 and 6. These data can then be interpreted as in Figures 6, 7 and 8 for potentials for rainfed agriculture, irrigation agriculture, or engineering uses, respectively. These final investigation products are those which are of value in the planning and project design. Further descriptions of the procedures and results are presented in "Soils Resources of Southern Sudan and Potential for Agricultural Development", Report No. SDSU-RSI-78-11, presented to the Permanent Joint Technical Commission for Nile Waters, Khartoum, Sudan.



200
scale
km

Fig. 1. Mosaic of 14 scenes of "dry-season" MSS 5 (0.6 - 0.7 μm) Landsat data of the 167,474 km^2 of Southern Sudan. Original scale of the base mosaic was 1:500,000.



Legend

[1] Level Sedimentary Clay Plain Soils (IA,B,C,D,F,G,H,I)

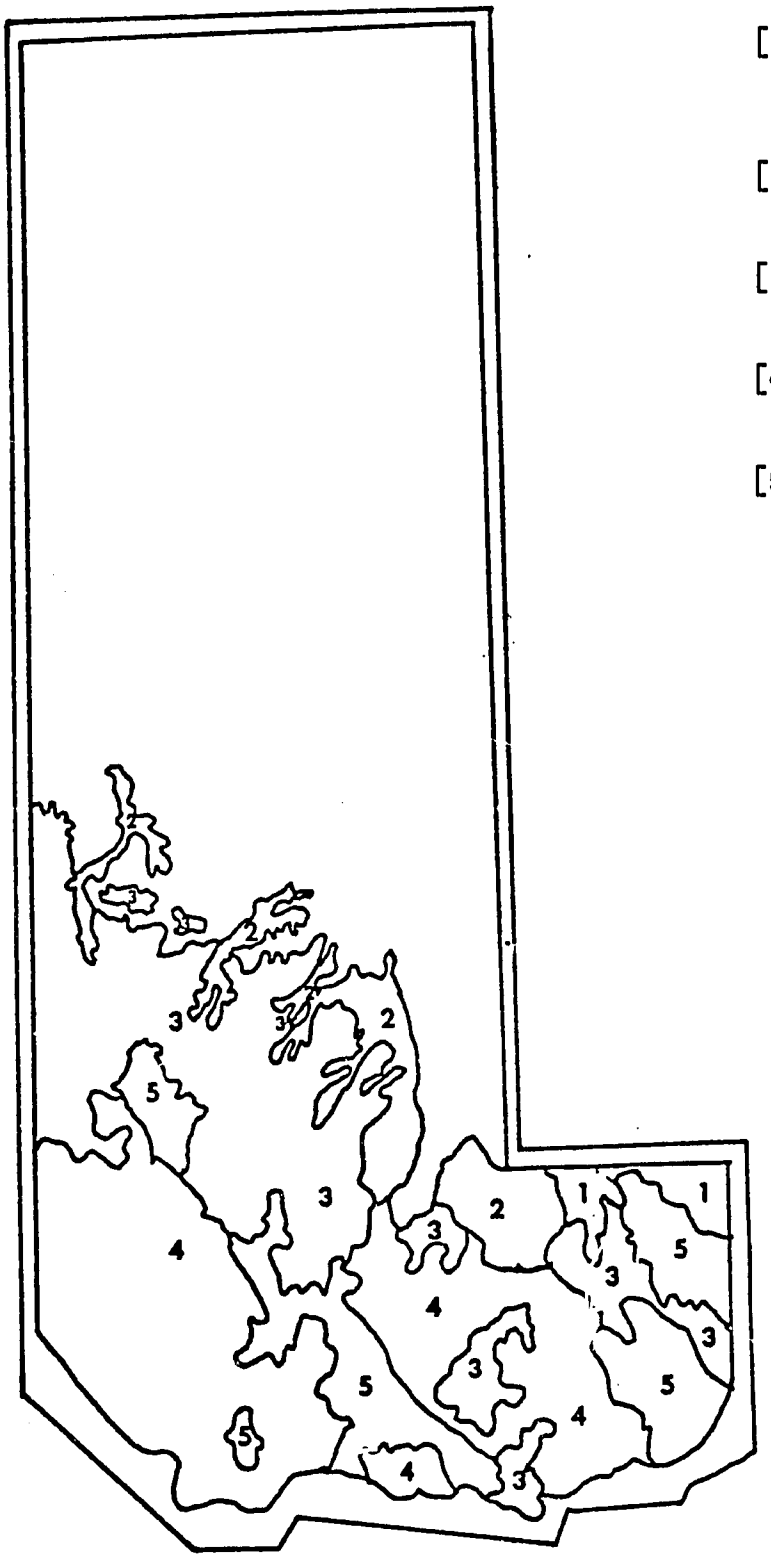
[2] Permanent or Seasonally Flooded Lowlands (IIA,B,C,IIIA)

[3] Recent Alluvium (IIIB,C,D,E,F)

[4] Undulating and Rolling Uplands (IVA,B,C,D,E,F,G,H,I J,K,L,M,N)

[5] Hilly and Steep Uplands (VA,B,C,D,E,F,G)

Figure 2. Generalized interpretive soils map.



Legend

[1] 0 - 2% Slope
(All I,II&III Soils except IIIE,F)

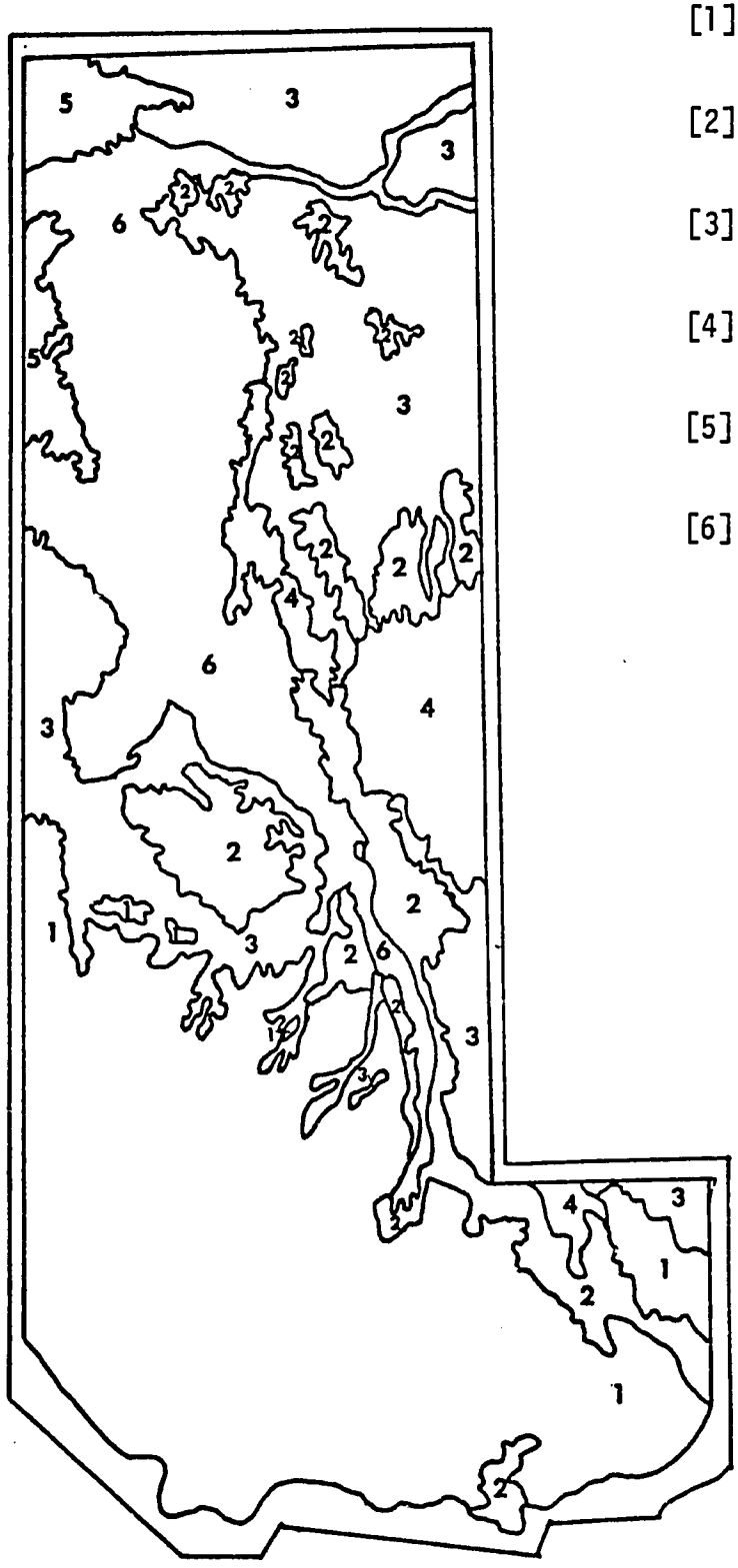
[2] 2 - 5% Slope
(IIIE,F,IVJ,O)

[3] 5 - 15% Slope
(IVA,B,D,H,I,K)

[4] 15 - 30% Slope
(IVA,B,D,H,I,K)

[5] 30 - 50% Slope
(VA,C,D,E,G)

Figure 3. Map of soil slopes.



Legend

[1] Well to Excessive
(All IV except K&H and all V)

[2] Moderately Well
(IIIC,C,F,IVK,N)

[3] Somewhat Poorly
(IA,B,C,D,G,IIID,E,)

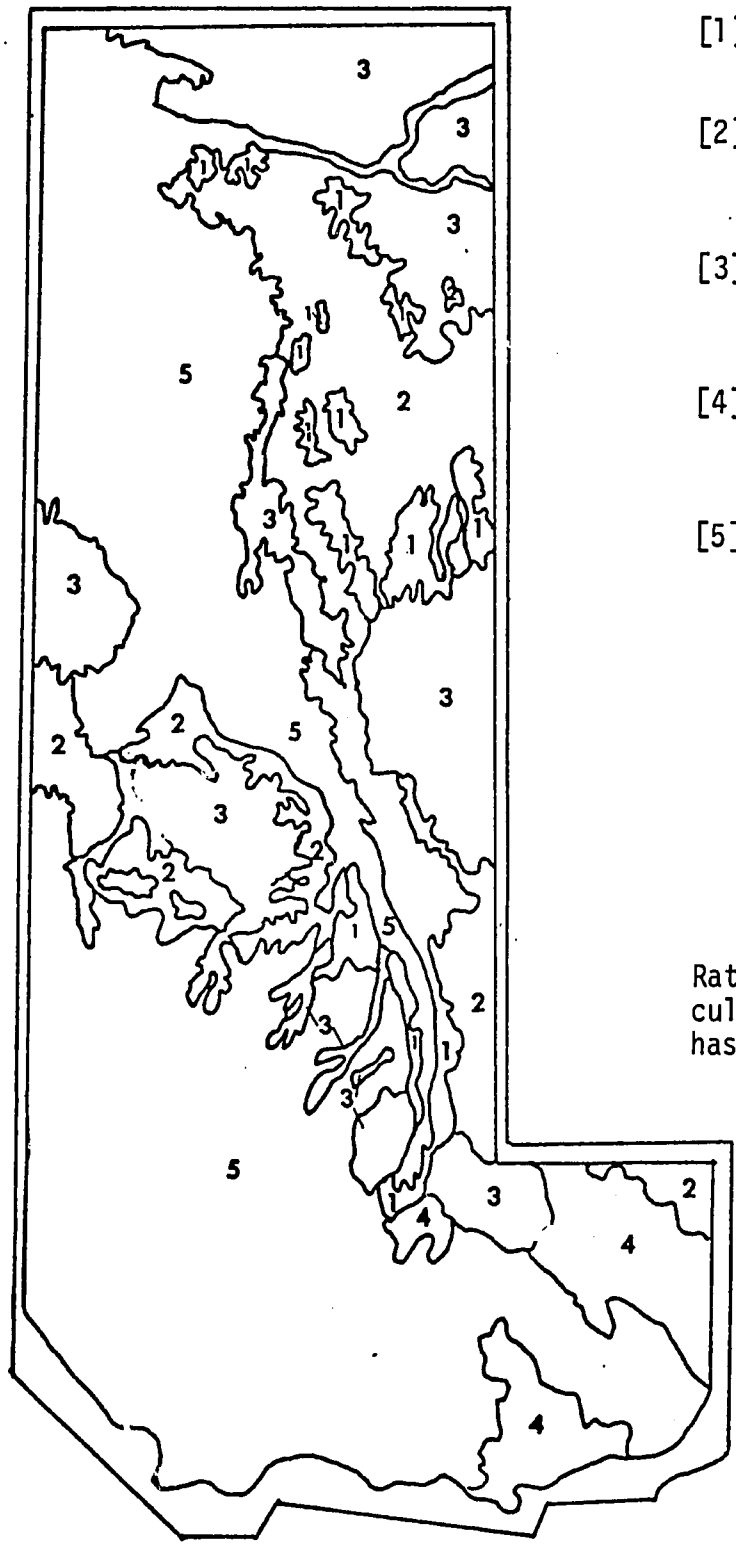
[4] Poor
(II,F,H)

[5] Very Poor
(IIC)

[6] Swamp - Open Water
(IIA,B,IIIA)

Soil classes of drainage conditions in growing season.

Figure 4. Map of soil wetness during the growing season.



Legend

[1] Good. Moderately Suitable. (IIIB,C)

[2] Fair. Moderately and Marginally Suitable. (IC,D,G,IIID)

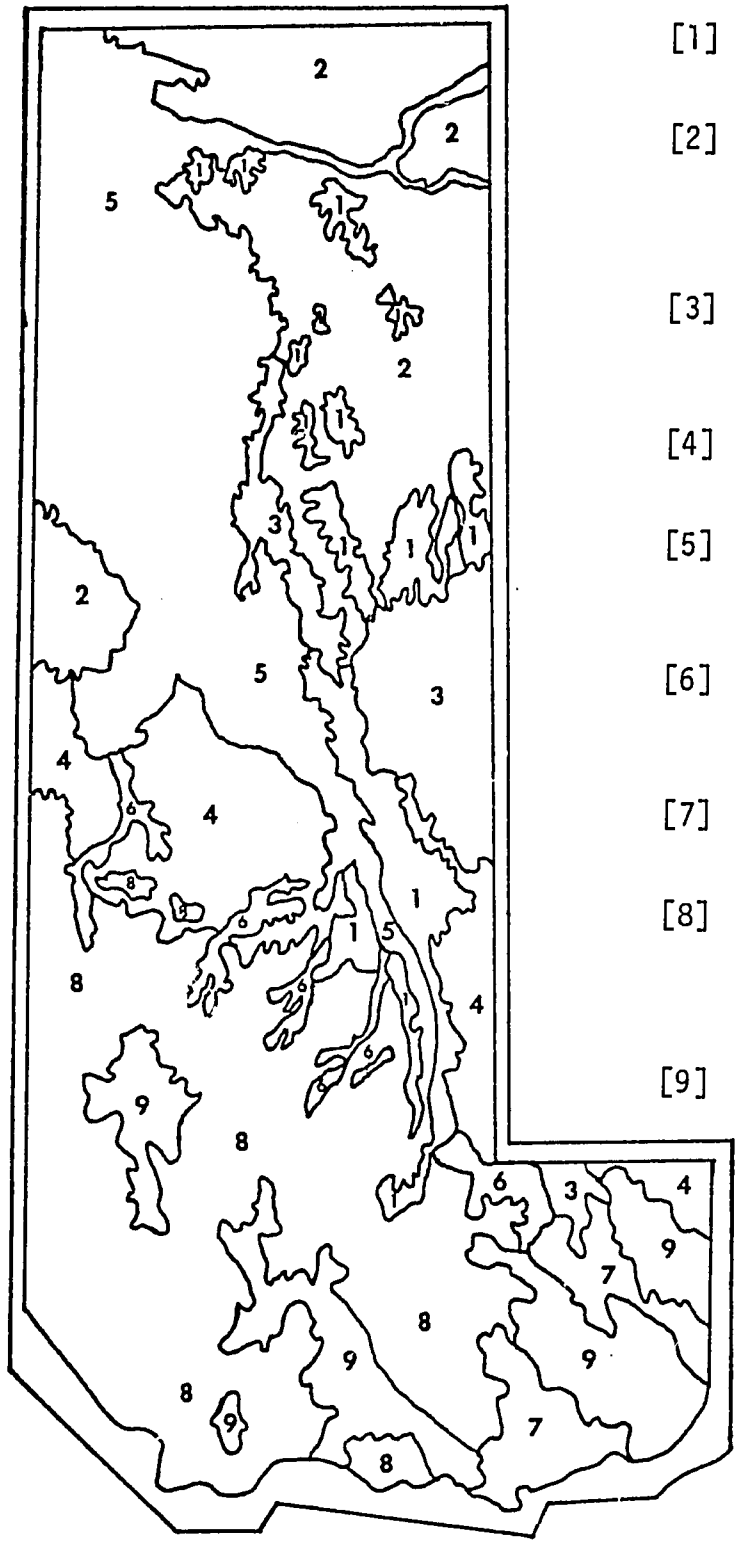
[3] Poor. Marginally Suited and Unsuited. (IA,B,F,H,IIIE,F,IVJ,N)

[4] Very Poor. Unsuited and Marginally Suited. (II,IVI,K,L,)

[5] Extremely Poor. Unsuited. (All II, All IV except I,K,L, and All V)

Ratings apply to common cultivated crops. Rice has a separate rating.

Figure 5. Interpretive map of soil potential for rainfed agriculture.



Legend

[1] Soil Moisture and Fertility Deficiency (IIB,C)

[2] Very Slow Permeability Dense Clay, Moisture Deficiency, Sodium. (IA,B,C,D)

[3] Very Slow Permeability Dense Clay, Wet, Seasonally Flooded (IF,H,I)

[4] Slow Permeability, Clayey, Seasonally Wet (IG,IIID,IVN)

[5] Flooded Seasonally, Permanently Wet. (IIA,B,C,IIIA)

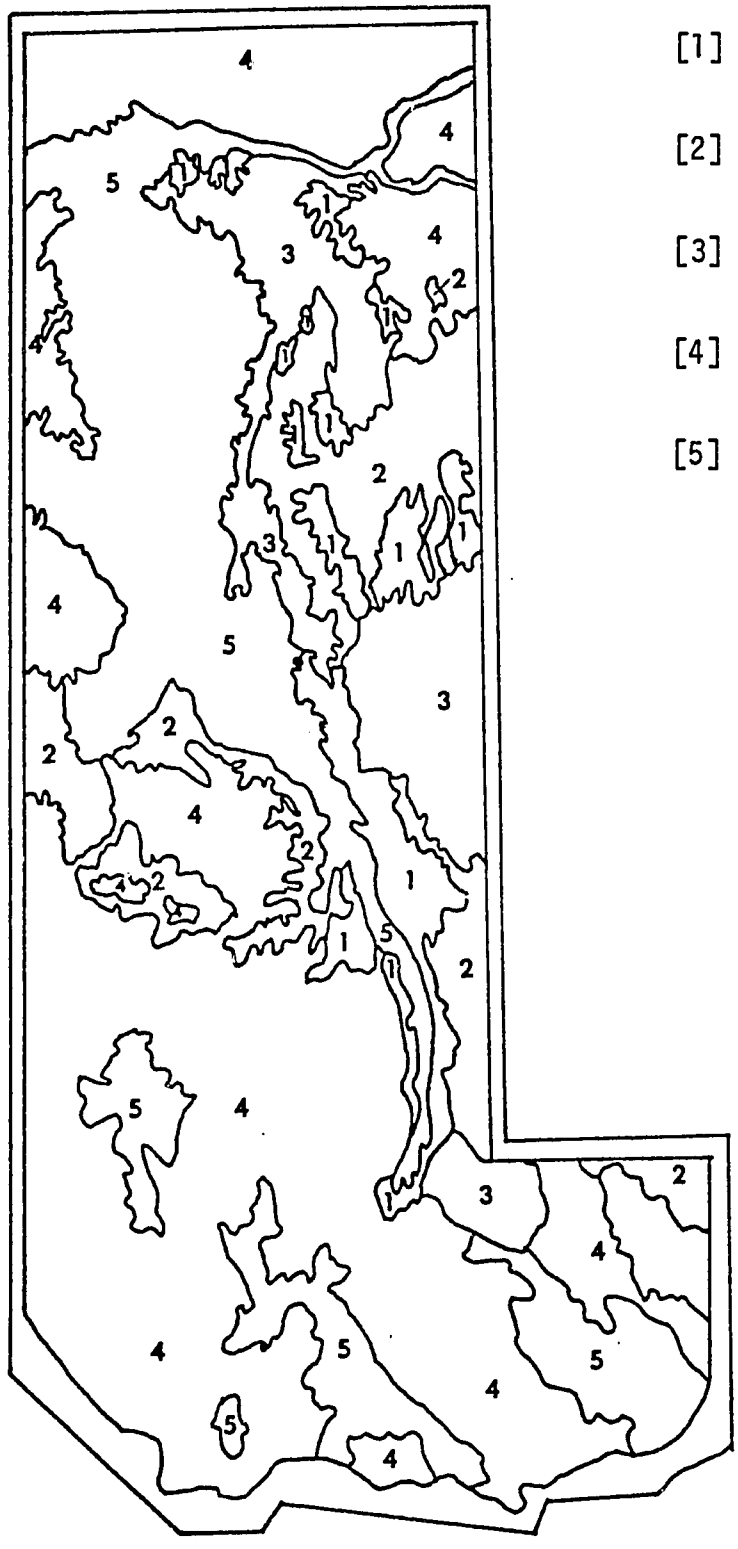
[6] Shallow Depth, Sloping, Seasonally Wet (IIIE,F)

[7] Shallow & Moderately Deep, Sloping, Clayey (IVK,L)

[8] Shallow, Sloping, Low Ferility, Coarse Fragments (All IV except K,L,N)

[9] Very Shallow, Steep, Stony (All V)

Figure 6. Map of interpreted soil limitations for rainfed agriculture.



Legend

[1] Good
(IIIB,C,)

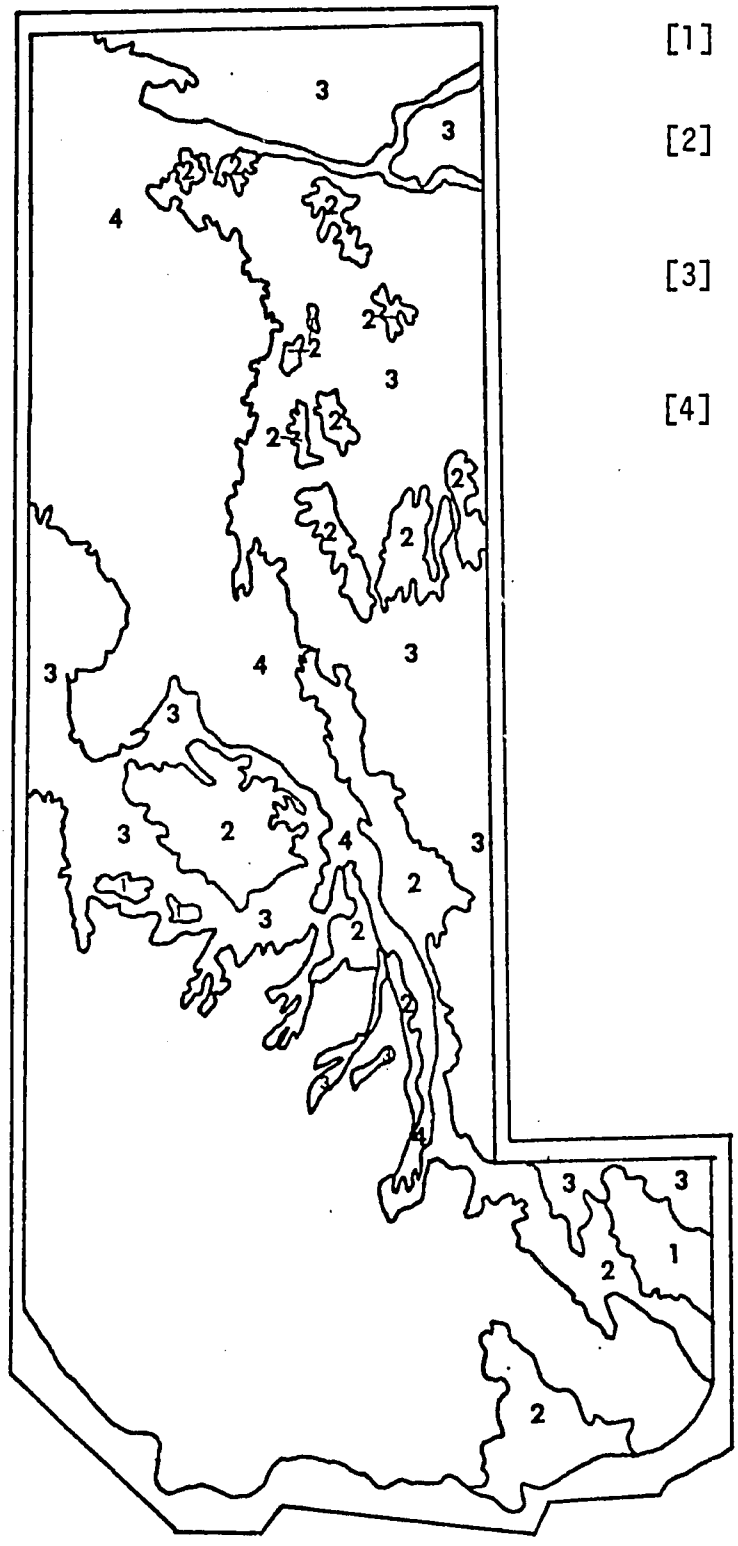
[2] Fair
(ID,G,IIID)

[3] Poor
(IC,F,H,IIIF,IVJ)

[4] Very Poor
(IA,B,C,AII IV except J)

[5] Extremely Poor
(AII II,IIIA and all V)

Figure 7. Interpretive map of soil potential for irrigation of common cultivated crops.



Legend

[1] Good
(SM;GM / A2-4)*

[2] Fair
(SM;SM-SC / A2-4)
IIIB,C,F and IVK,L,N

[3] Poor
(CH /A7)
All I Soils and IIID

[4] Very Poor
(OH;CH / A7)
All II Soils and IIIA

* Unified / AASHO engineering classification systems, USA

Figure 8. Interpretive map of soil bearing qualities for engineering uses.

HOW TO APPLY LANDSAT IMAGERY FOR GEOLOGIC MAPPING, MINERAL EXPLORATION, AND HYDROGEOLOGY

by

Amazis Samuel Andrawis*

INTRODUCTION

As geologists realized the value of Landsat data in geologic mapping, mineral and oil exploration, hydrogeologic investigations, and other branches of geologic sciences, they became the main users of Landsat imagery in their studies.

Vast parts of the world are still not surveyed geologically, others are only roughly studied. Now is the time to apply all available tools and technologies to speed up and to up-date the geologic information of these regions. This will help overcome, to some extent, the threatening shortage in natural resources.

The world-wide and repetitive coverage of Landsat imageries provides a unique tool in the hands of geologists in different specializations. This tool helps them go far beyond the limited capabilities of traditional methods of survey in regard to time, cost, and accuracy.

In an ideal case where maximum information can be extracted from Landsat imagery, most or all of the following conditions should be satisfied:

1) The geologist should be well trained in field work to be able to recognize and relate all features he traces on the imagery.
2) He should also be knowledgeable about the characteristics of the different bands of the multispectral scanner (MSS) of

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Landsat and what is the expected effect concerning reflectivity of the different surfaces in the area.

3) It is preferable that the interpreter has worked in parts of the region he is studying, or other areas of similar nature. The first approach to interpretation is to prepare a landscape model of image features to be identified for interpretation. An individual must be knowledgeable of the specific area to prepare such a model.

4) Imageries of appropriate quality and of the proper season should be available for the area of study. The conceptual model or interpretation key can be used for selecting appropriate dates of imagery based upon surface vegetation or hydrologic changes which aid in the interpretation.

5) Some data should be in hand for parts of the study area, or the area around it. These will help in checking the versatility of the interpretation keys applied.

6) The area to be studied should not be concealed under a thick cover of vegetation or superficial deposits. If seasonal coverage aids in reducing the vegetative effect, then appropriate seasonal data should be acquired. In some instances a biological model can be of advantage to use the vegetation occurrence and distribution as an aid to understanding the geology.

COLLECTION OF DATA

To achieve the maximum possible accuracy in the final product of the study, it is essential to collect all available data on the area of study. The data may include:

1) Topographic contour maps of the area
2) Geologic and structural maps of the area or parts of it
3) Soils, land use, vegetation, and drainage maps of the area
4) Mineral occurrence map of the area
5) Operational Navigation Chart (ONC) of the area (particularly useful in the control of 1:1,000,000 mosaics)
6) Available reports dealing with subjects related to the purpose of study.

SELECTION OF IMAGERY

A computer printout of available Landsat imagery of the area should be obtained from the EROS Data Center, Sioux Falls, South Dakota or your regional center in Nairobi. Going through the list you should mark out the imagery that covers your entire area, preferably with extra coverage all around. In your selection you should consider the following:

1) Select imageries of the best quality and minimum cloud cover
2) Get one set of images for the wet season and another for the dry season
3) Get one set of images with close dates of acquisition and with no gaps between images to use in making a mosaic of the area
4) Imagery of certain dates or certain seasons may be ordered to serve a specific purpose of the study as a function of changes in the surface
5) If temporal changes are to be studied, a sequence of dates has to be decided on for the selection of imageries

TYPES OF IMAGE PRODUCTS TO USE

The selection of the type of image formats to be used depends mainly on the equipment available for interpretation, the degree of accuracy required, and the amount of time and funds allocated for the study.

1) Computer Compatible Tapes (CCT) can be obtained for use in highly sophisticated and costly computers designed for the interpretation of digital data.
2) Diapositives of the four bands (4, 5, 6 & 7) in a 55 mm format are used with the color additive viewer (such as the I^2S) to create different combinations of color composites of the scene. These can be directly interpreted on an overlay on the screen or photographic shots can be taken to be used later for interpretation.
3) Contact prints from a 9" x 9" negative of a scale 1:1,000,000 or enlargements to scales of 1:500,000, 1:250,000 or larger may be obtained from black and white individual bands.
4) False Color Composites (FCC) can be generated from bands 4, 5 & 7 (or other combination of bands) by printing through blue, green and red filters, respectively, and the suitable enlargement may be obtained.

PROCEDURE

Geologic interpretation of Landsat imagery can be successfully done using a simple magnifying lens and a set of different Landsat prints by following these steps:

1) Compile all useful data on an overlay(s) of the same scale as your Landsat prints. The most appropriate scale is 1:500,000 for individual scenes, and 1:1,000,000 for mosaics but this is dependent on your application needs.
2) Put the overlay on the different individual bands and the false color composite one at a time, and compare on each the features you identify on the print and the data on the overlay, together with your own knowledge about the area.
3) Now you can develop your interpretation keys from step number 2 using differences in tone, texture, lineaments, drainage density and pattern.
4) Lineaments can be more visible if viewed from a low angle while rotating the print.
5) More features can be revealed by comparing imageries of the wet and dry seasons due to the differences in vegetation growth or variable degrees of moisture in different formations or along faults and fractures.
6) Make your interpretations on an overlay by tracing geologic boundaries, linear features and structures from the different prints you have.
7) Prepare a mosaic for the whole area using 1:1,000,000 scale prints, either color or band 5 or 7. It is preferable that the mosaic covers a slightly larger area than the study area. This is particularly helpful in the study of major structures and faults.
8) Transfer your interpretations of the individual scenes onto an overlay for the mosaic, reducing it to the scale of the mosaic by

using the reflecting projector or a pantograph. Then add the extra features you recognize on the mosaic as major structures and long lineaments.

9) Mark on your preliminary map the points that have to be checked in the field, and make notes about them and the expected possibilities.

10) Make a comprehensive field check by visiting all uncertain and problem locations. Record all your observations and measurements.

11) Prepare your final maps and report in the office.

For Regional Geologic Mapping:

Prepare your geologic map by identifying the different geologic units and the relationships among them. Construct a geologic column for the area. Describe each unit and its main characteristics on the imagery of the different bands, and its main identification clues.

Draw all structures (it might be drawn on a separate map if it will be too crowded to have both geology and structures on one map), faults (and any displacement that might be noticed), folds, fractures and joints, ring dykes, batholights, and domes. From your structural map identify the sequence of tectonic events.

For Mineral Exploration:

Plot on your geologic and structural maps all the know locations of mineral occurrence. Find the relationship between mineralization, geology, and structures. You can then locate areas of high mineralization potential.

For Hydrologic Investigation:

Trace all the drainage systems of the study area. Delineate the different basins and sub-basins and measure their areas. Notice any feature that might have a hydrologic indication such as a stream that narrows or fades out downstream indicating a great amount of seepage or a valley that might have dense vegetation to a certain point after which the vegetation becomes scarce which indicates the existence of an underground barrier. The study of dry season and wet season imagery will help locate areas of high moisture content.

Locate all wells and bore holes on the map, examine their yields and the static water level in each, and compare these data with the hydrologic characteristics of the geologic formations. Calculate the amount of recharge from the data you have about precipitation, catchment area, and runoff. Tabulate your results, and delineate the areas of high ground water potential.

Map Finalization

The initial map prepared by the accumulation of available historic data and by Landsat interpretation provides an excellent base for optimizing field observations. Field observations by low-level aircraft reconnaissance flights and on-ground inspection can be planned using the previous interpretations. All apparent geologic boundaries and other properties must be field checked to assure that anomalous interpretations of artifacts in the image have not been mapped and to fully characterize the surficial geologic materials. The preceding steps and conditions should be accomplished and the data compiled and analyzed to guide the drilling program for studying the

subsurface. Adequate initial map estimate will save time and costs in this final and most expensive drilling phase.

IMAGE PROCESSING AND INFORMATION SYSTEMS

Mary DeVries*

Introduction

Remotely sensed data are generally available to users in either an image or computer compatible tape format. Information is obtained from image (analog) data by a process called interpretation. The unaided human eye is, without doubt, the best image interpretation tool available. However, several other devices and techniques have been developed to aid in image interpretation. Some of these are discussed in the initial portion of this paper.

Analog data are defined as being continuous, whereas digital data are discrete or numeric. Thus, techniques for processing digital data must differ from those for analog data. Some digital processing techniques which are frequently utilized are described in the second portion of this paper.

The final portion of this paper addresses the geographic information system concept. Such a system is useful for the integration of remotely sensed data with other geographically oriented types of data.

Analog Processing

Three types of analog processing are discussed in this section. They are photographic processing, density slicing and color additive viewing. The discussion concerning these processing techniques will

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be heavily oriented toward Landsat data because of its current popularity among remote sensing scientists.

Photographic Processing

Two types of photographic processing which are frequently employed are the generation of false color composites (FCCs) and contrast enhancement. False color composites are generally associated with multispectral data, such as that from Landsat. A Landsat FCC is typically produced by using the MSS 4 (green) black and white transparency in conjunction with a blue filter, MSS 5 (red) with a green filter and MSS 7 (near infrared) with a red filter to expose the three layers of color film. Imagery of the same scale for different dates can also be composited for temporal change analyses.

Photographic contrast enhancement is a technique which results in greater density differences among scene features for the purpose of increased image interpretability. The technique involves identifying the density range of the image and "stretching" that range over the entire dynamic range of the film. Contrast-enhanced FCCs are generated by enhancing each of the individual black and white band transparencies before compositing them.

Density Slicing

Density slicing is an analog processing technique which separates the film density range of an image into several black and white or color levels. A typical density slicing system consists of a light table, a vidicon camera and a color monitor. Although many density slicing systems are capable of 32 or more levels, the number of levels actually used is generally less due to the combination, elimination or reassignment of levels. This manipulation of density levels is done to reveal the desired image information such as soils, vegetation or surface water information. By assigning different

colors to similar image density levels, the differences are made much more apparent to the interpreter. Thus the density slicer can be thought of as an electronic tool to enhance the contrast among image tones.

Color Additive Viewing

A color additive process can be used to produce FCCs, as opposed to the "color subtractive" photographic method. The color additive method involves positioning each continuous-tone black and white transparency in front of a light source. Each image is projected through a filter (red, green, blue or none) onto a common screen. As is the case using the photographic method, various band/filter combinations can be used to achieve the desired effect. Temporal FCCs can also be generated. An advantage of the color additive method is that several combinations can be viewed in a short period of time and the optimum combination can then be chosen for hardcopy. A typical color additive viewing system consists of light sources, filter wheels, a projection screen, film holders, registration controls (x, y and rotation) and light intensity controls.

Digital Processing

Digital image data are generally acquired directly as computer compatible tapes (CCTs). However, it is possible to generate digital data from a film transparency using a densitometer or image digitizer. This type of digital image data is generally considered to be of inferior quality because of the many variables associated with the film.

The term "pixel" is often used to refer to a basic unit of digital data. For the Landsat system, a pixel is an integrated radiance value for a 57 x 79 meter area. Raw pixel values typically range from zero to 127.

Three general areas of digital image processing will be addressed in this paper: preprocessing, enhancement and classification. Again, the discussion will be oriented toward Landsat data.

Preprocessing

Digital image data in their raw form may require preprocessing to correct systematic data anomalies. Radiometric and geometric corrections are often applied to Landsat data. Radiometric correction is necessary for anomalies such as striping and bad data lines. Striping is caused by using incorrect gain and offset values to standardize detector sensitivity and is characterized on an image by systematic light and dark lines across the image. The striping effect is corrected by calculating new gain and offset values for each detector. Bad data lines often occur because of transmission losses or sensor saturation. Among the algorithms which have been devised to correct the bad data lines are repeating the previous data line and averaging the previous and following data lines.

Geometric correction is necessary because of distortions which are caused by factors such as the earth's rotation, non-uniform mirror velocity, sensor delays and orbit and attitude variations. Geometric correction involves two steps, the first of which is the determination of the correct spatial location of each pixel in a corrected image. The second step is the determination of new digital values for the pixels in the corrected image.

Enhancement

As is the case for analog image enhancement, digital image enhancement is performed for the purpose of making an image more interpretable. Among the many available enhancement techniques are contrast enhancement, edge enhancement, band ratioing, and data transformations.

Digital contrast enhancement is analogous to photographic contrast enhancement. A histogram of pixel values for the band(s) to be enhanced is generated for the area of interest. The range of pixel values for that area is determined and that range is then expanded to cover the entire dynamic range of the system. Various algorithms for expanding the data are available.

Edge enhancement is a digital processing technique to enhance boundaries between features which exhibit subtle differences in brightness (pixel) values along their edges. This technique is especially valuable for terrain applications such as structural geology (location of fracture and fault zones) and hydrology (drainage network analysis).

Band ratioing is an enhancement technique which is often used in conjunction with multispectral data such as Landsat MSS data. Ratioing involves dividing the brightness value in one band by the brightness value in another band on a pixel by pixel basis throughout the scene. After ratioing, the data are scaled to cover the dynamic range of the system (usually 0-255) for maximum contrast. Three ratioing techniques which are commonly used are: (1) ratioing two individual spectral bands (e.g. MSS4/MSS5), (2) ratioing the difference to the sum of the bands (e.g. (MSS5-MSS7)/(MSS5 + MSS7)), and (3) ratioing each band to the sum of all the bands (e.g. MSS5/(MSS4+ MSS5 + MSS6 + MSS7)). Because ratioing occurs on a pixel-by-pixel basis, exact registration among the bands is necessary.

Band ratioing is actually a type of data transformation. Various ratio combinations have proven valuable for vegetation analysis and for reducing the effects due to topography. Other types of data transformations are canonical analysis and principal components analysis. Both techniques

involve transforming the multispectral data into a series of uncorrelated axes. Canonical analysis uses data that have already been assigned to classes (training data). The data are transformed into a set of uncorrelated axes in such a way as to maximize the variance between classes and minimize the variance within each class. In principal components analysis the data have not been previously assigned to classes and are transformed in such a way that the first axis accounts for as much of the total variance as possible, the second axis accounts for as much of the remaining variance as possible, etc. In addition to being transformation techniques, canonical analysis and principal components analysis can also be thought of as supervised and unsupervised classification techniques, respectively (see next section).

Classification

The ultimate goal of digital image processing is to extract useful information from an image. Preprocessing and image enhancement techniques are preliminary steps to this goal. Information which is extracted from an image is often classified into useful themes or categories. Two basic classification strategies exist: supervised and unsupervised. Supervised classification schemes utilize a priori or training information, whereas unsupervised classification schemes use only the statistics of the data to govern the analysis.

Two of the most common supervised classification techniques are the parallelepiped and maximum likelihood algorithms. The training data are used in the parallelepiped method to determine the spectral (pixel value) limits for each of the spectral bands for each class of data. Thus a

spectral "volume" is defined for each class of data. Each pixel in the area to be classified is then assigned to one of the classes based upon the "volume" in which it fits. The maximum likelihood method uses the training data to generate a set of statistics (means and covariance) which is used to determine which class each pixel of data most likely belongs to.

Unsupervised classification examines all of the pixels (or a random sample) for statistical relationships to determine "natural" groupings or clusters of data. It is then the interpreter's responsibility to attach physical meaning to the clusters.

Geographic Information System

It is often desirable to integrate remotely sensed data with other resource information into a spatially-oriented data base. Because of the large amounts of data involved it is necessary to automate the process. The geographic information system described below is one of many which are presently available.

Data which are input to the geographic information system may originate from a variety of spatially-oriented sources. Both already existing thematic maps and those interpreted from remote sensing imagery can serve as input. The basic questions which must be resolved prior to the input of data concern the cell size and the map projection which will be used. Factors such as the complexity of the input maps and the limitations of the sensor resolution need to be considered when the cell size is determined.

The process of digitization of the resource input data involves coding on a row-by-row basis those columns where a boundary condition exists.

Row and column numbers are determined from a grid which has been computer-plotted at a scale to fit the map. When the digitization for a given input resource map is completed the encoded data are error checked in two steps. The first step involves a computer run which checks for obvious coding errors. Once these errors are eliminated the second error check is implemented which involves the generation of a computer plotted map at the same scale as the original input map. Any discrepancies between the two maps are corrected and, if desired, the two-step error-checking loop may again be entered.

Additional interpretations may be made from each input resource map. For example, basic soils data which have been entered into the geographic information system can be interpreted for slope classes.

An additional feature of the geographic information system is the theme overlay capability which is extremely valuable when the interaction among various types of resource data need to be analyzed. Any combination of resource data sets which are spatially registered and have the same cell size may be overlaid.

Several options are available for output of the results from any of the operations mentioned above. Computer-plotted maps can be drawn at any scale desired, frequency and areal information can be tabulated, and color film products can be generated.

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REMOTE SENSING AND CARTOGRAPHY IN THE SUDAN

by

Dr. Hassan Mohammed Hassan*

I. Need for Image Maps

The Sudan is the largest country in Africa. Its area is approximately 2.5 million square kilometers. It stretches from a tropical rain forest in the South at about 4° north latitude up to the Sahara Desert on the tropic of cancer at 22° north of the equator. The Sudan has nine neighbors. It borders Egypt and Libya on the north, Chad and Central Africa on the west, Zaire, Kenya and Uganda on the south and Ethiopia on the east. It shares borders with Saudi Arabia across the Red Sea.

For a country that size, image maps are not only desirable but almost inevitable. It is extremely expensive to have complete coverage of such a huge country with line maps of reasonably large scale or even medium scale. That explains why the only total coverage we have of the Sudan is at 1/250,000 scale; and even at that scale it requires some 170 sheets of 1° by 1° 30' to cover the whole country. These map sheets which are available are really more or less considered to be sketches and are not up to international standards of 1/250,000 maps. As a matter of fact they were printed at the turn of the century with methods and procedures available at that time. They were mostly compiled from reports and diagrams supplied by British army officers who were not well versed on the subject of surveying. For lack of any other maps of better quality in most of the areas,

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these maps are still in use. That is why it was thought that updating these maps through the use of Landsat images can never be overstressed. The Sudan is considered by most experts, including the United Nations and the World Bank, to be one of three countries in the world that is the future bread basket of the world. It is estimated that there are more than 200 million acres in The Sudan suitable for agriculture. Of these only 15 million acres are in use today. That means there is more than 90% of the arable land still virgin. Though these estimates are considered fairly accurate, they are still to be proved. Without Landsat images it is almost as difficult to actually assess these lands as to put them in production.

II. Present Status of Mapping

As was mentioned earlier, the only total coverage we have of the whole country is at 1/250,000 scale and smaller and even those are not really up to international standards. The survey department has recognized this fact and is thinking seriously of doing something about it. It was decided that some type of a base map be adopted for the whole country which will be suitable for most map users. Scales 1/25,000 and 1/50,000 and larger were ruled out as base maps because it would require a huge number of sheets to cover the whole country. The government does not have the financial resources or the man power to adopt that type of base map. Again the economic development is moving so fast that those types of maps will be out of date before they are put to real use. A 1/100,000 scale was adopted as the base map. Even at that scale it would require 920 map sheets for total coverage. It was also decided that larger scales,

1/50,000 and 1/25,000 and larger, should be used only in areas which are thought to have high economic potentials.

Up to now only about 15% of the country is covered by 1/100,000 scale maps (see figure 1). Those are mostly in the northeast and center of the country. There also exist some 100 odd sheets at scales 1/25,000 and 1/50,000 that cover some areas that are economically valuable or strategically important (see figure 2).

With regard to cadastral lands and records of individual holdings, there exist large scale maps that record these rights but most of these maps are based on local grids and projections.

III. Status of Geodetic Control

The country is traversed from north to south by the famous arc of the 30th meridian that stretches from Cairo to Cape Town. This arc nearly divides the country in two. The 12th parallel chain also traverses the country from west to east. This chain also stretches from the coast in West Africa to the coast in East Africa. Numerous other chains of first and second order triangulation form a close mesh covering the northeast and the central parts of the country. The southeast and the southwest are sparsely covered with geodetic control. Only the north west part of the country is bare of any control as it is also bare of any evidence of life. This area is part of the Sahara Desert. Precise level lines follow the triangulation net very closely (see figure 3). Recently Doppler observations were introduced in the country. Some 20 stations were observed in different parts of the country. Most of them were observed on old first order triangulation stations in order to check the conventional

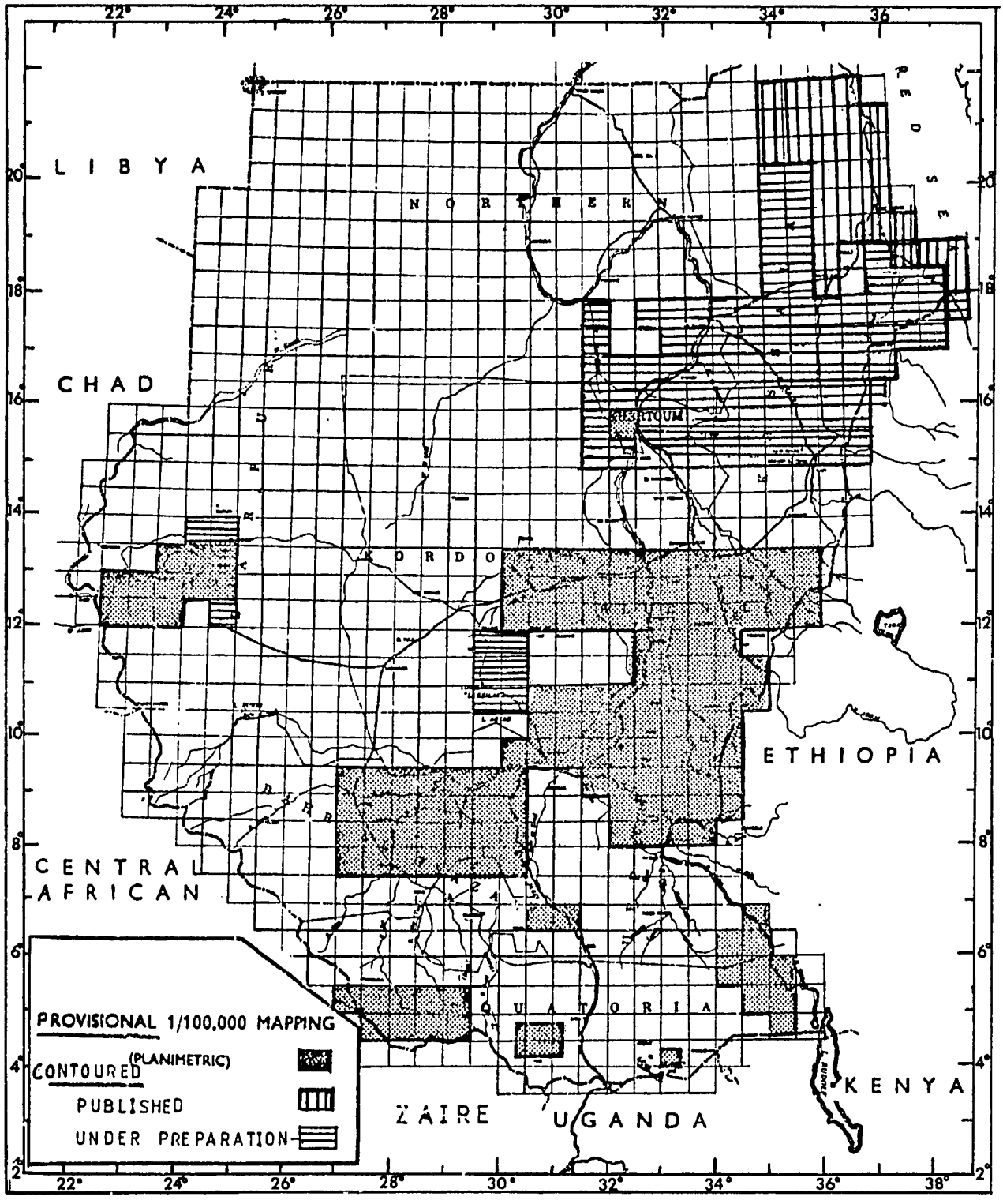

Figure 1. Map showing areas which have been mapped at 1/100,000 scale.

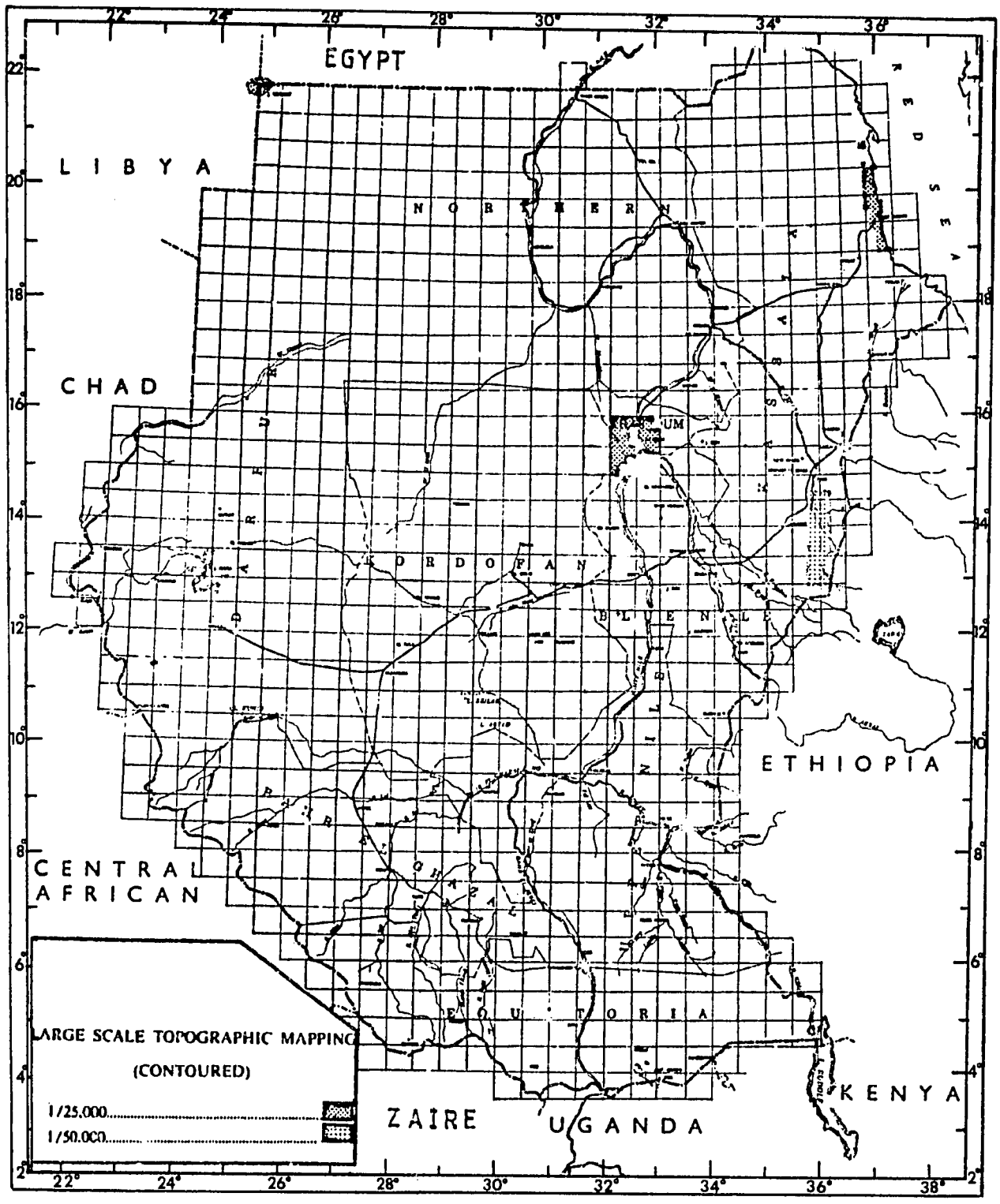

Figure 2. Map showing areas which have been mapped at 1/25,000 and 1/50,000 scales.

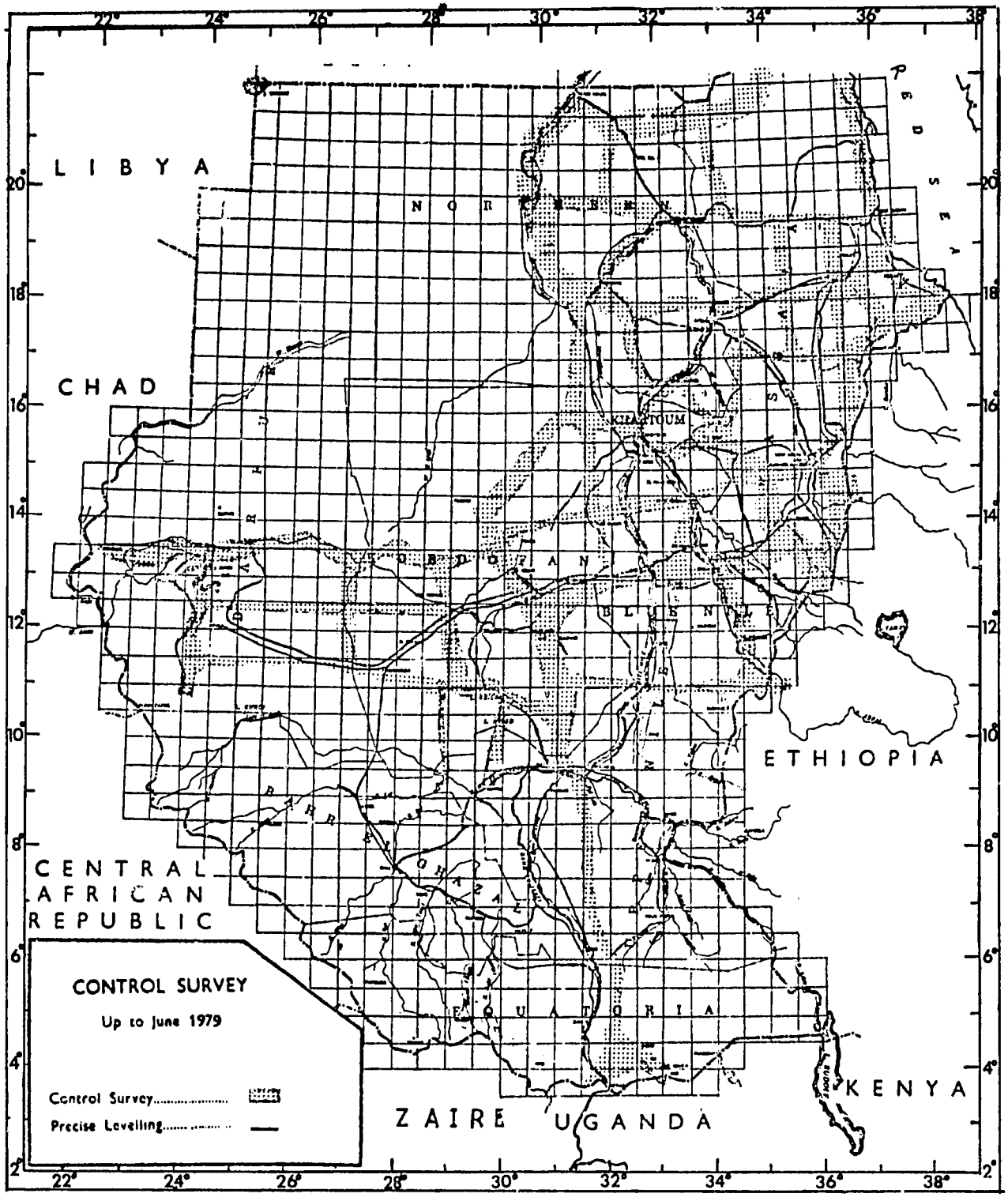

Figure 3. Map showing areas of control survey as of June, 1979.

net in order to readjust it. A proposed Doppler net has already been accepted by DMA (the Donor Agency). This net is supposed to form a mesh of 200 kms on a side. The field work for this proposed net is supposed to start next October. It is intended to observe tellurometer traverses between these Doppler stations to complete the control mesh of the whole Sudan.

IV. Availability of Landsat Imagery

Although The Sudan does not own a receiving station and though there is no operational receiving station on the continent, yet there is at least a complete coverage of the whole country from Landsat 1 and 2. This coverage is mostly with less than 10% cloud cover. This is mostly due to the cloud-free skies that prevail most of the year in Sudan even though some regions of the country are considered within the tropics. I am not sure if there is any coverage from RBV of Landsat 1 and 2 of reasonable quality. I have come across some scenes of The Sudan on RBV on Landsat 3 which were of excellent quality. I am not certain of the total extent of this coverage.

During the Skylab mission two small strips of photographs were taken; one was on the west side of the country and the other more or less on the central part. I don't think that each strip exceeds 200 kilometers in length, yet these could be very useful for studying those areas.

Seasonal coverage exists but is not as available. This is mainly due to the fact that there is not yet any line of sight receiving station to relay this information directly. The availability of tape storage on the satellite governs the availability of seasonal coverage. Yet it is possible to find more than one date of coverage in different bands and from different

seasons to give reasonable information for environmental studies using Landsat images.

The Sudan Survey Department obtained one complete coverage from MSS on Landsat 1 some years back. Although this coverage is not of a single band or date, we find it very useful despite its sporadic nature. It is particularly useful to our navigators in the survey plane where they find it more dependable for flight planning than our old 1/250,000 maps.

V. Proposal for Image Mapping

It has already been realized that our 1/250,000 maps (the only total coverage we have) does not satisfy the users. It has also been realized that it will take us at least 30 years (provided that we have the funds) to complete the coverage at 1/100,000 scale. It is worth mentioning that according to recent prices it will cost on the average about $60,000 per sheet. Noting that the whole Sudan is to be covered by more than 920 sheets at that scale, the total cost of a complete coverage will run to over 55 million dollars. I am quite sure that the Sudan government will not venture to go into such a project - at least not in the near future. The first reason is that they do not have the funds to tie up in the project although it is admitted to be very important; secondly, it will still take at least 30 years to finish the project provided that everything is available.

The Survey Department has realized these facts and have put out a program to solve this problem. The program involves keeping 1/100,000 mapping going at about 20 sheets per year mostly through aids from the United Nations and friendly nations. Together with this the department entered into an agreement with the Defense Mapping Agency of the United

States (DMA) and the United States Geological Survey (USGS) by which these American agencies will assist the department in updating the 1/250,000 maps through the use of Landsat images. This agreement is to take effect this year and is to continue until all of the 170 sheets of 1/250,000 scale have been updated.

The project involves the use of existing 1/250,000 scale maps together with any large scale coverage that is available. It also involves the use of all available aerial photographs plus flying selected areas to reduce the amount of ground truth required. The project will make use of all the geodetic control that exists in the country and will supplement that by the use of Doppler satellite stations. These Doppler observations are included in the project; the stations will be observed where no ground control exists or where the control is rather sparse.

It may be worth mentioning that we have participated in such an exercise with IGN of France. The technical feasibility of the project was determined through a pilot project in the Khartoum area (this can be seen at the poster session). The Landsat images were processed by an electronic system called System 101. The pilot project was indeed impressive. However, it was found that a single sheet of 1/250,000 scale will cost the Sudan about $15,000.00. Although the project was technically very sound and attractive, it was economically impossible to implement due to lack of funds.

The DMA/USGS/Sudan project is hoped to give results which are similar to those of the IGN project with little or no financial oblication on the part of The Sudan.

THE USE OF SKYLAB S-190B PHOTOGRAPHY FOR SMALL-SCALE MAPPING

By

Dr. Ismat M. El Hassan*

SUMMARY

The application of the Skylab Earth Terrain Camera (S-190B) 1:946,000 scale photography for small scale mapping was investigated. The paper describes the procedure used in making the measurements on the Skylab imagery. An analytical absolute orientation was performed and the results proved that the photography could be used for mapping at 1/100,000 scale and smaller.

INTRODUCTION

The manned Skylab project was planned and implemented by the U.S. National Aeronautics and Space Administration (NASA), the satellite or space station being launched into a circular orbit of 435 km above the earth on May 14, 1973. Six optical and electronic remote sensing systems or devices were mounted in the satellite for the Skylab earth observational program. These systems formed the Earth Resources Experiment Package (EREP) and comprised the following:

(1) Multispectral Photographic Camera (S-190A)

(2) Earth Terrain Camera (S-190B)

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(3) Infrared Spectrometer (S-191)

(4) Multispectral Scanner (S-192)

(5) Microwave Radiometer (S-193)

(6) L-Band Radiometer (S-194)

The photographic components of EREP are the first two items listed. The objective of these two cameras was to photograph various parts of the earth's surface over the whole spectral range for which photographic emulsions are available, i.e. from the blue end of the visible part of the spectrum to the near infrared. High resolution photography with sufficient spectral definition was required to simplify the work of specialists in interpreting and analyzing the photography.

The first item is the S-190A multispectral photographic system. It consists of six Itek 70 mm film cameras each with its optical system, shutter and film transparent assembly, but sharing a common mount or platform and synchronized so that all six shutters are operated simultaneously. The focal length of each camera is 6 in. (152 mm), giving a film negative scale of 1:2,850,000. The image format is 57 x 57 mm so that the ground coverage produced by a single frame is 163 km sqaure. The second part of the photographic system is the S-190B Earth Terrain Camera (ETC).

The object of this paper is to give an account of the investigation which has been carried out into the application of the S-190B photography to the production of small scale maps.

The S-190B Camera

The S-190B camera was built by Actron Industries, Inc. under contract to NASA (McLaurin, 1972). The body of the camera is a modified Hycon KA-74 43connaissance camera equipped with a bi-directional focal plant shutter and vacuum film flattening. Internal Motion Compensation (IMC) is achieved by rocking the entire camera in its mount during the exposure. This allows the use of quite long shutter speeds (1/100, 1/40, 1/200 sec.) which allows finer grained, higher resolution film to be used than might be expected from a fast-moving satellite. This IMC system can be set to operate within a range of 0 to 25 mrad/sec.

The camera was equipped with a lens having a focal length of 18 in. (460 mm), a maximum aperture of f/4 and a maximum radial distortion of ± 10 μm. The format size of 11.5 x 11.5 cm at the Skylab altitude (H=435 km) covers a terrain area of 109 x 109 km at the scale of 1/945,000.

The S-190B camera was to provide high resolution color infrared or monochrome photography within the field of view of the smaller scale, lower resolution S-190A camera. The three Kodak films used with the S-190B camera are given in Table 1.

Table 1. Films used with the S-190B Camera

Type	Description	Wavelength (um)
50-242	High resolution colour	0.4 to 0.7
EK-3414	High resolution Panchromatic	0.5 to 0.7
EK 3443	Colour infrared	0.5 to 0.88

The on-axis resolution estimates of the second generation S-190B photographs, as determined by Welch (1976) are shown in Table 2.

Table 2. Resolution Estimates for Second-Generation S-190B photographs (Welch, 1976)

Film/Duplicating Film	Resolution Estimates (L/mm for 1.6:1 target contrast	Ground Resolution (m)
3414/2430	60 - 70	15
50-242/2447	35	25
50-131/2447	30	30

The image frame of the S-190B camera is a part of the removable film magazine, hence the principal point cannot be precisely located and therefore analytical applications will be limited. The S-190B has a limited field of view of 14°. When the camera is operated for 60% overlap, the base: height ratio is only 0.10; thus, the use of the S190B for stereoscopic height determination will be especially limited.

PHOTOGRAPHY:

The photography used in the test consisted of a strip of three photographs exposed on the 50-242 high resolution colour film. Second generation film transparencies made from the original film were used in the actual test. These, together with the small scale maps covering the area, were very kindly made available by professor R. Welch of the University of Georgia, U. S. A. The three photographs used - Nos. 01334/5/6 formed two stereomodels with a 60 percent longitudinal overlap. The photographs have good illumination and high resolution throughout the format. No clouds were present nor was there an excessive amount of haze so that the observation conditions were good.

TEST AREA AND GROUND CONTROL:

The area covered by the photography was the central part of the State of Illinois in the U. S. A. This area extends from $39^{o}30'$N to $40^{o}45'$N in latitude and from $88^{o}15'$W to $90^{o}0'$W in longitude.

The small-scale map coverage for the area comprised 33 maps at 1/24,000 and 25 1/62,000 scale. All these maps had been produced by the U. S. Geological Survey (USGS), being plotted on a polyconic projection and compiled to U. S. National Accuracy Standards.

Mirror stereoscopes were used to select and identify suitable control and check points on the Skylab photography which could also be accurately located on these maps. Road intersections were found to be the most suitable points and a series of these were selected to give a set of control and check points which were fairly evenly distributed over the stereomodel. A careful sketch was made for each point so that it could be identified easily when measuring its photocoordinates.

A Hoag streit coordinatograph of 0.1 mm scaling resolution was used to measure the positions of 98 ground control points (of which 14 points were in the common area between the two models). The measurement of position was performed three times for each point. The mean measured rectangular coordinates (in mm) were then transformed to geographical coordinates by direct linear interpolation between the ticks at 2'30" intervals of latitude and longitude on the 1/24,000 scale maps or 5'00" intervals on the 1/62,600 scale maps.

According to the U. S. National Map Accuracy standards, the accuracy of these points is $\pm$ 0.3 mm on the map scale.

Therefore, points measured on the 1/24,000 scale maps will have an accuracy of ± 7.2 metres on the ground, and points measured on the 1/62,500 scale maps will have an accuracy of ± 18.75 metres on the ground.

For model 01334/5, 10 points were measured on the 1/24,000 scale maps and 50 points were measured on the 1/62,000 scale maps. For model 01335/6, 22 points were measured on the 1/24,000 scale maps and 30 points were measured on the 1/62,500 scale maps. The elevations of the points used were the spot height values on the printed map sheets given to the nearest foot (0.3m).

MEASUREMENT OF PHOTO-COORDINATES

Since the highest possible accuracy in the measured photo-coordinates was required, and because the principal distance of the S-190B photography (18 in, 460mm) could not be accommodated by conventional stereoplotting machines, a high precision stereo comparator was used for the measurements.

The stereometor measures the x-coordinate of the left hand photograph (x') and the y-coordinate of the right hand photograph (y") together with the parallaxes in x and y i.e. px and py. Since the measuring ranges in the x' and y" directions are 0 to 280mm, the two different formats of the test photographs were easily accommodated. The film transparencies were clamped to the holders by means of swivel

brackets. Glass cover plates were used to ensure the flatness of the transparencies and to keep them from sliding about. The values of x', y", px and py were measured with a resolution of 2 μm using rotary shaft encoders attached to the lead screws which are used as driving agents. The measured values were automatically recorded in digital form on punched paper tape using a Facit 4070 punch and in printed form using a teleprinter.

In metric cameras, the fiducial marks defining the principal point are located (i) in the corners of the camera focal plane, (ii) at the midpoints of the sides of the focal plane or (iii) the principal points are marked directly on the register glass (in the case of reseone cameras). The marks are normally a part of the focal plane and thus remain in a fixed position relative to the camera lens.

In the case of the S-190B camera the image frame is a part of the removable film magazine and hence even this is not a fixed position relative to the camera lens. However, the S-190B camera has a series of holes drilled around the perimeter of the image frame. These holes created photographic images having an approximate diameter of 330 μm. Four holes situated at the four corners of the frame were selected to serve as fiducial marks (Fig. 1). The measuring mark was centered in each of the circular holes. The photocoordinates for each of the fiducial holes were then recorded to determine the coordinates of the geometric centre.

Because of the very small scale of the photos (1/945,600), attempts were made to use the highest possible magnification in the comparator (14 x), but it proved difficult to observe due to the poor resolution of the measured points at this setting. The magnification was therefore reduced to 9 x which gave an acceptable compromise between resolution and magnification. Two sets of observations were performed for each point and the mean was taken.

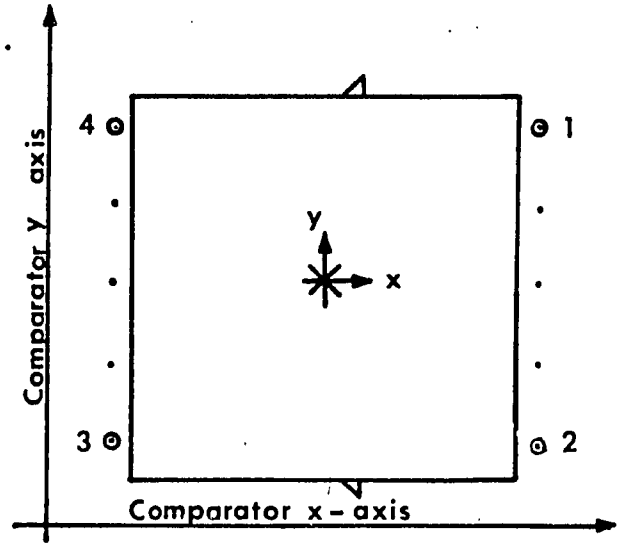

Fig. 1. The Photocoordinate System and the Fiducial Holes.

DATA PROCESSING

Since the lens distortion is insignificant (maximum± 10 μm) and due to the fact that the atmospheric refraction at camera altitudes above 40 miles is relatively negligible no attempt was made to refine the image coordinates.

The data processing starts by a relative orientation program which comprises an interrelated geometric fitting of each pair of overlapping photos independent from ground control data. The positions of all the test points in each of the

two models were determined in a three-dimensional coordinate system.

Since the computations require the ground positional data to be in a common three-dimensional coordinate system, and in order to compensate for the presence of the earth curvature in the data, the geographic positions and heights of all the test points were processed through the secant plane coordinate transformation program to obtain secant plane coordinates for each point. In this program, the geographic positions and elevations are first transformed to an orthogonal geocentric coordinate system having its origin at the centre of the earth as defined by Clarke 1866 Spheroid. The geocentric coordinates are then transformed to a secant plane coordinate system in which the secant plane intercepts the earth's surface near the edges of the test area, so that most of the terrain objects will have a positive Z (elevation) coordinate.

The model coordinates were then transformed to the secant plane coordinate system using an absolute orientation program. The program solves for the absolute orientative parameters and then transforms the model coordinates to ground coordinates making use of a minimum of two planimetric and three height ground control points. In this test four full control points (plan and height) were used in the solution for each of the two models.

TEST RESULTS

In this test the ground coordinates of the test points, measured from the 1/24,000 or 1/62,500 maps and transformed to the rectangular secant plane coordinate system were used as known values. Discrepancies between computed ground coordinates and their known values were determined. These were then used to determine the root mean square errors (RMSE's) of the residuals at the check points, given in Table 3.

Table 3 RMSE's of the Residuals at the Check Points

Model No.	No. of Check Points	M_x (m) (μm)	M_y (m) (μm)	M_{pl} (m) (μm)	M_z (m) (%.H)
01334/5	56	16.1 17	26.5 28	31.0 33	102.7 0.24
01335/6	48	26.3 28	14.5 15	30.0 32	95.6 0.22

DISCUSSION OF SKYLAB RESULTS

The results obtained for planimetry in the present test are reasonably satisfactory. The figures of 30 to 31 m. (corresponding to 31 to 33 μm at photo scale) must be considered in the context of the circumstances prevailing in the test. The ground resolution of S-190B colour photography is estimated at 30 m. and the accuracy of the untargeted test points is estimated to be up to 20 μm at the photo scale. Also the radial lens distortion (±10 μm maximum) has not been corrected. Therefore, the results obtained appear to be reliable and acceptable.

The major factor affecting height accuracy is the B/H ratio. The height accuracy to be expected from a particular test could be determined using the general parallax-height formula:

$$dh = \frac{H}{f.B/H} \quad dh$$

Where dh = error in height

dp = residual parallax

B = air base

H = flying height

If one estimates the precision of the parallax measurements (dp) to be 10μm (which could result from observational errors, uncompensated radial lens distortion and film deformation and errors in ground control), the corresponding height error (m_z) on the ground for the S-190B photograph (B/H=0.10, H-435 Km, f=460mm)

would be ± 96 m or 0.22% H. The mean height accuracy achieved in this test was ± 99m (0.23%H) which is reasonably close to the expected value.

CONCLUSIONS

The NATO standard specifications for topographic maps at 1/600,000 and larger stipulate a standard error of M_{pl} = ± 0.3 mm. On this basis the planimetric accuracy obtained for the S-190B photography (± 30m.) in the test conducted above would allow its use for plotting planimetric detail at the scale of 1/100,000 with just sufficient accuracy to meet mapping specifications and at smaller scales such as 1/250,000 and 1/500,000 with more than adequate accuracy. Such maps would replace those maps which are largely based upon observer's notes and sketch maps used in areas such as the Himalayas and Tibet, Southern Sudan, Southern Ethiopia and the Libyan desert.

There is little doubt however that, unlike planimetry, the heights as measured on the S-190B photography are in no way useful to even the smallest topographic mapping. As Petrie (1974) has pointed out, contour intervals of 20 to 25 m are not uncommon even in small scale series and there no hope of reaching such figures with photography of the S-190B type. A more definite answer as to the possibilities of heighting and contouring from metric space photography will come from the NASA-LFC and ESA-Zeiss RMK flights to be made with the space Shuttle in 1980 and 1981. These have the more favorable

B/H ratios required for the task, but even then it is doubtful if the required accuracy can be reached.

ACKNOWLEDGEMENTS

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HYDROGEOLOGICAL INTERPRETATION USING LANDSAT DATA IN DIFFICULT AREAS

By

Salah M. El Rabaa*

My topic concerns water resources in what the Sudanese geologists call "difficult areas". A simplistic view of the problem follows. For ground water resources to be available, you need a source of water, a mechanism to gather and concentrate water, a place for water to be stored, and a method to exploit and use the stored water. The source of water is from precipitation, whether local or carried to the area by flow. The water is gathered by what the hydrologist calls precipitation catchments, runoffs, infiltration or permeation zones. The porous medium that has spaces between solid particles for water to accumulate is called the aquifer or reservoir. To hold the water in the aquifer against the force of gravity, you must have a layer which is impermeable to the flow of water and we call this impermeable rocks. If all these conditions exist, then a water supply is stored and can be made available for use.

If one or more of these conditions does not exist, it can make an area a difficult area for ground water occurrence. These difficult areas are typical in Sudan. Sudan is mostly flat with some inselbergs of rock outcrops. Most of the conditions that make water difficult to find are the conditions associated with types of crystalline rocks that

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we refer to as "basement complex". Because they are not very permeable, they do not pass water. They are not porous and do not store water unless they are highly fractured, jointed or decomposed.

Those basement complex areas usually are defined by Sudanese geologists as difficult areas. This contrasts with sediments, especially thick sediments where the water level or water table is within it, when it is always easy to dig a well and get water. A typical basement complex terrain is a solid outcrop and a weathered pediment. The soils can be clayey or sandy. It depends on the history and their position. Many of the residual soils in the basement areas, especially older ones, are clay. Clay weathers from the felspars of the basement through hydration. If they are not washed away, they remain. But if they are washed away, you are left with the sandy particles.

If we introduce some other factors; here at Jebel Uweinat there is basement rocks and it is a difficult area. Here in the central Sudan between latitudes 10° N up to 16° N, there are also basement areas which we will see later in the geological map of Sudan. In the equatorial region in the south there are also basement areas which we can call difficult areas because of our definition. If our aim is to make water available, then the difficult areas would have possibly another meaning.

I would like to consider in particular those difficult areas in three land use plans. We must define the need for water. Is it needed for a particular job? Less water is needed for a soldier on the frontier than for a mine working in the Red Sea hills. In the southern Sudan, the precipitation is much beyond the 800 mm. isohyet. In this condition you

have plenty of surface water and the region should not be called a difficult area because the surface hydrologist can readily get water. In only a few conditions where you are afraid of surface water pollution or a site must be placed in a strategic location such as a gas station on a highway, some wells may be needed.

These are areas that the international committee call difficult areas from another point of view. They are areas of desertification hazards. They are also areas that by some are considered already affected by severe desertification.

Unfortunately, I do not have the right map to show the vegetation, animal population, and mechanized agriculture in Sudan. These are the most productive areas. At the same time, they are economically high potential areas. These areas are not only difficult for water but difficult for other things. Most of the decline in productivity is in our geological difficult areas as well. Why does desertification occur along the margin of this area? Such an area includes our "supposed" defense front against desertification.

In this diagram, I put the basement as difficult areas and the sedimentary areas as without difficulty. In the sedimentary area, we normally find water, once a few conditions are satisfied. The basement area is very marginal and water may be found in small amounts around the basement outcrops in lenses in the coarse pediments, or in most cases the well would not bring any water.

If you look from the development point of view, this contact which is either basement/sandstone is a very popular contact in Sudan. The

Nubian sandstone often is covered by reworked sands or "silicious" soil. Another is the "cotton" soil covering the basement. So in one place we have a suitable agricultural area without water and in another area we have a sandy area with plenty of water. It is common that one lives here and cultivates there. The people live on the margin of the sandstone where they can have plenty of water and they go to the agricultural area carrying their water supply.

There are a few conditions that will make it possible for a basement to contain water. The most significant is to increase the permeability of the basement by having fracturing. Fracturing is a planar feature showing in two dimensional Landsat data as lineaments. The pediments surrounding the basement often contain water. Almost any basement in Sudan in the pediment has a village with a well. The last type of waterbearing basement is a buried channel that is due to erosion of the basement and subsequent filling with another material which is porous. These are exceptional cases where water can be obtained from a difficult area. Different features may be expressed on Landsat data such as fractures where controlled drainage is expressed. The buried channel might show on the surface as a type of controlled drainage. Therefore, the interpreter must know the terrain well and develop a model for interpreting the surface features to relate to the subsurface. Having this model in mind, you can proceed with the interpretation of Landsat. For example, lineaments by definition are linear features on the surface. They can be present for many reasons. A narrow resistant bed will appear as a line in the Landsat image. A dyke can

appear also as a line. Systems of fractures appear as lines. However, a very important fracture with no dipping in an undulating terrain may not appear as a lineament. F-F2'-F3' on the diagram is a proper fracture, but it will be eroded because of its inclination. The lineament represents the intersection of two planes. One of these planes is the surface of the earth and the other is the plane that makes the lineament. When the attitude is vertical, whatever the terrain, the lineament will be a straight line. But with a changing topography, all those that have no attitudes will not appear as straight lines.

Let us discuss what features can be associated with lineaments, that of fractures. This is a single case that there is a fracture and water permeates along the fracture until it stands somewhere. Fractures can cause erosion of the area and in the end you get a valley along the trend of the fractures. It is not necessary that we see the fracture. You can see indirectly an erosional feature along a relatively less resistant part of the rock. That is an indirect indication of a fracture. It might develop a good stream. Usually we call this type a controlled drainage system because it usually forms into a linear feature itself. This is because it is controlled by the trend of the fracture. These fractures may indicate an area of special rocks buried under alluvial deposits creating high permeability. A special type of tree may grow along the linear zone. Now this linear forest becomes a biogeologic indicator. A very famous tree in Sudan is "Dom Palms" which is found linearly oriented and which reflects a buried channel. Perhaps this channel is due to erosion along a fracture.

One example that I have used in this study is land use pattern. The fields that the human has made are often placed where well yields are good. A linear arrangement of the fields for the most exploited land often coincides with a fracture. You can see that in the area around El Nuhud systems of villages lie on a straight line. The simple explanation is the inhabitants must drink water, so each village must have a well. There is a geologic feature that made those wells in alignment.

Salt deposits also indicate infiltration and by capillarity, evaporation and deposition, they can often be in a linear feature. One can see this west of the Nile near Dongola. Another feature is permanent animal tracks. Animal tracks in an area of high precipitation will follow buried channels because the areas of high infiltration do not become sticky. The animals can walk over the region without getting stuck. In a dry season in an arid land this area supports more vegetation, and they keep grazing along those lines until it is overgrazed. These are only indicators and do not always have a 1:1 correlation but in exploring for subsurface water, we must use any and all possible indicators to guide our drilling programs.

Lineaments that display an intersection of a fracture with the earth's surface are something that are related to a very regular system. We call this "the stress system". It is the force that is displayed by a magnitude and direction. The most important part to concentrate on is the direction. A force operates in three dimensions and its operation is usually in reference to the earth's crust. If you

apply a stress, then things separate just like pulling each other. The line of separation is a regular line. It does not occur only in one place. It is repetitive and all these geological structures are due to tectonic processes resulting from an application of stress. The structure is the result of interaction between energy and matter; between the stress and the rocks. All geological structures are regular structures as they are controlled by regular forces defined by magnitude and direction. The most important geological process operate over very large areas, such as the American continent separating from Europe over a distance of 25,000 miles. These stresses do not exhibit themselves within a small scale. So you can pick a piece of fracture here and you can relate it to a piece of fracture there. The fractures may be separated by a hundred kilometers.

Let us give an example of the forces that may produce more than one set of fractures. You should realize that geological processes producing fractures that give us lineaments are regular processes throughout large regions. Now with lineaments one has to be very careful and many geologists make mistakes. This is a fracture and this is the intersection with the surface so this is a lineament, and this is another lineament. Where the lineaments intersect is thought as a beautiful place to have a well. Indeed those two lineaments are intersecting lineaments. There are two surfaces intersecting along a line. This inclination regulates the depth from the surface to which we should drill and some of the intersections look the same because they trend in the same way.

According to this principle, if they are parallel and regular,

you do not know how they behave. This is one thing the geologist must understand in the field. The third dimension of what they see as a lineaments is the knowledge sought. If they are repetitive or you can see an exposed outcrop, you can assume the third dimension easily. In other cases lineaments become very difficult to interpret and the lineament section can be very steep. The geographic trend is then calculated with difficulty and to locate a well is quite a tricky business.

To use Landsat data for your problem, try to use, as much as possible, different bands and different dates because it is not only geology that is going to be an indicator of water supply, say the channel or the fracture. An indicator can be vegetation if in an area with relatively more moisture producing flourishing vegetation. You need to view the image in the band where vegetation is better. A striking feature will be observed if healthy vegetation is on a line as if it were man-made. These linear features will attract your attention.

For example, I will illustrate a few points of interest. This general area is Nubian sandstone, but look at the surrounding area which is comparable in brightness to the Nubian. They are not similar materials but by projection of this as a geological structure, both areas will be included in one mapping unit. It must not be a different basement but is simply a different rock type. It can not be Nubian sandstone because it starts to support more vegetation (represented by the red color), and it starts to have a drainage pattern that is not as simple as the one in the Nubian sandstone. The area is different because a nearby basement adds to the clay content of the soil which supports better vegetation while both areas are in a similar precipitation range.

Also you can see some of the basement structures start to expose. This is termed a near-surface basement. A hydrologist may map the area all as sandstone which would support wells. This image shows that the basement is covered by sandstone but it is thin since the basement exhibits an influence on the surface as indicated by the vegetation. It would therefore not be an appropriate place to establish a bore hole. Also, observe the drainage. At certain locations the drains become rounded. The drainage goes over a fold hinge. If you follow a rock or fold like this and connect it and go along this fold hinge you get a real fold. The core of the fold can easily support a well. A geologist can interpret this through the changes in drainage patterns.

This type of controlled drainage is not the fracture type. These are drainages that cut through a crestal part of a fold. Because they are usually areas with a high amount of fracturing in the top, there is a linear erosion around them. A fold also occurs when you push up a rock from both sides. The fold extends along the axis and then breaks. Usually there is a perpendicular fracture system which is referred to as the axial trend of the fold. A feather type of controlled drainage results.

Along a major rectangular drainage system shows small white areas on the Landsat image. They appear well on band 5 and also on band 7. Along these drainage lines you find areas of intensive land use. Band 4 indicates the villages better, and you find many villages are located here. I used these two interpretation features as indicative of linearity. Both wells and extensive land use could be used to extend the drainage system. This explains why the people found this a better

area to cultivate and why they located their villages on these two lines.

With knowledge of local practices and a model of the landscape, the surface of the earth as viewed from Landsat can provide indicators of subsurface water. Many additional examples of regions in Sudan can be displayed but these previous examples provide a general methodology for establishing interpretation models.

GEOLOGICAL APPLICATION OF LANDSAT DATA TO CENTRAL SUDAN

By

Shadul Ahmed Shadul*

ABSTRACT

The objective of the study was to evaluate Landsat data for geologic mapping, and particularly for updating the geologic map of Sudan.

Many parts of the country are inaccessible. The geologic work done in other areas was not tied together. The major part of the geologic studies made did not agree with one another due to the different purposes of the surveys; difference in personal opinion; or difference in the extent of detail and accuracy.

Mapping of the whole area of 2 1/2 million km^2 of The Sudan by the traditional method and available capabilities will not be completed before 20 years. Meanwhile, the pressing need for development and the exploitation and proper management of all of the country's resources requires a reliable geologic map of the country immediately.

Landsat data proved to be a useful tool in the production of a corrected geologic map of the Sudan at a scale of 1:2,000,000. It helped to correct several geologic boundaries, and revealed a number of unknown features and structures.

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PLANNING THE USE OF REMOTE SENSING FOR RESOURCE ASSESSMENT AND MONITORING

Donald G. Moore*

ABSTRACT

Landsat data offer a unique opportunity to rapidly conduct small-scale reconnaissance mapping of large regions in a timely and cost-effective manner. Landsat data are effective when used appropriately but are of no benefit and are even detrimental if used where the scale is not appropriate, where adequate provisions for larger-scale aircraft or ground data are not included, where they are not available, or where adequate planning for information needs and methods of analysis is not employed. To use the data most effectively, a general understanding of data characteristics and of planning and survey steps is necessary. This paper provides a general outline of procedures for incorporating Landsat into a resource survey/monitoring program. The procedures must be altered as conditions and information needs vary but those presented are procedures which have been successfully applied in other studies.

INTRODUCTION

Landsat data have been successfully used as a tool for large-area reconnaissance inventories for many types of landscapes. The multidate, multispectral views of the earth's surface from Landsat are generally available worldwide. The synoptic view and recent coverage features of the

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imagery provide an excellent data base for map compilation and for landscape interpretations. Interpretation of resources information from the data relies on the same principles as air photo interpretation. The useful image characteristics are tone, texture, and pattern. Advantages of Landsat are (1) the near-orthogonal viewing angle which allows uniform land surface illumination over the entire scene, (2) the cartographic accuracy associated with the high altitude of the satellite and narrow viewing angle of the sensor which reduces parallax, (3) the multispectral view, including reflective infrared (beyond 0.9 um to 1.1 um) which is not captured by film in cameras but can be captured by the Landsat electronic system, and (4) the ability to acquire inexpensive multidate coverage. These characteristics are advantageous for large-area, reconnaissance coverage since one image covers approximately 34,000 km^2. The same coverage with traditional aircraft images would require large numbers of prints. Therefore, image analysis and preparation costs are greatly reduced.

The characteristics that provide an advantage in small-scale mapping provide a disadvantage if large-scale mapping is required. The data work well at scales of 1:250,000 and smaller but have serious limitations if larger-scale interpretations are required. Each picture element or pixel is ≈0.4 hectare; therefore, if a scene feature highly contrasts with its surroundings (i.e. salt flats, surface water, irrigated crops growing in an otherwise soil moisture deficient area), the spectral analysis for each 0.4 hectare pixel can be pursued. Therefore, for specific applications, Landsat can be used for acquiring detailed information even with its synoptic regional view. This paper will not discuss the use of the

return beam vidicon cameras (RBV) of Landsat, since only limited worldwide data are available and the data are typically not used for landscape analysis, but rather for cartographic map updates.

The following sections will attempt to document the steps and time required to conduct a large-area, small-scale inventory. The procedures must be adjusted according to the region, available roads, and many other factors, but can be used as a general guide for planning. At key points in the flow charts are provided descriptions concerning management or technical decisions which must be made. If the proper planning is conducted and if the information needs are appropriate, Landsat can be a very helpful tool to accelerate timing and decrease the costs of your surveys. If these conditions are not met, the project may be very frustrating.

The survey needs are assumed to be a 1:500,000 land resources inventory of ≈200,000 km^2. It would be an integrated survey of vegetation, soils, surface water hydrology (including surface drainage), and surficial geology (both surface exposed structures and surficial materials). Again, I emphasize that these procedures must be tailored to the particular location and personnel. However, they have been previously used for inventories and provide an initial planning base for your use.

GENERAL PROGRAM STEPS

The steps for the inventory can be grouped into four major categories as listed in Figure 1. Each of these steps has many work statements which must be planned individually and often fall within the timing of a previous category. Time required for the survey is a function of the complexity of the terrain, efficiency of field personnel, administrative support available, etc.

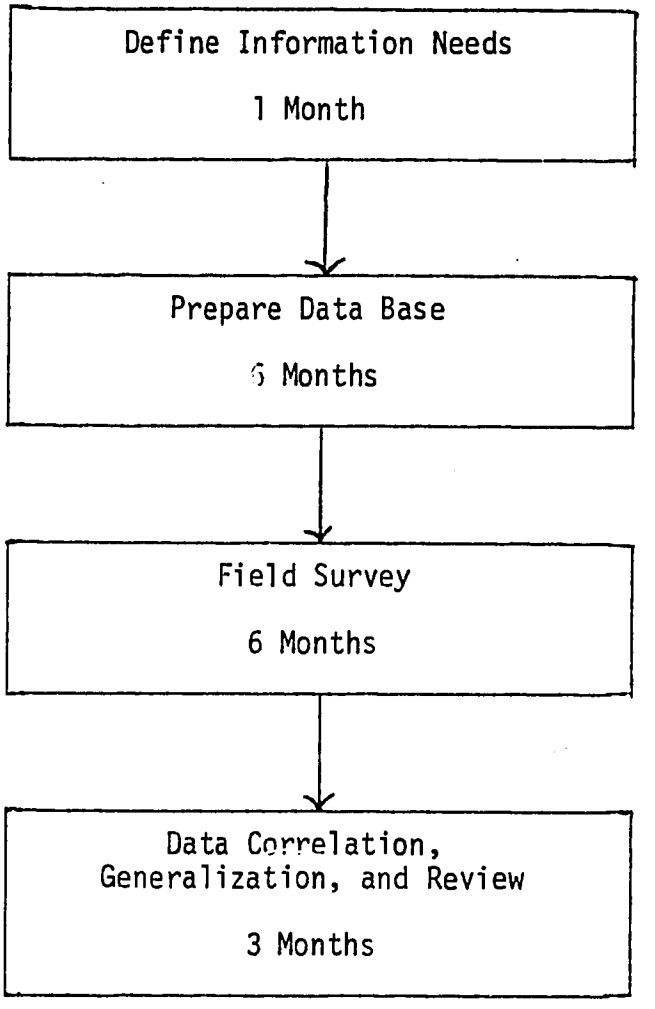

Figure 1. Major steps in resources inventory and probable timing for each step.

The definition of information needs involves necessary coordination of many sectors of government and the society. The information to be acquired must have a final use which reflects a need. This use defines the scale, legend, type and amount of ground data, and thematic products which require generation. If the need is for generalized land capability maps at 1:500,000 scale, Landsat can provide the necessary data. If the need is for counting rural housing units of a country, then Landsat can only play a small part in the investigation. An informed interpreter may be able to associate the number of housing units with the productivity of the terrain and derive a statistical estimate, but the accuracy will be a function of the validity of the correlation. However, Landsat data may provide a role in stratifying the landscape into census tracts, thus improving the efficiency and accuracy of the ground or aircraft sampling.

Preparing the data base in a timely manner and securing the most interpretable data are critical to succesful operations. Landsat data are available from the United States at the EROS Data Center, Sioux Falls, South Dakota in a variety of image types and formats. Data may also be available from a regional center in your area. The data base mosaic may require special processing and attention as defined by terrain characteristics. This will be discussed later. The important point is that an individual who has an understanding of Landsat technology and of the area to be inventoried should be involved in determining data selection and processing.

The field survey is a combination of low-altitude aircraft observations (or analysis of stereopairs of aerial photographs) and traditional field checking, sampling, and analysis. The low-altitude observation allows the

resource scientist to describe the composition of the mapping units, e.g. the percentage composition of different soils within the association, the percent canopy cover of forests, or the species of trees.

The aircraft checks update the delineations from the image interpretations. Certain landscape units may not be visible in the Landsat data but their delineation is required for an accurate inventory. Using Landsat data and topographic sheets (if available) as the base map to c mpile visual interpretations and aircraft observations works well to update the original interpretations. Landsat data are an excellent navigation guide when given to an experienced pilot.

Data correlation and product generation follow traditional techniques. The Landsat data can be printed as a map base for delineations. This allows the user to see details within mapping units which are not delineated at the map scale thus offering interpretations of resources other than the theme displayed on the map, creating interest in viewing the map, and assessing the validity and rationale for the image interpretation.

DETAILED PROGRAM STEPS

Specific work statements can be defined to accomplish the four major steps listed in Figure 1. We are again preparing for a hypothetical, multidisciplinary, 1:500,000 inventory of 200,000 km^2.

Step A: Define Information Needs

1. Liaison with potential users: Since an integrated survey can satisfy information needs for many disciplines, definite economies to scale are derived by making exact definitions of user needs for the survey during the planning stages. Having all users involved in defining the survey needs will also promote use of the investigation results.

2. Prepare legend: The legend should be a function of information required, not information that can be derived with Landsat data bases. The legend should be defined as a taxonomic system which can offer interpretations for the mapping units based on your and other experiences.

3. Determine necessary scale: The scale should be defined based upon user needs. In general, the larger the scale the higher the total costs. If detailed information is required, do not try to force Landsat data beyond its useful scales. In general, the detail on the original 1:1,000,000 transparency is that available and enlarging only makes the mapping units larger and does not provide added detail. If greater detail within the broad units derived from Landsat is required, two approaches can be used. The interpretation procedures of Landsat tied to aircraft and ground observations generate a mapping unit composition estimate which provides added detail in the form of statistics. For example, a specific soil mapping unit contains two different soils, each of which are defined and estimated. You know that a certain percentage of each soil is present but it is not documented where within the mapping unit each soil is located. If the location is important, the next level in terms of larger-scale mapping will be required. Landsat small-scale mapping can still play a very significant role even though larger-scaled information is required.

The second approach is to use the Landsat data base for the general overall survey to locate the specific areas which need larger scale mapping. The exact area is thus defined for inventory planning. The proximity of the area to roads, government facilities, flight navigation aids, etc. is documented along with the precise size and location of the area for collecting

aerial photography of only the regions in question. A stratification such as this provides an advantage for ground sampling if actual counts of livestock, people, crop fields, etc. are the necessary output. Stratification to optimize sampling using area-frame sampling techniques provides maximum efficiency and accuracy when expanding the ground sample estimates to the total population. Why count corn fields for a region if there are no corn fields in the area. Landsat data are operationally used for these stratifications.

4. Define output format of investigations: Output formats should be defined early in the investigation and adhered to throughout the investigation. If the data will be used in a specific form, they should be acquired in that form. This avoids redrafting maps and altering statistics to a usable form. The ultimate justification for a resources inventory is the use of the data. If the format of the resulting data is not readily usable, organizations will tend not to use the data.

5. Define useful thematic interpretations: A soil map has little use until the soil data are interpretted thematically as a land potential map for some specific use. For example, using the data to determine irrigability would require different soil testing than using the data for road engineering purposes. If the survey is specifically designed to locate regions with high potential for growing deep-rooted crops, field data collection efforts should be concentrated in those regions, once they have been generally located. In short, the data should be acquired spatially and thematically to yield maximum information for your needs.

Step B: Prepare Data Base.

1. Training personnel: Requirements for traditional survey personnel are well known and will not be discussed. The major training required for those who have not used Landsat data is (1) to understand the Landsat system, including data processing and enhancement techniques, (2) to adjust interpretation skills from the large-scale panchromatic or color photography to the small-scale Landsat multispectral data, and (3) to develop an appropriate procedure for taking full advantage of multidate data. Other skills such as mosaicking cartography, etc. are normally available within various departments. The additional necessary training can be provided during the first few months of the investigation without impeding the speed of the investigation. We, Visiting International Scientist Program personnel, have collaborated with many other countries on surveys and have used the first six months for training in the various aspects of remote sensing while preparing the data base providing initial interpretations as outlined in Step B. This approach offers custom photographic laboratory facilities, digital processing capabilities, interpretation equipment, and experienced personnel. If these facilities are available within your country or are offered by a regional facility, acquiring resident advisors who have the necessary background and experience may be appropriate and sufficient to fill your needs.

2. Acquire historic maps and statistical data: Prepare all historic maps as transparent overlays for the 1:500,000 mosaic. Compile statistical data in a format such that information can easily be extracted. Often these data can be summarized in a map form. It is essential to use all existing

information together with Landsat to make the best possible initial interpretation. Often historic surveys were conducted without the benefit of using aerial photography as a base map for expanding ground sample point data and thus the spatial aspects of the historic maps have considerable error. However, the ground observations and detailed descriptions provide an excellent data source for aiding your initial interpretations of the Landsat data.

3. Conduct initial aircraft reconnaissance or locate resource scientists who have been in the field for the area in question: Interpreting imagery is a process of recognizing, in a two-dimensional photographic format, those landscape features with which you are familiar on the ground. Therefore, your field experience in the area will have an impact on your ability to interpret the image. Well-experienced interpreters can transfer their observations in other areas to the interpretation of your area. However, differing cultural practices often obscure or change those image features used in interpretation which may limit this transferability. Often these cultural practices yield information on landscape differences because man normally adapts his practices to landscape properties. If you develop an understanding of this relationship, these practices as reflected in the image can be used advantageously.

4. Develop interpretation models: As previously described, we recognize in an image those landscape features which we can mentally correlate with ground features. With the advent of multispectral and multidate data, it is to our advantage to document in the form of reflectance models the various land surface features we expect in the area. For example, if we wish to assess soil color as an interpretation, this can best

be accomplished when the soils are fallow. To locate irrigated crops in water-deficient environments, acquire data when the crops have a full, green canopy and contrast with the surroundings. If surface drainage or standing water are important, acquire data during seasons when water is present. If changes in surface water are important, acquire multiseason data to maximize the difference between wet and dry. If the crown coverage of sparse forest is to be interpreted, select a season when the understory grass is dormant and the trees are in full canopy. The MSS band 5 data fall in the chlorophyll absorption band so the greater the amount of active growing vegetation, the lower the reflectance. This effect generally reverses in Bands 6 and 7. This simple generalization offers a basis for associating seasonal terrain reflectances to the Landsat image tones.

An experienced resource scientist should document the types of landscapes and vegetation anticipated (if any), should describe the phenologic stages of the vegetation, and should develop seasonal reflectance models for the mapping units he expects to encounter. These models should also document other interpretation keys on a seasonal and spectral basis, e.g. surface drainage, surface water, soil brightness, etc. The models will be used for selecting data and later for image interpretation.

If advanced knowledge of the landscape is not available, often the interpreter acquires "wet" and "dry" season data for land surfaces which have vegetative cover. Regions which are not at the equator and have relief features to be observed should be imaged at the lowest possible yearly sun elevations adding the third date of data.

The development and use of interpretation models should be described in a long book, not a section of a short paper. However, this step is

essential for optimal use of any remote sensing technique. Hopefully, this sketchy outline gives an idea of methods necessary to develop your own model. All models are site specific and must be developed for your specific area and application.

5. Assess Landsat Data Availability: Landsat data are archived at the EROS Data Center (EDC), Sioux Falls, South Dakota in an easy retrieval system. They are noted as per quality, cloud cover, date, and other necessary information. A search of all data which are archived and available for distribution for a specific area is easily procurred at no cost by specifying date, location, quality and cloud cover constraints. The type of data (MSS or RBV) should also be specified. Skylab data are also available at EDC. If data for your country are available through a regional center, you should contact them to determine what is available. The row/path system allows you to plot the approximate frame coverage on a map for indexing.

6. Acquire appropriate multiseason data: The interpretation model discussed in Step 4 should be used to define the type and season of data which will provide the greatest information. Data from at least two seasons should be obtained. Centers such as EDC provide imagery in both digital and photographic formats. Photographic products can be purchased with standard enlargement factors. The scale of their photographic products is not exact and often varies with satellite pass. Also, differences in atmosphere and sun elevation on different dates cause different image tones (and different interpretability). EDC provides standard processing, rather than scene-specific processing which optimizes interpretability for each scene. EDC has many thousands of images to process and can not

individually process data for maximizing contrast and interpretability. Therefore, a custom laboratory for photographic tone adjustment for tone-matched mosaicking and for specific tailoring of image tones to cover the total dynamic range of the film is essential. Tone matching between adjacent images allows across scene analysis of tones for interpretation and offers a cosmetically attractive mosaic for data background when publishing maps. Enhancing or "stretching" tonal contrast in the scenes allows the interpreter to detect smaller changes in actual scene reflectance on the image display. The custom photo laboratory can enlarge the images so that adjacent images are the same scale, and can control enlargement to a base map for determining the scale. If you do not have a color photographic laboratory, the custom laboratory at EDC is available and/or many other laboratories provide custom processing specifically oriented to remote sensing needs.

Digital processing is often used to display the Landsat data in its most interpretable form. Where landscapes are extremely dark or bright, the standard photographic image is not sensitive to scene reflectance changes. The data are recorded on the computer compatible tapes and can be reprocessed into an image which is superior to the standard product. Many processing algorithms have been investigated and used effectively. An experienced remote sensing specialist can help in deciding whether or not to incur the additional costs. Only a few speciality laboratories are equipped to handle such processing. Today's costs are about $3,000 per scene, which seems high but amounts to only $0.08 per square kilometer. If the step reduces field or reconnaissance flight time, the cost may be returned by increased efficiency and accuracy in the image interpretation.

7. Prepare 1:500,000 scale mosaic: The base mosaic should be controlled as well as possible with existing controlled maps. The mosaic will be used for interpretation purposes and for mapping unit delineations. Mosaics of at least two seasons should be prepared. The overlays of historic data and the field experiences of the interpretor should be used with the multidate mosaics and the interpretation model to make initial delineations and mapping unit definitions.

8. Prepare field sheets at 1:250,000 scale: The same mapping unit delineations as on the base mosaic should be transferred to 1:250,000 prints for field use.

Step C: Field Survey

1. Define and order survey equipment: The types of equipment are a function of the local area and of the specific outputs of the survey. This equipment must be ordered early to avoid delays, especially if the source is international and not local.

2. Establish testing laboratories: This again is a function of the type of data to be acquired. For reconnaissance mapping often simplistic testing methods can be conducted in the field with only a few samples sent for accurate laboratory analyses results which are then correlated to the simpler field methods.

3. Aircraft reconnaissance: The purpose of aircraft reconnaissance is to (1) adjust delineations of mapping units conducted in the laboratory, (2) assure that no mapping units which were not spectrally apparent and were consequently not interpreted from the Landsat data were omitted, (3) add delineations of map units as necessary to original interpretation, and (4) define the composition of the mapping units. Our experience

has been that a multidisciplinary team should be involved with these observations at a flight altitude of about 1,000 meters above ground level. Recent aerial photography can often replace a large portion of the flight time.

Recent Landsat data is excellent as a navigation chart for correlating aircraft position to the ground. Prints of 1:1,000,000 data should be used for easy handling in the aircraft. Approximately four hours of flight time are required per Landsat image. This, however, varies significantly with the complexity of the terrain, the experience of the interpreter of the original mosaic, and the effectiveness of Landsat for spectrally capturing the landscape on an interpretable image.

4. Ground data collection: The mapping unit distribution and composition as determined from the previous steps of the survey define the sites for ground data collection. Each major variation in components of the mapping unit should be described with detail on the ground. Samples and information are recorded according to need to allow the final interpretation. Approximately two field man weeks per Landsat scene per discipline should be budgeted. This is highly variable and depends on the location of roads, complexity of data needs, and the terrain.

5. Adjust interpretations on the 1:250,000 field sheets: Adjust original interpretations as appropriate after the aircraft and ground observations have provided new information.

6. Conduct laboratory analyses: As required.

Step D. Data Correlation, Generalization, and Review

1. Compile corrected 1:250,000 field sheets to 1:500,000 base map.

2. Prepare statistical and tabular summaries: As appropriate to describe observations.

3. Combine new data with other available data types: i.e. yield trials, borehole observations, etc.

4. Prepare thematic interpretations: A map of soils, geology, etc. is not valuable but the interpretations of that map by experienced disciplined scientists are the products desired for use.

5. Prepare a report describing methods and observations: Full documentation of procedures and results are especially required when using any new technique. Skepticism of any new technique is always encountered when individuals do not fully understand what the technique is and how it is used. Therefore, complete documentation on procedures is essential for acceptance and understanding of the final products.

6. Prepare final maps and duplicate: Maps displaying the spatial distribution of mapping units with accompanying legend of the resources or thematic interpretation maps should be printed using Landsat data as a map background. This background provides additional information to the user whether or not it is associated with the map theme.

SCHEDULING

A general scheduling of steps is provided in Table 1. Many steps must be conducted simultaneously for assuring uninterupted procedures. These are a function of the specific area, government, logistics available, etc. but are presented as a general guide.

TABLE 1. SCHEDULING OF TASKS

WORK STATEMENTS	Start	6 Months	12 Months	16 Months
Step A. Define information needs (month 1)				
1. Liaison with potential users				
2. Prepare legend				
3. Determine necessary scale				
4. Define output format of investigations				
5. Define useful thematic investigations				
Step B. Prepare data base (months 2-7)				
1. Train personnel				
2. Acquire historic maps and statistical data				
3. Conduct initial aircraft reconnaissance				
4. Develop interpretation models				
5. Assess Landsat data availability				
6. Acquire appropriate multiseason data				
7. Prepare 1:500,000 scale mosaic				
8. Prepare field sheets at 1:250,000 scale				
Step C. Field Survey (months 8-13)				
1. Define and order survey equipment				
2. Establish testing laboratories				
3. Aircraft reconnaissance				
4. Ground data collection				
5. Adjust interpretations on 1:250,000 field sheets				
6. Conduct laboratory analyses				
Step D: Data correlation, generalization, and review (months 14-16)				
1. Compile corrected 1:250,000 field sheets to 1:500,000 base map				
2. Prepare statistical and tabular summaries				
3. Combine new data with other available data types				
4. Prepare thematic interpretations				
5. Prepare final report				
6. Prepare final maps and duplicate.				

SUMMARY

All surveys have a planning phase. The planning is conducted initially with only limited information and the plan must be altered as the survey progresses. Effective planning is the key to successfully completing an inventory in a timely and cost-efficient manner. Frustrations develop when appropriate planning was not conducted. Plans and schedules are a function of many variables so they are only general guidelines. The plan presented in this document is only an outline of the major considerations necessary for a successful inventory. A well-coordinated group of experienced specialists can change the initial plans as necessary to complete the survey.

GENERAL PRINCIPLES OF APPLICATION OF REMOTE SENSING IN URBAN AND REGIONAL PLANNING

Mohamed El Hadi Abu Sinn*

I will discuss the use of remote sensing in urban and regional planning. I intended to introduce a new element in this study by introducing the cultural landscape, that is to say, the features which are normally put on the land by man. It is well known that is a very dynamic phenomenon and that urban center towns will exist in a very few years. Irrigated agriculture will be coming in a very few years and therefore will present very serious problems to planners because of the speed of change. The planners must act very quickly to follow up on these changes which are normally very swift. These problems can be summarized as follows: 1) how to detect the changes in land use patterns at either the regional or the urban level, 2) the magnitude and direction of that change, and 3) the socioeconomic impact of that change which is really the core of the whole setup.

Planners actually need very accurate and up-to-date information about these changes. But for what objective? The basic objective is effective land use decision. Unless there is accurate, up-to-date information, one cannot follow the land use changes and assess the trend of the change in terms of time, in terms of area, and in terms of money.

The last and very important thing is the ability to establish a model for the prediction of the land use and the use of the resources. This is

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emerging from two major points: (The dynamic or increasing rate of population, particularly in the third world countries, and (2) the increasing needs of these populations. In the past planners detected or acquired this information by what we call the "traditional" means of acquisition of information. "Traditional" methods, however, continue to be very important and supporting elements because sometimes some information cannot be acquired without them. For example, "traditional" methods are valuable for assessing population dynamics population density, housing, and transportation.

Historically, aerial photography was a breakthrough in the acquisition, storage, and presentation of information at regular periods of time. Landsat is a second major breakthrough which has proved to be very essential for planning purposes. Landsat data provide a very fast tool for the detection and monitoring of change. It is a system that acquires and transmits information to certain ground stations in such a way that there is a continuous flow of information at regular intervals or when needed.

A very important contribution of Landsat for planning is that it shows an area or a city within the regional context, which is very essential. You cannot plan by studying a single point. Rather you must look at the city as a component of a set of variables; this is the kind of data that Landsat supplies to us.

Thus the regional context of Landsat for planners is very essential because, definitely, the interest of planners is to minimize the land use friction in a way which meets the first objective stated. One of the drawbacks of Landsat, particularly in the area of urban studies, is that individual objects cannot be clearly detected because the area of a Landsat picture element (pixel) is 0.4 to 0.45 hectare. Thus, it is impossible to

detect single houses or single trees. It is also difficult to study features which cannot be seen or do not have a detectable signature on the image.

A lot of work is done in the area of enhancement. One of the enhancement procedures improves the quality of the photographic product by stretching the tones of the area in which we are interested to cover the full tonal range, thus providing more contrast among the different scene features. However, the enhanced product does not provide increased resolution for details such as single houses and trees.

There are usually two or three features which you need to identify to detect the trend of change in an urban setup. There are features which can be detected from Landsat imagery, such as aggregates of commercial areas, industrial areas, residential areas of different classes (1st order, 2nd order squatter settlements), and recreation areas.

The second feature which can be recognized on Landsat imagery is urban land use changes, that is to say the encroachment of the built-up areas into agricultural land. For example, you can recognize an area that was a forest and then cleared for industrial expansion.

Some of the important features which may be indirectly detected from Landsat imagery are: house quality, density of population, and ethnic structure. All these changes may be identified by association. That is to say, if you have a residential area of a specific tone or signature on the image you can identify this as a 1st class, 2nd class, new or squatter settlement. So, by association you can have an idea of the income of the people. If an area can be identified as a squatter settlement you can conclude from this that this is a low income area.

It should be borne in mind that it is very important to collect some ground truth for the verification of interpretation. But the use of Landsat

imageries might minimize the extent of data collection. For example, if one is investigating the income standard in Khartoum, th- use of Landsat imagery will minimize the cost and time required to make a survey on income or quality of housing. The detectable features could be identified in the image by spatial characteristics of pattern, shape and texture. One can identify, for example, an industrial area by the pattern of the buildings and the high reflectance from a large built-up area. A new residential area appears gray on the image because of teh sparse vegetation cover.

There are two ways to detect land use changes within the regional concept. The first one is the rationing method, which compares imagery of the same area for different dates to see whether the urban area is horizontally expanding and encroaching on agricultural land. Another method is the digital method in which image data for each date are computer-classified. The classification results are then compared and analyzed for both the extent and direction of change.

The possible uses of the Landsat products resulting from after these techniques include: (1) a map of land use changes, both urban and regional. A map indicating the changes and the direction of these changes at regular intervals can be prepared so that the necessary actions can be taken accordingly. (2) a time dimension map showing how much change has taken place at various time intervals. This is one of the advantages of Landsat, i.e. supplying a continuous flow of information. (3) tabulating the aggregates of spatial changes which took place in the study area. So if a change map of The Sudan is drawn from Landsat imageries, it will be readily apparent which region is experiencing the most rapid change and planning can take place accordingly.

An important aspect is the spontaneous detection of hazards like the Gezira flood, and the impact of that hazard in retarding development.

Finally, one might review the value of the end product to users. There are many agencies and individuals at different levels that would be very much interested in this end product. At the single city level, for example, this end product is very useful for detailed analysis and for assessing the urban economy, the urban ecology, and the urban environment. We can also obtain information about the spatial extent of a city's growth whether it is growing vertically and/or horizontally, and what is the impact of this growth on transportation and on the encroachment over agricultural lands. Going up a step from the city to the regional level, Landsat data are valuable for obtaining an overall picture of the region.

Finally, at the national level, the National Coordinating body can use this end product to construct a model for future planning. Thus, at all these levels Landsat data are valuable for planners. However, one must keep in mind that ground truth is very essential and that a balance must be maintained between remote sensing and "traditional" methods.

KHARTOUM AREA EXAMPLE OF URBAN AND REGIONAL PLANNING USING REMOTE SENSING TECHNIQUES

Yagoub Abdalla Mohamed*

Looking at a town, any town which is the consequence of interactions between physical factors and cultural-historical factors, the satellite images or air photographs provide dependable, as well as economic resources and also quick, obtainable information. Looking at the three towns of Khartoum, Khartoum North and Omdurman, you cannot appreciate the morphology of a town unless you view its historical development, its colonial history or the computed history.

Looking at the pattern of Omdurman one can see that it was influenced by its history during the Mahdia period. The streets and the planning of the town during that period affected its growth.

Khartoum, contiguous to it, is a new town. During the colonial time the diagonal grid pattern of the streets was laid out and later the railway provided a kind of ringroad south of the town hindering its growth southwards.

By simple visual interpretation of Landsat false color composites of the Khartoum region, we can derive certain information from the image; you can see the physical limits of the town, the Blue Nile, the White Nile, the green belt, the agricultural areas, and the Sunt forest to the west on the flood plain of the White Nile.

After scanning the general features, we move point by point. First, we have to know something and then understand it. You can locate the airport and the features associated with the airport in that area such as the buildings. Then also we can see the built-up areas. Some areas are red

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indicating vegetation. In Khartoum the vegetation is mainly within the eastern section of Khartoum, in the Hai El Matar area, and the first class area to the south. In these areas the people who are economically well off can afford to grow trees, which are easy to identify in the Landsat imagery.

Thus, we start by studying the image point-by-point, beginning with the obvious features and progressing to the unknown ones. By this method, you can obtain information about the general direction of growth using Landsat imagery.

What factors influence or limit the growth of a town in a certain direction? For many years the airport was a kind of barrier to growth. Of course people now have moved to these other areas beyond the airport.

The green belt may also provide another barrier to expansion. We know that as a result of squatter shanty towns, people are now living beyond the green belt and as I mentioned earlier as far as the Sunt forest to the west on the flood plain of the White Nile. The same thing also goes on with Omdurman and Khartoum North, and you can see the direction of growth. The growth of the shanty towns is evident at the edge of both towns. Of course with the advancement of these squatter settlements, the original city of Khartoum is not just expanding outward to its surrounding area. The town is interacting with its surrounding area. There is high demand for housing in densely populated areas and people are therefore encroaching on agricultural land. In a number of areas there has been a change from agricultural land settlement areas.

Other features which you can detect from Landsat are the aggregates, residential areas, industrial areas and the agricultural areas to the east at "Hillat Kuku" village and "Belgravia" dairy farm. Moving from the

general idea about the aggregates (industrial, commercial, etc.), we must move further to the vegetative aspect. Of course you can associate a settlement with green vegetation. Vegetation may indicate that a residential area is a high class area. It is very important to identify the various types of areas; to be able to locate the high classed areas and the low classed areas, second classed areas, and shanty towns. It is also very important to supplement and complete the picture of Landsat. If advanced techniques are available, such as the "Image 100" and computer compatible tapes, they will also provide additional information and dimensions to the study of urban growth. (Figures not available.)

CLOSING SESSION ADDRESS

Dr. Ibrahim Hassan Mohamed*

This is the final session of this symposium and workshop. It has been a successful one, and for that we thank the US/AID and the staff of the Remote Sensing Institute, SDSU, Dr. Moore, Dr. Morain, Mr. Andrawis, and Ms. DeVries for their participation and assistance in this workshop. Indeed, I think we have acquired a good knowledge and background of this new technology. The technical papers were very illustrative and showed us the benefits of space technology for the survey of natural resources. The speakers illustrated how we can interpret the different imageries which will be provided from the National Remote Sensing Center at NCR. These imageries that have been provided by RSI through US/AID are available for anybody wanting to borrow them and will be located in the documentation center of the NCR. I hope we can put them in a final binding so that anybody can look at and borrow the series of imageries needed.

I also thank the participants, the instructors, the Sudanese scientists who participated in the preliminary course before this workshop and also in the workshop, for the fruitful discussion along with all the participants from the different departments, units and universities.

To conclude, I am going to ask the representative of each of the different four groups to give us a brief account of the practical exercises, their evaluation of the workshop, what they think for further future planning, along with any other suggestions and recommendations. Before presenting the four heads of the groups, may I ask Dr. Moore to give us a brief account on his views on this workshop.

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FAREWELL ADDRESS

By

Donald G. Moore*

On behalf of Mary, Stan, and Amazis, I would like to thank NCR for being an excellent host and for cosponsoring this workshop. Our sincere appreciation is extended to the U. S. Agency for International Development for their participation in and sponsorship of this collaborative project. To the Sudanese speakers, you have presented your evaluations of Landsat technology and have served effectively as team leaders in your respective disciplines very well. I personally charge you with continuing your role in transferring this remote sensing technology to your peer scientists in your respective departments. To the workshop participants, I can truthfully say that you have been one of the most eager and informed groups that we have ever worked with in a workshop. If our explanations were not in sufficient detail or clarity, you immediately asked questions or provided comments to establish further discussion. It has been a pleasure working with you. I hope you feel you have benefited from the workshop as much as we feel that we have benefited from the past two weeks. As you know, part of our team visited the Soils Department at Wad Medani. We found them to be just as enthusiastice and receptive as you have been.

For many of you, this has been your first acquaintance with satellite or Landsat remote sensing. Most of you who are resource scientists have an

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excellent working knowledge of air-photo interpretation and use. The interpretation of small-scale data from satellite uses the same principles as interpreting large-scale data with which you are accustomed. There is no magic to the interpretations. Many use fancy machines and "mystical" approaches. As you have seen throughout the workshop and in your working groups, these fancy and expensive techniques are normally not required to extract useful information from the data. What is required is to have a carefully prepared Landsat data product in the hands of a skillful interpreter who is knowledgeable about the terrain. The Landsat products for almost complete coverage of The Sudan are available through NCR and you are the most qualified experts on Sudan to conduct interpretations for The Sudan. If you need any help, the Sudan scientists who were at RSI or other institutions for training are locally available to discuss your specific applications and interpretations. Please use their experiences for your benefit.

Keep in mind that Landsat is a tool for your use in acquiring information for which you and the Government of Sudan have a need. Landsat is at a satellite altitude and the data are small scale. If you have needs for information at large scale, Landsat is not suited for your application except perhaps to make stratifications for large scale sampling. Do not try to force the data where the data are not suited. If you need data at small scales over large regions, Landsat is the best available data source at this time. After you have fulfilled all of your large area, small-scale mapping needs, future generations of satellites promise data which will be useful at a larger scale than Landsat provides. Satellite remote sensing is only in its infancy and the next few years should provide us with the benefits of improved spatial, spectral, and temporal resolution.

My final comments are to urge you to evaluate the Landsat data in your programs. Do not rely totally on Landsat data to acquire your information; for disbanding traditional techniques for another technique, that of Landsat, without a thorough evaluation within a specific program would be "fool hardy". Evaluate Landsat within your existing program to determine what information you can acquire that could not feasibly be acquired using traditional methods and what traditional techniques are replaced concerning cost and accuracy comparisons of both systems. Use techniques such as those presented in this workshop. Do not give up after looking at one band at one scale for one date. You have many data types available through NCR. If you need help in interpretation or in determining the appropriate data, ask one of the Sudanese who have had more experience than you for their advice and comments. You, the administrators and scientists of The Sudan, have a responsibility to acquire and use scientific information for an extremely large country. Landsat and other remote sensing data may help you, if the tool is used properly, in your service to the People of Sudan. Again, thank you for allowing us to share with you an excellent workshop.

CONCLUDING ADDRESS OF LAND USE AND VEGETATION GROUP

Yahia Bushara*

I would like first to thank the National Council for Research for arranging this workshop, and the Remote Sensing Institute of South Dakota State University for initiating the program, training some of us, bringing all the materials, and presenting several lectures which we have attended.

Speaking about the pre-workshop training course, I believe everybody was enthusiastic and attendance was full. There are some points which we should not miss. Some shortcomings actually existed because the pre-workshop training did not have a specific program for lecturing about vegetation, geology, or other disciplines. There wasn't much coordination and material available so that the training was theoretical with very little practical handling of the imageries, photographs, and instruments. The color additive viewer (I^2S) is still not functioning properly and we hope it will be fixed and will be available for all of us to use.

However, regarding vegetation and land use, I believe that a good introduction was given to the group during the pre-workshop training course. Later, almost all aspects were fully covered by Dr. Moore, Dr. Morain, Ms. DeVries, and Mr. Andrawis from the Remote Sensing Institute. As you have all seen they have beautiful and explanatory slides. I think everybody gained by the good experience and we now have a good idea about remote sensing.

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One point one may stress is that it is always wise if you are doing remote sensing and working with an image which covers a very large area to have people with more than one specialization work on that image. A multidisciplinary team investigating one area is more efficient than a one discipline approach, such as one doing vegetation studies only or some other specialist doing only a soil survey.

Moreover, field checking always brings up many points when there is more than one specialist. They discuss problems which arise and try to solve them using a multidisciplinary approach. Preparation of a map for representation of the land surface can be made by many specialists in different disciplines much better than by one scientist in one specialization.

CONCLUDING ADDRESS
SOIL SURVEY GROUP

Abbas Doka*

On behalf of the Soil Survey Administration at Wad Medani and the Soil Group, I would like to express our thanks to the National Council for Research (NCR) and in particular to Dr. Ibrahim Hassan for his great efforts before and during the symposium. Many thanks are extended to Dr. Donald G. Moore, Dr. Stanley Morain, Ms. Mary DeVries, and Mr. Amazis S. Andrawis for their valuable lectures and discussions. Also, I would like to thank them again for their visit to Wad Medani.

The Soil Survey Group attended a two-day workshop organized by the Soil Survey Administration in cooperation with the NCR and the Remote Sensing Institute, South Dakota State University. During this time valuable lectures were given, followed by a very interesting study tour, ending with a short visit to the Gezira Scheme Headquarters at Barakat.

Although there were valuable discussions and comments during the two days of the workshop, we did not have enough time to come up with final recommendations. Nevertheless, I will summarize the discussions and the comments agreed upon by the participants:

1. A library containing all publications pertaining to remote sensing and its applications should be established at the Remote Sensing Center at Khartoum.

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*Soil Survey Administration, Ministry of Agriculture, Food and Natural Resources, Wad Medani.

2. The Soil Survey Administration is about to complete the generalized soil map of The Sudan using Landsat data; this is a good achievement which is highly appreciated. Such a vital effort should be supported by the National Remote Sensing Center when established and should be given top priority.
3. Facilities and equipment should also be available at Wad Medani to help the different departments in applying remote sensing techniques, such as simple equipment for visual interpretation (a considerable number of departments are now using Landsat imageries).
4. In-depth training for all the soil scientists who are applying remote sensing is essential to help them in soil surveys and particularly in conducting the regional soil mapping aiming towards a soil map for the whole country.
5. The symposium and the Soil Survey Group workshop was very useful. The lectures were informative and the discussions were interesting. The multidisciplinary and interdisciplinary scientific background of the participants is very much appreciated and it should be emphasized on any future study or conferences on remote sensing.

Thank you.

CONCLUDING ADDRESS

WATER RESOURCES AND SURVEY GROUP

By

A. Rahim A/Aziz*

I would like first to thank the NCR for looking after the training course, especially under such conditions when the center is still not yet established. I do realize that it is very difficult for somebody before being established in the basic requirements for the center, say at least to have offices and with such a start. This is greatly appreciated and I think that Dr. Ibrahim has done a good job for motivating this start.

Secondly, I should like to thank the staff of the Remote Sensing Institute of South Dakota State University for the training we had during our stay for six months there. Even though it was a very short period of study for such a field of science, they did a lot in giving us many lectures in different disciplines, and still till now we have many contacts with the staff in different fields to follow the progress and receive the latest literature in the field of remote sensing.

As for the training, I think it is a good start for introducing the science of remote sensing. Based on my moderate experience in remote sensing, I found that the application of remote sensing is of great help for one's field of interest or discipline. For example, in the field of soil science, forestry or water resources, it will give many chances to evalute one's knowledge and to deal with a newly advanced science with respect to his own field.

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* Hydraulic Engineer, Rural Water Corporation, Khartoum

Of course, I can not say the training was ideal because of its short period, but at least it gave us a good introduction to the field of remote sensing and one can extend his interest by reading the literature and studying the available imageries.

As for my recommendations, it is too difficult for the time being to say exactly what is the necessity. Unless we establish a proper center for remote sensing I cannot say much except some recommendations for immediate necessities. For example, if we can ask for color composite images (MSS) coverage for the area between 10°N and 18°N latitudes for the time being since this is an area of immediate development for Sudan. If we can have the coverage by the time we have an established center for remote sensing or at least extend the training course with the workshop to have such coverage especially for the participants to extend their interpretation in their different fields.

Secondly, I think some basic photographic laboratory equipment is necessary. For example, image enlargement equipment, and some flexible arm ring magnifiers. I think these are important until we have an established center. After the establishment of the center I think many recommendations will arise.

CONCLUDING ADDRESS
GEOLOGY GROUP

Shadul Ahmed Shadul*

In fact in our section, I feel it might be good if the participants would give their own opinion about the course and the workshop. It might be good even for the other participants to give their opinion other than these summary statements.

I feel by this workshop two goals have been achieved: the first is to introduce this new technique of remote sensing to all natural resource scientists; second, is to bring together different scientists from different natural resource disciplines to work together. This is a new type of approach to solve natural resource problems. An example may be one natural resource problem as desertification or any other topic. By putting the thoughts and efforts of all different scientists as a group, the approach might help a lot in solving our problems by looking at the problems from different angles.

Another aspect of remote sensing is this new technique of remote sensing using Landsat imagery only recently introduced and we would like to extend the knowledge of this technique even to a lower standard. This technique might be given not only to scientists from different disciplines of natural resources but even at the secondary school (high school) level because this new technique is frequently mentioned

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in the media; on the television, the newspapers. We would like everybody to have some idea about this new technique so as to follow what is going on, the applications of this technique, and then try to make use of it.

We feel in the field of geology that it is very helpful for us here in The Sudan because we have a very large country and can not cover it with our traditional methods. There are several remote areas that we can not work in under the present conditions, such as the vast desert to the northwest, and the jungle in the south which is not safe to work and to examine each type of rock. We have limited funds and limited manpower to work at this time, so we need a lot of time to survey the whole country. By using this technique, this will minimize our field work and our main job in the field will be limited to the checking of certain locations in our Landsat interpretation. This will give quick results and that might help in future planning to make a detailed study in complex areas, difficult areas, or areas of interest.

In the Geological Survey Administration we have about 40 scientists and geologists that are trained in remote sensing. We were trying to establish a separate remote sensing unit in our department, but we feel that it might be more useful if we can have a National Remote Sensing Center under the NCR to serve all interested departments, which will bring together scientists from different disciplines, making available to them all the necessary equipment and material, and to provide a place to give a short training course and to work together in groups. This would be of much help and would minimize our spending in such a unit rather than having a unit for remote sensing in every department.

The plan is to establish a central remote sensing center to serve all disciplines. We will support the efforts and cooperate together in starting a remote sensing center until it is well established and carries fully all its responsibilities.

This remote sensing symposium and workshop is a good start for a further effort. It might not be an ideal thing but it is a good start and we hope that it introduces the technique and brings all of the interested scientists together. Communication is getting easier between the different departments as all of them now speak the same language. This is the first step for establishing this center. I hope that soon we will see this center going steady and well established.

CLOSING ADDRESS

Dr. Hassan Mohamed Hassan*

On behalf of the National Council for Research and on behalf of the Sudanese participants, whether lecturers or students, we wish to thank those from very far away who offered a helping hand in giving this very wonderful experience and very nice and well organized workshop with the limited capabilities we have. I think it is a great experience and with one, very important, element which Sayed Shadul touched upon, is that if this workshop has done nothing more, it has at least brought us together. People of all different disciplines working on a common goal, that of understanding remote sensing. This was almost impossible to do without this workshop. So on behalf of the National Committee of Remote Sensing which has been as an ad hoc committee for a long time, trying that we could bring about something like this. This is the first symposium and workshop we have put together and it is a very good experience for us, even putting together a lecture. I think all concerned did a very good job and should be complimented.

The general assessment of the workshop; I think it was a very good experience and I think people learned many things, both the students and the lecturers. Everybody heard different things we never knew before and we saw something we never hoped to see in a country like ours. Anyway, as a general assessment of the workshop, I think it was a very good experience and we have learned a lot.

---

* Director, Surveys Department, Khartoum.

The I^2S instrument was assembled for the workshop and some of the students have used it as well as some of the staff. It is not a secret to say that this instrument has been in Sudan for almost two years. This is the first opportunity for the instrument to be actually used, so I think there have been several benefits from the workshop other than giving lectures to people and giving them new knowledge.

From the cartographic point of view, for me being the Director of Survey, we have expressed cartographic activities a lot and we have shown what we have in The Sudan in the field of cartography. We have also shown them what we need in Sudan and I think every participant here from different disciplines was interested to know about cartographic information. I think again this is another benefit of the symposium that people knew what kind of mapping was available and what the necessary steps are to conduct this mapping.

In this respect I would like to say something personal - this is maybe my last day as the Director General of the Survey Department and it may be tomorrow that I will be a lecturer in the university. So being a lecturer in the College of Engineering and Architecture I think we have already started a regular course of remote sensing in the four year curriculum of the B.Sc. degree in surveying. So, I think and hope, other departments in the University will follow the same. We hope through the Department of Surveying, at the University of Khartoum, we will promote remote sensing in the other departments of the university.

I should like to say a few words about the National Remote Sensing Center. It has been almost two years now working on this idea, talking about it, and I should like to say that the dream has come to reality and we expect very soon, maybe before the end of this year, that we will start putting down the instruments, and sit down and do some work. The project document is already out. The financial support, which is the most important part is already out, and this symposium of ours, a similar symposium, has put together the technical staff which we could use from all the different disciplines from all the different departments. So I don't think there is any problem with starting the National Remote Sensing Center and hopefully before the end of the year, or maybe in the beginning of next year we will have a National Remote Sensing Center. The experience we gain from this workshop will give us better workshops and better symposia to come.

In this respect I would like to thank Dr. Moore because he willingly has accepted to take the project document of the NRSC and look at it and give us his opinion as to the contents of that document and we hope very soon to hear from him. We hope that very soon that the United Nations will be in action, and we will be in action.

We were hoping and this might be very good news for the participants to give a short exam by the end of the workshop. I would like to announce that it has been decided that our people here are responsible enough. They have learned a lot and do not need exams, and we do not need to know more than that they already have learned a lot.

I would like also to mention that though you are not given exams, you will get certificates, and Dr. Moore and his group have accepted willingly that they are going to give each member of the group a certificate stating that he has participated in the remote sensing workshop in Sudan.

The real assessment of the workshop is not our idea. We have been working in remote sensing for a long time and we know that you gained a lot, but the real assessment is from you, from the participants, how much you gained in this one month and half of experience. It is a very short time, with very limited resources, but still I thank all the lecturers and demonstrators. I think all of us tried to give what we have and we hope that we did give it in the right way. That is why I will give the floor to two of the participants to comment on what they learned, what they think went right, and what they think went wrong.

Moawia El Badawi, Soil Survey (Participant):

I think it was a very good experience. Right from the beginning I noticed that there was a lot of overlap in the lectures, so I might say it lacked coordination between the lecturers who taught us in the pre-workshop. But again I expected to do a lot of manual work, but unfortunately I found that most of the information we had was limited to the theoretical part. These are the main points I wished to point out.

Musa Al Ahmar, Forests Department (Participant):

It was noticed that all participants in the pre-workshop and the workshop courses attended punctually and with great enthusiasm. Everyone had the willingness and desire to learn about remote sensing.

We received plenty of papers, and took a lot of notes, all of which we read carefully and understood.

The first remark was that we did not have much practical work. We did not practice working on all of the instruments we learned about. If we had

had all these instruments available, and practiced working on them, we could have benefited more from what we learned from the lectures and the notes.

The second point is that the course was too short. The whole course lasted for forty days, during which we had the pleasure to attend and learn about remote sensing. We were hoping that the period of the course will be extended so that we can get more knowledge and more experience.

We also hope that most of us will have the chance in the future to go abroad to attend more advanced courses on remote sensing.

Dr. Hassan Mohamed Hassan:

I think that these two participants represent the group very well. I am sure that the time was very short and we were in need of instruments. We have tried to put together these instruments for demonstration and most of the group did see the instruments, but the time was so short, and there was a lack of facilities to give everybody a practical training. But as I said, this is the first workshop and we expect that in other workshops the people will be more involved. It is expected that when the participants go back to their particular departments they will get more involved in remote sensing. When the Remote Sensing Center opens, its doors will be open to everybody. It is a national center for remote sensing. It will be open for any department, and any interested person to come and do his work. That is why we are interested in having this center in the National Council for Research, because it will be an impartial place for anyone in any discipline to come and do his work.

Finally, I would like particularly to thank the visitors from the Remote Sensing Institute, South Dakota State University, Dr. Donald Moore and his

group, for the very precious time they spent with us. We all really enjoyed it. We had a very nice experience; we have seen lots of things we have not seen before, and we thank them for their time they spent here in Sudan. We hope that The Sudan has given them the welcome they expected. I thank Mr. Amazis Samuel who participated with both the Sudanese and Americans.

I thank them again for participation and I thank them for publishing the proceedings of this symposium, and I hope to see it on the shelf very soon. Once again I thank Dr. Moore for looking at the project document given to him by the National Council for Research.

I would like to thank U. S. AID for the financial support and all the help they extended to us.

I would like also to thank all the Sudanese departments for participating in the symposium and the workshop and for giving their participants free time to attend this wonderful experience and we hope that we will return back to our departments with a little more knowledge and be a little more useful to them than we have already been.

I would like to thank the University of Khartoum for giving us this place, and for the place for the poster session.

Last but not least, I would like to thank the participants because without them we would not have had a workshop. I think they did a very good job, especially for the attendance. I have never seen a group so punctual in my life. This shows their interest in remote sensing. I thank them for being so punctual, so interested and so cooperative, and I hope that they will get more chances for more participation in remote sensing either inside or outside the country.

Finally, I thank all of you and declare this meeting adjourned.

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PROCEEDINGS OF SUDAN SYMPOSIUM AND WORKSHOP ON REMOTE SENSING

October 1980

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حلقة دراسية للاستشعار من البعد

انعقد صباح امس الاول بمجلس الابحاث العلمية والتقنية اجتماع اللجنة المشرفه على تحضير حلقة فى مجال الاستشعار من البعد .

وذكرت مصادرنا ان اللجنة توصلت الى اقرار البرنامج الذى اعده مجلس الابحاث العلمية لقيام حلقه تدريبية لاستخدام تكنولوجيا الاستشعار من البعد لدراسة الموارد الطبيعيه تستغرق اربعة اسابيع تبدأ من اول سبتمبر القادم .

يجئ هذه الحلقة التدريبية فى اطار استعدادات المجلس القومى للبحوث بصفته مركز قومى للاستشعار من البعد . وصرح مصدر مسئول بمجلس الابحاث العلمية والتقنية التابع للمجلس القومى للبحوث انه فيما يتعلق باستخدام تكنولوجيا الاستشعار من البعد يقوم المجلس القومى للبحوث بالتعاون مع هيئة المساحة الامريكية بالاعداد لتنظيم هذه الحلقة التدريبية لاستخدام تكنولوجيا الاستشعار من البعد فى الفترة من ١ر٩ الى ٣٠ر٩ وحتى ١٠ر١٠ فى ١٤ر١٠ر١٩٧٩ على التوالى .

ويقوم بتنفيذ هذه البرامج معهد الاستشعار من البعد بجامعة داكوتا الجنوبية بالولايات المتحدة الامريكية ومعهد الدراسات البيئية بجامعة الخرطوم هذا وقد بعث المجلس القومى للبحوث الى المصالح والوزارات والهيئات ذات الصلة بترشيح من تراه مناسبا للاستفادة من هذه الحلقة الخاصة بعمل استخدامات تكنولوجيا الاستشعار من البعد هذا وكانت جامعة داكوتا الجنوبية بالولايات المتحدة الامريكية قد شاركت بتدريب بعض السودانيين فى هذا المجال سيسهمون فى تدريس حوالى ٢٥ دارسا من السودان بالاضافة الى بعض الدارسين الذين يمكن استقبالهم من بعض الاقطار المجاورة والتحدث باللغة الانجليزية ..

Desert Encroachment

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REMOTE SENSING FOR MONITORING SOIL RESOURCES AND AREAS AFFECTED BY DESERTIFICATION IN CENTRAL SUDAN

Abbas Doka M. Ali*

ABSTRACT

An integrated study using Landsat data for monitoring areas affected by desertification in Central Sudan (Figure 1) was proposed as a framework project for six Sudanese professionals who attended the training program at the Remote Sensing Institute, South Dakota State University, U.S.A. The training program was part of a joint effort between the Agency for International Development (AID) and the National Council for Research (NCR), Sudan, with the objective of establishing a Remote Sensing Center in Sudan. This study demonstrates the value and use of Landsat imagery in mapping soil resources in Central Sudan.

The study first broadly outlines the major landscape units and describes the climatic zones and their relation to the geographic setting. Next, the study was divided into two parts. The first part describes the soils, their limitations and potential for agricultural development. The second part shows how areas of high soil blowing potential can be located and how stabilized and active sand dunes can be identified by using Landsat imagery. With this perspective, the study provides basic information on the land resources and the physical environment which so greatly affect the land use of Kordofan.

The area was divided into five climatic zones, from the dry desert in the far north to the dry monsoon climate in the southern part of the Study

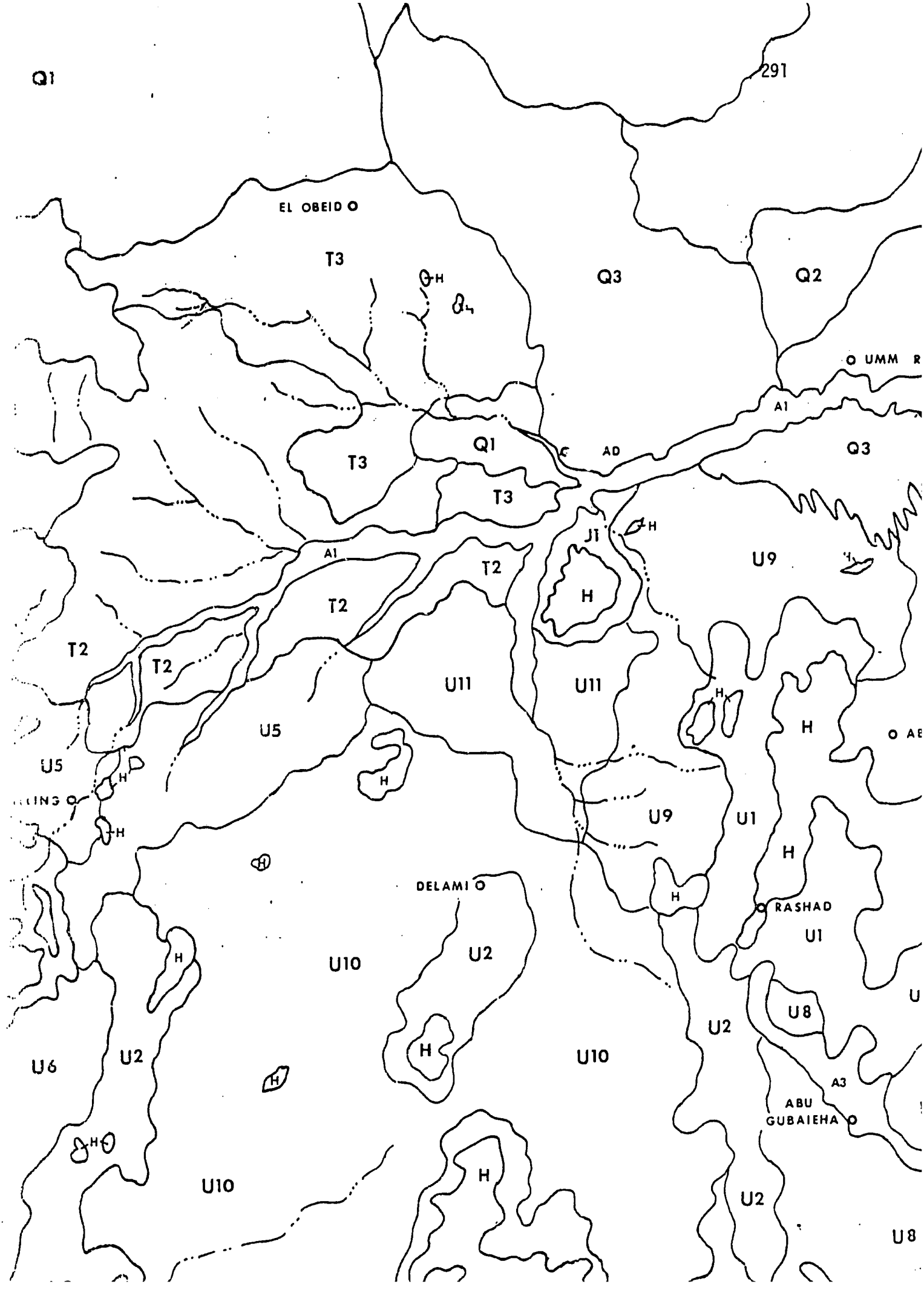
---

* Soil Survey Administration, Wad Madani. Report prepared while in training at the VISP at RSI.

Fig. 1. Central Sudan, Remote Sensing for Monitoring Soils for Desertification Study. Original scale of 1:1,000,000 covering region between 11°00'N - 16°30'N latitudes and 28°30'E - 32°30'E longitudes.

An example area of the map at the original scale is on the following page. The original map is available from the author. The map Legend is:

MAP SYMBOL	LANDSCAPE UNITS	NUMBER OF COMPONENTS PER UNIT	UNIT AREA IN FEDDANS
N	NORTHERN PLATEAUS AND PEDIPLAINS		
N1	Rocky Plateaus	2	1 313 361
N2	Piedmonts	3	4 508 440
N3	Sandy Plains	2	4 540 697
N31	Sandy Pediplains	2	1 668 199
N4	Rocky Lands	2	2104 450
N5	Reg Areas	3	3 986 167
N6	High Dunes; Semi-desert	1	1302 608
N10	Wadi El Milk Basin	2	1 866 355
N12	Wad. El Muhbes Basin	2	2119 811
Q	SANDY OOZ LANDS		
Q1	Sand Sheet and Low Dunes	2	5 353 291
Q2	High Dunes; Arid Climate	1	6162 814
Q3	Longitudenal Dunes	3	1121 349
Q4	Transversal Dunes	1	763 439
Q5-Q51	Sand Dunes and Clay Plain Complex	1-2	1632 868
Q6	Babanusa-Khawi Sandy Peneplain	2	688 170
Q61	El Nuhud-Abu Zabad Plateau	2	460 828
Q21	High Dunes; Semi-desert	1	1604 291
T	OOZ TRANSITIONAL (DEFLATION) AREA		
T1	Wadi El Gallah Basin	2	1658 582
T2	Khor Abu Habil Western Basin; Sandy	2	1394 774
T3	Khor Abu Habil Northern Basin; Loamy	2	82 380
U	NUBA UPLANDS		
U1	Jebel Piedmont Outwash	3	866 357
U2	Dissected Plateaus	3	1552 992
U3	Talodi Peneplain	2	233 486
U5	Dilling Upland Plain	2	292 625
U6	Lagwa-El Berdab Plain	3	2 465 432
U8	Eastern Intermediate Clay Plain; Undulating	4	2463 896
U9	North Eastern Undulating Clay Plain	3	698 923
U10	Habila Clay Plain	3	2698 919
U11	Jebel El Dier Clay Plain	1	399 384
L	FLAT CLAY PLAINS		
L1	Eastern Flat Clay Plain	2	3 821 804
L2	Southern Clay Plain; nearly Flat	2	215053
A	SEASONAL WATER COURSE ALLUVIUM		
A1	Khor Abu Habil Flood Plain	3	1413207
A2	Wadi El Gallah Flood Plain	2	27649
A3	Southern and Eastern Flood Plains	3	642 087
R	RIVERAIN LANDS (WHITE NILE)		
RN	White Nile Flood Plain	2	153 609
RT	White Nile Upper Terrace	2	855605
H	MOUNTAINS AND HILLS		1 978 490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EL OBEID
T3
Q3
Q2
UMM R
A1
Q1
AD
Q3
T3
T3
J1
U9
A1
T2
H
T2
T2
T2
U11
U11
U5
H
AE
U5
H
H
U9
U1
H
H
DELAMI
H
RASHAD
U1
H
U10
U2
U8
U2
U6
U2
H
U10
A3
ABU
GUBAIEHA
U10
H
U2
U8

Area. Agriculture is related to these climatic zones and to the soils and geomorphic conditions in these zones. Most of the dry areas in the desert and semi-desert are used for extensive grazing mainly by camels and goats, but in the arid zone cattle and sheep are also grazed. There is no water available for irrigation. Nearly two-thirds of the area has a semi-desert or dry monsoon climate. Both traditional and modern (mechanized) forms of agriculture are common here, together with grazing of cattle, sheep, goats and camels.

The major landscape map (Figure 2) shows 15 landscape units, each of which exhibits certain geomorphological characteristics, and contains, like or unlike soils forming a homogeous association different from those occuring on other landscapes. Moreover, each association has some characteristics of practical significance to agriculture that made separate delineations necessary. The different components of each association were also described regarding the soils of each area.

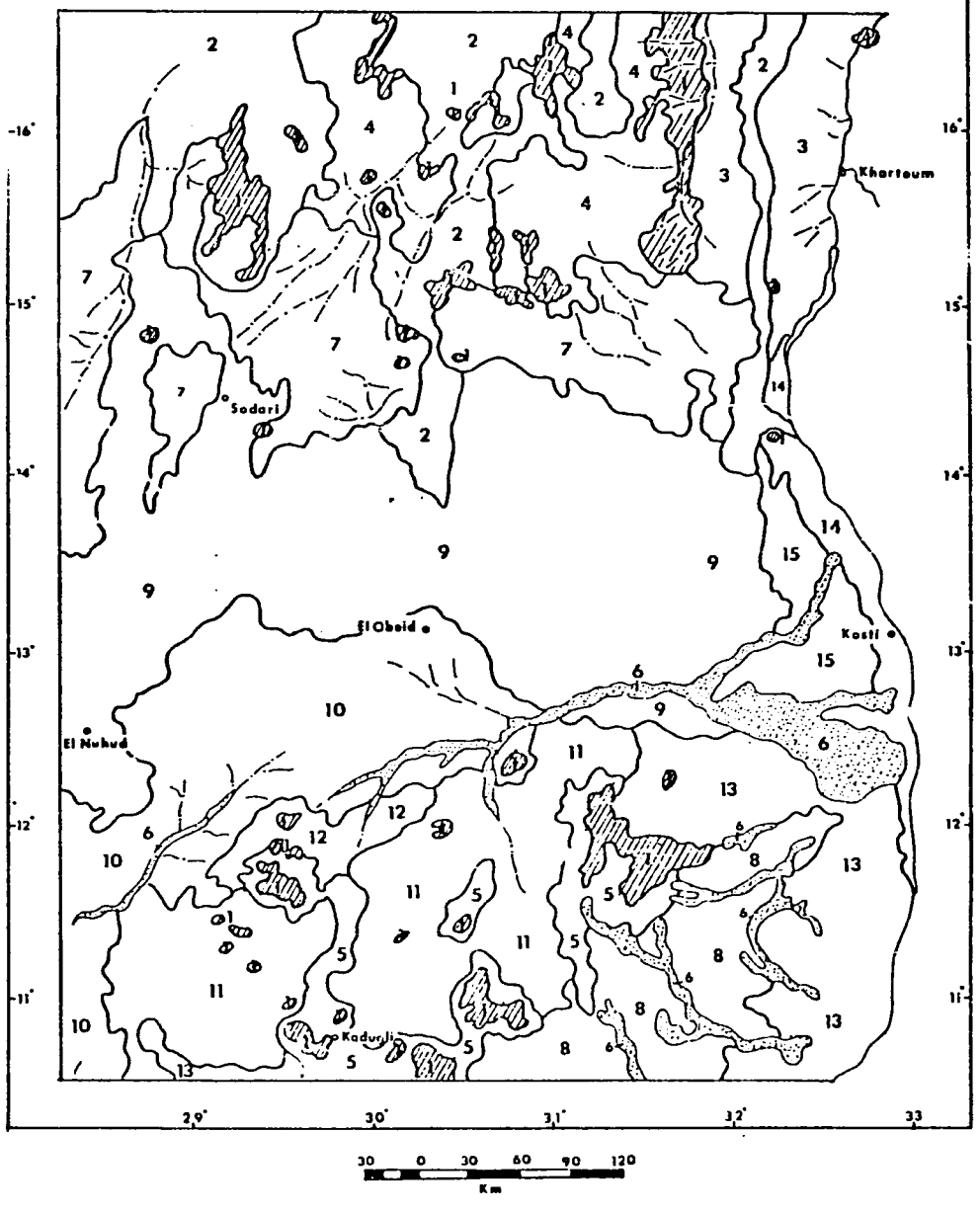
The limitations and potentials of the land associations and components for traditional and modern agriculture aredesigned for broad regional planning and not for detailed planning. Traditional agriculture is possible on coarse textured soil distributed in the semi-desert or arid climatic zones. Hills and ridges that occur in cropped areas are bare and have no agricultural value. Modern and traditional rainfed agriculture is possible on the dark cracking clay soils. These soils occur in the southern Kordofan under semi-and/or dry monsoon climate and have considerable potential for rainfed agriculture. Very shallow soils on rough, steep, stony Nuba uplands are grazed or left under natural vegetation. They are unsuited for cultivated crops.

LEGEND

1 - Hills and Mountains (shaded)
2 - Northern Sand Plains
3 - Northern Sandy Peneplains
4 - Northern Piedmonts and Reg. areas
5 - Nuba Piedmonts and Dissected Plateaus
6 - Recent Alluvium Plains
7 - Northern Pediplains and Basins
8 - Nuba Upland Clay Plains
9 - Qoz Lands (sand dune areas)
10 - Transitional Zone
11 - Intermountain Clay Plains
12 - Dilling Dissected Uplands
13 - Low Flat Clay Plains
14 - White Nile Flood Plains
15 - Sand Dunes and Clay Plain Complex

(Original scale of all maps in this report at 1:1,000,000.)

FIG. 2 MAJOR LANDSCAPES AND SOILS



INTRODUCTION

Arid and semi-arid regions (Figure 4) cover extensive areas of Central Sudan. They are located between the desert peripheries at the north and regions of wetter climate (dry monsoon) at the south. Drought resistant herbs, grasses and low shrubs are supported by the light rainfall at the northern part which is inhabited by nomadic people who herd camels, sheep and goats.

The central part of the region is occupied by vast areas of Ooz lands (sand dunes) which receive more rainfall than the northern parts. These lands form one of the most productive rainfed agricultural areas in the Sudan. Crops like seasame, groundnuts and millet are grown here in addition to the production of "Gum Arabic". Gum Arabic is the main cash crop which is produced from Acacia Senegal trees growing in most parts of these lands. The abundant short to medium grasses with scattered shrubs and small trees provide good grazing lands for camels, sheep and cattle.

The clay plains and uplands are located at the southern part of the region and receive the highest amount of rainfall in the region. Traditional and modern rainfed agriculture are widely practiced in this area to produce dura and cotton. The natural grassland on clay plains and on Ooz lands provides most of the grazing lands which in turn give the highest contribution of animal production in Sudan.

Due to the combined pressure from man and changes in weather upon the land of this region, the grazing and the agricultural lands are now experiencing a decline in productivity (lower carrying capacity for animals and reduction in crop production) and an increase in environmental deterioration due to soil blowing resulting in a reduction in people's standard of

living. This problem is now known worldwide as desertification. Desertification is the process of an impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in those ecosystems that can be measured by reduced productivity of desirable plants, undesirable alternations in the biomass and diversity of the micro and macro fauna and flora, accelerated soil erosion and increased hazards for human occupancy (Dregne 1978).

The UN Conference on Desertification (Kenya 1977) concluded that the desertification in arid regions is a man-made problem. Drought aggravates the condition but is not the cause. As the problem is of worldwide concern, much effort has been devoted to define it, locate the areas affected, study the causes and its impacts. Recently Landsat data were introduced as a new tool to study desertification in different parts of the world (Myers et al., 1978; Dalsted and Worcester, 1978). The Soil Survey Administration in Sudan (Wad Medani) produced a soil map based on Landsat imagery covering six provinces in central and eastern Sudan. Soil potential for agriculture was also studied (SSA reports No. 81 and 80, 1976).

Many articles have been written in Sudan discussing the problem and suggesting some solutions but in addition to these efforts, a practical approach needs to de developed. The process of desertification can be halted and reclamation procedures initiated only if there is a physical assessment of the process involved, an estimate of the magnitude of the problem along with locating the potential areas for reclamation (Myers et al., 1978). The main objective of this study was to integrate soils and climate with geology, hydrology, forestry, land use and range management. The ultimate objective was to provide a basis for studying desertification and to

show the effectiveness of using Landsat data in that respect. A soil map will provide a base for making estimates and projections for determining the source, location, extent, and degree of desertification.

GENERAL DESCRIPTION OF THE STUDY AREA

The study area (Figure 1) is located in Central Sudan between latitudes $10^{o}45'$ and $16^{o}35'$ north and it extends from the White Nile to longitude $27^{o}15'$ west. The area includes the western parts of Khartoum, White Nile and most parts of North and South Kordofan Provinces. The study area is one of the largest potential areas in the country affected by desertification.

The area is highly populated as compared with other parts of the country. Most of the population is in rural areas. Some people are nomadic cattle and camel herders and a few live in the main towns and villages where water is available. District administration centers are linked by motor tracks of varying quality. Most of them become closed during the rainy season. The railway from Khartoum to western Sudan passes across the central part of the study area. Some of the main cities are served by scheduled airflights from Khartoum. Lorry and bus services move products and people along the main lines of communication. A modern system of tele-communication connects the main towns of the provinces.

Rainfed agriculture is widely practiced all over the region but decreases toward the northern part of the area. Due to the inadequate rainfall, shifting cultivation is practiced on sandy soils to produce seasame, dukhn and groundnuts. Cotton and dura are produced on clay plains at the southern part of the region. It is also considered as one of the important regions for its high animal production.

Fifteen landscape units shown in Figure 2 consisting of thirty eight soil associations were identified in the study

area. Within the thirty-eight (38) soil associations, eighty-two (82) soil components have been identified and described in Table 29. The major landscapes (Figure 3) are the Northern Plateaus and sandy plains, the Qoz land, the transitional or deflation areas, the seasonal water courses of alluvium, the Nuba upland clay plain, the White Nile alluvium and the hills and the mountains.

The northern plateaus and the Nuba uplands at the southern part occupy the highest physiographical position in the region. The transitional areas and the Qoz lands which lie between the two highest physiographic areas occupy an intermediate position. The flat clay plains and the White Nile alluvial valley occupy the lowest physiographical position. Numerous seasonal water courses collect their water from the northern plateaus, the transitional zone and the Nuba uplands. Due to the differences in climatic conditions, these seasonal water courses carry more water and have wider alluvial plains at the transitional and Nuba uplands. Hills, mountains and the rocky plateaus are associated with the northern plateaus and the Nuba uplands.

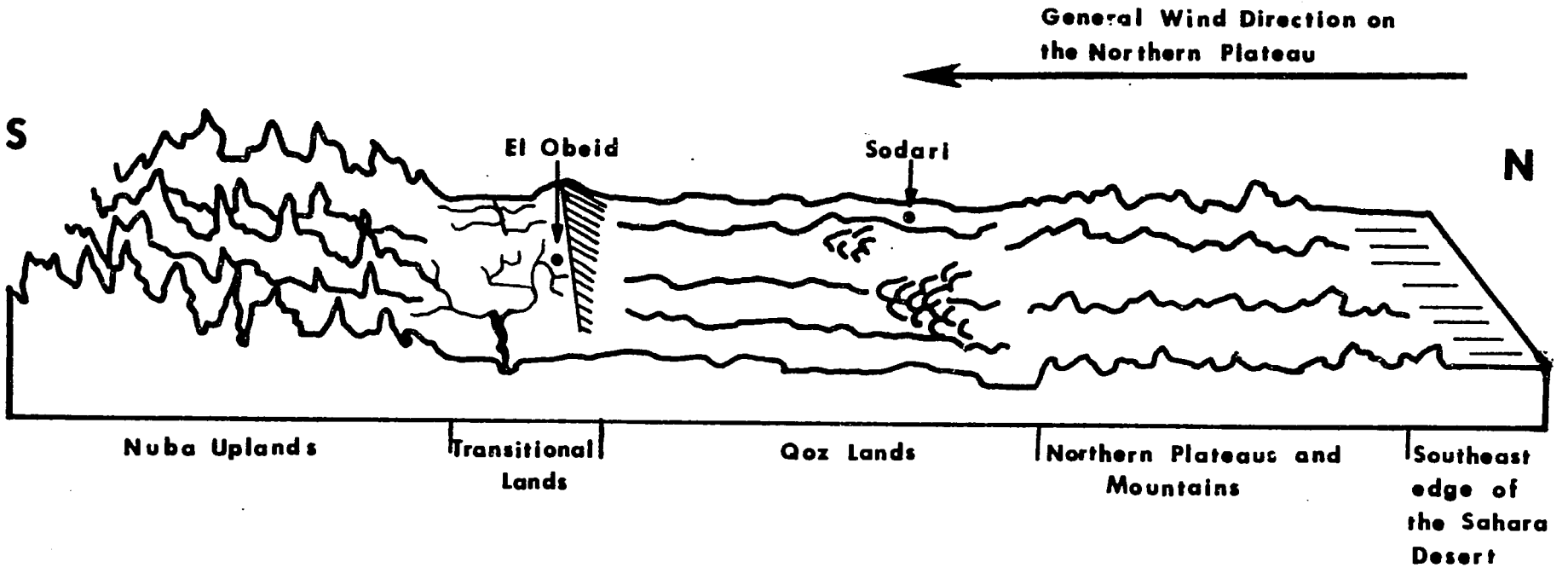


FIGURE 3 Hypothetical Sketch Diagram of the Study Area Showing the Different Physiographic Features

CLIMATIC ZONES IN THE STUDY AREA

GENERAL CHARACTERISTICS OF THE CLIMATE

The climate ranges from semi-desert to dry monsoon with over 500 mm of precipitation in the south. The climates have certain features in common such as very high temperatures late in the dry season, warm winters and summer rainfall mainly from May through October. Two air movements determine the general nature of the climate; one, a very dry air movement from the north that prevails throughout the year but lacks uniformity; two, a major airflow of maritime origin that enters from the south and carries moisture and brings rain. The extent of penetration into the region by the airflow from the south determines the annual volume of rainfall and its monthly distribution. The average monthly rainfall for selected stations is shown in Table 2 and indicates a decrease of rainfall as one moves from south to north.

Considering the average annual rainfall and the resulting vegetation, the region has been divided broadly into four major climatic zones (Van de Kevie, 1976). These zones are shown in Figure 3 and a brief description of them is given below. A separate legend for the climatic zones is shown in Table 2.

Semi-desert Zone:

Summer temperatures are very high, and although winters are warm, cold winds are common. There is a considerable daily and annual temperature range. The average rainfall increases from 100 mm in the north to about 200 mm in the south. It is less than 50% of the potential evapotranspiration

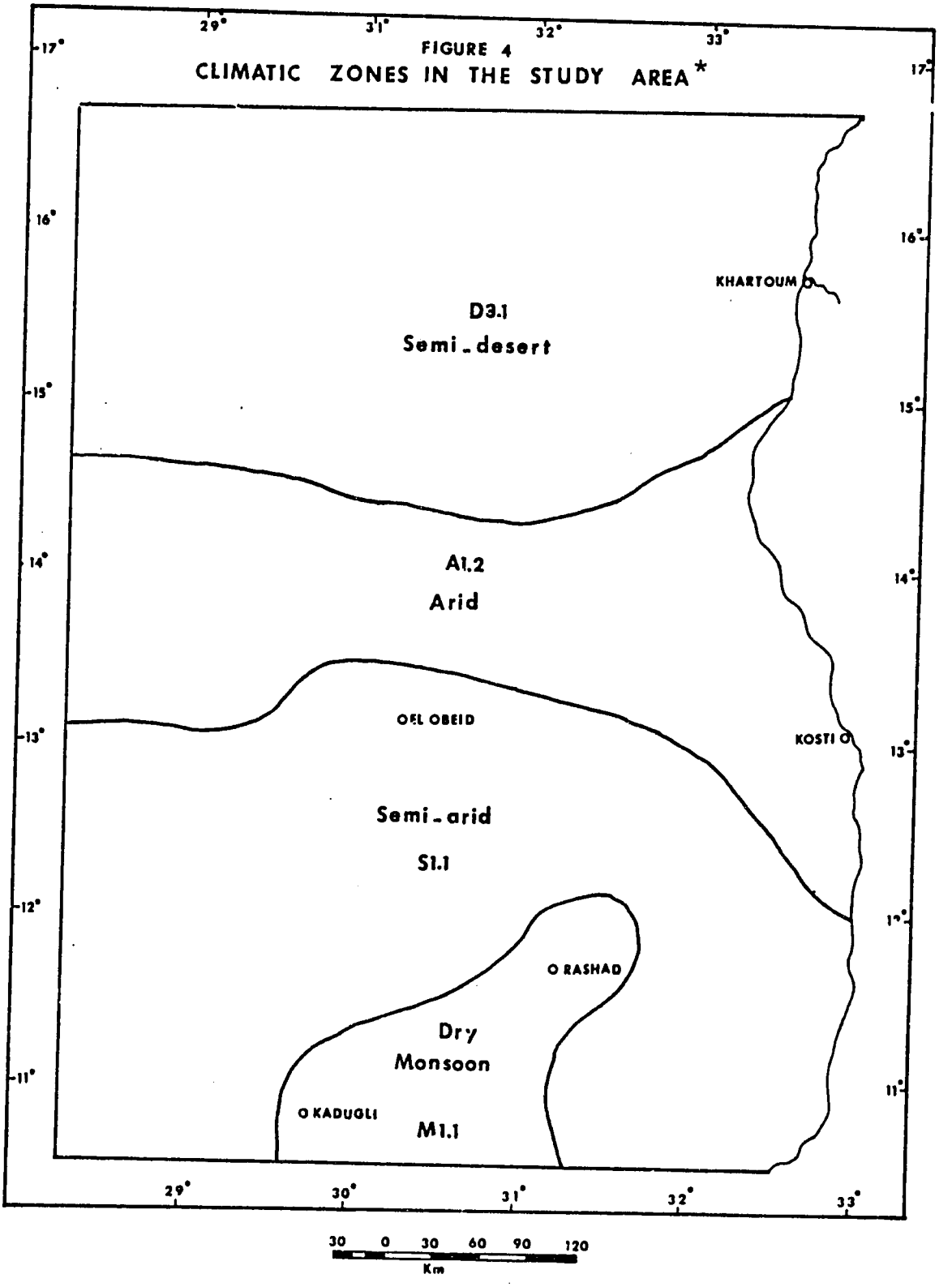
TABLE 1

SOME CLIMATIC DATA FOR SELECTED STATIONS

WITHIN THE REGION

Stations	Mean monthly and annually rainfall (mm)													Annual Potential Evapotr. 1	Water Surplus 2	Humid Months 3	Growing Season (Rainfed)
	J	F	M	A	M	J	J	A	S	O	N	D	Annual				
Khartoum	0	0	1	1	4	8	64	79	19	5	0	0	181	2,274	0	0	0
El Obeid	0	0	0	2	24	40	110	128	67	16	0	0	387	1,823	10	1	3
Kosti	0	0	1	3	23	53	116	145	57	28	1	0	427	2,190	0	0	2
El Nuhud	0	0	0	5	27	46	98	136	86	23	1	0	422	1,681	7	1	3
Kadugli	0	2	1	15	86	108	167	157	140	82	6	0	764	1,337	202	5	7

Source - Soil Survey report No. 81.



* See Table 1 for legend.

TABLE 2

LEGEND FOR MAP SHOWING CLIMATIC ZONES IN THE STUDY AREA
(See Figure 4)

Symbol	Climate	Humid Month	Dry Month	Growing Season	Ave. Annual Rainfall (mm)	Mean Max. Temp. in Hottest Month	Mean Min. Temp. in Coldest Month	Diagnostic Characteristic
D3.1	Semi-desert, summer rain cool winter	0	12	0	100-225	40-42	13-16	RW 0.2 EW TC 13
A1.2	Arid, summer rain, cool winter	0	10-11	1-2	225-400	40-42	18-13	RW=0.5-1.0 EW TC 13
S1.1	Semi-arid summer rain, warm winter	1	9	3	400-750	39-40	13-17	RW 1.0 EW TC 13
M1.1	Dry monsoon, long dry season warm winter	3-5	5-7	5-7	750-1000	36-41	17-20	R 0.44 E Ln=0.1-o.2 E

RW = Average Rainfall in wettest month in mm
R = Average annual rainfall in mm
EW = Average potential evapotranspiration in wettest month (Penman) in mm.
Ln = Leaching rainfall (surplus of rainfall over potential evapotranspiration in humid months)
Dry month = month in which rainfall is less than half the potential evapotranspiration

TC = mean minimum temperature of coldest month in ^{o}C
Tw = Mean maximum temperature in hottest month in ^{o}C
Humid month = Month in which rainfall exceeds potential evapotranspiration
Growing season = 12 minus number of dry months.

in all months but (unlike the desert climate) has at least one month when the rainfall exceeds 20% of the evapotranspiration. The variation in annual precipitation is great. The relative humidity is low for most of the year (15-45% at 1200) and strong winds and dust storms intensify the drought.

Arid Zone:

This climatic zone occurs in a narrow belt south of the semi-desert zone extending southwards up to a line crossing approximately Bara town. Here the average annual rainfall varies from 225 to 400 mm. There is no month in which the average rainfall exceeds potential evapotranspiration- "humid month", though there is at least one month in which rainfall exceeds 50% of the potential evapotranspiration- "intermediate month". Most of the area has summer rains and a cool winter. The rainfall is in June through August. The mean maximum temperature of the hottest month is May with 40° to 42° C and the mean minimum temperature of the coldest month is January with 8° to 13° C.

Semi-arid Zone:

This climatic zone covers the largest area in the region. The average annual rainfall varies from 400 mm to 750 mm which is less than 44% of the annual potential evapotranspiration. In at least one month the average rainfall exceeds the potential evapotranspiration "humid month" and one or two "intermediate" months. The growing season ranges from two to four months. The mean maximum temperature of the hottest month (April or May) is 39° to 40° C and the mean minimum temperature of the coldest month (December or January) is 8° to 13° C. The rainfall occurs during the summer months.

The most important rainfed developments, including mechanized farming and animal production, in the Sudan at this time lies in this zone. In Qoz lands, sorghum, millet and oil seeds are produced using traditional methods of cultivation. Southwards in the clay plain areas (Soil Areas 13 and 14), away from the margins of Jebel Piedmonts, governmental promotion of agriculture, especially mechanized cotton cultivation has encouraged settlement.

Dry Monsoon Zone:

This climate occurs between the Eastern and Western Jebels of the Nuba Mountain ranges and includes low lands of the southwestern corner of Kordofan. The average annual rainfall ranges from 600 mm to 850 mm. There is a pronounced dry season. Three to four months are "humid" and a grazing season of five months exists. The average water surplus in the "humid" months is 10% to 20% of the annual potential evapotranspiration. The growing season is about five to six months which is suitable for many rainfed crops. The relative humidity is higher in the rainy season and the potential evapotranspiration is markedly lower during most of the year than in the semi-arid climate. This is of importance for plant growth, because even heavily irrigated crops wilt during the day in the drier climates because they cannot lift enough water to meet the need for transpiration. The grass firing method of cultivation "Harig" is popular because less weeding is needed after sowing and the total labor requirement is less.

METHODS

Characteristics of LANDSAT Imagery

The Landsat satellite circles the globe in a near polar, sun-synchronous orbit at altitudes of 920 km. Although Landsat carries a return beam vidicon camera, the principal source of data has been the multispectral scannar (MSS). The MSS records reflected energy from the earth in four distinct spectral bands: band 4 has a wavelength range of 0.5-0.6 microns; band 5, 0.6-0.7 microns; band 6, 0.7-0.8 microns; and band 7, 0.8-1.1 microns. The band 4 corresponds approximately to the green-yellow-orange portion of the electromagnetic spectrum, band 5 to the red portion, and bands 6 and 7 to the reflected near infrared. Each Landsat scene covers an area of 185 by 185 km. or 34,225 square kilometers (about 8 million feddans).

Landsat scenes are available in 9 inch by 9 inch transparencies and 70 mm. chips. In addition, computer compatible tapes of each scene are available. Either positive or negative contact and enlargement prints can be made from transparencies. In addition, false color composite transparencies can be prepared by registering and projecting two or more of the bands through appropriate color filters. Transparencies may be viewed directly over a light table and/or contact or enlargement color prints can be made. If a "color additive viewer" is available, each band can be projected through a different filter and enlarged for a visual display to select the appropriate combinations of bands and filters for the specific enhancement desired.

LANDSAT Imagery and Other Data Used

Fourteen Landsat color composites (1 = 1,000,000 scale) were used to

produce an uncontrolled stick down mosaic covering the study area. The color additive viewer (I^2S) available at the RSI was used for the enhancement needed in the visual interpretations. A general soil map was prepared from visual interpretations made on Landsat imagery. Pattern analysis was the method generally adopted for such interpretations and the pattern elements used were landform, drainage, erosional features, image color or tone and any other special features that may be present. This method combined with soil properties taken from field surveys in Sudan, topographic and other resource data allowed for a recognition of the geomorphic units in relation to geographic location.

Each soil association was delineated and the main components within each mapping unit described. The percent of each main component within a mapping unit was determined from field observations and Landsat data. The mapping units were divided into several components so that more specific interpretations could be made for each unit.

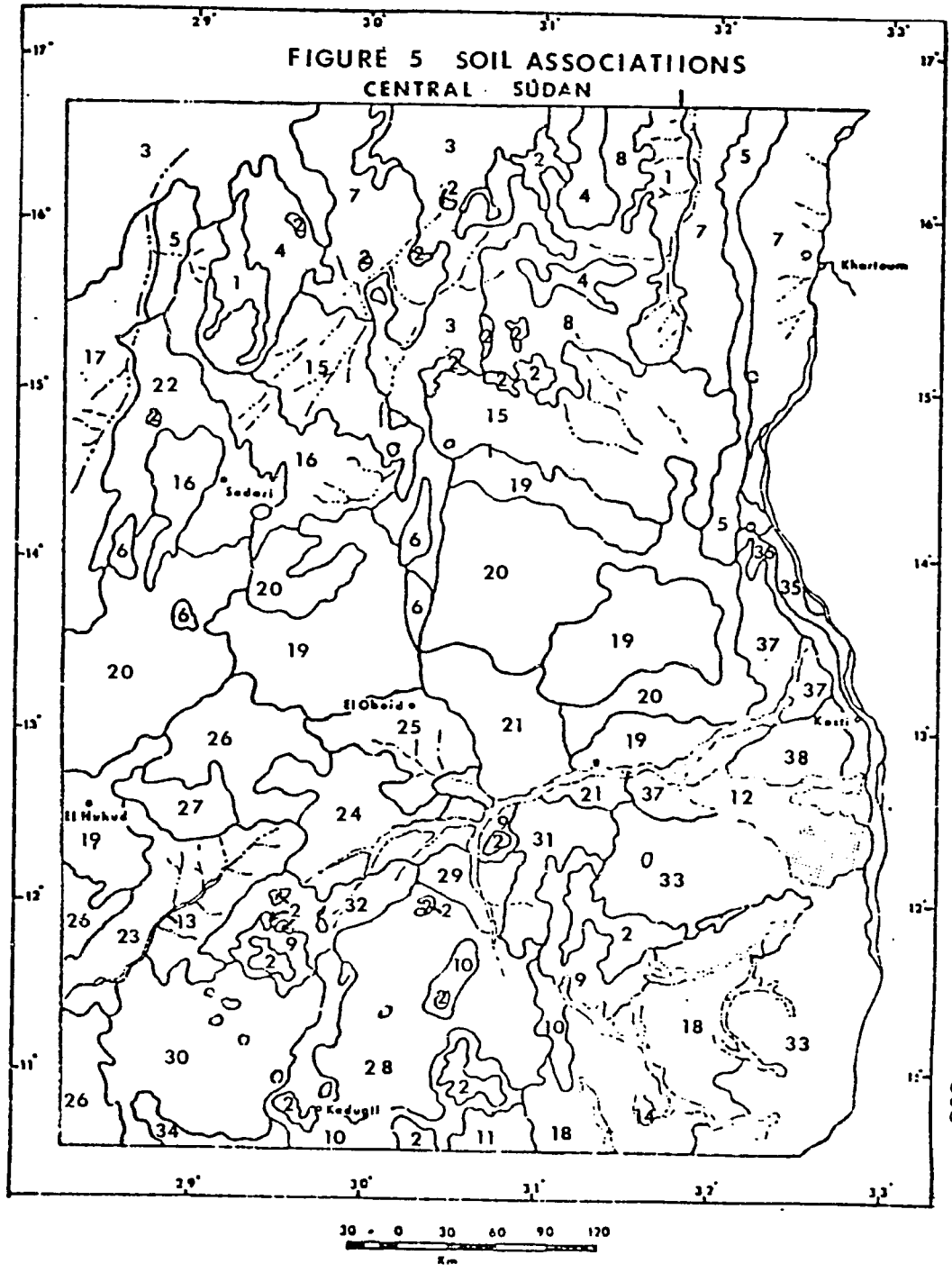
Good quality, cloud free Landsat scenes from a single pass could not be found, so it was necessary to utilize several passes. Some scenes were used which differed in dates, 30 to 60 days, and although this was undesirable, it could not be avoided.

The resulting maps are presented in Figures 5 and 6. The original maps were at a scale of 1:1,000,000.

LEGEND

* Note all original maps were at 1:1,000,000 scale.

1 - Rocky plateaus
2 - Mountains and Hills
3 - Sandy plains
4 - Sandy pediplains
5 - High dunes, semi-desert
6 - Transversal dunes
7 - N. Kordofan Piedmonts
8 - Rocky lands
9 - Jebel Piedmont out-wash
10 - Dissected plateaus
11 - Talodi peneplain
12 - Abu Habil flood plain
13 - Wadi El Galla flood plain
14 - Southern and Eastern flood plain
15 - Reg area
16 - Wadi El Muhbas basin
17 - Wadi El Milk basin
18 - E. Intermediate clay plain
19 - Sand sheet, low dunes
20 - High dunes, arid climate
21 - Congehidenal dunes
22 - High dunes, semi-desert
23 - Wadi El Galla basin
24 - Khor Abu Habil western bais
25 - El Obeid Old Peneplain
26 - Babanusa-Khowi Peneplain
27 - El Nuhud-Abu Zabad Plateau
28 - Habila clay plain
29 - Jebel El Daer clay plain
30 - Lagawa-El Berdab plain
31 - Northeastern clay plain
32 - Dilling upland
33 - Eastern flat clay plain
34 - Southern clay plain
35 - White Nile flood plain
36 - White Nile upper terrace
37 - Tendelti complex
38 - Kosti complex



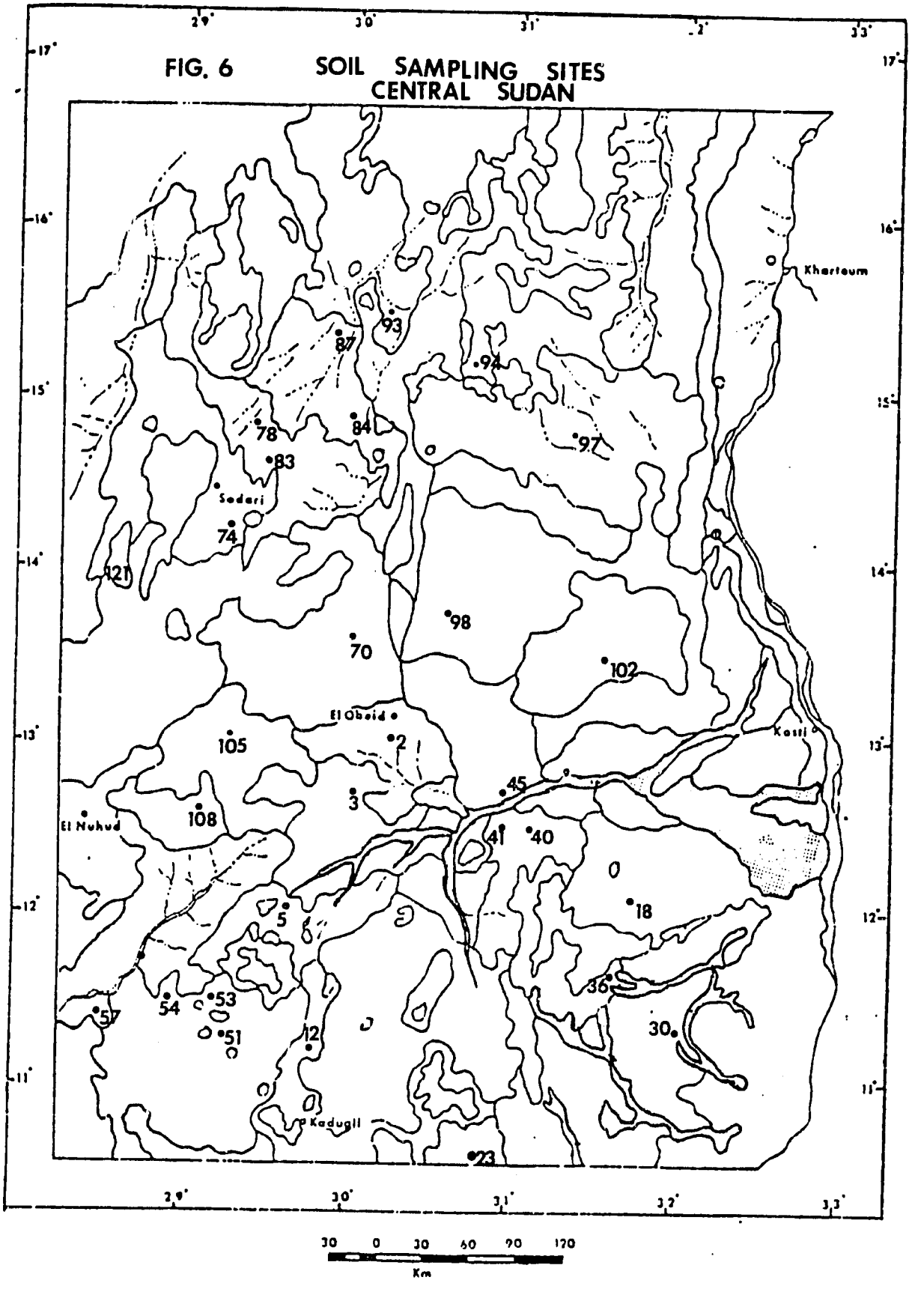


FIG. 6 SOIL SAMPLING SITES
CENTRAL SUDAN
Khartoum
Sodari
El Obeid
El Nuhud
Kadugli
93
87
94
78
84
97
83
74
121
98
70
102
105
2
3
45
108
41
40
18
5
36
54
53
57
51
12
30
23
30 0 30 60 90 120
Km

DESCRIPTION OF MAJOR LANSDCAPES

AND SOIL ASSOCIATIONS

1. HILLS, MOUNTAINS AND ROCKY PLATEAUS

H - Hills and Mountains

The entire unit consists of hills, inselbergs and low ridges of North and South Kordofan. At the North they are of Nubian sandstone formations and basement complex rocks. The basement complex hills are higher and steeper than the Nubian sandstone hills. Under desert and semi-desert climatic conditions there is no soil formation and they are bare rocks.

In South Kordofan the unit consists of steep to very steep hilly areas of granites, syenites, gneisses and other metamorphic igneous rocks of the basement complex. Many trees are growing on skeletal soils, within these hills.

Unit H is unsuited for rainfed agriculture and grazing potential is very low.

N1 - Rocky Plateaus

Component #1 70% - Consists of sandstone outcrops, boulders and stones. They are occupying higher physiographic position of very rough surfaces. Narrow seasonal water courses have their origin from such areas.

Component #2 30% - This component is nearly level or gently sloping sands or loamy sands lacking a diagnostic horizon. The soils are generally deep and in some places there is a concentration of stones or boulders. They have yellow to red color, non calcareous neutral in reaction and subject to wind erosion.

The association (NI) provides poor grazing lands only for camels. The main problems are dryness and stoniness.

2. NORTHERN SANDY PLAIN AND DUNE FORMATION

N3 - Sandy Plains

Component #1 90% - The soils are derived from wind-sorted sand materials and they are mostly yellow red, reddish brown, coarse textured, non calcareous and neutral in reaction.

Component #2 10% - These soils are derived from residual material (Nubian Sandstone and Basement Complex rocks) and they are dark brown to dark grayish brown. Textures of the upper horizons are generally clay loams overlying gravelly sandy clay materials. Some of these soils are slightly calcareous and have mildly alkaline reaction.

The low rainfall in unit N3 limits vegetation mainly to sparse grasses and shrubs on the desert zone and stunted trees on the semi-desert areas. All the soils of this unit are used for grazing. They are too arid for anything but very poor (desert zone) and poor (semi-desert zone) grazing for camels and goats. The soils require measures against wind erosion.

Analytical data of pit KR 94 for Component #1.*

N31 - Sandy Pediplains

Component #1 75% - The soils surround some areas of Nubian sandstone outcrops and they are gently sloping. They are generally deep, coarse textured, non calcareous and neutral in reaction. They have very low water holding capacity, and are subject to wind erosion.

Component #2 25% - It is the stony phase of the association. The stones and the boulders are most probably co-associated from the Nubian sandstone outcrops. The soils have the same characteristics like component #1.

Unit N31 is of no agricultural potential. It is too arid except for poor grazing.

*For sample site locations see Figure 6.

SOIL ANALYTICAL DATA

TABLE No. 3
LOCATION: N. Kordofan
DATE OF SAMPLING:
DATE OF ANALYSIS:

PROFILE NO.: KR 94

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
791	0-10	7.6	7.9		0.18			68	26	3	3	20
792	10-35	7.5	7.7		0.2			55	35	5	5	21
793	35-75	7.7	3.1		0.2			5	33	3	7	17
794	75-120	7.8	3.[illegible]		0.29			57	34	2	7	21

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
791		0.05		0.0	0.2			1			
792		0.0		0.0	0.1			1			
793		0.0		0.0	0.1			1			
794				0.0	0.1			1			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
791	0.3		1.2	0.1	1.0		0.8	0.0				
792	0.3		1.3	0.2	1.2		0.6	0.0				
793	0.4		1.5	0.2	0.8		0.6	0.0				
794	0.5		2.1	0.2	1.0		0.7	0.0				

N6 - High Dunes, Semi-desert

The entire unit consists of high sand dunes without any marked differences in soils between the dunes and the inter dunes. The soils are very deep brown, to yellowish red, sand or loamy sand textures. They are non calcareous, mostly neutral in reaction with extremely low organic matter content.

The limitations are very low moisture availability, very low productivity status and high susceptibility to wind erosion. These lands are unsuitable for grazing or agriculture.

Q4 - Transversal Sand Dunes

This unit is of minor extent. The sand dunes are aligned east-west and the relief is rolling, without soil profile development. They are deep, excessively drained, coarse textured, neutral and non calcareous. They have dark brown sands underlain by strong brown loamy sands.

The unit is uncultivated and seldom used for seasonal grazing. The limitations are very low available moisture, very low productivity status and high susceptibility to wind erosion. They are unsuitable for agricultural use and have poor grazing potential; they should be kept under natural vegetation to protect them against wind erosion.

Analytical data of profile KR 121 represent this unit.

3. NORTHERN SANDY PENEPLAINS

N2 - North Kordofan Piedmonts and Peneplains

Component #1 65% - This unit is gently sloping and dissected by seasonal water courses (wadis). It comprises a sequence of fans, piedmont aprons and terraces. The soils are dark brown and brown silt loam is over clay loams or silty clay loam. They are mildly alkaline in reaction and non to slightly calcareous.

Analytical data of profile KR 93 represent this component.

Component #2 25% - Reddish brown loamy sand soils have been developed by loose materials deposited by wind. They are non calcareous, have low water holding capacity and low cation exchange capacity.

This association (N2) is used only for grazing. The main limitations are moisture shortage due to dry climate and in some places due to the sandy nature of the soil. Since the area receives low rainfall, there are no possibilities for improvement beyond poor grazing for camels and goats.

Component #3 10% - Rocky and stony lands with no potential.

4. NORTHERN ROCKY LANDS

N4 - Rocky Lands

Component #1 80% - They are gently sloping and dissected areas.

SOIL ANALYTICAL DATA

TABLE No. 4
LOCATION: N. Kordofan
DATE OF SAMPLING: March 1976
DATE OF ANALYSIS:

PROFILE NO.: KR 121

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
917	0-5	7.1	7.3	6.8	0.39		0.2	53	34	8	5	22
918	5-30	7.3	7.5	6.7	0.19		0.2	56	35	4	5	21
919	30-55	7.4	7.6	6.7	0.15		0.6	60	32	2	2	20
920	55-80	7.5	7.7	6.7	0.18			55	36	3	6	22
921	80-120	7.7	7.9	6.9	0.23		0.4	66	26	3	5	21

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
917				0.0	0.4			5			
918				0.0	0.2			4			
919				0.0	0.2			4			
920				0.3	0.2			4			
921				0.0	0.1			4			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
917	0.54	0.3			1.4		2.5	0.0				
918	0.54	0.0			1.0		0.5	0.0				
919	0.45	0.13			1.5		1.1	0.0				
920	0.54	0.13			1.0		1.4	0.0				
921	0.54	0.0			1.4		1.4	0.0				

SOIL ANALYTICAL DATA

TABLE No. 5
LOCATION: N. Kordofan
DATE OF SAMPLING:
DATE OF ANALYSIS:

PROFILE NO.: KR 93

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
786	0-15	8.0	8.5		0.22	8	2	35	19	17	29	35
787	15-30	8.0	8.6		0.29	7	1	33	21	14	30	34
788	30-55	7.9	8.4		1.8	5.5	23	36	21	12	31	44
789	55-80	7.9	8.5		2.2	7.0	7	37	20	13	31	45
790	80-120	7.9	8.4		2.2	5.0	4	33	22	14	31	49

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
786		0.16		0.3	1.1			29			
787		0.12		0.3	0.7			25			
788		0.1		0.7	0.5			27			
789		0.05		1.6	0.4			27			
790				1.1	0.4			27			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
786	0.5		1.3	0.0	0.9		1.3	0.0				
787	1.7		1.1	0.0	1.5		1.5	0.0				
788	7.2		7.5	2.5	1.5		0.6	0.0				
789	8.6		8.6	2.8	4.0		1.0	0.0				
790	9.0		9.0	2.0	1.3		0.8	0.0				

The landscape consists of flat topped sandstone ridges, mostly unweathered bed rock as well as areas dominated by masses of loose boulders.

Component #2 20% - These soils are wind sorted sand materials among the rocks. They are coarse textured soils, neutral in reaction and non calcareous. Much of the land is unsuitable for grazing.

5. NUBA PIEDMONTS AND PLATEAUS

U1 - Jebel Piedmont Out-wash

Component #1 50% - These soils are characterized by having a dark reddish brown, massive or weakly developed surface horizon underlain by dark reddish brown to dark red, B horizon of clay accumulation. Lower subsoil is gravelly clay loam to gravelly clay with fragments of weathering rocks. The soils are non-calcareous and strongly to slightly acid in reaction.

Component #2 30% - It consists of a dark reddish brown loam to silty clay loam surface horizon underlain by a dark reddish brown clayey B horizon. The soils are moderately deep, well drained, non-calcareous and acid to slightly acid in reaction.

Component #3 20% - It is a stoney and shallow phase of a less red color soils which have a subsurface horizon of clay accumulation. Soil characteristic like Component #1.

In unit U1 land use is extensive grazing with few small and scattered fields beside the villages. Main limitations are shallowness and stoniness of the soils, low soil moisture storage and soil erosion. These lands are unsuitable for agricultural use, grazing potential is low.

Analytical data of Pit Kr 36 for Component #1.

U2 - Dissected Plateaus

Component #1 50% - The soils are very deep, well drained, have dark reddish brown surfaces underlain by a dark red B horizon of clay accumulation. The soils are well developed, non-calcareous, and strongly to slightly acid in reaction.

Analytical data of Pit KR 12 represent Component #1.

Component #2 35% - The soils are deep, reddish brown loam underlain by a dark reddish brown clayey B horizon. They are non-calcareous and acid to slightly acid in reaction.

Component #3 15% - They are dark clay soils occupying a different physiographic position. Generally they are deep and moderately well drained, non-calcareous and mildly alkaline to neutral in reaction.

This soil association (U2) is dominated by extensive grazing. There is scattered small limited rainfed agriculture (Component #3). Agricultural potential is marginal. Over-grazing should be avoided to protect the lands against water erosion.

U3 - Talodi Peneplain

Component #1 65% - These soils are formed on gently sloping plains. They are deep, well drained, non-calcareous and neutral in reaction. The surface horizon is dark brown, hard, sandy loam underlain by dark brown moderately structured clay loam to clay subsoil.

Analytical data of Pit KR 23 represent Component #1.

Component #2 35% - Consists of deep, well drained, non-calcareous soils, slightly acid in reaction. They have a dark brown, sandy loam to loam surface horizon, underlain by a yellowish red, clay loam, weakly to moderately structured subsoil.

In this land association (U3) the land use is extensive grazing with shifting cultivation of dura and millet on a small scale. The soils of this association are low in fertility and the water holding capacity is low. Agricultural potential is marginal and the grazing potential is low to moderate.

6. RECENT ALLUVIAL PLAINS

A1 - Khor Abu Habil Alluvium Flood Plain

Component #1 60% - They are very dark gray to nearly black cracking clay soils. They are deep, poorly drained non-calcareous and mildly alkaline to neutral in reaction. They have a very high clay content and have a cation exchange capacity of 50-60 meq/100 g.

Component #2 25% - The soils are very dark grayish brown cracking clay. They are deep, moderately well drained, non-calcareous and mild to neutral in reaction. The clay content is high but with a rather low cation exchange capacity.

Component #3 15% - The soils have been developed on reworked material, transported by a main tributary water course draining into the wide Khor. The soils are deep, non to slightly cracking, non calcareous, mildly alkaline with sandy clay to clay texture.

In Khor Abu Habil (A1) part of the land is used for irrigated cotton and dura. Agricultural potential is variable but the main problem is low available moisture and weeds.

A2 - Wadi El Galla Flood Plain

Component #1 60% - It consists of a deep, very dark grayish brown cracking clay. They are moderately well drained, non-calcareous and mildly alkaline in reaction. Dense vegetation of tall tree undergrowth dominates this unit.

SOIL ANALYTICAL DATA

TABLE No. 6
LOCATION: S. Kordofan
DATE OF SAMPLING: May 1975
DATE OF ANALYSIS: September 1975

PROFILE NO.: KRO 12

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
509	0-12	65	6.6	6.0	0.45			37	33	23	7	24
510	12-28	5.5	6.3	4.6	0.34			39	28	23	10	24
511	28-50	6.1	6.5	5.3	0.24			36	26	22	17	27
512	50-70	8	8.4		0.9			40	12	18	30	41

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
509				0.0	0.3	3.4	0.4	4			
510				0.2	0.1	2.3	1.5	4			
511				0.2	0.1	4.8	1.4	10			
512				1.5	0.3	21.2	5.8	16			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

Analytical data of Pit KR 56 represent Component #1.

Component #2 40% - The soils are dark gray to nearly black cracking and slightly cracking clay soils. They are deep, moderately to poorly drained soils, non-calcareous and mildly alkaline in reaction.

In Wadi El Galla (A2) grazing is the main land use. Agricultural potential is variable and waterlogging is the main limiting factor.

TABLE No. 7

LOCATION: S. Kordofan Province

DATE OF SAMPLING: May 1975

DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 36

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
579	0-9	6.9	7.2	6.6	1.05			31	18	37	14	32
580	0-18	6.0	6.2	5.5	0.8			27	12	40	21	38
581	18-40	6.0	6.2	5.5	0.7			19	9	42	30	41
582	40-60	6.3	6.5	5.7	0.35			14	7	43	36	46
583	60-100	7.0	7.1	6.3	0.51			19	6	39	36	43

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
579				0.0	1.7	5.6	1.5	9			
580				0.0	1.0	5.2	3.2	11			
581				0.0	0.3	5.8	5.7	11			
582				0.2	0.3	9.7	4.7	15			
583				0.2	0.3	13.7	5.8	20			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

SOIL ANALYTICAL DATA

TABLE No. 8
LOCATION: S. Kordofan Province
DATE OF SAMPLING: May 1975
DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 23

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
536	0-15	7	7.1	6.3	0.2			18	22	40	20	45
537	15-30	6.5	7.0	5.7	0.24			12	13	37	38	45
538	30-60	7	7	5.6	0.27			10	18	37	35	49
539	60-85	6.8	7.3	5.9	0.37			18	31	26	25	40
540	85-100	7.2	7.5	6.2	0.42			46	17	21	16	35

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
536				4.1	0.6	9.9	3.0	18			
537				2.1	0.5	9.6	8.8	23			
538				3.7	0.4	10.3	6.0	22			
539				2.6	0.3	7.7	3.0	18			
540				5.0	0.2	5.4	2.2	11			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

A3 - Southern and Eastern Flood Plains

Component #1 60% - It consists of dark brown to very dark grayish brown non to slightly cracking loamy and clay loam soils. The soils are non-calcareous and usually have a neutral reaction. Most probably they are formed by the seasonal streams draining the hills.

Component #2 30% - They are very dark grayish brown cracking clay soils. They are deep, non-calcareous and mildly alkaline in reaction.

Component #3 10% - These are stratified soils with sandy loam to clay texture. They are deep, well drained, non-calcareous and mildly to slightly acid in reaction.

At the southern and eastern flood plains (A3) the lands are marginally suitable for rainfed agriculture, but moderately suitable for grazing.

SOIL ANALYTICAL DATA

TABLE No. 9

LOCATION: S. Kordofan Province

DATE OF SAMPLING: May 1975

DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 56

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
629	0-8	5.6	5.7	4.7	0.2			2	4	17	77	79
630	8-30		7.2		0.11			3	4	15	78	70
631	30-60		7.3		0.1			3	4	15	78	85

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
629	0.109	1.6	14	o.2	1.2	16.8	9.6	34			
630	0.580	0.9	16	0.2	0.9	19.1	1o.0	38			
631	0.039	0.55	15	0.5	1.1	19.2	14.4	36			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

7. NORTHERN CLAY PEDIPLAINS AND BASINS

N5 - Reg. Areas

Component #1 65% - They are deep sandy soils formed on wind blown materials. They are non-calcareous, neutral to slightly acid in reaction. They have no diagnostic horizon with low capability status and very low water holding capacity. They are subjected to wind erosion.

Analytical data of Pit KR 87 represent this component.

Component # 2 35% - They are inter-plateau valleys formed by alluvial infills of hill water courses. Outwash material eroded into rocky pavement is the source of "regs." Stones are concentrated on the surfaces which are sometimes covered by "desert varnish." The soils are stony, shallow to moderately shallow, brown colored, with clay loam surface horizon over gravelly sandy clay loam subsoil. They are slightly calcareous and mildly alkaline in reaction.

Analytical data of profiles KR 84, KR 97 represent this component.

Component # 3 10% - These are Basement Complex rock outcrops and small ridges scattered in this landscape association.

The soils of this unit (N5) are used for grazing. The main limitations are moisture shortage and the stony and sandy nature of the soils. There are a few possibilities for improvement beyond poor grazing. Currently they are suitable for agriculture.

SOIL ANALYTICAL DATA

TABLE No. 10
LOCATION: N. Kordofan
DATE OF SAMPLING: February 1976
DATE OF ANALYSIS: March 1976

PROFILE NO.: KR 84

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
751	0-15	8.1	8.7		0.25		3	54	34	7	5	21
752	15-30	7.8	8.1		0.36		5	52	33	6	9	22
753	30-40	7.3	7.7		1.1		19	56	25	6	13	23
754	40-70	6.4	6.8		4.0		64	50	14	3	33	32
755	70-110	5.9	6.3		0.74		2	75	8	6	11	28

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
751		0.03		0.5	0.2	2.4	0.7	1			
752		0.02		0.5	0.2	3.2	0.5	1			
753		0.06		0.2	0.2	2.3	1.5	3			
754		0.13		0.9	0.3	3.7	3.4	5			
755				0.5	0.1	1.5	1.3	5			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
751	3.6		1.6	0.2	1.0		1.6	0.0				
752	2.7		2.0	0.2	1.7		1.2	0.0				
753	5.4		1.2	6.6	1.7		1.3	0.0				
754	1.2		21.5	16.8	1.0		0.9	0.0				
755	1.3		3.1	0.6	1.0		0.6	0.0				

SOIL ANALYTICAL DATA

TABLE No. 11
LOCATION: N. Kordofan
DATE OF SAMPLING: February 1976
DATE OF ANALYSIS: March 1976

PROFILE NO.: KR 97

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
803	0-8	7.0	7.3	6.7	0.23		4	50	41	5	4	26
804	8-30	6.7	7.1		0.25		1	53	29	11	7	20
805	30-45	6.6	6.8		0.25		2	33	20	9	38	32
806	45-75	7.2	7.5		0.29	2.8	9	35	13	14	38	38
807	75-115	7.3	7.6		0.32	2.8	5	47	15	13	25	34

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
803		0.08		0.0	0.0			1			
804		0.06		0.0	0.1			2			
805		0.12		0.0	0.1			8			
806		0.05		0.0	0.1			9			
807				0.0	0.0			5			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
803	0.27		1.6	0.4	0.3		1.0	0.0				
804	0.38		1.4	0.6	1.5		0.9	0.0				
805	0.45		1.6	0.6	1.0		0.7	0.0				
806	0.45		1.7	0.9	0.9		0.8	0.0				
807	0.45		1.7	0.6	0.9		0.6	0.0				

N12 - Wadi El Mahbas Basin

Component #1 65% - The soils are deep, well to moderately well drained, calcareous to strongly calcareous, with moderately alkaline reaction. The surface horizon is mainly dark brown, with loamy texture and slightly calcareous over a loamy to sandy clay loam, calcareous subsoil, underlain by a hard strongly calcareous substratum. They have a cambic and a calcic horizon.

Analytical data of Pit KR 83 represent this component.

Component #2 35% - They have dark reddish brown clay loam surface horizon over a thin textural B horizon which overlies a gravelly sandy clay upper substratum. These soils are slightly calcareous and have a moderately alkaline reaction.

The soils of Wadi El Mahabas (N12) are dominated by drought resistant trees and grasses. Land use is extensive grazing. Currently the agricultural potential is low. Limitations are dryness, shallow soils, and wind erosion hazards. Agricultural production is not envisioned and grazing potential is moderate for camels and goats, but marginal for cattle and sheep.

Analytical data of Pit KR 78 represent this component.

SOIL ANALYTICAL DATA

TABLE No. 12
LOCATION: N. Kordofan
DATE OF SAMPLING: February 1976
DATE OF ANALYSIS: March 1976

PROFILE NO.: KR 87

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
762	0-5	7.9	0.3		0.62		2	62	23	5	4	19
763	5-30	7.9	0.2		0.3		1	64	24	7	5	17
764	30-55	7.7	0.0		0.34		2	61	27	2	10	17
765	55-96	7.0	0.2		0.65		4	59	25	10	6	10

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
762		0.04		1.0	0.3			2			
763		0.01		0.0	0.2			2			
764		0.02		0.3	0.2			2			
765		0.02		0.0	0.2			2			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
762	0.9		3.6	0.7	3.0		1.6	0.0				
763	0.7		2.0	0.7	1.0		1.5	0.0				
764	0.3		2.4	0.3	2.0		2.0	0.0				
765	1.1		4.1	1.4	1.0		2.0	0.0				

SOIL ANALYTICAL DATA

TABLE No. 13
LOCATION: N. Kordofan
DATE OF SAMPLING: February 1976
DATE OF ANALYSIS: March 1976

PROFILE NO.: KR 83

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
747	0-20	8.0	8.6		0.35	7.2		25	30	21	24	35
748	20-50	8.0	8.6		0.33	8.3		29	26	15	30	39
749	50-75	7.9	8.7		0.87	8.0		27	26	14	33	47
750	75-100	8.1	8.8		0.97	25.7	5	30	23	16	31	48

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
747		0.40		1.4	1.2			27			
748		0.38		1.4	0.4			29			
749		0.33		2.3	0.3			31			
750				1.6	0.2			26			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
747	2.7		2.4	0.1	2.0		1.5	0.0				
748	2.7		1.5	0.5	0.5		2.3	0.0				
749	7.2		3.6	0.3	1.0		1.9	0.0				
750	9.0		3.8	0.2	0.2		1.5	0.0				

SOIL ANALYTICAL DATA

TABLE No. 14 330
LOCATION: N. Kordofan PROFILE NO.:
DATE OF SAMPLING:
DATE OF ANALYSIS: KR 78

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
723	0-2	7.9	8.1		0.51	2.8	1	69	23	4	4	16
724	2-20	8.1	8.5		0.43	3.3	12	52	29	8	11	22
725	20-45	8.0	8.5		0.68	4.8	2	39	41	8	12	24
726	45-65	8.0	8.5		0.85	4.0	6	44	37	7	18	24

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
723		0.243		3.0	0.5			6		50	
724		0.203		3.0	0.7			12		25	
725		0.190		2.5	0.4			15		17	
726		0.144		3.0	0.2			16		19	
727				5.0	0.1			7		71	

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
723	0.6		3.5	1.1	2.1		3.0	0.0				
724	0.8		3.4	0.2	1.5		0.7	0.0				
725	1.3		5.0	0.2	1.3		1.5	0.0				
726	1.6		5.8	0.8	2.5		1.5	0.0				
727	5.4		16.7	2.8	3.0		1.4	0.0				

SOIL ANALYTICAL DATA

TABLE No. 15
LOCATION:
DATE OF SAMPLING:
DATE OF ANALYSIS:

PROFILE NO.:
KR 30

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
559	0-9	7.8	7.9		0.28	6.5		4	5	27	64	71
560	9-40	8.3	8.3		0.33	6.5		3	5	27	65	72
561	40-90	8.6	8.6		0.38	6.0		3	5	25	67	69
562	90-120		8.7		0.95	6.7		3	5	25	67	81
563	120-150		8.8		0.30	7.0		3	4	26	67	90

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
559	0.074	1.01	13	0.2	1.0			69			
560	0.048	0.90	18	1.1	0.7			69			
561		0.83		2.2	0.6			67			
562				5.0	0.5			51			
563				6.0	0.4			66			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
562	7.2											

N10 - Wadi El Milk Basin

Component #1 65% - They are moderately deep to shallow dark brown soils with weak to moderate subangular blocky structure underlain by a massive gravelly clay substratum. They are non-calcareous and have mildly alkaline reaction.

Component #2 35% - The soils are deep, well drained, non-calcareous and neutral in reaction. They are characterized by having a dark brown, loamy sand to sand loam, upper horizon with a weak subangular structure over a dark brown sandy loam subsoil and a sandy loam massive substratum.

Land use in Wadi El Milk Basin (N10) is extensive grazing. Agricultural potential is poor and grazing potential is low to moderate provided that there is available water for livestock.

8. NUBA INTERMEDIATE CLAY PLAINS

U8 - Eastern Intermediate Clay Plains

Component #1 55% - The soils are deep, very dark gray and brown cracking clay soils. They are poorly drained non-calcareous and moderately alkaline. Below the granular surface layer they have a moderate to strong blocky structure overlying a coarse subangular blocky layer. In general the subsoil is massive. Pressure faces and slikensides are common in such soils. The clay content ranges between 50 - 60%.

Analytical data KR 30 represent this soil.

Component #2 25% - They are developed on recent colluvial-alluvial materials. They are dark brown colored non-cracking soils with sandy loam textured surfact horizon overlain by a sandy clay loam or clay loam weakly structured cambic horizon. They are non-calcareous and neutral in reaction.

Component #3 15% - The soils are developed on low ridges and residual parent materials. The soils are yellowish red to dark red, non-calcareous, slightly acidic and have strong to moderate structure. Generally they are moderately deep to shallow with sandy loam and loamy horizons overlying clay to gravelly clay subsoils.

Component #4 5% - These are Basement Complex rock outcrops scattered all over the association.

In unit (U8) the land use is extensive grazing with scattered rainfed fields (dura, millet). The main limitations are poor management practices (traditional) on the cracking clay areas and low permeability status and low water holding capacity of the reddish soils. The soils are moderately suitable for rainfed agriculture and for grazing of livestock.

9. QOZ SANDS

Q1 - Sand Sheet and Low Dunes

Component #1 70% - The soils are very deep, dark yellowish brown or dark brown overlying dark brown to strong brown subsoil. They are excessively drained, with low water holding capacity, low organic matter and low cation exchange capacity. They have a loamy sand texture and they lack structural development. They are non-calcareous and slightly acidic.

Analytical data of profiles KR 102 and KR 70 represent this component.

SOIL ANALYTICAL DATA

TABLE No. 16

LOCATION: N. Kordofan

PROFILE NO.: KR 102

DATE OF SAMPLING:

DATE OF ANALYSIS:

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
824	0-20	6.8	7.1		0.16	2		60	33	2	5	25
825	20-55	7.1	7.4	6.5	0.13	2		52	35	7	6	24
826	55-100	7.0	7.4	6.4	0.13	2		28	45	21	6	23

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
824		0.12		0.0	0.1			3			
825		0.03		0.0	0.0			4			
826				0.0	0.1			5			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
824	0.4		0.9	0.2	0.7		0.7	0.0				
825	0.5		0.9	0.2	0.4		0.6	0.0				
826	0.6		0.9	0.0	0.4		0.3	0.0				

SOIL ANALYTICAL DATA

TABLE No. 17
LOCATION: N. Kordofan
DATE OF SAMPLING:
DATE OF ANALYSIS:

PROFILE NO.: KR 70

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
699	0-23	7.5	7.8		0.23			54	38	3	5	24
700	23-40	7.7	7.9		0.23			60	33	2	5	25
701	40-62	7.5	7.8		0.18			51	40	3	6	22

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
699	.137	0.137	1	0.0	0.2			2		0.0	
700		0.05		0.0	0.2			3		0.0	
7001		0.031		0.0	0.2			3		0.0	

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at.	dry
699	0.3		1.4	0.0	0.9		0.9	0.0				
700	0.4		1.4	0.0	1.0		0.9	0.0				
701	0.3		1.4	0.3	0.8		0.6	0.0				

Component #2 30% - The soils are deep yellowish red loamy sand to sandy loam, non-calcareous and slightly acid in reaction. They show some profile development. Cyclical changes in rainfall associate with cycles of erosion and deposition may explain the presence of such transitional soils on some surfaces which appear to have been stable for longer periods.

Unit Q1 is widely distributed in north central Kordofan. The relief is nearly flat to very gently undulating. Land use is traditional rainfed agriculture, dukhn, sorghum, groundnuts and seasame. In drier areas (north) extensive grazing is dominant. Main limitations are moisture availability, low fertility status of the soils and wind erosion hazards. Most of the unit has a marginal agricultural potential for rainfed farming. With improved soil and plant management practices, low to moderate yields of the main crop could be expected. Grazing potential varies from low to moderate but overgrazing is common particularly around villages and watering sites.

Q2 - High Dunes; Arid Climate

Component #1 100% - The relief is somewhat rolling and landscape is occupied by very deep coarse textured (sand and loamy sand) soils. Essentially these soils have similar characteristics to the dominant soils of unit Q1. In these sandy soils, extremely small changes, either alterations, translocations or additions are apt to produce some visible color changes. The soils of this unit have been mapped separately from the sandy soils based on relief and land use differences. Less than 20% of this landscape occurs in the arid belt.

Rainfed agriculture in the form of shifting clutivation is also practiced but on lesser scale than in the low fixed dunes areas. Main limitations are low available water, low fertility status and short growing season. Shifting cultivation includes millet, seasame and water melons. In arid areas there is very little cultivation (millet, water melons) and crop failures due to drought are frequent. The agricultural potential is marginal and grazing potential varies from low to moderate. Improvement of traditional agriculture, though difficult, may be attempted by improving crop management practices and introducing suitable crop rotations.

Analytical data of Profile KR 98 represent this unit.

Q3 - Longitudinal Dunes

Similar to Q1 except 60% of the area consists of deep, dry, longitudinal dunes that are moderately high with low potential and subject to soil blowing. The soils between the dunes commonly have low to moderate potential.

SOIL ANALYTICAL DATA

TABLE No. 18
LOCATION: N. Kordofan
DATE OF SAMPLING: February 1976
DATE OF ANALYSIS: March 1976

PROFILE NO.: KR 98

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
808	0-15	7.4	7.6	6.7	0.27			56	37	4	3	21
809	15-65	6.9	7.2		0.2			52	39	3	6	23
810	65-110	6.9	7.1		0.15			52	40	2	6	21

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
808		0.05		0.0	0.0			2			
809		0.03		0.0	0.0			2			
810				0.0	0.0			2			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
808	0.27		1.5	0.2	0.7		0.8	0.0				
809	0.36		1.5	0.1	0.9		0.7	0.0				
810	0.36		1.2	0.08	0.8		0.5	0.0				

Q21 - High Dunes; Semi Desert

Essentially these soils have similar characteristics like Q2. They have been mapped separately based on relief and land use. They have rolling relief and the dunes are higher than in unit Q2 and the inter-dune space is less. The soils are very deep, excessively well drained and highly susceptible to wind erosion. They are non-calcareous, slightly acidic in reaction without any horizonation development. Land use is extensive grazing only. They are currently unsuitable for rainfed agriculture. Overgrazing should be avoided. The grazing potential is low.

Analytical data of Profile KR 74 represent this unit.

10. TRANSITIONAL ZONE

T1 - Wadi El Galla Basin

Component #1 60% - These soils are characterized by having a deep, dark reddish brown, hard coarse loamy surface horizon overlying a dark red, fine loamy sub-surface horizon of clay accumulation. They are non-calcareous and the soil reaction is slightly acid.

Component #2 40% - The soils are deep, yellowish red without clay accumulation and having a very low cation exchange capacities, low fertility status, low moisture availability and susceptibility to erosion. The land use is mostly seasonal grazing with small scale shifting cultivation, the main crops being sorghum, ground nuts and karkadeh. The agricultural potential of these soils under present management is marginal. Grazing potential is low to moderate.

Analytical data of Profile KR 57 represent this component.

SOIL ANALYTICAL DATA

TABLE No. 19

LOCATION: N. Kordofan

PROFILE NO.: KR 74

DATE OF SAMPLING:

DATE OF ANALYSIS:

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
705	0-20	7.4	7.7		0.26			64	27	4	5	23
706	20-40	7.4	7.8		0.25			67	25	3	5	23
707	40-60	7.2	7.5		0.20			68	25	2	5	24

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
705		0.1763		2.0	0.3			4		50	
706		0.0842		0.3	0.2			4		7	
707		0.0562		0.3	0.2			4		7	

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
705	0.1		1.4	0.4	0.9		1.0	0.0				
706	1.0		1.4	0.3	0.6		0.8	0.0				
707	0.1		1.3	0.2	0.7		0.8	0.0				

SOIL ANALYTICAL DATA

TABLE No. 20
LOCATION: S. Kordofan Province
DATE OF SAMPLING: May 1975
DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 57

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
632	0-3	5.7	6.0	5.1	0.16			27	54	15	4	23
633	3-20	4.7	5.4	4.1	0.13			30	52	13	12	26
634	20-40	5.4	6.0	4.9	0.39			30	45	13	12	26
635	40-60	5.1	5.7	4.7	0.69			39	36	10	15	27

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
632				0.5	0.3	1.2	0.6	2	100		
633				0.2	0.3	1.1	0.4	2	100		
634				0.2	0.7	2.5	1.1	4	85		
635				0.2	0.7	2.5	1.1	7	63		

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

T2 - Khor Abu Habil Western Basin

Component #1 70% - The soils are deep, dark red with a loamy surface horizon over a loamy subsurface horizon of clay accumulation. The soils are well drained, non-calcareous and acid to meduim acid in reaction. The unit is gently sloping and slightly dissected by seasonal water courses.

Analytical data of Profile KR 03 represent this unit.

Component #2 30% - They are characterized by having a dark brown, sandy surface horizon underlain by a yellowish red loamy sand subsoil and upper substratum. The soils are deep with coarse texture and a very weak, if any, profile development. They are somewhat excessively drained, non-calcareous and are generally medium acid in reaction.

T3 - El Obeid Old Peneplain

Component #1 55% - The soils are deep, moderately well drained with subsurface horizon of clay accumulation. They are characterized by having a yellowish red, loamy sand thin upper horizon overlying a dark reddish brown, sandy clay, structural B horizon. Soil reaction is acid in upper horizons, becoming mildly alkaline with depth. Color of the substratum varies from dark grayish brown to olive brown.

Analytical data of Profile KR 02 represent this unit.

SOIL ANALYTICAL DATA

TABLE No. 21
LOCATION: N. Kordofan
DATE OF SAMPLING:
DATE OF ANALYSIS:

PROFILE NO.: KR 03

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
838	0-3	5.2	5.6	-	0.17			31	53	4	12	26
839	3-20	4.3	5.4		0.13			29	51	5	15	29
840	20-60	4.8	5.4		0.18			27	53	5	15	29
841	60-100	5.7	6.3		0.18			27	51	6	16	27
842	100-115	6.0	6.7		0.15			27	46	9	18	30
843	115-145	5.9	6.6		0.13			23	51	7	19	32

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
838		0.06		0.0	0.3			5			
839		0.08		0.0	0.3			8			
840		0.06		0.3	0.3			9			
841		0.06		0.3	0.2			10			
842				0.3	0.3			15			
843				0.3	0.4			15			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
838	0.6		1.2	0.1	0.7		0.3	0.0				
839	0.3		0.9	0.0	0.3		0.1	0.0				
840	0.5		0.9	0.3	0.7		0.3	0.0				
841	0.6		0.9	0.2	0.8		0.4	0.0				
842	0.8		0.8	0.1	1.0		0.5	0.0				
843	0.3		1.0	0.1	0.8		9.6	0.0				

SOIL ANALYTICAL DATA

TABLE No. 22
LOCATION: N. Kordofan
DATE OF SAMPLING:
DATE OF ANALYSIS:

PROFILE NO.: KR 02

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
832	0-10	6.8	7.0		0.35	2.6		33	51	6	10	25
833	10-20	5.6	6.3		0.11	4.6		37	45	6	12	24
834	20-50	6.7	7.5		0.11	4.7		31	41	6	22	30
835	50-80	8.7	9.0		0.3	3.6		27	12	10	21	35
836	80-100	8.2	9.1		0.39	3.2		29	38	9	24	40
837	100-130	8.4	9.1		0.39	3.0		27	41	8	24	28

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
832		0.11		5.3	0.3			5			
833		0.11		0.3	0.3			7			
834		0.09		0.6	0.2			17			
835		0.13		1.4	0.3			18			
836				1.8	0.4			20			
837				2.5	0.4			20			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
832	1.4		1.4	0.2	0.9		0.45	0.0				
833	0.5		0.5	0.0	0.4		0.3	0.0				
834	0.6		0.5	0.0	0.4		0.2	0.0				
835	2.5		0.6	0.1	0.7		1.4	0.0				
836	3.8		0.9	0.2	1.0		2.3	0.0				
837	3.3		0.7	0.0	1.0		2.0	0.0				

Component #2 45% - The soils have a dark brown, sandy loam surface horizon underlain by a dark reddish brown, sandy clay, well structured B horizon. They are non-calcareous and mildly alkaline in reaction.

In soil association (T3) the main limitations are low available moisture, soil erosion hazards and the hard consistence of the soils. Land use is extensive grazing with scattered rainfed fields. Agricultural potential is marginal; grazing potential is low to moderate.

Q6 - Babanuse - Khowi Sandy Peneplain

Component #1 70% - The soils consist of deep well drained non-calcareous, acid to neutral in reaction. They have a yellowish red loamy sand top soil with a massive or weak subangular blocky structure underlain by a dark red sandy loam, weakly to moderately structured upper subsoil. The lower subsoil, generally below 70 cm is finer in texture.

Analytical data of Profile KR 105 represent this unit.

Component #2 30% - The soils are dark red, deep well drained, non-calcareous and slightly acid in reaction. They have an argillic horizon of clay accumulation below the sandy loam surface.

This soil association (Q6) is extensively used for grazing with few localized rainfed farms. The limitations are low fertility status of the soils, low moisture availability. Agricultural potential is marginal and grazing potential is moderate provided water is available.

Q61 - El Nuhud - Abu Zabad Sandy Plateau

Component #1 80% - This unit is dominated by many buried seasonal water courses due to wind and water erosion. The soils are covered by vegetation. The soils have deep, yellowish red sandy loam top horizons underlain by dark red sandy loam. They are weakly developed, non-calcareous and slightly acid in reaction.

Analytical data of Profile KR 108 represent this unit.

Component #2 20% - The soils are deep, well drained dark red loamy soils. They are non-calcareous, slightly acidic and have a horizon of clay accumulation after the loamy surface. They are characterized by having low fertility, and low water holding capacity.

The land use in this unit (Q61) resembles that of Q6. The unit is extensively used for grazing. The limitations which are fertility status of the soils, low water availability makes the agricultural potential marginal and grazing potential moderate.

SOIL ANALYTICAL DATA

TABLE No. 23
LOCATION: N. Kordofan
DATE OF SAMPLING: March 1976
DATE OF ANALYSIS: April 1976

PROFILE NO.: KR 10

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
849	0-20	6.4	6.6	6.0	0.23			53	36	6	5	22
850	20-45	4.1	4.8	3.7	0.17			49	33	5	13	26
851	45-70	4.0	4.4	3.7	0.47			54	29	4	13	26
852	70-120	4.1	4.5	3.7	0.24			49	32	5	15	28

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
849				0.3	0.2	1.1	0.5	2			
850				0.3	0.3	1.0	0.5	4			
851				1.0	0.4	1.1	1.0	5			
852				0.6	0.4	1.0	1.5	5			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
849	0.5	0.3			1.3		0.6	0.0				
850	0.4	0.2			0.1		0.3	0.0				
851	0.8	0.2			0.3		0.2	0.0				
852	0.6	0.0			0.0		0.3	0.0				

11. NUBA MOUNTAINS CLAY PLAINS

U10 - Habila Clay Plain

Component #1 55% - The soils are deep, very dark grayish brown cracking clays. Cracks are up to 10 cm on the surface and reach 70 - 80 cm in depth. They are non-calcareous, neutral in reaction and the clay content generally is 40 - 55%. This unit is gently undulating.

For chemical and physical analysis consult soil survey reports SSD 31, 34, 57 published by Soil Survey Admin. WAD-MEDANI - Sudan.

Component #2 30% - They are very deep, very dark gray or nearly black cracking clay soils. They are occupying low lying areas and have darker color if compared with soil of component #1. They are non-calcareous, neutral to mildly alkaline in reaction.

Component #3 15% - They occur on small, slightly higher areas, weathered ridges or near basement rock outcrops. They have loamy surface horizons overlying a fine textured B horizon. They are non-calcareous and have an acid soil reaction. Colors range from brown to red. They are characterized by their low water holding capacity and low fertility status.

In unit (U10) the land use is grazing and rainfed agriculture. Most of the agriculture is mechanized; cotton and dura are the main crops. There is still a large potential for rainfed agriculture in this unit. The unit comprises moderately suitable lands for mechanized rainfed agriculture and for grazing.

U11 - Jebel El Daier Clay Plain

It has a gently sloping relief toward Khor Abu Habil. The soil has a sandy clay, slightly cracking surface. They are very dark grayish brown, non-calcareous and they are slightly alkaline. They have high clay content and slikensides and pressure faces at lower depth.

The land use is grazing and rainfed agriculture. The soils have marginal potential for mechanized rainfed agriculture and they are moderately potential for grazing.

SOIL ANALYTICAL DATA

TABLE No. 23

LOCATION: N. Kordofan

DATE OF SAMPLING: March 1976

DATE OF ANALYSIS: April 1976

PROFILE NO.: KR 108

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
860	0-15	4.0	4.4	3.6	0.18			30	44	9	17	28
861	15-30	3.8	4.3	3.7	0.78			31	43	6	20	30
862	30-70	3.8	4.3	3.6	0.34			29	45	5	21	32
863	70-100	3.9	4.5	3.6	0.25			28	43	7	22	32
864	100-120	4.0	4.3	3.6	0.31			29	40	9	22	34

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
860				1.5	0.5	1.0	0.9	5			
861				0.6	0.4	1.3	1.6	5			
862				0.6	0.4	1.0	0.6	6			
863				0.6	0.4	0.8	0.7	6			
864				0.6	0.4	0.8	0.8	7			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
860	0.5	0.0			1.2		0.5	0.0				
861	0.9	0.0			1.5		0.5	0.0				
862	0.5	0.0			0.9		0.3	0.0				
863	0.6	0.0			1.0		0.4	0.0				
864	0.5	0.0			0.8		0.6	0.0				

U6 - Lagawa El Berdab Plain

Component #1 50% - The soils are deep, very dark grayish brown cracking clays. They crack deeply and have a well developed subangular blocky structure in the top 30 cm., massive or subangular below. The soils are non-calcareous, and mildly to moderately alkaline in reaction.

Analytical data of Profile KR 54 represent this unit.

Component #2 35% - The soils are developed on low ridges and gently sloping piedmont areas near the Jebels (hills). They consist of deep well drained soils with loamy surface horizon over a fine clayey subsurface horizon of clay accumulation. They are non-calcareous and medium acid in reaction.

Analytical data of Profile KR 51 represent this unit.

Component #3 15% - The soils are deep, very dark grayish brown to nearly black cracking clay soil, occupying depressional sites. They are non-calcareous, and medium acid in reaction with clay content more than 50%. They have deep cracks, moderately developed structure at the top and massive below.

Analytical data of Profile KR 53 represent this unit.

A high percentage of this unit (U6) is used for grazing. Dark cracking clay soil, are used for traditional and mechanized rainfed agriculture. The main limitations are heterogenity of soil pattern distribution, low water hold capacity for the reddish soils, and waterlogging at the depressional sites. The agricultural potential varies from marginal to moderately good. Grazing potential is good.

SOIL ANALYTICAL DATA

TABLE No. 25
LOCATION: S. Kordofan Province
DATE OF SAMPLING: May 1975
DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 54

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
621	0-5		7.2		0.39			8	18	28	51	59
622	5-30		7.2		0.32			8	14	26	52	63
623	30-60		7.4		0.42			8	12	27	53	62
624	60-90		8.3		0.6			8	13	26	53	67

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
621	0.05	1.35	22	0.5	0.7			31			
622	0.04	0.86	21	0.5	1.5			31			
623	0.03	0.65	19	0.5	0.6			28			
624		0.67		1.3	0.6			34			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

SOIL ANALYTICAL DATA

TABLE No. 26

LOCATION: S. Kordofan Province

DATE OF SAMPLING: May 1975

DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 51

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
610	0-10	5.1	5.7	4.3	0.12			56	20	17	7	23
611	10-25	4.9	5.6	4.1	0.1			58	15	16	11	27
612	25-35	4.9	5.5	3.9	0.1			56	12	15	17	28
613	35+	4.7	5.3	3.7	0.11			47	8	14	31	44

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
610	0.052	0.74	14	0.0	0.2	1.6	0.9	4	67		
611	0.043	0.59	13	0.0	0.2	1.6	0.8	6	43		
612	0.048	0.51	11	0.2	0.3	1.9	1.3	8	43		
613	0.057	0.34	6	0.2	0.5	2.0	1.0	13	30		

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

SOIL ANALYTICAL DATA

TABLE No. 27

LOCATION: S. Kordofan Province

DATE OF SAMPLING: May 1975

DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 53

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
618	0-10	6.1	6.4	5.1	0.15			4	3	32	61	68
619	10-45	6.3	6.6	5.2	0.13			4	3	32	61	58
620	45-90	6.7	6.7	5.3	0.15			4	3	32	61	59

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
618	0.067	1.2	17	0.5	1.0			29			
619	0.060	1.1	17	0.5	1.1			36			
620		0.12	-	0.5	1.3			32			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

U9 - North Eastern Undulating Clay Plain

Component #1 65% - The soils are deep, moderately well drained cracking clays. They are very dark grayish brown, slightly calcareous and medium alkaline in reaction. They have a moderately developed structure at the top horizons and massive below. They are characterized by having pronounced gilgai, potholes and common $CaCO_3$ concretions.

Analytical data of Profile KR 40 represent this unit.

Component #2 25% - They are deep, non cracking clay soils. Generally they have a very dark brown grayish color and weak to moderately developed horizons. They are non-calcareous and mildly alkaline in reaction. The texture of the top horizon is clay loam or sandy clay loam becoming clay below the top horizons.

Analytical data of Profile KR 41 represent this unit.

Component #3 10% - The soil in this unit is characterized by slightly cracking dark grayish brown clay loam surface horizon over a silty clay subsoil. They are deep, moderately well drained, non-calcareous and mildly alkaline in reaction.

Rainfed agriculture and grazing is the land use in unit (U6). The main limitation is the low rainfall. Agricultural potential is moderate for short cycle crops and marginal for cotton. Grazing potential is moderate.

SOIL ANALYTICAL DATA

TABLE No. 28
LOCATION: S. Kordofan Province
DATE OF SAMPLING: May 1975
DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 40

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
584	0-3		8.5		0.28	8		2	31	30	37	55
585	3-15		8.7		C.26	10		2	24	28	46	65
586	15-30		9.2		0.34	9		2	21	26	51	55
587	30-50		9.3		0.49	7		13	8	28	51	55
588	50-90		9.3		0.5	7		1	18	29	52	59

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
584	0.066	0.90	14	0.2	1.7			30			
585	0.074	0.86	12	0.2	0.5			39			
586	0.046	0.57	12	2.7	0.3			42		7	
587	0.041	0.43	11	5.9	0.3			38		16	
588		0.52		4.8	0.3			43		11	

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

SOIL ANALYTICAL DATA

TABLE No. 29

LOCATION: S. Kordofan Province

PROFILE NO.: KR 41

DATE OF SAMPLING: May 1975

DATE OF ANALYSIS: September 1975

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
589	0-4	7.5	7.6		0.44			1	26	40	33	54
590	4-30		8.0		0.23			1	18	43	38	56
591	30-44		8.0		0.27			1	16	41	42	56
592	44-80		8.4		0.6			1	12	40	47	55

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
589	0.053	0.51	10	0.2	1.1			22			
590	0.049	0.39	9	0.2	0.5			29			
591	0.032	0.18	6	0.2	0.4			30			
592		0.37		0.2	0.5			29			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
592	5.4											

12. DILLING DISSECTED UPLAND

U5 - Dilling Upland Plain

Component #1 90% - They are deep, moderately well drained loamy soil with a very dark grayish brown surface over dark brown clay loam and clay B. horizon. The soils are non-calcareous and medium acid to moderately alkaline in reaction. Small seasonal water courses have a lot of dissection throughout this sloping unit.
Analytical data of Profile KR 05 represent this unit.

Component #2 10% - These are developed on eolian sand deposits basement rock outcrops. They have yellowish red color, coarse texture with a textural B horizon. They are non-calcareous, slightly acidic in reaction with a moderately well developed profile. They are susceptible to wind and water erosion.

In unit (U5) extensive grazing is the main land use. Low rainfall, and erosion are the main limitations. Agricultural and grazing potentials are marginal.

13. LOW FLAT CLAY PLAINS

L1 - Eastern Flat Clay Plain

Component #1 95% - The soils are well developed vertisols with high clay content and are strongly cracking. The soils have a very dark grayish brown color, non-calcareous and mildly alkaline in reaction. These soils are developed on alluvial deposits similar to other clays of the central clay plain.
Analytical data of Profile KR 31 represent this unit.

Component #2 5% - This component is considered as an inclusion to mapping unit L1. They are small inselbergs of basement complex with rocky lands.

In this mapping unit (L1) of the eastern flat clay plain land use is rainfed agriculture and grazing. Agricultural potential is marginal to moderate for traditional and mechanized rainfed farming respectively. Main limitations is the physical properties of the clays (workability). Selection of the appropriate sowing-date is a limiting factor in such areas.

SOIL ANALYTICAL DATA

TABLE No. 30
LOCATION: S. Kordofan Province
DATE OF SAMPLING: May 1975
DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 05

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
614	0-5	7.2	7.3	6.1	0.19			8	9	33	50	53
615	5-25	7.0	7.4	6.0	0.18			8	9	32	51	55
616	25-40	7.1	7.7		0.21			8	8	33	51	58
617	40-60		8.1		0.3			9	7	30	54	58

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
614	0.051	0.82	16	0.2	0.6	20	12.6	43			
615	0.048	0.78	15	0.5	0.4	17.7	13.0	39			
616	0.046	0.62	13	0.5	0.4	20.7	11.1	41			
617	0.036	0.61	16	1.1	0.4	23.4	10.4	43			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry

SOIL ANALYTICAL DATA

TABLE No. 31

LOCATION: S. Kordofan Province

DATE OF SAMPLING: May 1975

DATE OF ANALYSIS: September 1975

PROFILE NO.: KR 31

Sample No.	Depth cm	pH Paste	pH H_2O	pH KCL	EC mmhos cm	MEC $CaCO_3$	MECHANICAL ANALYSIS : 2mm	CS	FS	Si	C	Sat %
564	0-8	7.6	8.0		0.26	5.0		10	7	24	59	58
565	8-28		8.5		0.32	6.0		8	7	24	61	59
566	28-46		8.5		0.21	6.0		9	6	24	61	59
567	46-70		8.6		0.30	6.0		8	7	24	61	62
568	70+		8.6		0.65	6.0		8	6	25	61	64

Sample No.	N %	C %	C/N	EXCHANGEABLE CATIONS MEQ/100 G. Na	K	Ca	Mg	CEC	Base Sat.	ESP	SAR
564	0.052	0.93	17	1.1	0.3			53			
565	0.036	0.64	17	0.5	0.3			46			
566	0.042	0.57	14	1.1	0.4			44			
567	0.035	0.47	13	2.7	0.3			38			
568		0.51		3.6	0.4			41			

Sample No.	SOLUBLE CATIONS AND ANIONS MEQ/L IN SATURATION EXTRACT Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	AGGREGATE STABILITY	HYDRAULIC CONDUCTIVITY	BULK DENSITY 03at	dry
568	4.1											

L2 - Southern Clay Plain

Component #1 90% - The unit has been distinguished from L1 component #1 because it is most probably related with Bahr El Arab and Bahr El Gazal alluvium. They are deep, moderately well drained, very dark grayish brown and very dark gray cracking clays. They are non-calcareous and mildly alkaline in reaction. In some places a thin layer of very fine sand occurs on the surface.

Component #2 10% - These are deep, moderately well drained non cracking soils occupying gently sloping smooth convex sites. They have a sandy clay and clay loam to clay textures. They are non-calcareous, mildly alkaline to neutral in reaction.

Grazing with limited rainfed agriculture is the main land use. Wetness and workability are the main limitations. The agricultural potential is moderate and grazing potential is good.

14. WHITE NILE ALLUVIUM

RN - White Nile Flood Plain

Component #1 85% - The soils are brown, somewhat poorly drained, having silty clay loam or silty clay textures. Due to the prolonged flooding and saturation conditions, the soils are distinctly mottled. The soils are non-calcareous and mildly alkaline.

Component #2 15% - These are inclusions of coarser textured soils developed along the flood plain. They are deep, excessively well drained, non-calcareous slightly acidic in reaction.

On such flooded soils (RN) irrigated agriculture is praticed by controlling the flood. There is need to improve the present irrigation systems, increase yields, and grow a greater variety of crops.

RT - White Nile Upper Terrace

The region comprises the riverlain lands along the White Nile that are almost flat sloping towards the river. The soils are dark gray, slightly cracking clays. They are poorly drained and slowly permeable. Although there is a wide range of clay content, the clays are not generally heavy. The soils are moderately to strongly alkaline, becoming less alkaline towards the south. They are mostly calcareous, often saline and mainly sodic. The low cracking capacity of the terrace soils north of Kosti is attributed to the structural deterioration by contamination with wind blown sands.

Limited traditional rainfed cultivation and grazing is the only land use. They are unsuitable for rainfed mechanized agriculture.

15. SAND DUNES AND CLAY PLAIN COMPLEX

Q5 - Tendelti Sand Dunes and Clay Plain Complex

Component #1 70% - These are recent sand deposits covering the subrecent clay plain. They have soils similar in appearance to those on longitudinal sand dunes. They are loamy sand in texture and have a yellowish red top soil over a dark red subsoil and substratum. They are non-calcareous, neutral to slightly acid in reaction.

Component #2 25% - These are inter ridges soils, having a finer texture, a dark brown color and a neutral to mildly alkaline reaction. They are noncracking with a sandy clay horizon on the top overlying a deep clay subsoil and substratum.

Component #3 5% - These are slightly cracking, deep, very dark grayish brown soils, occupying depressional sites. They are poorly drained, non-calcareous and neutral in reaction.

Land use in unit (Q5) is a mixture of rainfed agriculture (low scale) and seasonal grazing. Rainfed agriculture is marginal and grazing potential is low.

Q51 - Kosti Clay Plain and Sand Dune Complex

Component #1 60% - They have similar soil characteristic to Q5 component #2 but occupying the major part in this unit.

Component #2 40% - They have similar soil characteristic to Q5 component #1 but occupying less area in this unit.

In this unit the noncracking clay soils are dominating. Agricultural potential is marginal and the grazing potential is low. The main limitation is the erosion hazard. Urgent conservation measures should be used to protect the remaining clay soils.

Agricultural Potential

Introduction

The factors which determine the potential for specific kinds of land use include environmental conditions such as climate, hydrology, topography and soil conditions as well as economic and social factors, such as price of produce, distance to markets, transport facilities and skills of the population.

This report is mainly concerned with the physical factors which influence agricultural potential. The many physical characteristics of the land can be grouped in a limited number of land qualities concerning their influence on the suitability of land for a specific kind of land use (FAO; 1974; Van der Kevie, 1976). Land qualities considered are soil fertility, soil workability, erosion hazards, possibilities for mechanization and seedling establishment. These qualities were evaluated utilizing all laboratory data and field observations of the soil units.

For a broad, qualitative evaluation of the agricultural potential of the study area, the potential land suitability of a 38 soil associations for traditional and rainfed agriculture is given in Table 32. The symbols used to indicate different suitability levels are those of the new land evaluation system proposed by FAO (FAO, 1974a; Van der Kevie 1976).

Land Suitability Classes

Definitions of the land suitability symbols are given below.

S1-Highly Suitable Land

Land which is (or is expected to be after improvements) highly productive

Table 32

SELECTED SOIL PROPERTIES AND RELATED DATA

Map Unit Symbol	Component of Unit	Area Fed-dans	Area %	Soil Slope %	Soil Depth Class	Soil Texture A	Soil Texture B	Course Frag-ments	Perme-ability Class	Soil Drainage Class	Soil Wet-ness	Avail. Water Cap.	Soil Reaction PH A	Soil Reaction PH B	Soil Reaction EC A	Soil Reaction EC B	Total Precip. (mm)	Climate Soil (Mo.) Moist	Climate Soil (Mo.) Dry	Climate Wind Vel. (days) Low	Climate Wind Vel. (days) Med.	Climate Wind Vel. (days) Hi
N1	#1	394008	30	5 - 10	SH-MD	S	LS	3	VR	E	1	4	7.1	8.3	0.1	0.5	100-150	6-9	10-5	200	120	40
	#2	919353	70	40%	Rock Out Crops												100-150	6-9	10-5	200	120	40
N2	#1	2930486	65	1 - 3	MD-D	L	CL	3	M	MW	1	2	7.2	8.0	0.2	1.0	100-150	6-9	10-5	200	120	40
	#2	1127110	25	2 - 5	D	S	LS	3	VR	E	1	4	7.6	8.4	0.2	0.5	100-150	6-9	10-5			
	#3	450844	10	Rocky and Stoney Lands													100-150	6-9	10-5			
N3	#1	14086627	90	1 - 2	D	S	LS	1	VR	E	1	4	7.5	8.5	0.2	0.3	100-200	6-9	10-5	200	120	40
	#2	454070	10	Scattered Rock Out Crops													100-200	6-9	10-5			
N31	#1	11251149	75	2 - 5	MD	SCL	GSC	2	M	MW	1	3	7.6	8.8	0.2	0.4	150	6-9	10-5	200	120	40
	#2	417050	25	Scattered Rock Out Crops													150	6-9	10-5			
N4	#1	11683560	80	Rocks and Dissected Area (Sand Stone Ridges)													100-150	6-9	10-5	215	110	35
	#2	420890	20	2 - 5	SH	S	LS	4	VR	E	1	4	6.9	8.3	0.24	1.85	100-150	6-9	10-5			
N5	#1	12591009	65	0 - 2	D	SCL	SC	1	M	MW	2	3 - 2	6.6	7.9	0.3	2.0	200	6-9	10-5	230	100	30
	#2	21195850	30	2 - 4	SH	SL	GSCL	2	MR	W	2	4	7.8	8.8	0.3	2.3	200	6-9	10-5			
	#3	199308	5	Rock Out Crops Associated With Sands at Some Places													200	6-9	10-5			
N6	#1	11302608	100	5 - 15	VD	S	LS	0	VR	E	1	4	7.0	8.0	0.2	0.3	100-200	6-9	10-5	230	100	30
N10	#1	1213131	65	0 - 2	MD	SCL	CL	1	M	MW	1	3	7.6	8.8	0.2	3.0	150-200	6-9	10-5	230	100	30
	#2	653224	35	2 - 5	SH	SCL	GCL	3	M	MW	1	4	7.2	8.7	0.2	2.2	150-200	6-9	10-5			
N12	#1	11377877	65	0 - 1	D	L	SCL	1	M	MW	2	2	8.0	9.0	2.0	14.0	100-200	6-9	10-5	230	100	30
	#2	741934	35	1 - 2	MD	L	GCL	2	M	MW-W	2	3	3.0	8.8	2.0	10.0	100-200	6-9	10-5			

Table 32 (Continued)

SELECTED SOIL PROPERTIES AND RELATED DATA

Map Unit Symbol	Component of Unit	Area		Soil Slope %	Soil Depth Class	Soil Texture		Course Fragments	Permeability Class	Soil Drainage Class	Soil Wetness	Avail. Water Cap.	Soil Reaction				Total Precip. (mm)	Climate				
													PH		EC			Soil (Mo.)		Wind Vel. (days)		
		Feddans	%			A	B						A	B	A	B		Moist	Dry	Low	Med.	Hi
Q1	#1	3747304	70	2 - 5	ED	S	LS	0	R	SE	2	4	6.8	7.6	0.15	.18	200-400	6-9	10-5	260	80	20
	#2	1605988	30	0 - 2	ED	LS	SL	0	MR	WE	3	4	6.8	7.5	0.15	.2	200-400	6-9	10-5			
Q2	#1	6162814	100	10 - 25	ED	S	LS	0	VR	E	1	4	7.2	74	0.2	0.6	200-400	6-9	10-5	210	120	30
Q3	#1	672810	60	5 - 15	ED	LS	SL	0	VR	E	1	3	5.9	20	0.18	.21	400-750	5-9	10-4	210	120	30
	#2	392473	35	2 - 5	ED	S	LS	0	VR	E	1	4	4.7	5.8	0.15	.18	400-750	5-9	10-4			
	#3	56068	5	0 - 2	MD	SC	SCL	0	MR	MW	3	4	6.8	7.8	0.2	0.5	400-750	5-9	10-4			
Q4	#1	763439	100	5 - 15	ED	S	LS	0	VR	E	1	4	7.1	7.5	0.15	.39	200-400	6-9	10-5	200	120	40
Q5	#1	766665	70	2 - 5	ED	LS	LS	-	VR	E	1	3	6.5	7.5	0.15	0.2	200-400	6-9	10-5	210	120	30
	#2	273809	25	0 -0.5	D	CL	C	0	MS	SWP	4	3	7.0	8	0.2	0.3	200-400	6-9	10-5			
	#3	54762	5	0 - 1	D	SC	C	0	MS	P	4	3	7.0	8.0	0.2	0.3	200-400	6-9	10-5			
Q51	#1	522580	60	0 - 1	D	SCL	C	0	MS	P	4	3	7.0	8.0	0.2	0.3	200-400	6-9	10-5	210	120	30
	#2	215053	40	5 - 15	D	LS	SL	0	R	SE	1	3	6.5	7.5	0.15	.2	200-400	6-9	10-5			
Q6	#1	481720	70	1 - 5	D	LS	SL/SCL	0	MR	W	2	3	4.0	6.4	0.17	0.24	400-750	5-9	10-4	260	80	20
	#2	204451	30	0 - 2	D	SCL	SC	0	M	MW	3	3	3.8	4.1	0.27	2.1	400-750	5-9	10-4			
Q61	#1	368663	80	1 - 5	D	SL	SCL	0	MR	W	2	3	3.5	40	0.3	2.0	400-750	5-9	10-4	260	80	20
	#2	92165	20	2 - 5	D	LS	SL	0	R	R	1	3	4	6.5	0.2	0.3	400-750	5-9	10-4			
Q21	#1	1608292	100	10 - 25	D	S	S/LS	0	VR	E	1	4	7.0	7.5	0.2	0.5	200-400	6-9	10-5	200	120	40

Table 32 (Continued)

SELECTED SOIL PROPERTIES AND RELATED DATA

Map Unit Symbol	Component of Unit	Area Feddans	Area %	Soil Slope %	Soil Depth Class	Soil Texture A	Soil Texture B	Course Fragments	Permeability Class	Soil Drainage Class	Soil Wetness	Avail. Water Cap.	Soil Reaction PH A	Soil Reaction PH B	Soil Reaction EC A	Soil Reaction EC B	Total Precip. (mm)	Climate Soil (Mo.) Moist	Climate Soil (Mo.) Dry	Climate Wind Vel. (days) Low	Climate Wind Vel. (days) Med.	Climate Wind Vel. (days) Hi
T1	#1	995390	60	2 - 5	D	SL	CL	0	MR	W	2	3 - 2	3.8	4.0	.13	.69	400-750	5-9	10-4	285	60	15
	#2	663593	40	1 - 2	D	SL	SCL	0	MR	W	2	3	4.7-5.7		.18	.78	400-750	5-9	10-4			
T2	#1	976342	70	0 - 2	D	LS	SCL	0	R/MR	SE/W	2	3	4.8	5.7	.13	.18	400-750	5-9	10-4	260	80	20
	#2	418432	30	2 - 5	D	S	LS	0	VR	E	1	4	4.8	5.8	.15	.25	400-750	5-9	10-4			
T3	#1	45310	55	1 - 2	D	LS/SL	SC	0	M	MW	2-3	3	5.6	8.9	.3	1.7	400-750	5-9	10-4	260	80	20
	#2	37071	45	0 - 2	D	SL/SC	SC	0	M	MW	2-3	3	6.2	7.8	.19	.37	400-750	5-9	10-4			
U1	#1	433179	50	1 - 5	SH/MD	L	GCL/GC	3	MR	W	2	4	6.5	7.2	.2	.3	400-800	5-10	11-4	310	40	10
	#2	259907	30	1 - 2	MD/D	L/SCL	C	2	MR	MW	3	3	6.9	7.2	.3	.5	400-800	5-10	11-4			
	#3	173272	20	2 - 8	SH	SL	GC	4	MR	W	2	4	6.9	7.2	.18	.4	400-800	5-10	11-4			
U2	#1	776494	50	1 - 3	MD	L	CL/C	1	M	MW	2	3	6.6	8.4	.2	.9	400-800	5-10	11-4	310	40	10
	#2	543547	35	1 - 5	MD/D	SCL	C	2	M	MW/W	2	3	6.0	7.5	.2	.5	400-800	5-10	11-4			
	#3	232949	15	2 - 5	SH	SL	GSCL	1-2	MR	W	2	4	6.0	7.5	.2	.5	400-800	5-10	11-4			
U3	#1	151766	65	0 - 2	D	SL	CL/C	0	M	W/MW	2-3	2-3	5.0	7.5	.2	.5	700-900	4-10	10-3	335	20	5
	#2	81720	35	0 - 3	D	SL/L	CL	0	M	W/MW	2-3	2-3	7.0	7.5	.2	.4	700-900	4-10	10-3			
U5	#1	713363	90	0 - 2	D	CL	CL/C	0-1	MS	SP/P	3	2	7.0	7.2	.2	.3	400-750	5-9	10-4	310	40	10
	#2	79262	10	2 - 5	D/MD	SL	CL	0-1	MS	SP	3	3-2	6.8	7.2	.2	.3	400-750	5-9	10-4	-	-	-
U6	#1	1232710	50	2 - 5	D	C	C	0	S	R/SP	3	3	6.0	7.0	.13	.15	400-750	5-9	10-4	310	40	10
	#2	862902	35	0 - 2	MD	SCL	CL	1	M	W/MW	2-3	3	5.2	6.3	.12	.3	400-750	5-9	10-4			
	#3	369815	15	0 - .5	D	C	C	0	VS	VP	4	3	5.6	7.6	.11	.2	400-750	5-9	10-4			

Table 32 (Continued)

SELECTED SOIL PROPERTIES AND RELATED DATA

Map Unit Symbol	Component of Unit	Area		Soil Slope %	Soil Depth Class	Soil Texture		Course Fragments	Permeability Class	Soil Drainage Class	Soil Wetness	Avail. Water Cap.	Soil Reaction				Total Precip. (mm)	Climate				
													PH		EC			Soil (Mo.)		Wind Vel. (days)		
		Feddans	%			A	B						A	B	A	B		Moist	Dry	Low	Med.	Hi
U8	#1	1355143	55	2 - 5	EQ	C	C	0-1	S/VS	P	3	3	7.8	8.3	.3	.3	400-750	5-9	10-4	260	80	20
	#2	615974	25	2 - 5	D	SL	SCL	0-1	M	MW	2	3-2	6.5	8.0	.3	.5	400-750	5-9	10-4			
	#3	369585	15	2 - 5	MD	L	CL	1	M	MW	2-3	3	6.5	7.8	.3	.7	400-750	5-9	10-4			
	#4	123195	5	Rock Outcrops																		
U9	#1	454300	65	2 - 5	VD	C	C	0-1	S	P	3	3	7.0	8.8	.3	.5	400-750	5-9	10-4	260	80	20
	#2	174731	25	1 - 2	VD	L	CL	0	M	MW	2	1-2	5.6	8.8	.3	.9	400-750	5-9	10-4			
	#3	69392	10	1 - 3	D	CL	SIC	0	M/MS	SP	2-3	3	7.0	8.2	.3	.8	400-750	5-9	10-4			
U10	#1	1484406	55	2 - 5	VD	C	C	0-1	S	SP/P	3	3	2.0	8.0	.5	.8	400-800	5-10	11-4	310	40	10
	#2	809676	30	.5 - 1	VD	C	C	0	S	P	4	3	7.0	8.5	.3	.7	400-800	5-10	11-4			
	#3	404838	15	1 - 2	MD/SH	SCL	CL	1-2	M	MW	2	3	5.0	6.5	.3	.5	400-800	5-10	11-4			
U11	#1	399384	100	0 - 2	D	SC	C	0-1	MS	SP	3	3	7.0	8.0	.3	.2	400-750	5-9	10-4	285	60	15
L1	#1	3630715	95	0 - 2	VD	C	C	1	S	SP	3	3	8.2	8.8	.4	.7	400-750	5-9	10-4	235	100	25
	#2	191090	5	Scattered hills and rocky lands																		
L2	#1	193548	90	0 - 2	VD	SC/C	C	0	S	P	3	3	5.9	6.5	.2	.3	400-750	5-9	10-4	230	25	5
	#2	21505	10	1 - 2	MD	SCL	CL	0-1	MS/M	M	2	3	5.1	5.3	.2	.3	400-750	5-9	10-4			
A1	#1	847925	60	0 - 5	VD	C	C	0	VS	VP	4	3	5.6	7.0	.1	.2	400-750	5-9	10-4	235	100	25
	#2	353302	25	0 - 1	D	LS	CL/SC	0-1	MS	SP	3	3-2	5.0	7.2	.11	.22	400-750	5-9	10-4			
	#3	211981	15	1 - 2	D	LS	SL	1	MR	SE	3-2	3	4.5	5.3	.1	.2	400-750	5-9	10-4			

Table 32 (Continued)

SELECTED SOIL PROPERTIES AND RELATED DATA

Map Unit Symbol	Component of Unit	Area		Soil Slope %	Soil Depth Class	Soil Texture		Course Fragments	Permeability Class	Soil Drainage Class	Soil Weakness	Avail. Water Cap.	Soil Reaction				Total Precip. (mm)	Climate				
													PH		EC			Soil (Mo.)		Wind Vel. (days)		
		Feddans	%			A	B						A	B	A	B		Moist	Dry	Low	Med.	Hi
A2	#1	13825	60	0 - .5	VD	C	C	0	S	P	4	3	5.9	7.2	.15	.2	400-750	5-9	10-4	285	60	15
	#2	11060	40	0 - 1	D	SCL	CL/C	0-1	MS	SP	3-4	3-2	5.5	7.5	.1	.2	400-750	5-9	10-4			
A3	#1	385253	60	0 - 1	VD	SCL	CL/SCL	0	MS	MW	3	3-2	6.5	7.2	.4	.95	400-750	5-9	10-4	310	40	10
	#2	192626	30	1 - 2	VD	C	C	0	S/VS	P	3-4	3	6.2	7.6	.4	1.05	400-750	5-9	10-4			
	#3	64088	10	0 - 2	VD	SCL	SC	0	MS/S	SP	3	3-2	6.5	7.2	.4	.9	400-750	5-9	10-4			
RN	#1	130569	85	1 - 2	VD	CL	C	0	S	P	3-2	2	7.0	8.0	2.0	4.0	200-400	6-9	10-4	235	100	25
	#2	23042	15	0 - 1	VD	C	C	0	S/VS	P	4	3	6.0	7.2	.1	1.8	200-400	6-9	10-4			
RT	#1	855605	100	1 - 3	D/VD	C	C	0	S/VS	P	2	3	7.0	8.8	4.0	8.0	200-400	6-9	10-4	235	100	25
HM	#1	1978490	100	Mountains, inselbergs and rock outcrops																170	150	40

for the defined land use type and yields high benefits, amply justifying the required capital and current inputs. There are no significant limitations that will reduce yields or increase recurrent costs for production or conservation.

S2-Moderately Suitable Land

Land which is (or is expected to be after improvements) moderately productive for the defined land use type and yields moderate benefits, which are sufficiently high to justify the required capital and recurrent inputs. There are moderately severe limitations likely to reduce yields and/or increase recurrent cost for production and conservation.

S3-Marginally Suitable Land

Land which has (or is expected to have after improvements) a low productivity for the defined land use type and yields benefits that are just high enough to justify recurrent costs and capital inputs. These are limitations which in aggregate are sufficiently severe to reduce yields and/or increase recurrent costs for production and conservation.

N1-Currently Unsuitable Land

Land with very severe limitations which at present cannot be corrected economically and which preclude successful sustained use in the defined manner.

N2-Permanently Unsuitable Land

Land with very severe limitations precluding any possibility of successful use of the land for agricultural production.

The definitions given above are very broad and permit only a comparative assessment of potential land suitability for any of the two land use types.

No subdivision according to kind of limiting factors could be made at this scale of generalization on the soil map. However, in the tables of the land potential for use, the soil associations were divided into components with land suitability subclasses or major soil limitations. The components and interpretations were based on field observations and evaluation of soil properties data. Predictions on some areas could be made with reasonable accuracy. On others we could only make estimates.

Land Suitability Subclasses (Major Soil Limitation)

Subclasses are subdivisions of the classes reflecting the kind of the major limitations to profitable land use which determine the class level. They also reflect the general direction of required improvements and so distinguish lands that differ in the nature of their management requirements. The sequence of the letters follows the severity of the limitations, the most severe limitations show first.

The following limitations were recognized:

c - climate limitation caused by adverse climatic conditions (climate too wet or too dry or adverse temperature regime)

t - unfavorable topography limitation due to unfavorable relief (macro or micro) or relative elevation limiting its use

e - erosion limitation caused by erosion hazards or past erosion damage

w - wetness limitation due to waterlogging caused by a high water table, slow permeability or slow surface drainage or combination of these

a - alkalinity limitation due to alkaline soil reaction and high exchangable sodium

i - inundation limitation caused by inundation (flooding) of the land from rivers

m - moisture deficiencies due to soil conditions

f - fertility limitation due to low chemical fertility

v - vertisolic limitation due to a high content of swelling clay

g - surface gravel stones limitation due to the occurence of gravel or stones covering the surface, hampering cultivation and seedling establishment.

p - physical soil deficiencies limitations due to adverse physical soil properties (other than mentioned under v)

d - depth and stoniness limitation due to shallowness or stoniness or both, restricting root development

Suitability for Different Land Use Types

A land use type or land utilization type is a system of land use, land management and farming. Many types are possible but to be practical any system should be suitable to the current social, economic and physical conditions within the region under consideration. Traditional and modern (mechanized) land use types have been chosen as other studies will cover the rest of the main land use types in the study area.

LV - 1 Rainfed Traditional Agriculture

In this type of land use all cultural operations are undertaken by manual labor. Before cultivation and sowing, the land is cleared of grass, bush and trees, but they are not uprooted, and branches and grasses are burned. Instead of ploughing, the soil is only superficially hoed. Sowing is done by broadcasting or by planting in holes made by the hoe or by a digging stick (seluka). Small seeded crops like seasame are always broadcasted. Dura is mostly planted in holes. Harvesting is done by hand.

Most generalized systems of traditional rainfed agriculture practiced in the region are shifting cultivation mainly in the Savanna belt; "harig" (burning) cultivation in Nuba Mountains region, and "terus" (bunds) in the arid parts of the province (small extent). Crop rotation is normally not applied due to abundance of land.

Rainfed agriculture is practiced throughout the area except in semi-desert and desert areas. There is a little cultivation in the arid areas because crop failures due to drought are frequent. The heavy clay soils are not very suitable for traditional agriculture as they are difficult to work and may be subject to waterlogging in the wetter areas. In addition, hazards such as plant diseases and poor soil management practices cause low yields.

Improvement of traditional agriculture, though difficult, should be encouraged by improving extension services to show the farmers how to use animal drawn implements for ploughing, sowing, weeding and the like.

LV - 2 Rainfed Modern Agriculture

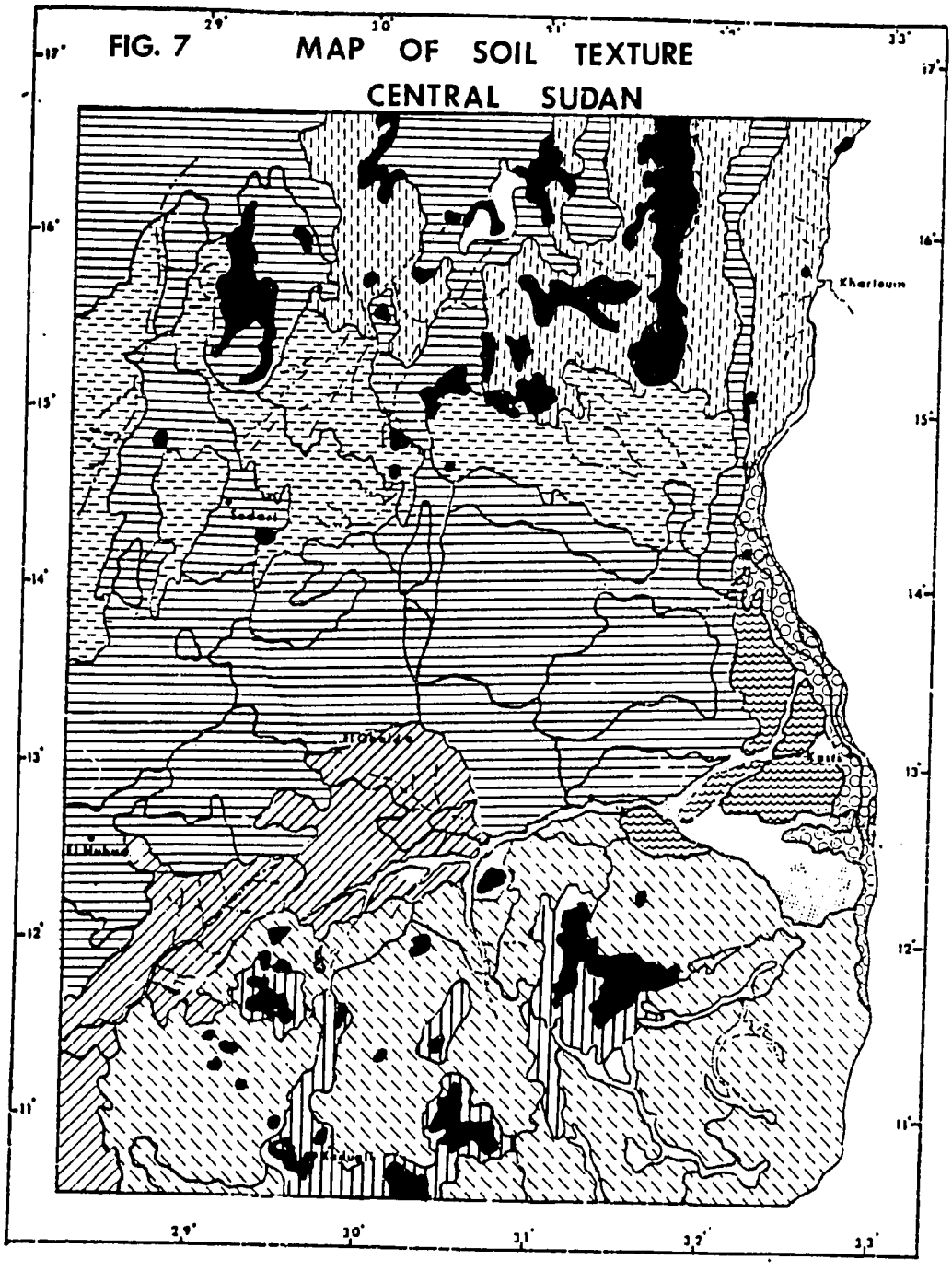
Modern rainfed agriculture using tractor drawn disc-ploughs, seed drills and some mechanical harvesters is found in the clay plains of South Kordofan Province (U10). This type of land use is found in large mechanized crop production projects in which the land has been cleared and divided into holdings of 1000-1500 Feddan (Mechanized Farming Corporation) or to much smaller holdings of 5-10 feddans (Nuba Mountains Agricultural Production Corporation). Dura, cotton and sesame are the main crops of this land use type.

Land suitable for such crops (dura, cotton, seasame) is found in most of the South Kordofan clay plains. In the wetter parts, mechanzied cultivation becomes marginal (especially for dura, seasame) due to prolonged waterlogging. It is probably feasible to improve part of the lands that are subject to waterlogging by the control of runoff and provision of superficial drainage, which may be achieved by excavating some of the Khors (seasonal water course channels) to increase their capacity to absorb peak discharges. Appropriate timing of sowing is another possibility. Soil and water practices are required for sustained mechanized agriculture on the undulating clay plains.

The cracking clay soils are moderately fertile with sufficient available potassium and phosphorus, but with a low nitrogen content. Crop rotation and fallowing to restore fertility are essential management practices and application of nitrogen fertilizers may prove economically beneficial as well. Lands occupying higher positions in the semi arid zone are better suited for seasame.

These data for the test site are summarized and presented in Figures 7,8 and 9 and Table 33.

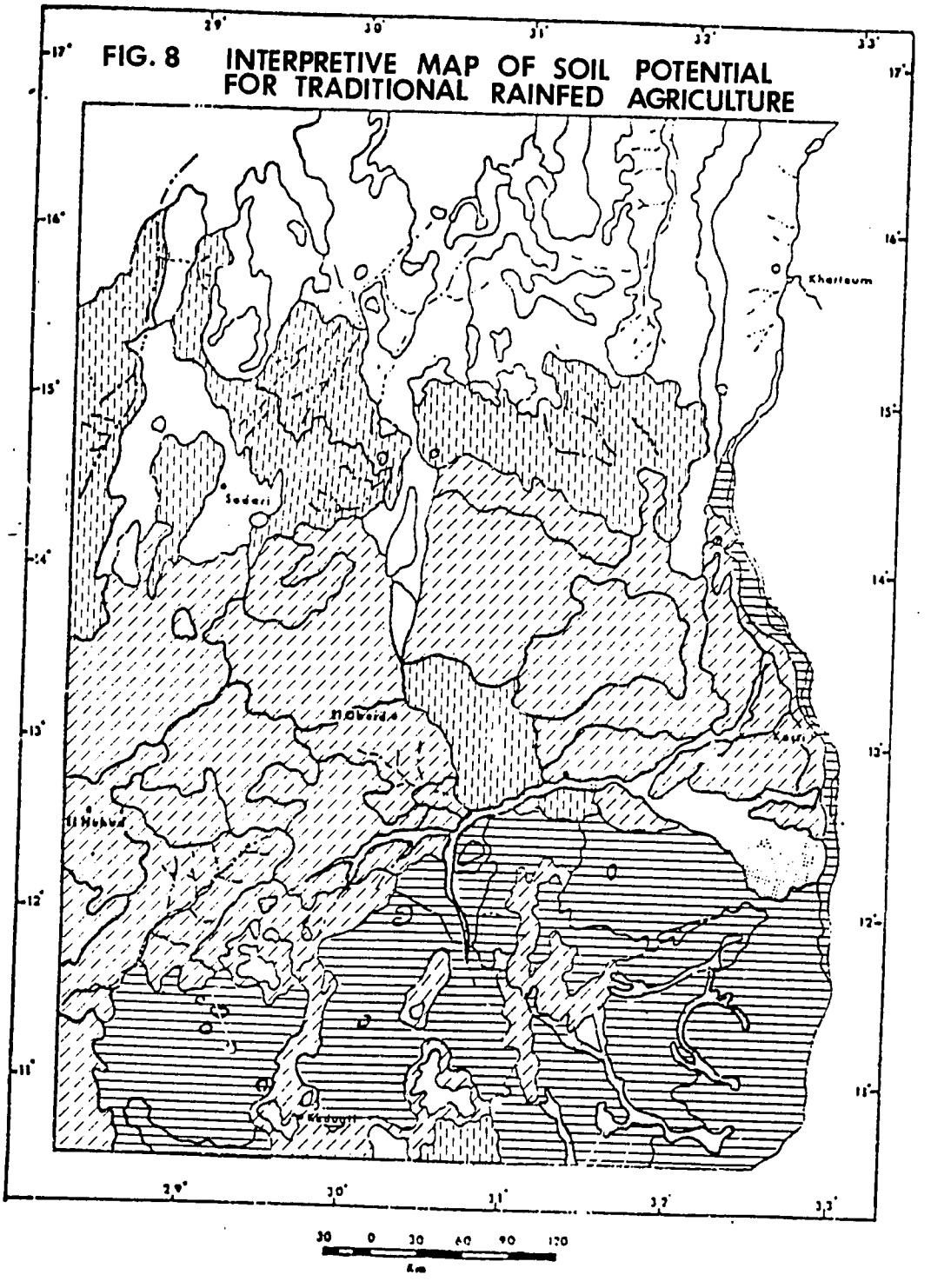
FIG. 7 MAP OF SOIL TEXTURE CENTRAL SUDAN



LEGEND

- Loamy sand
- Sandy loam and sandy clay loam
- Sandy loam alternative with clay
- Sandy clay
- Clay
- Loamy soils
- Sand and sandy clay accociated with rocks
- Clay and sandy clay accociated with rocks
- Rocks

FIG. 8 INTERPRETIVE MAP OF SOIL POTENTIAL FOR TRADITIONAL RAINFED AGRICULTURE



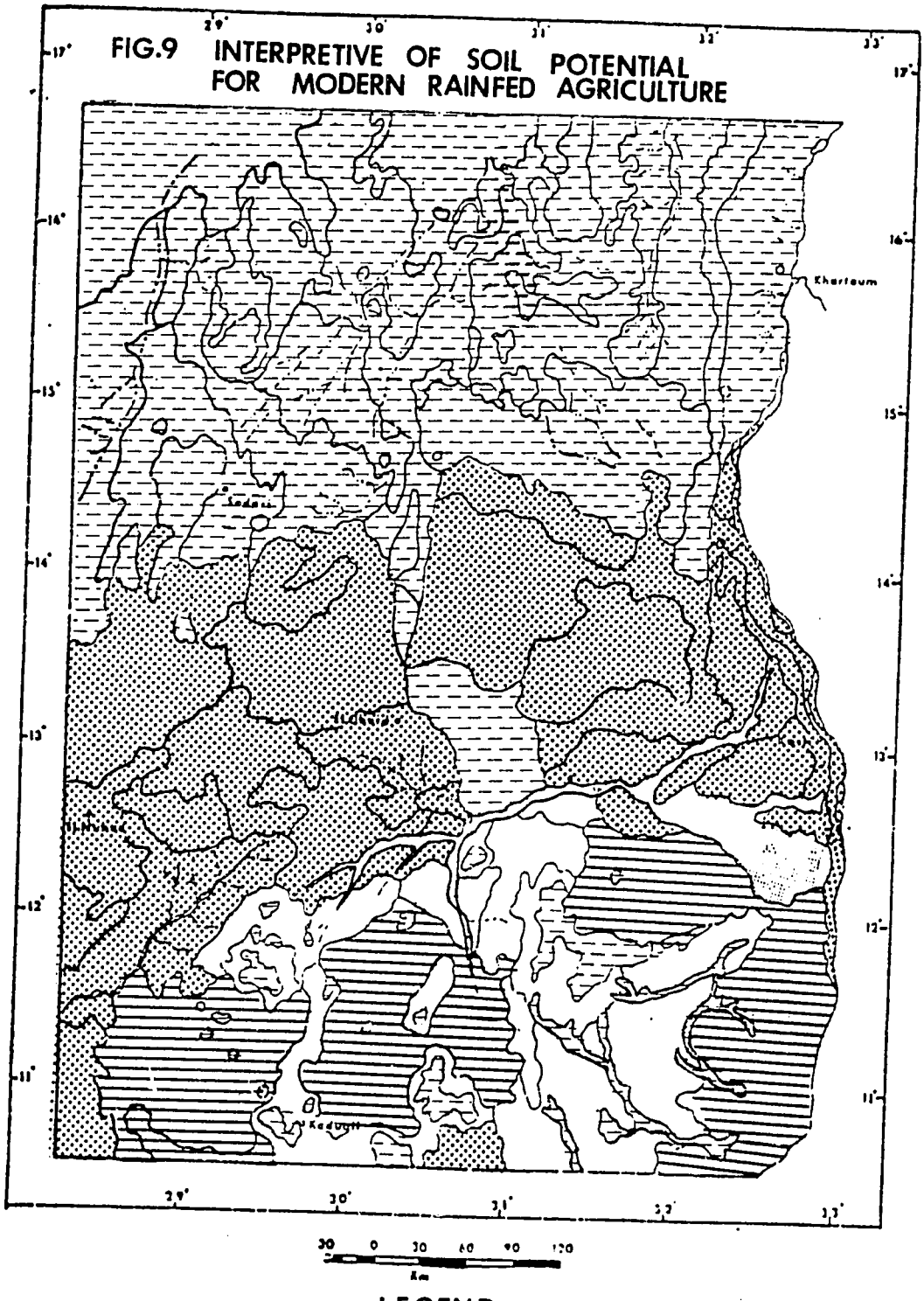
S_2 Moderatly Suitable

N_1 Currently Unsuitable

S_3 Marginally Suitable

N_2 Permanently Unsuitable

FIG.9 INTERPRETIVE OF SOIL POTENTIAL FOR MODERN RAINFED AGRICULTURE



LEGEND

S_2 Moderately Suitable

N_1 Currently Unsuitable

S_3 Marginall Suitable

N_2 Permanently Unsuitable

Table 33

SOIL LIMITATIONS AND POTENTIALS

Map Unit Symbol	Component of Unit	Area Feddans	Area %	Seedling Establishment	Work Ability	Potential Mechanization	Erosion Hazard	Fertility	Potential Suitability for Use Rainfed Agriculture Traditional	Modern	Major Soil Limitations
N1	#1	394008	30	1	3-4	3-4	4	4	N2	N2	m,g,e,d,f
	#2	919353	70	4	4	4	4	4	N2	N2	
N2	#1	2930486	65	1	3-4	2-3	3	3-4	N2	N2	m,g,e,d,f
	#2	1127110	25	1	2-3	3-4	4	4	N1-N2	N2	m,e,g,d
	#3	450844	10	4	4	4	4	4	N2	N2	
N3	#1	4086627	90	1	1	3	4	4	N2	N2	m,e,f
	#2	454070	10	4	4	4	4	4	N2	N2	
N31	#1	1251149	75	3	3-4	3	3	3-4	N2	N2	m,g,e,d
	#2	417050	25	4	4	4	4	4	N2	N2	
N4	#1	1683560	80	4	4	4	4	4	N2	N2	
	#2	420890	20	1	3-4	3	4	4	N1-N2	N2	m,g,d,e
N5	#1	2591009	65	3	2-3	2	3	2	N1	N2	m,g,e
	#2	1195850	30	3	2-3	3-4	3	2	N2	N2	m,g,d,e
	#3	119308	5	4	4	4	4	4	N2	N2	
N6	#1	1302608	100	1	1	3	4	4	N2	N2	
N10	#1	1213131	65	3-2	2	3	3	3	N1	N2	m,g,d,t,e

Table 33 (Continued)

SOIL LIMITATIONS AND POTENTIALS

Map Unit Symbol	Component of Unit	Area Feddans	Area %	Seedling Establishment	Work Ability	Potential Mechanization	Erosion Hazard	Fertility	Potential Suitability for Use Rainfed Agriculture Traditional	Modern	Major Soil Limitations
	#2	653224	35	3-2	3	3	3	3	N1	N2	m,g,d,e
N12	#1	1377877	65	3-2	2-3	3-2	2-3	2-3	N1	N2	m,g,e
	#2	741934	35	3-2	2-3	3	2-3	2-3	N1	N2	m,g,d,e
Q1	#1	3747304	70	1	1	3	3-4	3-4	S3	N1	m,f,e
	#2	1605988	30	1	1	3	3	3	S3	N1	m,f.e
Q2	#1	616281	100	1	1	4	4	4	N2	N2	t,e,m
Q3	#1	672810	60	1	1	4	4	4	N2	N2	t,e,m,f
	#2	392473	35	1	1	3-4	3-4	3	S3	N1	m,e,t,f
	#3	56068	5	3	3	3	3	3	N1	N1	p,e,t
Q4	#1	763439	100	1	1	4	4	4	N2	N2	t,e,m,f
Q5	#1	766665	70	1	1	4	4	4	N1	N1	e,t,m,f
	#2	273809	25	3	3	2	3	3	N1-S3	S3	e,w,p,t
	#3	54762	5	3	2	3	1	3	N1-S3	S3	v
Q51	#1	522580	60	3	3	2	3	3	N1-S3	S3	e,w,p,t
	#2	215053	40	1	1	3	3	3	N1	N2	e,t,m,f
Q6	#1	481720	70	1	1	3	2	3-4	S3	N1	f.t,e

Table 33 (Continued)

SOIL LIMITATIONS AND POTENTIALS

Map Unit Symbol	Component of Unit	Area Feddans	Area %	Seedling Establishment	Work Ability	Potential Mechanization	Erosion Hazard	Fertility	Potential Suitability for Use Rainfed Agriculture Traditional	Modern	Major Soil Limitations
	#2	204451	30	1-2	2	2-3	2	3-4	S3	N1	f,e
Q61	#1	368663	80	1-2	2	2-3	2	3-4	S3	N1	f,e
	#2	92166	20	1	1	3	2	3-4	S3	N1	f,e
Q21	#1	608292	100	1	1	4	4	4	N2	N2	t,e,m,f
T1	#1	995390	60	1	1	3	2-3	4-3	S3	N1	m,f,ew
	#2	663593	40	1	1	3	3	4	S3	N1	m,f,ew
T2	#1	976342	70	1-2	1	3	3-4	2-3	S3	N1	e,m,f,p
	#2	418432	30	1	1	3	3-4	3	S3	N1	e,m,f,p
T3	#1	45310	55	2-3	2	3-2	3	2-3	S3	N1	e,m,f,p
	#2	37071	45	3	3	2	3	2-3	S3	N1	e,m,f,p
U1	#1	433179	50	3-2	2-3	3	4	3	S3	N2	d,e,f,t
	#2	259907	30	3-2	3	2	3-4	2	S3	N1	t,e
	#3	173272	20	3	3-4	4	4	3	N1	N2	g,d,e,t
U2	#1	776494	50	3	3	3	3	3	N1	N2	e,f
	#2	543547	35	3-2	2	2-3	2-3	2	N2	N2	e,f
	#3	232949	.15	2	3-4	4	3-4	3	N2	N2	g,d,e

Table 33 (Continued)

SOIL LIMITATIONS AND POTENTIALS

Map Unit Symbol	Component of Unit	Area Feddans	Area %	Seedling Establishment	Work Ability	Potential Mechanization	Erosion Hazard	Fertility	Potential Suitability for Use Rainfed Agriculture Traditional	Modern	Major Soil Limitations
U 3	#1	151766	65	2	2	3	2-3	4	N1	N2	f,e
	#2	81720	35	2	2	3	3	4	N1	N2	f,e
U5	#1	713363	90	3	2-3	2	2-1	2	N1	S3	p,w
	#2	79262	10	3	2	3	3	2	N1	S3	d,t,g,p
U6	#1	1232716	50	3	3	2	1	2	N1/S3	S3	v
	#2	862902	35	2	2	3	2-3	3-4	N2	N2	f,m,e
	#3	369815	15	3	3-4	3	1	2	N2	N1/S3	w,v
U8	#1	1355143	55	3	3	2	1	2	N1	S3	v,w
	#2	615974	25	3-4	3	3	2-3	2	N1	N1	p
	#3	369585	15	3-4	3	3	2-3	2	N1	N1	p
	#4	123195	5	4	4	4	4	4	N2	N2	
U9	#1	454300	65	3	3	2	1-2	2	N1	S3	t,p
	#2	174731	25	2	2	2	2	2	N1	S3	p
	#3	693921	10	3-2	2-3	2	2	2	N1	S3	p
U10	#1	1484406	55	3	3	2	1	2	N1	S3	v,e
	#2	809676	30	3	3-4	2-3	1	2	N1	S3	w,v,e

Table 33 (Continuation)

SOIL LIMITATIONS AND POTENTIALS

Map Unit Symbol	Component of Unit	Area Feddans	Area %	Seedling Establishment	Work Ability	Potential Mechanization	Erosion Hazard	Fertility	Potential Suitability for Use Rainfed Agriculture Traditional	Potential Suitability for Use Rainfed Agriculture Modern	Potential Suitability for Use Rainfed Agriculture Major Soil Limitations
	#3	404838	15	2	2	3	2	4	N2	N2	f,m,d
U11	#1	399384	100	3	3	2	1	2	N1	S3	e,p
L1	#1	3630715	95	3	3	2	1	2	N1/S3	S3/S2	v
	#2	191090	5	3	3-4	2-3	1	2	N1	S3	w,v
L2	#1	193548	90	3	3	2	1-2	2	N1/S3	S3	
	#2	21505	10	3	3-4	2-3	1	2	N1/S3	S3	w,i,v
A1	#1	847925	60	3	3-4	2	1	2	N1	S3	w,i,v
	#2	353302	25	3-2	2-3	3	2	2-1	N1	N2	t,w,i
	#3	211981	15	1	1	3	2	2-1	N1	N2	t,w,i
A2	#1	13825	60	3	3-4	3-4	2	2-1	N1	N2	t,w,i,v
	#2	11060	40	3	3	3	2	2-1	N1	N2	p
A3	#1	385253	60	2	2-3	3	2	2-1	N1/S3	N1	t,p
	#2	192626	30	3	3	2-3	1	2	N1/S3	N1	t,w
	#3	64088	10	2	2-3	3	2	2-1	N1/S3	N1	p,w
RN	#1	130569	85	2	2	2-3	2	1-2	S2	N1	i,w
	#2	23042	15	3	3	2-3	1	2	S2	N1	i,w,p

Table 33 (Continued)

SOIL LIMITATIONS AND POTENTIALS

Map Unit Symbol	Component of Unit	Area Feddans	Area %	Seedling Establishment	Work Ability	Potential Mechanization	Erosion Hazard	Fertility	Potential Suitability for Use Rainfed Agriculture Traditional	Modern	Major Soil Limitations
RT	#1	855605	100	3	3	2	1	2	S3	S3	a,s,p
HM	#1	1978490	100	4	4	4	4	4	N2	N2	

CONCLUSIONS

Development Possibilities

A summary of the main conclusions regarding development possibilities of the region is indicated in the following paragraphs.

1. Development strategy should be first concentrated on developing the potential for rainfed agriculture in areas containing the highest concentration of class S2 land and class S3. (figures 6 and 7). These two classes are respectively moderately suited and marginally suited for rainfed crop production. All uncultivated areas should be managed for maximum pasture and wood production.
2. The northern part of the region which lies in the desert and semi-desert consist of land that have a low grazing potential. There does not seem to be much potential for improvement of land for grazing. The dry climate and scarcity of drinking water impose strong limitations.
3. Lands located in the central part of the study area, mostly within the semi-arid climate zone, have a low to moderate overall potential for traditional rainfed agriculture and grazing. Currently a small part is dry farmed and the higher proportion is used for extensive grazing. Yields from main crops (dukhn, dura, seasame, groundnuts) are low because of the sandy nature of the soils, low fertility and low available moisture. Some improvement is possible by improving shifting cultivation practices, introducing crop rotation and deferred grazing. The

"Tongya" system of land rotation is advised by which cultivation gets both cash crop and "gum" garden and simultaneously aids soil conservation. Precautionary measures to protect arable lands should be investigated both technically and economically.

4. Large capital inputs would be required for full development of the cracking clay soils on the southern part of the area for mechanized crop production (providing machinery for mechanization, construction of roads, storing water for human and livestock use); but improvement can be made in the presently established schemes by application of known technology. Soil surveys and feasibility studies are recommended to be carried out. Other studies could include land rotation and crop diversification. In general terms, these soils are moderately suitable for common crops of the area (dura, cotton, seasame, etc.).

It is clear than many more surveys and studies, not only of technical nature, but particularly in the field of sociology and economics, will have to be made before specific development can be started. Some studies to be made are:

1. Detailed soil survey and feasibility studies on potential rainfed lands.
2. Urgent studies on desertification in northern and central parts (3 Qoz lands) to show the magnitude of the problem with locating the potential areas for reclamation or land conservation practices.
3. Expansion of studies on crop yields, tec. Crop statistics should be developed and applied at a wide scale and the records be made available to all workers in agricultural development.

4. A study of different livestock systems throughout a wide area to identify present constraints on production and possibilities for improvements.
5. Studies of underground water and trial drillings in order to find suitable reservoirs that may be tapped for drinking water for livestock and people.
6. Investigation of the possibilities for crop diversification in the rainfed areas and how crops other than the present major crops could be used in the rotation.

Landsat Data for Monitoring Soil Resources

1. Landsat imagery provided a quick and inexpensive means of establishing baseline information that was used in conjunction with other data (geologic and vegetation maps, climatological records, etc.) to produce soil maps. Remotely sensed imagery can be a valuable aid in mapping soil resources.
2. Imagery is not, however, the only tool needed to compile accurate, meaningful soil maps. The interpretation process may be enhanced and time efficiency improved, by incorporating other resource data.
3. Depending upon the detail required and/or the area to be mapped, different scales and types of imagery are required. Landsat imagery is useful for broad soil association level mapping, but does not have the resolution required for finer, more specific mapping. Both types of imagery are valuable for specifying areas on the ground that may require intensive field mapping.
4. Landsat is a very useful tool in locating and mapping aeolian geomorphic areas in central Sudan (Qoz lands) and areas of active sand dunes.
5. Repetitive coverage of Landsat provided a unique method for measuring and locating changes in different natural resources (e.g. desert encroachment-flooded areas).
6. Landsat imageries were also very useful in updating information on topography (e.g. Some hills and drainage channels were far out of place on the topographic map series of the Sudan 1:250,000).

ACKNOWLEDGEMENTS

This study was carried out during a training program on the applications of remote sensing for monitoring natural response as a joint effort between the U. S. Agency for International Development (U.S.AID) and the National Council for Research, Sudan. The training program was prepared by the Remote Sensing Institute, South Dakota State University, U.S.A. Assistance and valuable comments were received from Remote Sensing Institute staff and without their aid the compilation of data and final presentation could not have been possible.

Much gratitude is expressed to Mr. A.A. Klingbiel, soil consultant, for his supervision. His valuable comments, sincere advice and encouragement during the course of the study are highly appreciated.

APPLICATION OF LANDSAT FOR DETERMINATION OF LAND RESOURCES AND DESERTIFICATION MONITORING

Y. Yagoub Mohamed and M. Fadl Elmoula Idris*

ABSTRACT

This report is the result of a joint program between The Sudan Government and U. S. AID. The program was aimed at training Sudanese personnel to study the use of remote sensing for acquiring resource information in their home country.

The report describes the study which has been carried out at the Remote Sensing Institute. It comprises the following:

A. Use of Landsat data for determining different land use classes, vegetation associations, and signs of desertification.

B. Evaluation of land resources based on the existing regional soil map.

The study evaluated the use of Landsat as an economic and timely tool for collecting general resource information. Making use of the imagery tonal variations and contrasts, it was possible to determine the major physiographic landscape, as well as the general distribution of the associated types of land use and major vegetation associations. For the purpose of regional planning such information will be sufficient. However, small details and information to the types of crops and the understory vegetation could not be derived because of the scale and resolution limitations. This limitation should not be looked at as a serious disadvantage that hinders

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its application, since the technology is most useful for regional planning and as a supplementary tool for aerial photography. For more detailed studies of selected areas, therefore, aerial photography of the appropriate scale should be used instead of Landsat imagery. The Landsat imagery can be best used to select areas for more detailed photography which will optimize the benefit from that photography.

Signs of desertification in the form of bare dunes were easily recognized and mapped; however, the rate of the advance of the phenomenon in the period 1972 and 1976 could not be visually detected. Applying more advanced data analysis techniques, i.e. the Image 100 supported with ground truth might sometimes lead to a better evaluation because of its ability to enhance the tonal contrast. It is regarded as a useful tool for small details classifications. The second part of the report consists of evaluation of agricultural resources based on the soil information obtained from the field, with the use of Landsat imagery as a base map. A further step was made for the evaluation of soil blowing hazard. The approach involved rating the relevant soil properties such as: wetness, texture, slope and percent plant residue cover, by assigning to each of these properties an erodibility factor and accordingly classifying the soil mapping units for blowing at the critical wind period.

INTRODUCTION

a) Desertification and its causes

Desertification is the degradation of the biological productivity of land and the consequent reduction in plant composition, cover, reduced carrying capacity of the land and reduced crop yield. There are three schools of thought as to the causes of this phenomenon:-

--Long term climatic changes in the geological sense

--Weather fluctuations

--Human factor

The climate and weather factors as causes of desertification, have been subject to considerable debates and theories. The evidence is conjectural because of the lack of intensive and detailed records, and that of the complexity of the interrelated factors.

However, it is beyond no doubt that the over exploitation of the land by man and his animals, in an attempt to meet the demands of the rising populations has brought about these desert-like conditions; although this ecological upset has been going on for decades, it has only recently become acute and wide-spread in the country. Because of the continuing shortage of the world food supply, the problem has drawn man's attentions; but still very little practical work pertaining to monitoring desertification and assessing its rate of advance has been made. There is need for research in this field because the problem is of the Sudan's main concern and since the country's economy is predominantly agricultural. The main misuses that have brought desertification in the Sudan are overgrazing particularly around water points, the irrational cultivation,

wood cutting and deforestation, uprooting of shrubs for fuel and the burning of grasslands, forests and shrublands.

This misuse of land has resulted in soil deterioration especially in the Qoz country and the Gardud clays where land has been cultivated to exhaustion or its vegetative cover overgrazed. A certain amount of the surface protecting material becomes loose and subject to soil blowing hazards. The wind blowing of this fine material results in the denudation of the original soil and formation of bare surface crusts which buries the fertile soil downwind by the transported fine and sandy particles.

The signs of desertification in the form of bare active unstable dunes and surface crusts have long been observed in the region. In the clay plain where the grazing pressure is released especially during the growing season due to the unfavorable climatic conditions, the vegetative cover is maintained and consequently the rate of soil degradation is low. In both the Qoz country and the Gardud clays overgrazing and occasional accidental fires have resulted in the disappearance of the palatable perennial grasses and herbs and the domination of the fire-tolerant annual plants together with other fibrous undesirables.

b) Objectives:

The study was meant to fulfill the following:-

1. To evaluate the use of Landsat for determining land use, vegetation communities and for monitoring signs of desertification and land misuses of the area.
2. To evaluate the susceptibility of the soils to soil blowing hazard, including plant residue cover, during critical wind period.

3. To determine the soil suitability for presently grown crops based on the existing generalized soil map that has been prepared by A. Doka (Paper by Doka in this same proceedings.)
4. To estimate and relate: Ground cover, vegetation composition, herbage production, range condition, potential for improvement, to the components of kinds of soil under average to below average and above average rainfalls for the major climatic zones.

c) Materials:-

The following materials and equipment were used:

- A set of false color composite prints (MSS 4,5,7) at the scale of 1:500,000.
- Black and white paper prints for bands 4,5,7 at the scale of 1:500,000.
- Available reports and some ground truth data, refer to listing of names of publications used.
- Magnifier, optical pantograph, additive color viewer, and drafting and cartographic materials for imagery interpretation and map production.
- Soil map (by Doka) of the study area based on Landsat imagery interpretation.
- A list of predicted plant cover of the soil components at the critical wind period (refer to Table 1 in the appendix).

GENERAL DESCRIPTION OF THE AREA

a) Location:-

Bounded by Latitudes $10^{o}40'$ and $16^{o}50'$ N

Longitudes $28^{o}40'$ and $32^{o}30'$ E.

The area is covered by twelve Landsat scenes. However, preliminary land use and vegetation maps were restricted to the southeastern part of this area covered by six Landsat scenes. Please refer to the location map in Figure 1.

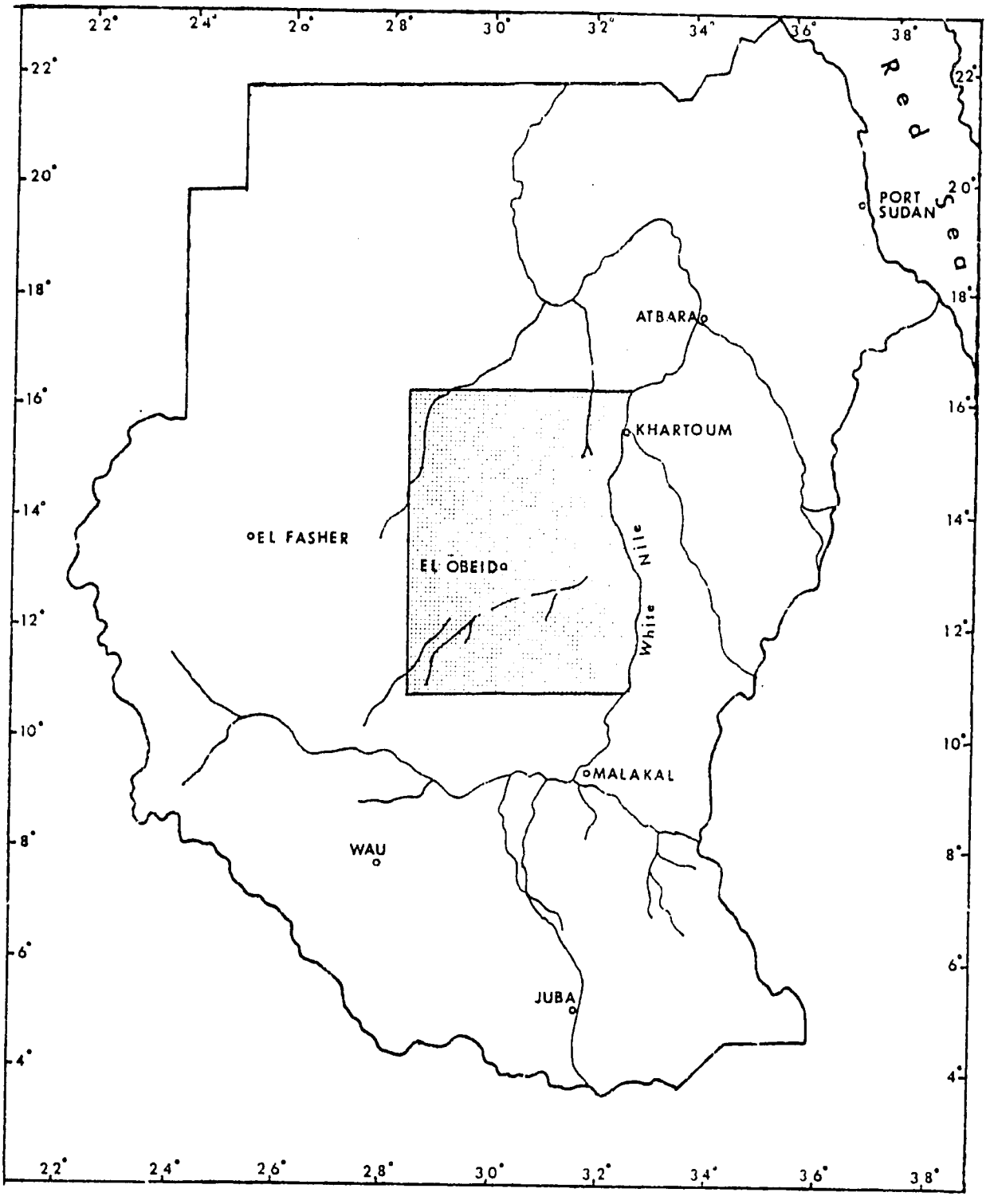
b) Climate:-

This area is exposed to a tropical continental type of climate which is characterized by a dry uniform air movement from the north. This dry air movement prevails throughout the dry season. A major air flow from the south determines the annual rainfall and its monthly distribution during the rainy season.

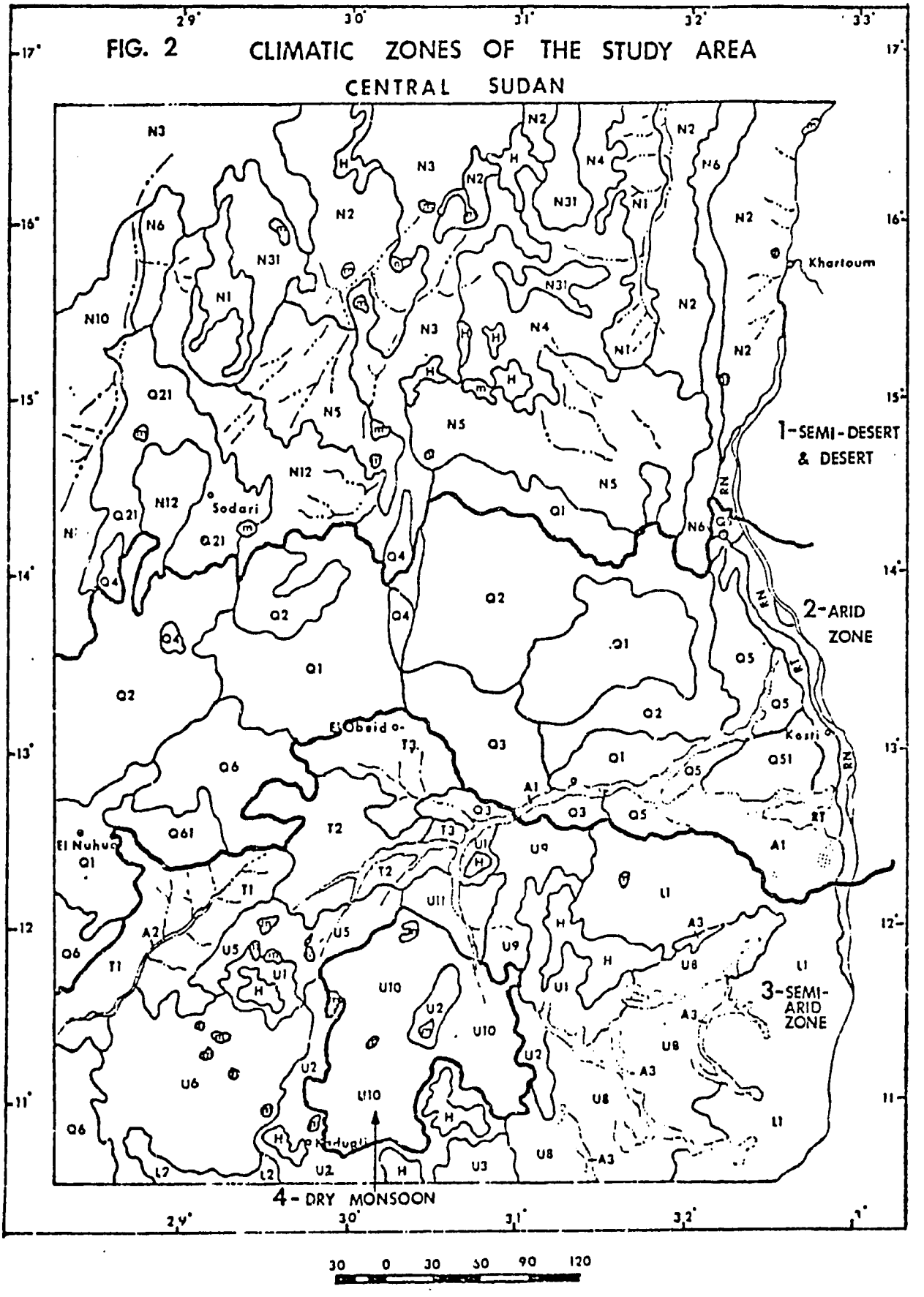
The annual rainfall ranges from 75 mm in the extreme north to 850 mm in the south. There are two distinct seasons, a short wet season (July - Nov.) and a dry season (Nov. - July). Temperatures are warm throughout the year. The mean of daily maximum temperatures of the hottest month (June) range from 43° C in the extreme north to 40° C in the extreme south. The mean minimum temperature of the coldest month (January) ranges from 8° C to 13° C.

According to the average annual rainfall and the resulting vegetation, the region has been broadly divided from north to south into four climatic zones, these are the desert and semi-desert, the arid, the semi-arid and the dry monsoon zones. Refer to climatic zones, Fig. 2.

FIG. 1 LOCATION MAP OF STUDY AREA
CENTRAL SUDAN



0 100 200 300 400 500 600
Km



* Heavy lines denote climatic regions.

c) Soils (Figure 3.)

The area broadly comprises the following main superficial deposits:-

1. The cracking clays: The dark-cracking clays are located in the southern reaches. They are part of the central clay plain of the country.
2. The sandy soils (locally known as Qoz sands) are located north of Latitude $11^{o}3'$.
3. The non-cracking clays. They are locally known as "Gardud" and occupy the transitional zone between the cracking clays and the Qoz sands.

For details refer to A. Doka's report no. 1 (Literature cited)

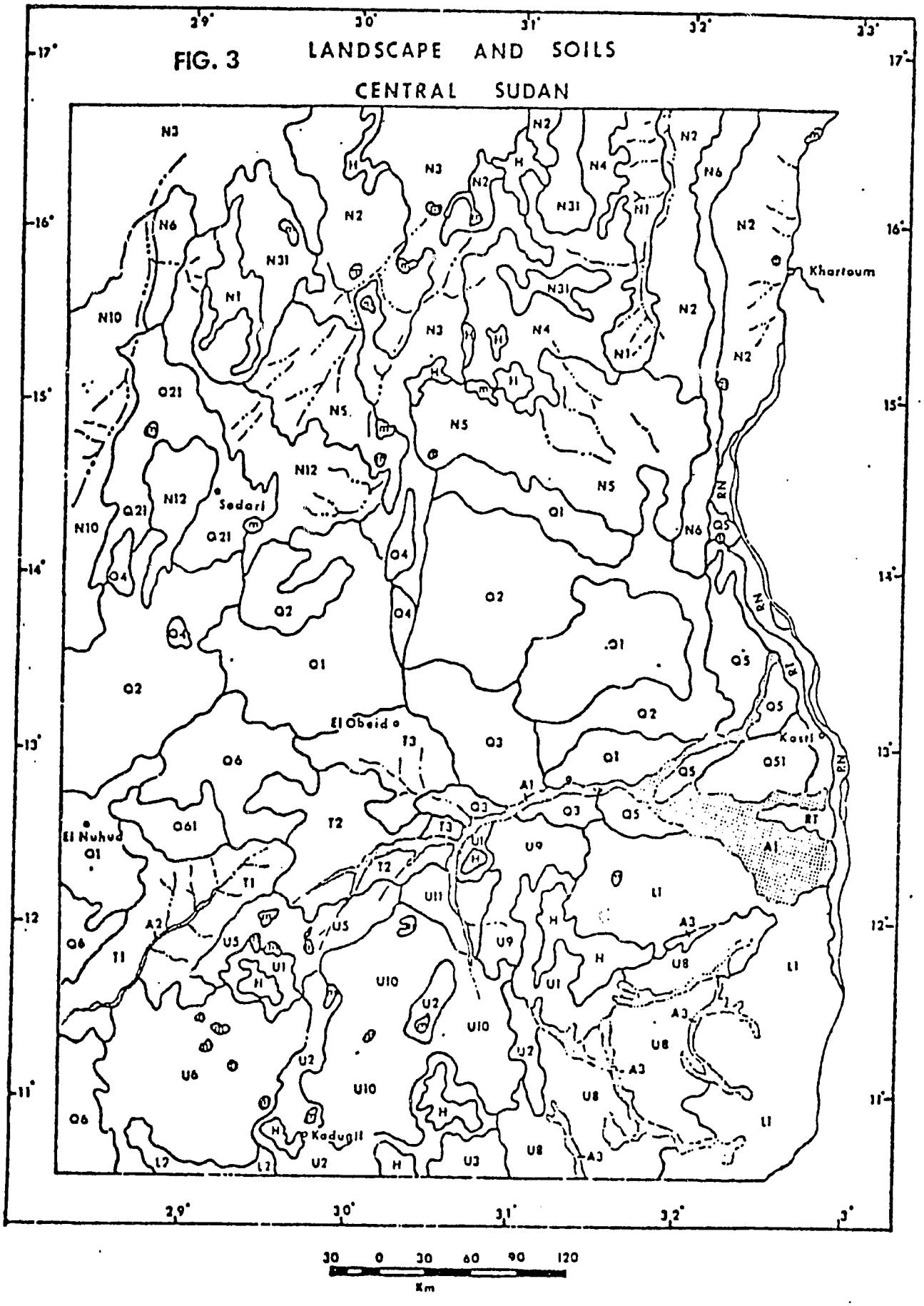
d) Vegetation

From the north to the south the region comprises three latitudinal belts which are closely correlated with the climatic zones as follows. Please note the vegetation map in Figure 4.

1. The desert zone: With the exception of drought-resistance stunted bushes and herbs along the water courses and drainage lines, the desert is virtually devoid of vegetation.
2. The semi-desert zone: There are three characteristic associations of vegetation in this zone namely - the semi-desert grassland on sand, - *Acacia tortilis*-*Leptadenia* and *Acacia Mellifera* - Commiphora *africana*. Associated understory vegetation is mainly of *Panicum turgidum*, annual *Aristida species*, *Chryzopogon aucheri*, *Tetrapogon species* and *Blepharis Linariifolia*.
3. Low rainfall woodland savannah: This belt has a composition of grasses, herbs, bushes and trees. Its two major subdivisions

FIG. 3 LANDSCAPE AND SOILS

CENTRAL SUDAN



* Legend on following page. Original map scale at 1:1,000,000.

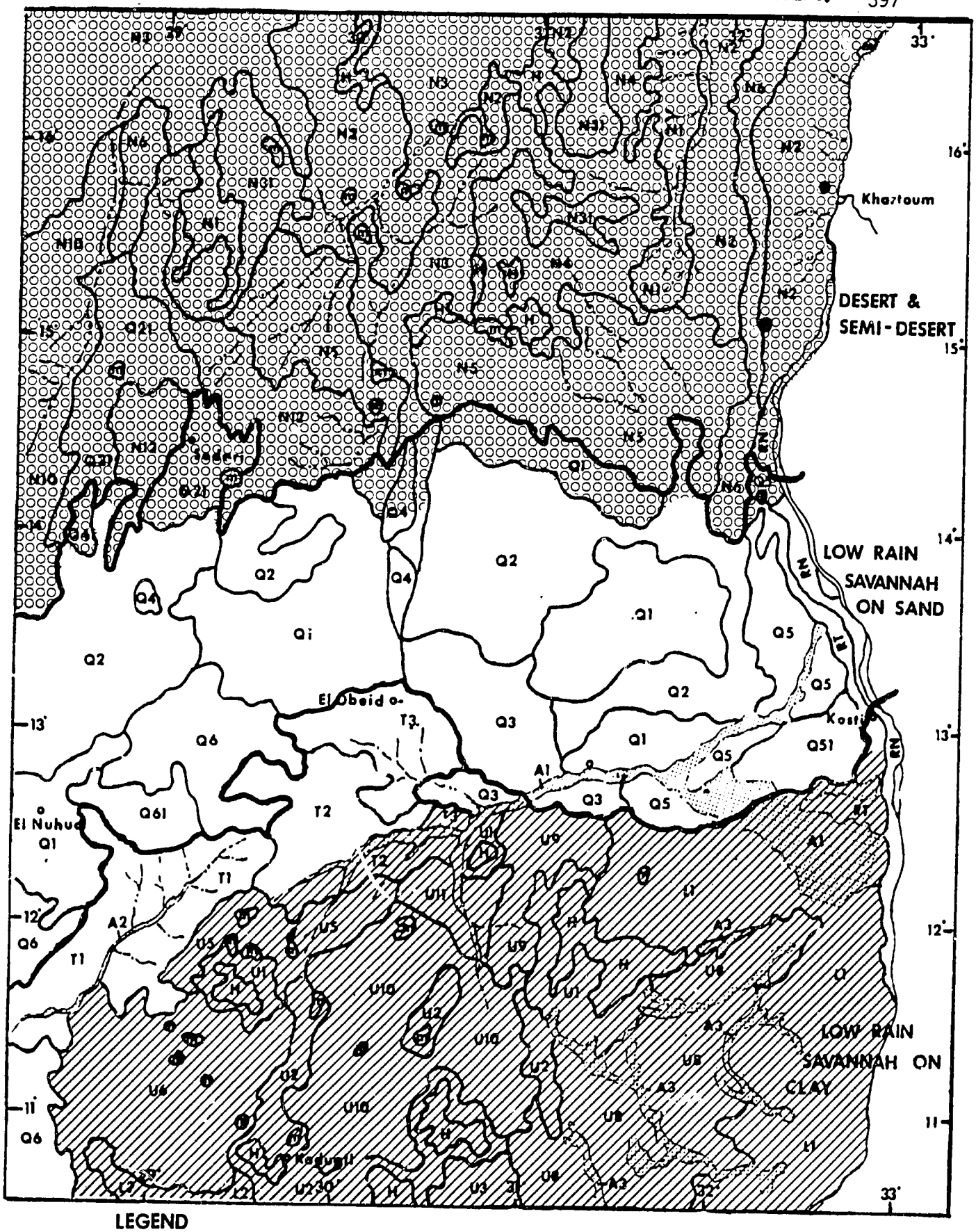
Map Symbol	Landscape Units
N	**Northern Plateaus and Pediplains**
N1	Rocky Plateaus
N2	Piedmonts
N3	Sandy Plains
N31	Sandy Pediplains
N4	Rocky Lands
N5	Reg Areas
N6	High Dunes; Semi-desert
N10	Wadi El Milk Basin
N12	Wadi El Muhbas Basin
Q	**Sandy Qoz Lands**
Q1	Sand Sheet and Low Dunes
Q2	High Dunes; Arid Climate
Q3	Longitudenal Dunes
Q4	Transversal Dunes
Q5-Q51	Sand Dunes and Clay Plain Complex
Q6	Babanusa-Khowi Sandy Peneplain
Q61	El Nuhud-Zabad Plateau
Q21	High Dunes; Semi-desert
T	**Qoz Transitional (Deflation) Area**
T1	Wadi El Gallah Basin
T2	Khor Abu Habil Western Basin; Sandy
T3	Khor Abu Habil Northern Basin; Loamy

Map Symbol	Landscape Units
U	**Nuba Uplands**
U1	Jebel Piedmont Outwash
U2	Dissected Plateaus
U3	Talodi Peneplain
U5	Dilling Upland Plain
U6	Lagwa-El Berdab Plain
U8	Eastern Intermediate Clay Plain; Undulating
U9	North Eastern Undulating Clay Plain
U10	Habila Clay Plain
U11	Jebel El Dier Clay Plain
L	**Flat Clay Plains**
L1	Eastern Flat Clay Plain
L2	Southern Clay Plain; nearly Flat
A	**Seasonal Water Course Alluvium**
A1	Khor Abu Habil Flood Plain
A2	Wadi El Gallah Flood Plain
A3	Southern and Eastern Flood Plains
R	**Riverain Lands (White Nile)**
RN	White Nile Flood Plain
RT	White Nile Upper Terrace
H	**Mountains and Hills**

Fig. 3 (continued) Soil Legend. Note same legend applies to Figures 2 and 4. (After A. Doka)

FIG. 4

VEGETATION ZONES OF THE STUDY AREA.



LEGEND

VEGETATION ZONE

- Desert & semi desert
- Low rain fall wood land savannah on sand.
- Low rain fall wood land savannah on clay.

30 0 30 60 90 120
KM

according to soil are:- (a) Low rainfall woodland savannah on sand: On the stabilized sand dunes and sand sheets, the dominant associations are - Acacia senegal, Acacia senegal-Combretum cordofanum, Dalbergia melanoxylon-Albizzia amara - Terminalia and sclerocarya birrea (on the soil mapping units (Q1,Q2,Q3,Q5,A51,A6 and Q61). The understory cover associated consists of Eragrostis tremula, Cenchrus biflorus, Aristida pallida, Zornia gluchidiata and Andropogm gayanus.

(b) Low rainfall woodland savannah on clay - This subdivision of the low rainfall woodland savannah includes a wide range of vegetation associations in the clay soils (U1,U2,U3,U5,U6,U8, U9,U10,U11, and L2,L3).

Areas with less than 600 mm rainfall are dominated by Acacia mellifera and above 600 mm rainfall Acacia seyal-Balanites agyptiaca association alternates with grassland areas. Sloping range sites are dominated by Combretum hartmannianum-Angoeissus sclerocarya while on the jebel pediments Boswellia papyrifera, Combertum- sclerocarya -Lannea-Lonchocarpus Laxifiorus predominate.

On the plateaus the characteristic association is Anogeissus leiocarpus-Combretum hartmanianum. The understory cover of the drier sites consists of Sorghum purpuresericum, Cymbopogon species, Pennisetum pedicellatum, and Hyparrhenia species. In addition to the above mentioned, the wetter sites also consist of Rottobelia exaltata, Brachiaria obtusiflora, Pennisetum ramosum and Andropogon gayanus as understory vegetation.

e) Land use

To the north of latitude 14°13' N the region has no importance for agriculture except as grazing area for camels, sheep, goats and cattle.

The Qoz sands are the main centre for production of gum arabic from Acacia senegal tree, rainfed sesame, ground nuts, millet and sorghum. Shifting cultivation is practiced and the individual's holding ranges from 9-15 feddans. The uncultivated sands provide most of the grazing land for camels and cattle.

The clay soils in the southern reaches are utilized for traditional and mechanized rainfed agriculture. The main crops are sorghum, cotton, sesame and groundnuts.

The White Nile upper terraces in the extreme eastern part of the region are under irrigated mechanized cotton production.

DETERMINING-PHYSIOGRAPHY-LAND USE-VEGETATION & DESERTIFICATION MONITORING

1. Landsat imagery interpretation for determining land use -

a) Background information

With the exception of the White Nile terraces in the extreme eastern part, the region is under uncontrolled communial grazing of camels, cattle, sheep and goats. This grazing practice has contributed to the present state of overgrazing. Traditional rainfed, shifting cultivation of sorghum millet, sesame, groundnuts and cotton is practiced around dwelling centers concentrated near drinking water sources. The Qoz sands are heavily cultivated, because of their easy workability, by using conventional methods. Cultivation on the Gardud soil is mainly confined to sandy of loamy sand soils.

Rainfed mechanized sorghum is produced on large scale on the clay plain of the southern part of the area.

b) Imagery interpretation for land use

A land use map was prepared using visual imagery interpretation (see appendix fig. A). The interpretation involved delineation of the main physiographic units and the type of land use practiced on each of these units.

The classes that have been identified and mapped are briefly described as follows:

A: The Qoz sands

A1 Dense traditional cultivation. These are the light colored areas on the Landsat imagery found mainly on the dunes and around the villages. The villages are clearly seen as dark spots.

A2 Light traditional cultivation. These are areas of less light tones scattered further away from inhabited areas - Reference is made to Fig. No. 5, below, showing both light and dense cultivation.

A3 Light forested grazing land: These are areas other than A1 and A2 reflecting relatively darker uniform tones.

A4 Open grass and scrub grazing land. This class is bordering the desert, exhibiting coarse texture on the imagery due to the scarcity of vegetation and presence of gravels and scattered rocks on the surface

A5 Reserved forests: The reserved forests around Elobied town and to the east of it are clearly shown in the imagery, because of distinct boundary.

Fig. 5. Landsat scene showing dense traditional cultivation (light colored A) around villages (dark spots) the light cultivation is relatively dark (B). (ID No. 1108-07482). (Original in color.)

A6 Nearly bare unused dunes: These ridges are located in the northern part of the area - they had distinguished ragged surface indicating wind blown sands.

B <u>The clay pediplain (Gardud)</u>

B1 The grazing bushland: These are areas used for wet season grazing, They reflect relatively dark tones with numerous drainage ways in contrast to the sands.

B2 Areas as B1 have some scattered small sand pockets that are predominantly cultivated.

C <u>The clayplain</u>

C1 The mechanized schemes in the clay plain were easily distinguished because of the regular shape and size of field boundaries.

C2 Forested grazing grasslands: This unit represents most of the clay plain, a more detailed classification could not be derived due to the uniformity of reflectance.

C3 Burned lands: These are black fire scars on the clay plain as a result of burning forest and grassland.

F <u>Flood plain</u>

F1 This represents the dry season browsing land along the main flood plains.

F2 This represents Essmeih irrigated scheme on Abu Habil flood plain. It was recognized because of its location, tone, and uniformity.

H1 & H2 Hills & Pediments: These are commonly used as browsing lands. Hills reflect a mixture of dark black and dark red tones because of bare rocks and vegetation. The pediments are of light tones because of the sparse vegetation and colluvial materials.

Discussion

This physiography and land use map is fairly informative and can be used as a base for more detailed surveys. In using Landsat data some of the detail is lost due to the scale and resolution limitation. A close correlation between the physiographic landscape and type of land use practiced was observed. This was evident in the Qoz sands where the dense cultivation was concentrated on the longitudinal dunes and in the Gardud country where the cultivation was confined to the sand pocket.

2. Mapping Vegetation Communities

Using the procedure followed for the land use mapping a vegetation map was prepared. It is of a reconnaissance nature since it was difficult to trace boundaries among the different vegetative associations. Riparian vegetation along the seasonal streams was distinct because of the dark reflectance indicating active growth, montane vegetation could also be delineated taking advantage of the physiography. Other vegetation associations on the sands and clays shown on the map are based on personal knowledge and experience rather than on the use of tonal variations because of the complexity of the imageries tones and textures. Herbaceous

cover needs to be determined from field surveys. Please refer to the vegetation map in Figure B in the Appendix.

3. Determination of Signs of Desertification

Imageries over the area for the years 72, 73 and 1976 were examined to monitor signs of desertification and misuse of land. Signs of desertification of bare or nearly bare active dunes were clearly observed on some of the scenes, Figure 6. However, it was difficult to judge whether there was an increase or decrease in the size of these dunes in the period 1972 to 1976.

Land misuse in the form of burned grassland which is a desertification contributing factor was evident. Reference is made to the 1976 scene compared to the 1972 scene of the same area, Figure 7A and B .

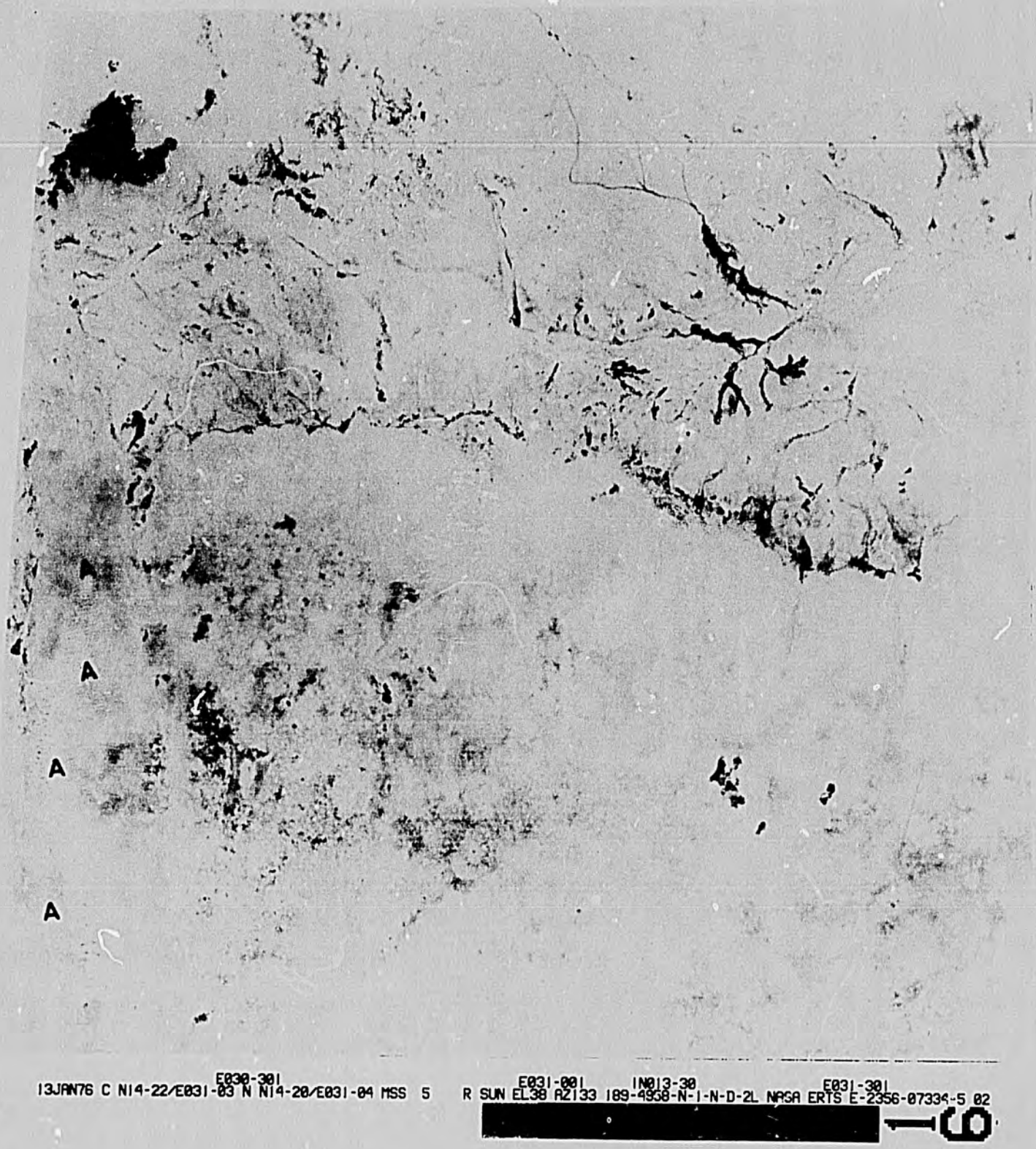


Fig. 6. Landsat scene band 5 January 1976 showing signs of desertification in the form of nearly bare dunes (A) (ID No. 2356-07334).

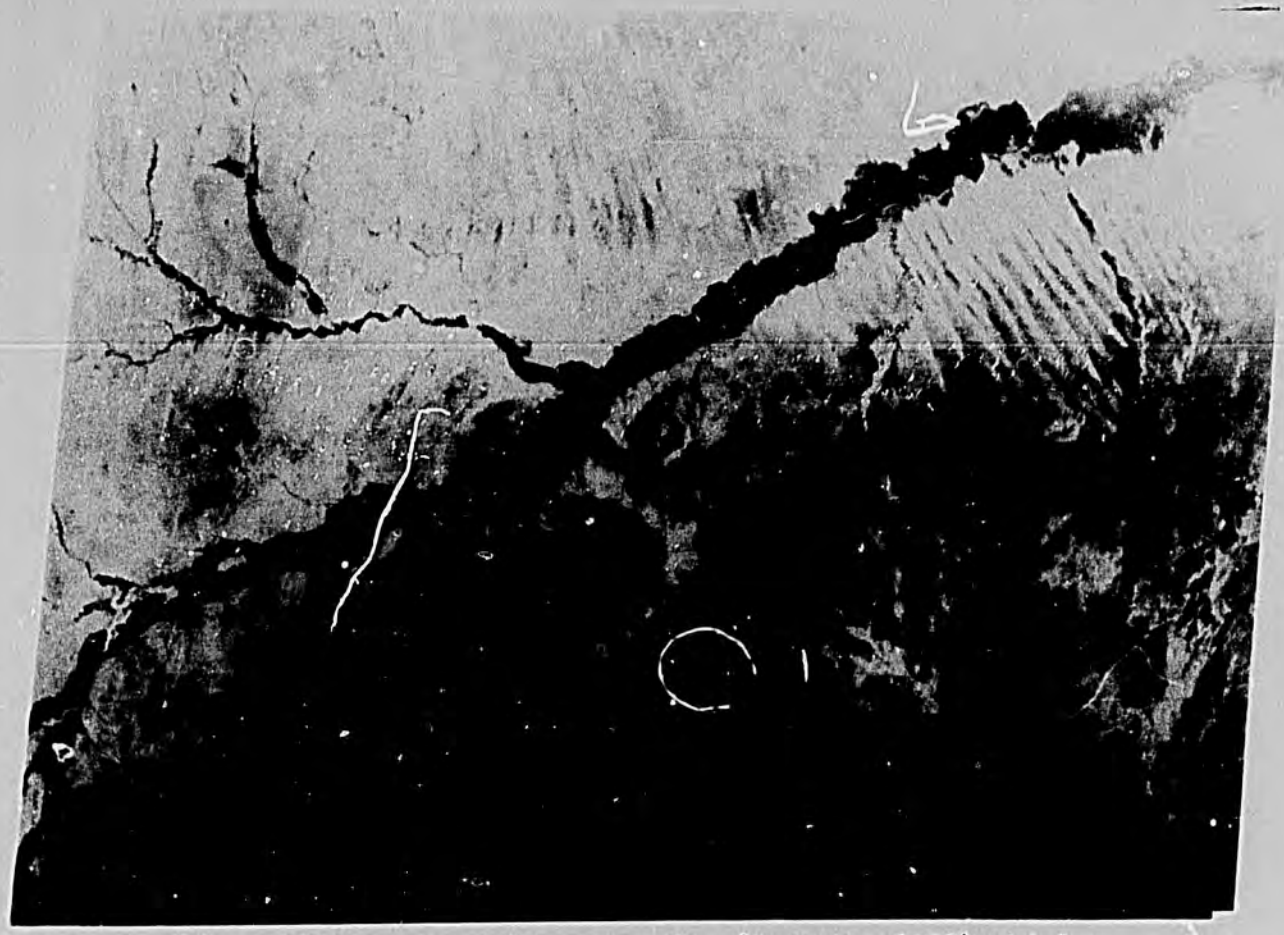


Fig. 7. (A) Landsat scene color composite (November 1972) showing little or no indication of burning. (ID No. 1108-07482).

Fig. 7. (B) Landsat scene color composite (January 1976) of the same area showing signs of burned land. (ID No. 2374-07335). (Original in color.)

PREDICTION OF RANGE RESOURCES OF THE SOIL COMPONENTS

Through the use of Landsat imagery and use of limited ground studies and measurements, estimates were made by kinds of soils within the major climatic zones for: present ground cover, composition of vegetation, forage production kilograms per feddan, range conditions and potential for improving the carrying capacity under different range conditions, at average precipitation, below average and above average precipitation.

Criteria Used for Estimation

1. Background Information

Ground cover is an important attribute of vegetation quantity. It is expressed in percentage ground cover and is used to measure changes in vegetation, resulting from fluctuations of climate, effects of grazing and responses to other management practices. Percentage of ground cover and percentage of vegetation composition have direct effect on the quantity and quality of herbage yield of the range sites and on the hazards of soil blowing. Based on ground cover, composition and herbage production, carrying capacity and range condition can be assessed.

Carrying capacity is the term used to define range use in terms of livestock grazing - or in other words "the maximum number of animal units which can graze each year on a given range area for a specific period without causing a downward trend in forage production or quality and a degradation of soil condition ".

Hence the determination of carrying capacity requires adequate range resources information, pertaining to vegetation composition, percent ground cover and amount of forage produced.

Range condition is simply defined as the state of range health, obtained when relating the present site situation to the potential to which it is capable. Classification of condition is based on the theory that vegetation is the product of its environment - of a cause and effect relationship. Factors of direct importance to range vegetation are edaphic, climatic and biotic.

2. Range sites situations

(a) The Qoz sands (refer to soil map, fig. 3, Q 1,2,3,4,5,51,6,61

Normally a balanced vegetation of trees, bushes, perennial and annual grasses and herbs characterizes the sand soils. With changes in climatic conditions, advent of overgrazing, fire or excessive cultivations, particularly around water sources, drastic change occurs as regards to ground cover and vegetation composition. Since the sand soils are deep, coarse-textured and highly permeable they readily absorb all the water that falls on them.

Usually revegetation of denuded sites commences, but with an increase in the percentage of undesirable (low value as grazing) plants, because animals tend to select the most desirable plants allowing the undesirable ones the chance to prevail.

Potential for improvement of plant composition, ground cover and herbage production in the sands can practically be achieved through natural reseeding and or artificial reseeding practices, in which case efficient grazing control is a prerequisite to revegetation, through the adoption of rotational or rest rotational grazing systems.

(b) The Gardud (non-cracking clays)(T1,T2 and T3)

Under ecologically balanced conditions the gardud soils support a distinct vegetation in equilibrium with the prevailing environmental

conditions. The equilibrium soon becomes upset with overgrazing or ill-timed grazing (during the active growing period) coupled with seasonal accidental fires. When retrogression factors operate, bare compacted spots become the prominant feature. A change in vegetation components take place and mainly plants which are fire-tolerant and rejected by the grazing animals become the dominant in the plant community.

Potential for improvement in the gardud soils is great, because it only requires fencing deteriorated areas and with or without artificial reseeding revegetation normally commences when conditions are favorable. Mechanical cultural practices that help to improve water infiltration rates result in good ground cover, composition, yield and carrying capacity. Practices such as thinning the profused bush thickest (Acacia mellifera and Acacia nubica) which sometimes prohibits the establishment of understory vegetation, offer a good opportunity for more grasses and herbs to regenerate.

These soils are being used as wet season grazing by cattle nomads, resulting in severe reduction in the range condition. Signs of overgrazing and erosion (water-caused) are evident.

(c) The Clay Plain (dark cracking clays)(U1,2,3,5,6,8,9.,10, & 11, L1,L2,A3.)

The dark cracking clays of the clay plain produce a dense vegetation of overstory and understory covers. The proportion of perennial grasses and herbs is higher because of the higher rainfall and the soil characteristics. The grazing resources are almost entirely deferred during the active growing season. The fact that they are mostly grazed during the dry period, when most of the plants are dormant, confirms that signs of overuse are only confined to scarifice areas on the proximity of population centres.

An immense potential for improvement is possible, by using the following practices:- Establishment of grass-legumes mixtures, incorporation of forage production in the machanized farming scheme, and control of range fires set by the nomads.

(d) The semi-desert grazing resources of the mapping units N1-N31

The browse species are utilized very heavily during the growing period while camel nomads are on their migrations. In years of low rainfall much damage is inflicted on the understory vegetation.

Only fencing deteriorated areas can be considered to achieve the potential improvement. Water spreading and soil pitting practices can be attempted where soil characteristics are favorable and water is available.

(e) The semi-desert (mapping unit N3)

Vegetation, if there is any, is confined to the fringes of seasonal water courses and drainage lines. Carrying capacity can be improved only in very limited areas where the soils are receptive, flat. Water spreading can be attempted in years of good precipitation.

3. Data Development

Data were developed by components of the major kinds of soils in the study area for the following:- percent ground cover, percent vegetation composition, herbage production in kg/Fedd., potential herbage production in kg/Fedd., percent utilization, allowable forage kg/Fedd., range condition classes and ground cover at critical erosion hazard period under:- average precipitation, below average and above average precipitation. Information was used from the soil survey data, limited range inventory data and from personal knowledge and experience. Estimates were made using the following criteria.

Out of eight recording exclosure (potential) sites and their surrounding open ranges, only two sites fall in the arid zone, six in the semi-arid, with one in the clay plain. The following ratios were obtained when relating the production of the open range sites to the exclosure (potential) production.

Zone	Ratio of Production	Potential
Arid zone (sand)	1.0	2.0
Semi-arid (sand + gardud)	1.0	2.0
Semi-arid (clay plain)	1.0	1.03
Dry monsoon (estimated)	1.0	1.03
Semi-desert & desert (estimated	1	2

% Ground cover

A procedure for estimating percent ground cover for below and above average precipitation was developed.

The estimated average is reduced by 10% for below average precipitation, and increased by 10% for above (10±).

% Composition Average ±10 (for above and below)

Production (production on the sands and gardud) of the -

Desert, semi-desert, arid, semi-arid climatic zones were estimated to average ±50 kg/Feddan for above and below average precipitation.

Semi-arid and dry monsoon climatic zones on the clays was estimated to average ±100 kg/Feddan for above and below average precipitation.

% Utilization (UT) assumed to equal the percentage of the desirable plants contribution in the vegetation composition.

Allowable kg/Feddan: $\frac{\text{Estimated production x \% UT}}{100}$

or $\frac{\text{Estimated production}}{100}$ x % of desirables (contribution in the dry matter)

Assuming

Animal unit (AU) live weight = 800 lb. or approx. = 360 kg.

Daily animal requirement (maintenance) = 3% of the live weight

Daily animal unit requirement of dry matter: $\frac{360 \times 3}{100}$ = 10.8 kg

approx. 11 kg/Au/day

Au. monthly requirement (DM) 30 x 11 = 330 kg.

Carrying capacity (Fedd./Au/Month = $\frac{330}{\text{Allowable forage kg/Fedd.}}$

Range condition (%) $\frac{\text{Allowable forage/Fedd}}{\text{Estimated potential kg/Fedd.}}$ = %

Range condition class - according to the following rating

=	Poor	1%	25%
=	Fair	26%	50%
=	Good	51%	75%
=	Excellent	76%	100%

According to this method Tables 2 to 7 in the appendix have been prepared showing the estimates in the rangelands of present carrying capacities, range conditions. These need to be modified to meet the needs of the study by actual field measurements.

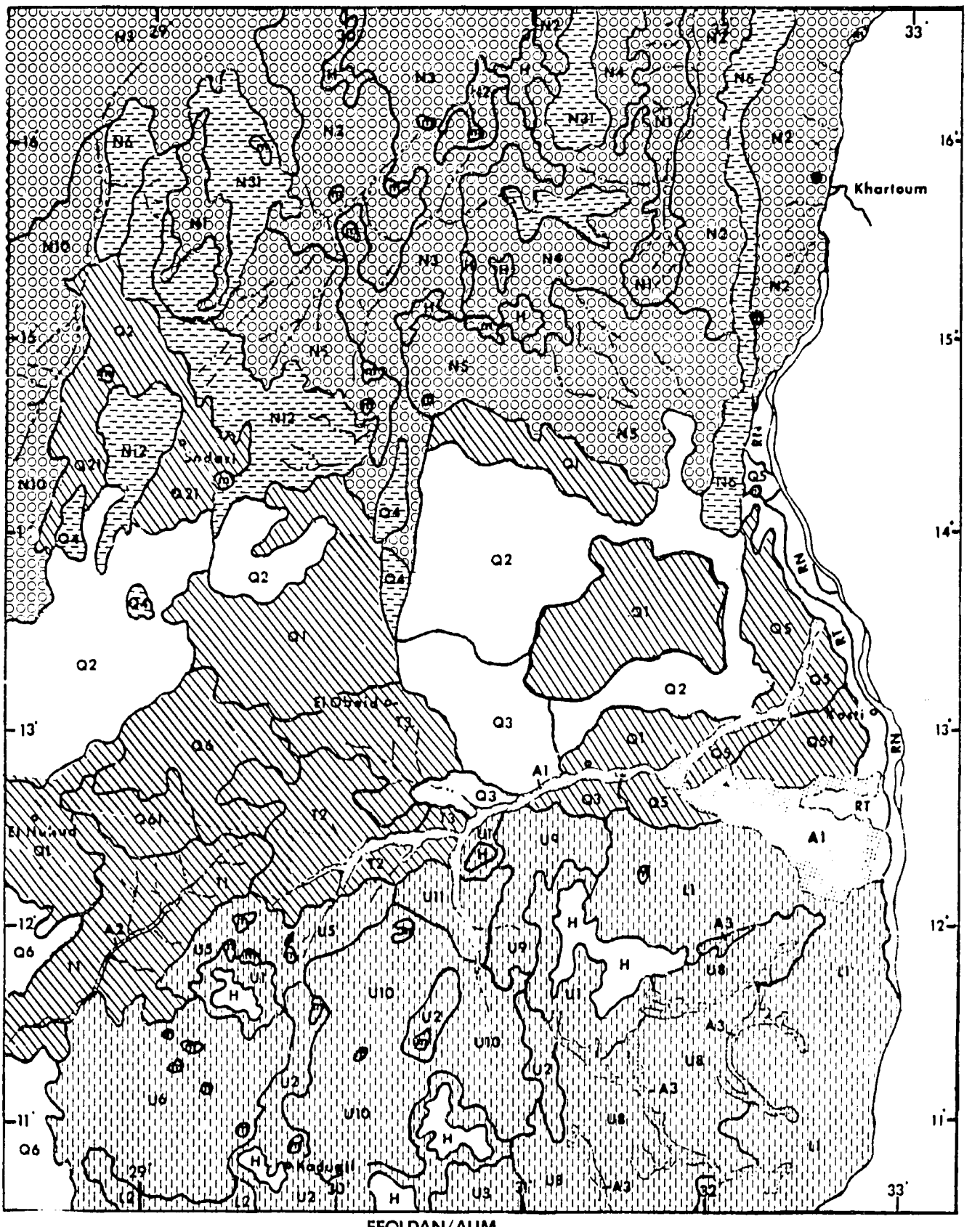
4. Definitions of rangeland carrying capacity classes

Refer to Figure 8 and 9 .

1 - High 0.5 - 1.0 Feddans per animal unit month.

The soils in this class are largely clays (U1, U2-3,5,6,8,9,10,11,L1, L2, & A3) that occur in the semi-arid and dry monsoon climatic zones. The natural vegetation is characterized by having a dense canopy and ground cover of perennial grasses and herbs predominate. The grazing resources are entirely deferred during the active growing season. Grazing takes place during the 5-7 month dry season.

FIG. 8 RANGELANDS CARRYING CAPACITY BY KINDS OF SOILS UNDER AVERAGE PRECIPITATION.



FEOLDAN/AUM

LEGEND

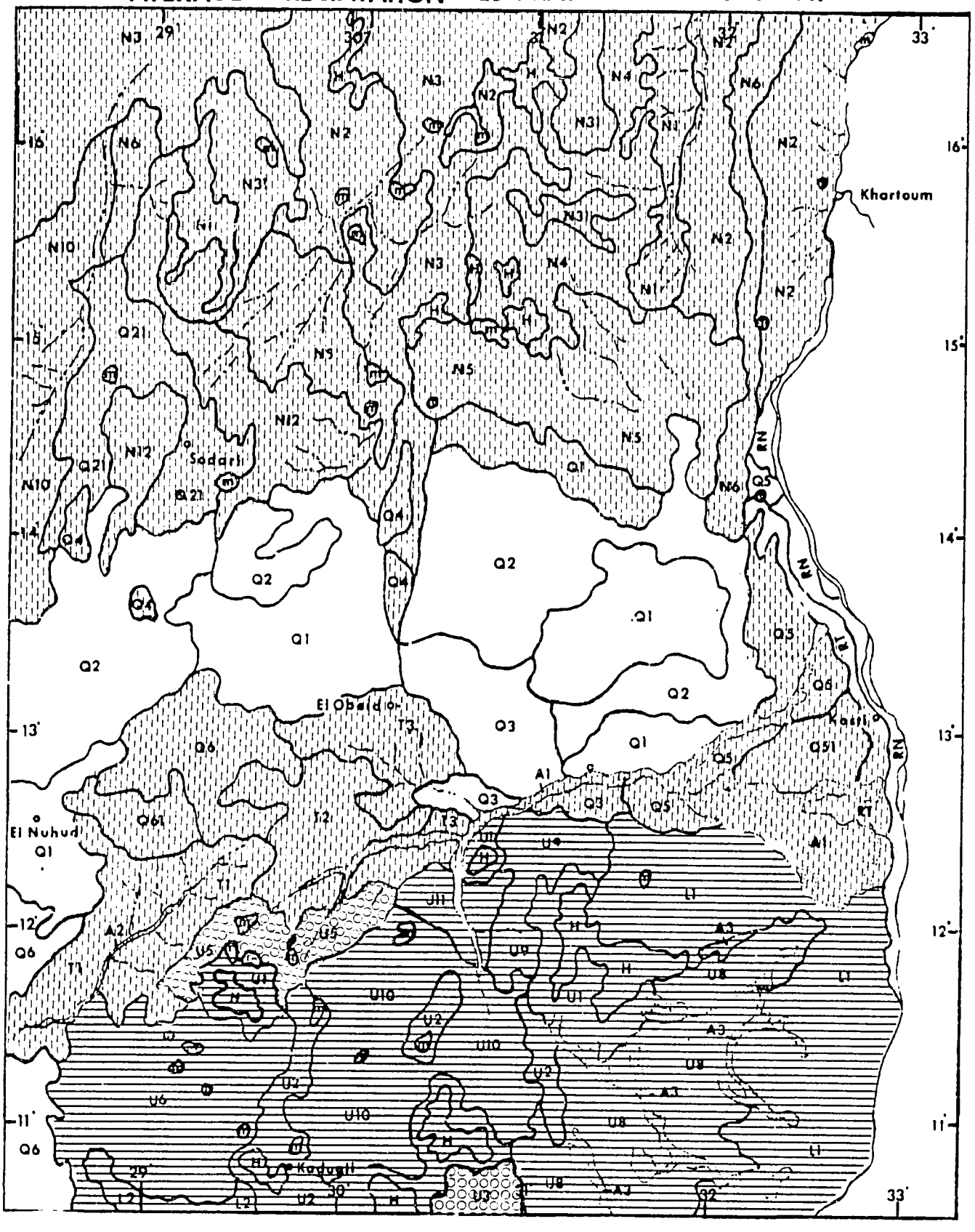
CLASS

- HIGH 0.5 - 1.0
- MODERATELY HIGH 1.0 - 3.0
- MODERATE 3.0 - 8.0
- LOW 8.0 - 15.0
- VERY LOW 15.0 - 30.0

30 0 30 60 90 120

KM

FIG. 9 HERBAGE YIELD CLASSES BY KIND OF SOIL UNDER AVERAGE PRECIPITATION ESTIMATED PRODUCTION.



CLASS

- HIGH > 800 KG/ FED/YEAR
- MODERATE 500 - 800
- LOW 200 - 300
- VERY LOW < 200

30 0 30 60 90 120
KM

2 - Moderately high 1.0 - 3.0 Feddans per animal unit month

These soils are largely sandy and loamy (A1,Q3a and Q6b) and occur in the semi-arid and arid climatic zones. Seasonality of water availability limits use to wet season and during migrations grazing. High grazing pressure near villages and water places presents a problem to good grazing management. Feed resources consist of Acacia senegal-Combretum, Acacia senegal-Leptadenia Associations on the stablized sand dunes and sand sheets and their associated grass cover.

3 - Moderate 3.0 - 8.0 Feddans per animal unit month

The soils in this class occur in (Q1,2,3A,5,5b,6a,Q21,T1,T2,T3, A1, A2) landscapes of the semi-arid, arid, and semi desert climatic zones. Grazing takes place on these soils in both seasons (9-10 months) by the camels and cattle nomads respectively. For this reason the range is over-grazed and is low in production. Heavy grazing pressure around water points is a prominant feature and the pressure decreases with distance away from water.

4 - Low 8.0 - 15.0 Feddans per animal unit month.

The soils in this class occur in the landscapes (Q4, N6, nL2 and N31) of the arid zone while the bulk falls in the semi desert climatic zone. The soils are unstable sand dunes and subject to overgrazing and soil blowing. Vegetation cover consists of sparse bushes and grasses. Most of the feed for animals (browsers) using the area comes from browse plants and occurs during 2 to 3 months grazing period during years of favorable moisture.

5 - Very Low 15.0 - 30.0 Feddans per animal unit month.

The soils in this class occur in the landscapes (N1,2,3,4,5,6 & N10) of the desert and semi desert climatic zones. The grazing resources are very sparse. The landscapes consist of dry sands and loamy sands

lacking diagnostic horizons which are subject to severe soil blowing. Over 60% of the feed is provided by browse plants. These areas are used for grazing only during very limited periods of 30 days or less and only when adequate precipitation occurs.

V

LAND SUITABILITY CLASSIFICATION

Using the information in the soil report and the authors' knowledge of the area, a general land suitability classification of the soil components was made for several existing rainfed land utilization types. Sorghum, millet and groundnuts have been selected for this classification because of their importance as food and cash crops. The latter two are traditionally cultivated using manual labor. Sorghum is cultivated under both traditional and modern systems, a brief summary of each is given as follows:

1 (a):

Rainfed traditional systems

In this type of crop production all of the operations are done by simple hand tools. Prior to cultivation the land is cleared of grass, trees and shrubs. This clearing is in the form of cutting branches of trees and burning them together with the dry grass and stubble. Sometimes this step is delayed until the beginning of the rainy season and germination of the weeds. The dry grass and the newly growing weeds are burned.

Sorghum, millet and ground nuts are sown by burying the seeds in holes made by hand tools (Seluka or Toria). Shifting cultivation is practiced and crop sequences, instead of a proper rotation system, is followed. The three crops are grown on most soils in the area except in the desert and semi desert zones.

Difficulty is encountered in harvesting ground nuts in the clays, because these soils are hard when dry. Water logging conditions are sometimes another limiting factor in the clays.

The sandy soils, unless carefully managed are subject to soil blowing.

1 (b):

Rainfed mechanized sorghum

Modern machinery is used for sorghum in the clays of the southern part of the area. The rotation adopted is sorghum, cotton, and fallow. No fertilizer

is applied since the use of fertilizer in most cases can be marginal. However, the clays are relatively more fertile than the sandy soils in the area.

2. Suitability Classifications

To determine the agricultural potential of the area, a land suitability classification was made by evaluating the soil components in relation to the four land utilization types: rainfed traditional millet, ground nut, sorghum and modern mechanized sorghum. Each component was evaluated according to its properties. The crop requirements shown in Table 8, and the influencing environmental factors are accordingly classified for each of the four land use types. The soil properties considered for classification were slope, depth, texture, permeability, internal drainage, pH, fertility, erosion hazard and workability. Based on the above, the components were grouped into four land suitability classes: S1,S2,S3 and N. These classes are defined as follows:

S1=Highly suitable: Lands that are highly productive for the specific land use type. They are very responsive to good management and have no limitations that reduce yield or increase cost for production or conservation.

S2= Moderately suitable: These are moderately productive lands for the specific land use type and yield moderate benefits which are sufficiently high to justify the required capital and recurrent input. Moderate to severe limitations are likely to reduce yields and increase recurrent costs for production and conservation.

S3=Marginally suitable: Lands that have (or expected to have after improvements) a low productivity for the defined land use type and yield benefits that are just high enough to justify recurrent costs and capital

input. There are limitations which when grouped together are sufficiently severe to reduce yield and/or increase recurrent costs for production and conservation.

N=not suitable: Lands that have severe soil limitations that cannot be corrected economically and that make them generally unsuitable for the specific land use type.

3. Results of Classification

The final suitability classification for each soil component is shown in Table 8 in the Appendix. The classification indicates both potential and current suitability.

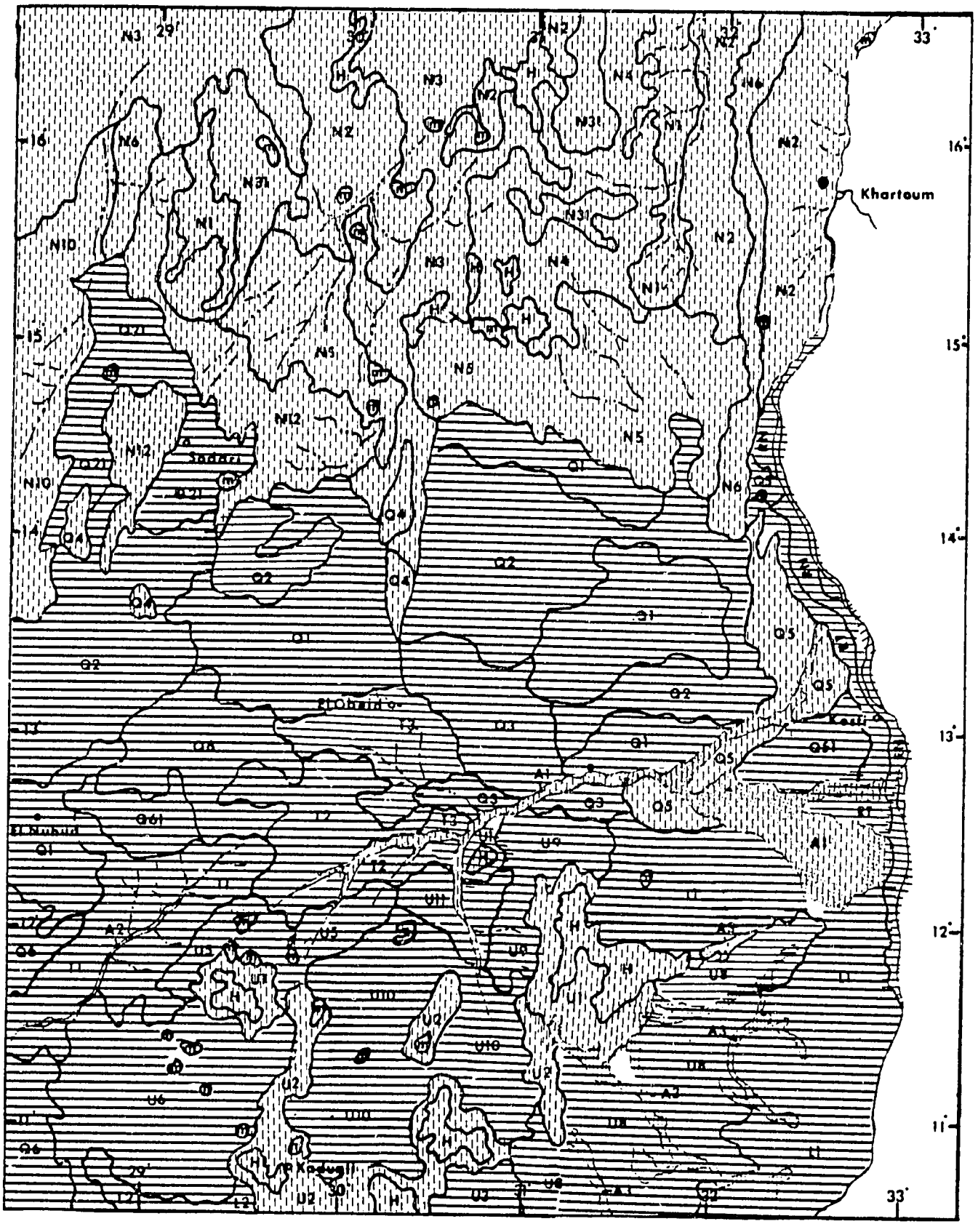
A general suitability classification of the soil mapping units for each land utilization type was then established. This was based on evaluating the average suitability of the mapping unit after weighing the combined qualities and limitations of the different soil components. This classification was superimposed on the soil map to indicate the high potential lands and the poor potential areas for each of the four utilizations Figs. 10,11,12 and 13 and table 8 in the appendix.

Resorting to yield data in some of the localities and the soil properties, an estimation of yield of the presently grown crops was made for all of the soil components, Table 9 of the Appendix. This step was meant to be a further evaluation of the component. The estimates indicate the expected yields under traditional agriculture, improved traditional agriculture, modern agriculture, the presently area cultivated and the potential for cultivation.

4. Discussion

Land suitability classification is an approach that considers all the details about the physical, human and environmental factors that have their

FIG. 10 CURRENT SUITABILITY FOR TRADITIONAL GROUNDNUTS

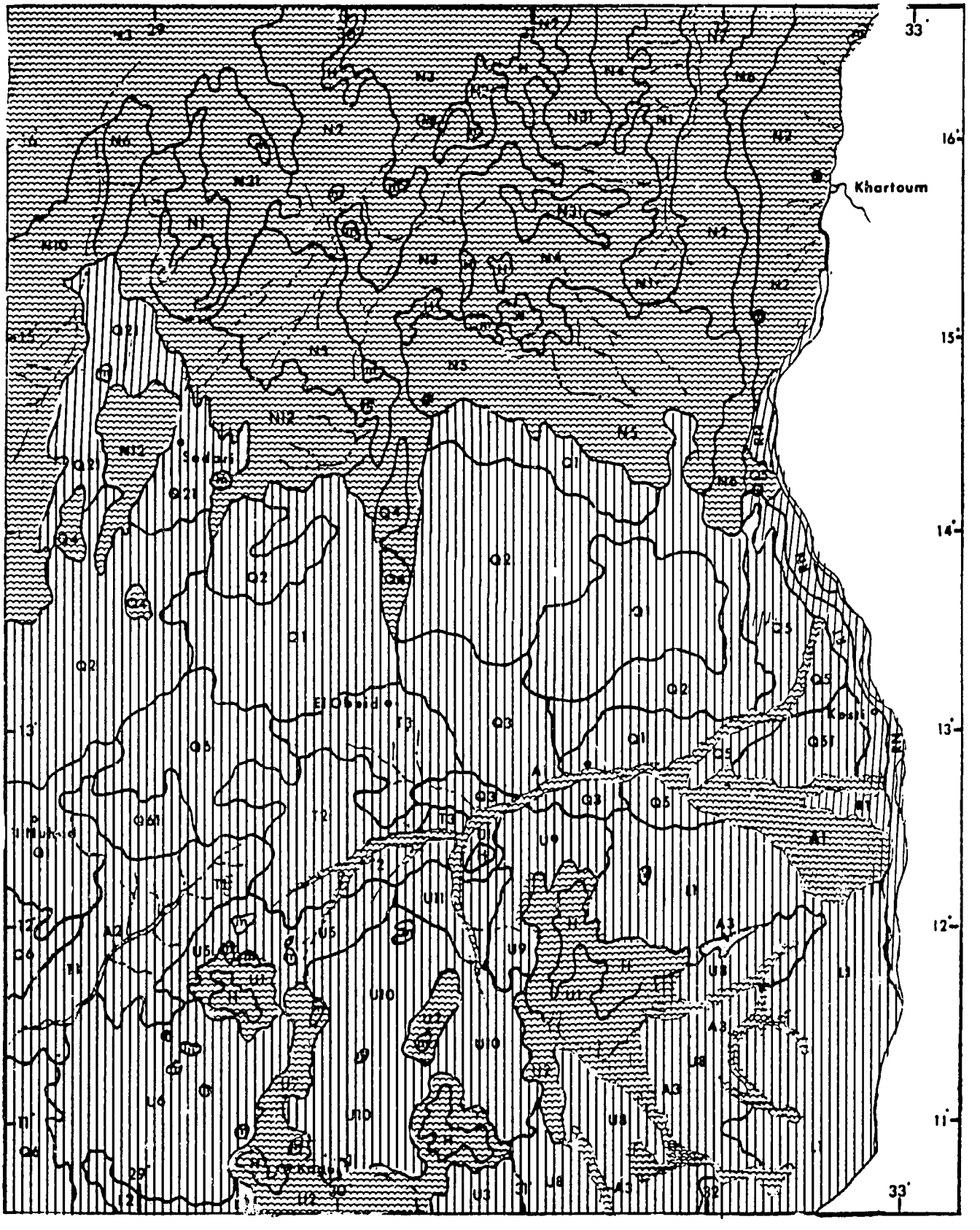


LEGEND

N - UNSUITABLE

S3 - MARGINALLY SUITABLE

FIG. 11 CURRENT SUITABILITY FOR TRADITIONAL MILLET

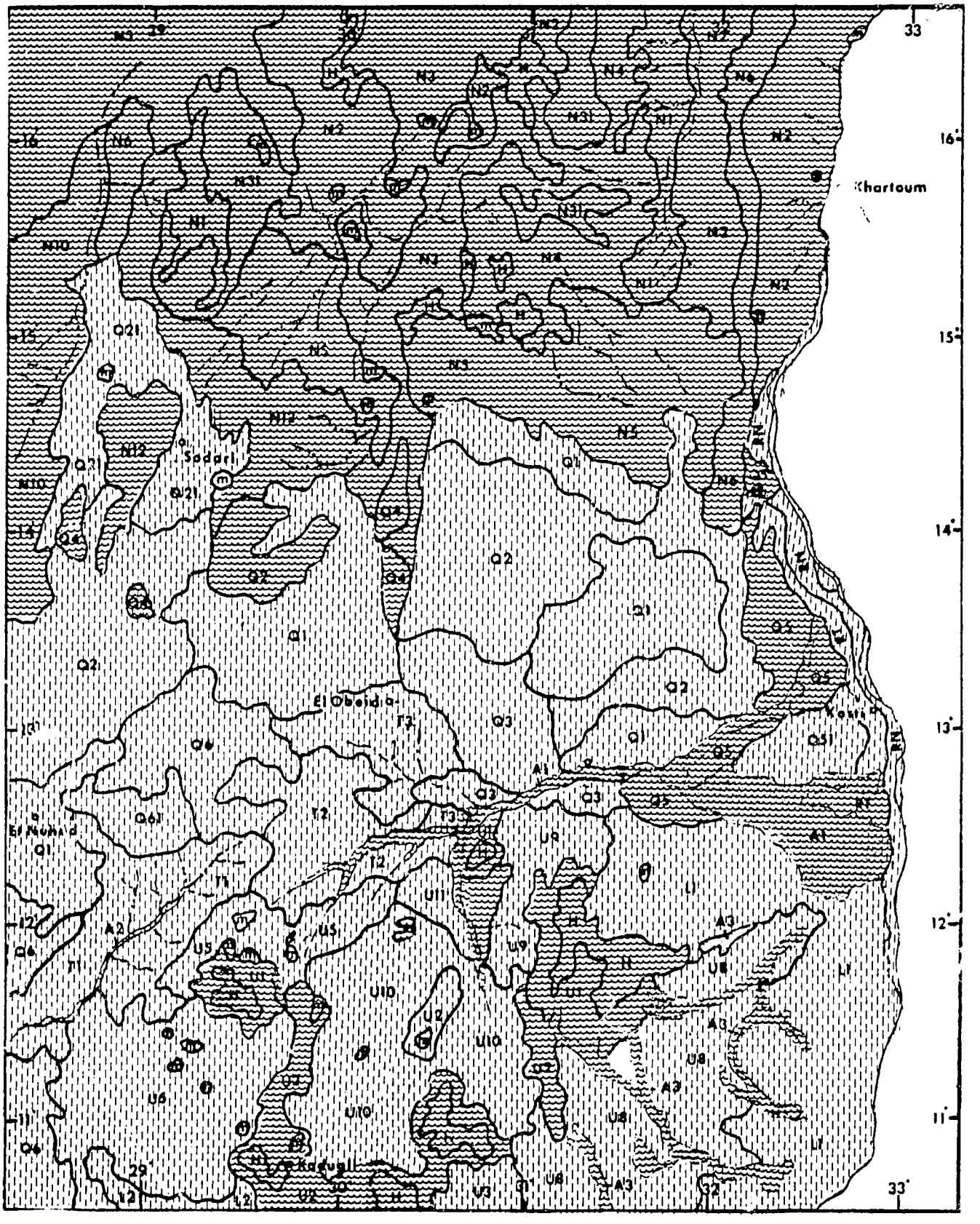


LEGEND

- N – UNSUITABLE
- S – MARGINALLY SUITABLE
- S – MODERATELY SUITABLE

30 0 30 60 90 120
KM

FIG.12 CURRENT SUITABILITY FOR TRADITIONAL SORGHUM



LEGEND

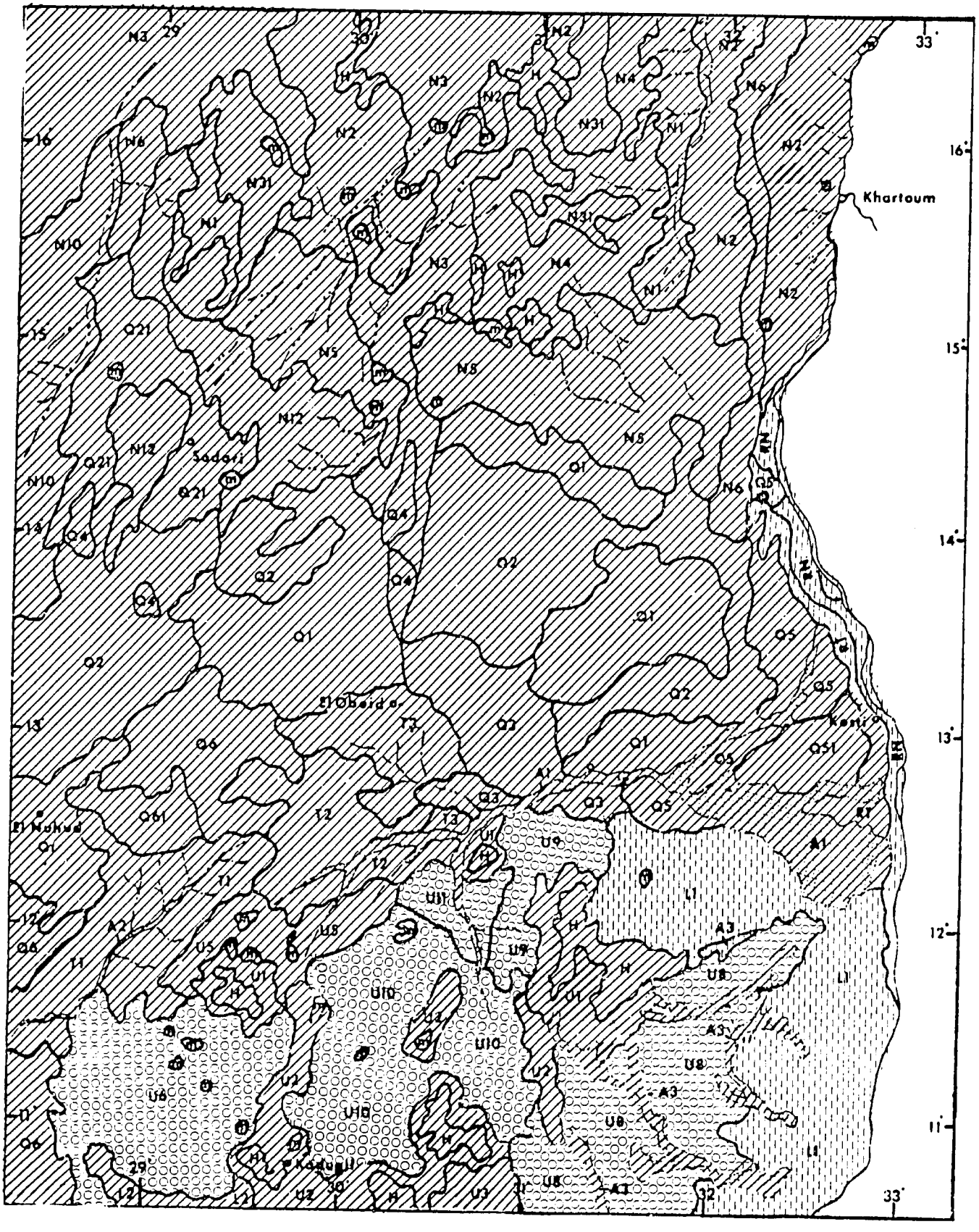
N - UNSUITABLE

S3 - MARGINALLY SUITABLE

30 0 30 60 90 120

KM

FIG. 13 CURRENT SUITABILITY FOR MECHANIZED SORGHUM



direct effect on the use of land. The classification presented in this report is general, because it is based on a general soil map and limited information. However, it can be considered as a step for planning of more detailed surveys in future.

EVALUATION OF SOIL BLOWING HAZARD

1. General Consideration

Soil blowing is a serious problem in the more arid section of the Sudan. Low precipitation and high wind velocities during the dry season together with sandy soils and overgrazing all contribute to this problem.

In evaluating this phenomenon a number of factors have to be incorporated. Surface soil properties, plant residue cover, presence of natural barriers, wind forces and direction and the critical wind period are most important. It is recognized that limited data were available in making estimates on soil blowing. However, based on research data related to the soil blowing (literature cited no. 8-0, 10, 11 page) and by using limited data from Sudan on climate, soil and vegetation studies and ground studies made by the authors, a method was developed for estimating the soil blowing hazard in the study area. The method is briefly described as follows:

Each of the selected soil properties, namely surface texture and moisture, plant residues cover, critical wind period, topography and tree canopy were evaluated according to hazards of soil blowing (refer to Table 10 in the Appendix).

The soil textures were assigned erodability factors ranging from zero for coarse fragments and permanently wet soil to 10 for dry sands. The erodability factor for the plant residues cover ranged from 1 for very good cover (more than 40%) to 10 for poor cover (less than 15%). The factor for the critical wind period ranged from 1 for the short period (less than 20 days) to

10 for the very long period (over 90 days). The factor for topography and tree canopy ranged from zero for the high topography (mountains and dense forests) to 10 for the none level to gently sloping with 5% canopy.

2. Classification for soil blowing hazard

According to the above evaluation based on grading the properties for soil blowing the components were grouped into four classes shown below:

Class	Erodibility factor
A None to slight hazard	0 - 15
B Moderate	16 - 27
C Severe	28 - 33
D Very severe	34 - 40

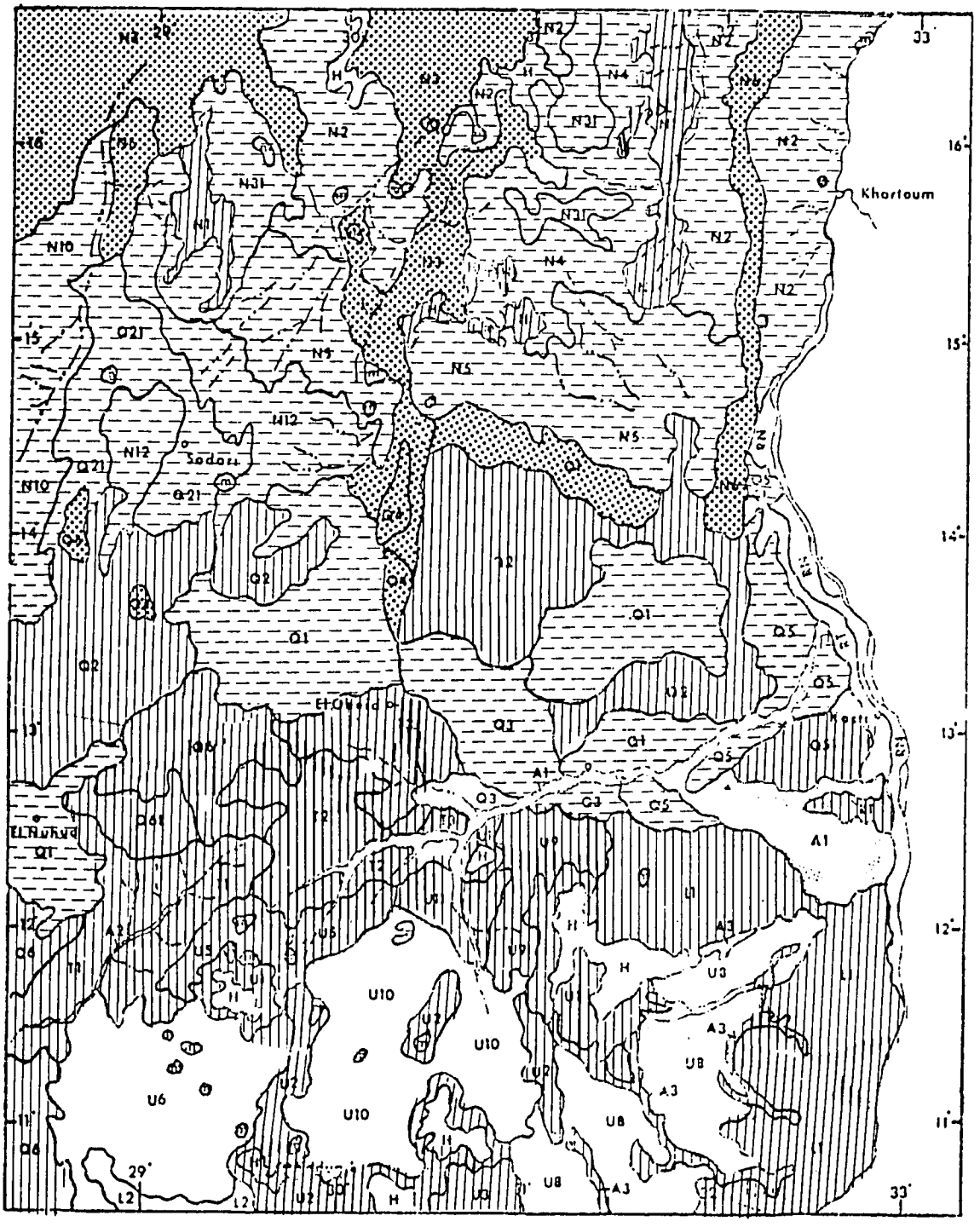
The components were classified at below average and above average rainfall. Based upon the average properties of their components, the soil mapping units were accordingly classified for soil blowing hazard. This classification was superimposed on the soil map to indicate less susceptible areas to blowing and areas that are subject to severe blowing and need immediate protective measures, refer to Fig. 14 and Table 11 in the Appendix.

3. Definition of classes

Class A None to slight

Soils that are not likely to be subject to severe blowing hazard under the prevailing conditions. These include the alluvial soils of the flood plains, the white Nile terraces, the hill and the heavy clays in the extreme southern part of the area.

FIG. 14 SOIL BLOWING HAZARD CENTRAL SUDAN



LEGEND

- NONE TO SLIGHT
- MODERATE
- SEVERE
- VERY SEVERE

30 0 30 60 90 120
KM

Class B Moderate

Soils that are or will be moderately blown and unless carefully managed under the present land use practices will be subject to severe blowing.

Class C and Class D

Soils that have already been or will be severely blown; unless immediate measures are taken.

Discussion

This method of grading soil properties as a base for classifying the soils for blowing hazard was done on personal judgement after consulting some of the research work in the United States. The method can be looked at as an approach that needs to be further improved and supported by research findings and by consideration of all other factors that influence soil blowing. These factors include the surface soil structure and surface sealing.

RECOMMENDATIONS

The Sudan is a country of one million square miles and has limited funds and a lack of up-to-date information about its natural resources. This information is basic for planning. For an economical method to acquire resource information to meet the urgent needs for development, the authors recommend that the country should pursue the application of remote sensing techniques, particularly Landsat data. The technology bears special advantages that make it unique and most applicable for urgent economic reconnaissance surveys, which are basic for further detailed surveys. Some of Landsat advantages are:

1. The repetitive coverage offering the opportunity to monitor and watch the advancing desert and other changes of the resources.

2. The synoptic view is another most important advantage to a large country like the Sudan where there is a need for recognizing large scale change of natural resources that are difficult by other means. A close association with the technology is justified by its more future prospects because of its continuing process of improvement in respect to scale and resolution.

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APPENDIX

Fig. A. Landsat Interpretation for Physiography and Present Land Use-Central Kordofan, Sudan. Original scale of 1:500,000 covering region between 11°00'N - 15°30'N latitudes and 29°00'E - 32°00'E longitudes.

An example area of the map at the original scale is on the following page. The original map is available from the author. The map Legend is:

PHYSIOGRAPHIC UNITS	LAND USE CLASSES	
A THE QOZ SANDS	A_1	DENSE TRADITIONAL CULTIVATION
	A_2	LIGHT TRADITIONAL CULTIVATION
	A_3	LIGHT FORESTED GRAZING LAND
	A_4	OPEN GRASS & SHRUB GRAZING LAND
	A_5	RESERVED FOREST
	A	NEARLY BARE UNUSED DUNES
B THE CLAY PEDIPLAIN (GARDUD)	B_1	GRAZING BUSHLAND
	B_2	UNDIFFERENTIATED GRAZING & CULTIVATION
C THE CLAY PLAIN	C_1	MECHANIZED SCHEMES
	C_2	FORESTED GRAZING LAND
	C_3	BURNED LAND
F THE FLOOD PLAINS	F_1	DRY SEASON BROWSE
	F_2	EMEIH IRRIGATED SCHEME
H HILLS AND PEDIMENTS	H_1	BROWSE ON HILLS
	H_2	BROWSE ON PEDIMENTS

SYMBOLS

MAJOR STREAMS

MINOR STREAMS

WATER RESERVOIR (W)

RAILROAD TRACKS

DRY SEASON ROADS

BIG TOWNS

SMALL TOWNS & VILLAGES

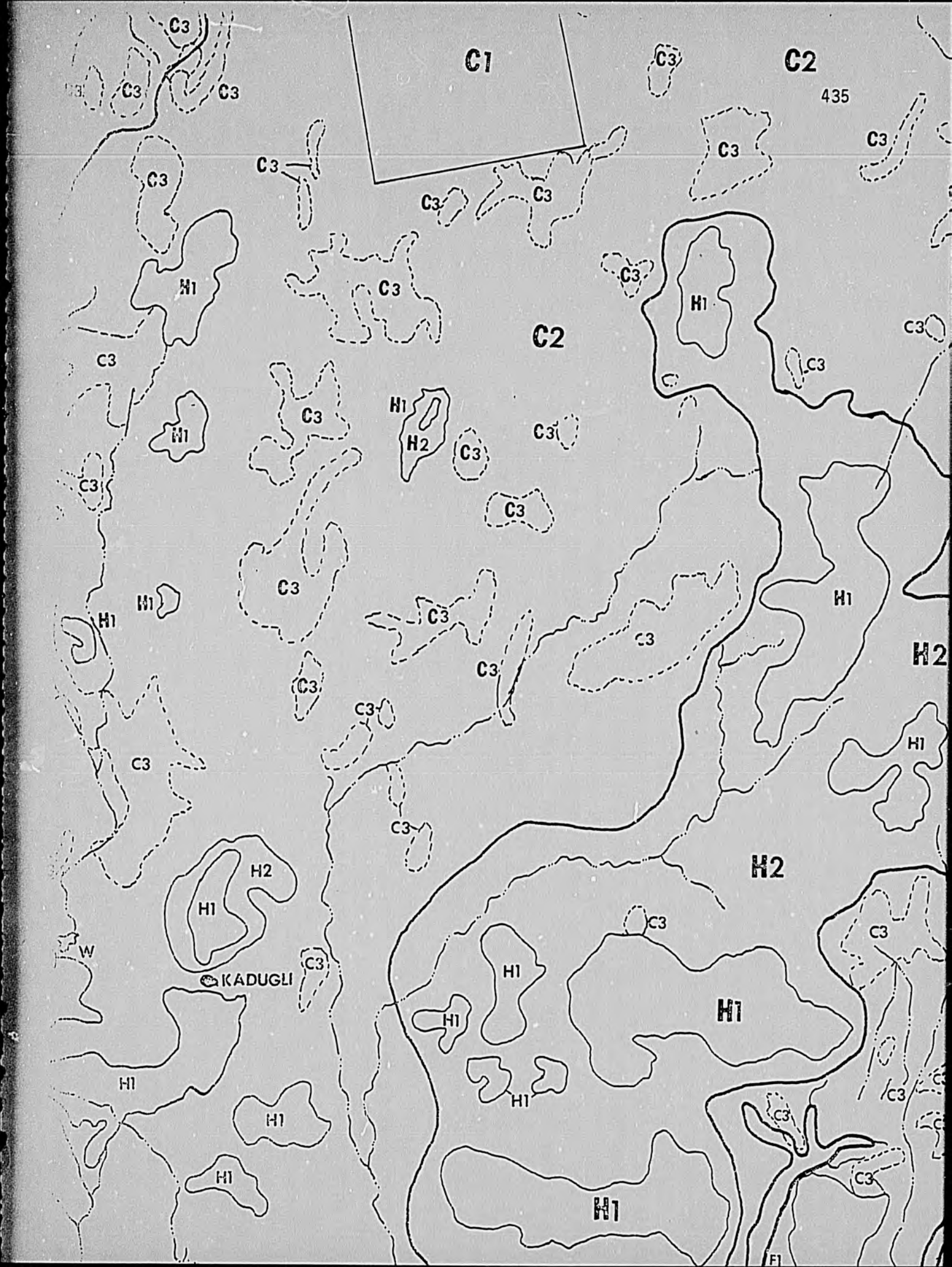

C1
C2
435
C3
H1
H2
KADUGLI
W
F1

Fig. B. General Vegetation Map of Central Kordafan, Sudan. Original scale of 1:500,000 covering region between 11°00'N - 15°00'N latitudes and 29°00'E - 32°00'E longitudes.

An example area of the map at the original scale is on the next page. The original map is available from the author. The map Legend is:

BARE SOIL (VISIBLE DUNES)

RAINY SEASON GRAZING AREA

TOWNS/VILLAGES

MOUNTAINS AND OUTCROPS

MECHANIZED FARMING

BURNED SITES

SEASONAL WATER COURSES

WATER RESERVOIRS

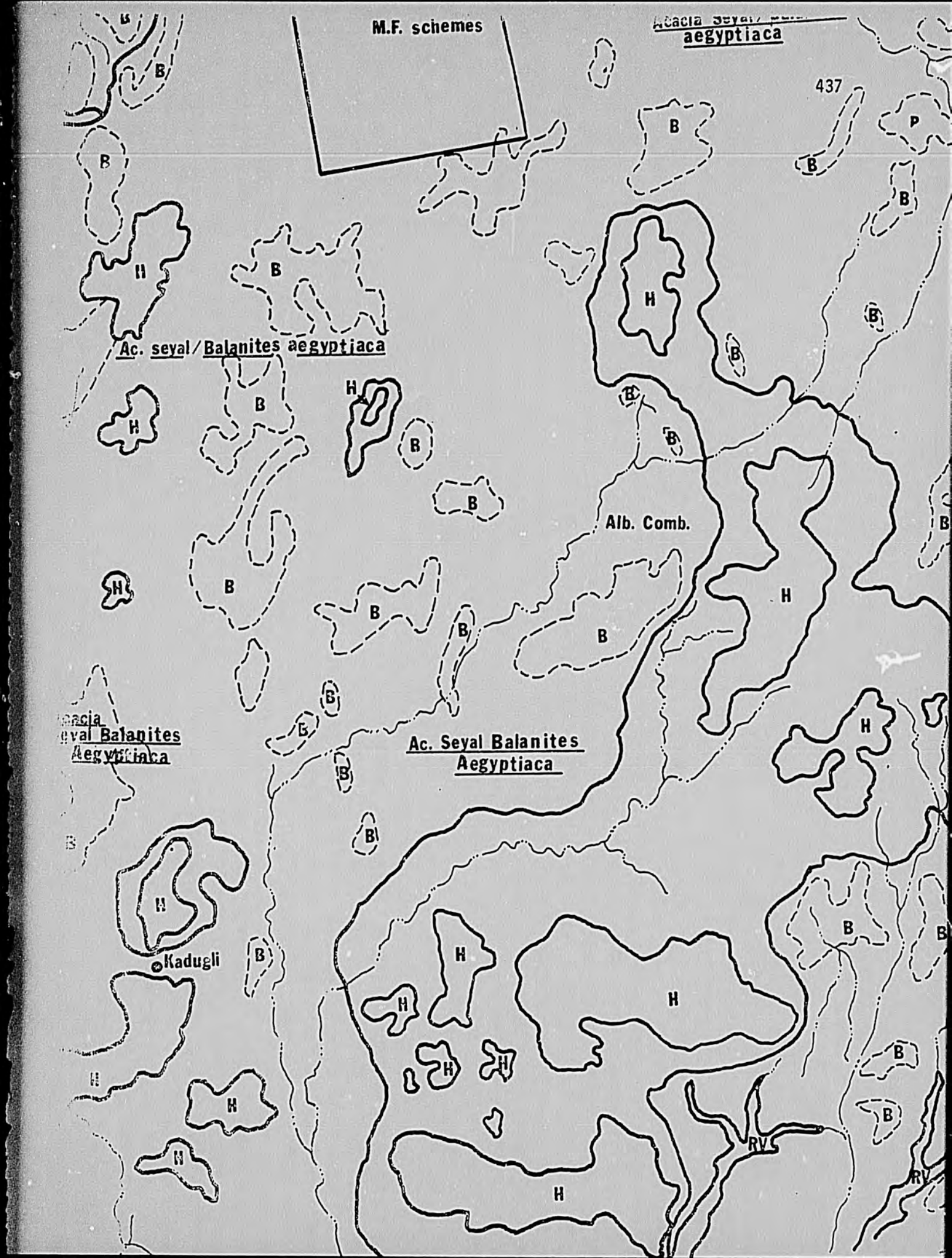

M.F. schemes
aegyptiaca
437
Ac. seyal/Balanites aegyptiaca
Alb. Comb.
Ac. Seyal Balanites
Aegyptiaca
Kadugli
RV
B
H
P

TABLE 1
ESTIMATES OF % GROUND COVER AT CRITICAL PERIOD (MAY --- JUNE)
UNDER BELOW AVERAGE, AVERAGE, ABOVE AVERAGE PPT

	Comp.	Texture	Below Average %	Average %	Above Average %	Remarks
Q1	1	S	15	20	25	Acacia tortilis/leptadenia ass. grazed during wet part of the dry season-termite and bush fires problem.
	2	L	10	15	20	
Q21	1	S	10	15	20	Semi-desert grassland on sand-used during migrations,bare sites are common in the northern parts.
Arid Zone						
Q1	1	S	5	15	20	Acacia Senegal, Acacia Tortilis-leptadenia-used during migrations, trade cattle both during wet and dry seasons, areas around villages-water yards are overgrazed.
	2	LS	0	10	15	
Q2	1	S	5	15	20	Fixed dunes/acacia senegal/acacia tortilis/leptadenia-numerous watering points, heavy cultivation
Q4	1	S	0	5	10	Fixed dunes/acacia senegal/acacia tortilis/leptadenia-numerous watering points, heavy cultivation, transverse dunes with or without canopy cover. Active dunes are seen.
Q5	1	LS	10	15	20	Sand ridges/interridges-reduced ground cover-transit use.
	2	CL	15	20	25	
	3	SC	10	15	20	
Q51	1	SCL	5	10	15	Close to major towns, disturbed and overgrazed.
	2	LS	5	10	15	
Semi-Arid						
Q1	1	S	0	10	15	Heavy cultivation, overgrazing, fires, termites-near watering sites-underuse in areas, lacking year round water supplies.
	2	LS	5	10	15	
Q3a	1	LS	15	20	25	Longitudinal dunes-seasoned grazing-heavy cultivation and overgrazing confined to village and wateryards vicinities.
	2	S	10	15	20	
	3	SC	15	20	25	

TABLE 1
ESTIMATES OF % GROUND COVER AT CRITICAL PERIOD (MAY --- JUNE)
UNDER BELOW AVERAGE, AVERAGE, ABOVE AVERAGE PPT

Comp.		Texture	Below Average %	Average %	Above Average %	Remarks
Q3b	1	LS	5	10	15	Longitudinal dunes south of Umruwaba-densely populated, heavy cultivation/ disturbance.
	2	S	0	5	10	
	3	SC	5	10	15	
Q5	1	LS	10	15	25	Clay main/deposited sand used during migrations and part of the dry season
	2	CL	15	20	25	
	3	SC	15	20	25	
Q6a	1	LS	5	10	15	Heavy use throughout the dry season-short grass, lack of perennials- overgrazing is prominant near watering sites.
	2	SCL	5	10	15	
Q6b	1	LS	20	25	30	Moderately used during migrations/woodland savannah/with a higher proportion of perennial grasses. High canopy cover approx. > 60%
	2	SCL	20	25	30	
Q61	1	SL	10	15	20	Cattle (nomadic) wet season grazing area-(hamaraya soil) subject to water erosion where the cultivation grazing pressure is reduced.
	2	LS	10	15	20	
T1	1	SL	5	10	15	Overused during early and late wet season.
	2	SL	5	10	15	
T2	1	LS	5	10	15	High density of undesirable bushes-heavily used during the growing season.
	2	S	5	10	15	
T3	1	LS	0	10	15	Acacia thorns, broad-leafed association-heavy use-cultivation/year round grazing.
	2	SL	0	10	15	
U1	1	L	20	30	40	Seasonally used, high bush density-fire problems.
	2	L	20	30	40	
	3	SL	20	30	40	
U2	1	L	15	25	35	Almost deferred during the active growing season-used during seasonal migrations.
	2	SCL	15	20	25	
	3	SL	10	15	20	

TABLE 1
ESTIMATES OF % GROUND COVER AT CRITICAL PERIOD (MAY --- JUNE)
UNDER BELOW AVERAGE, AVERAGE, ABOVE AVERAGE PPT

	Comp.	Texture	Below Average %	Average %	Above Average %	Remarks
	Desert					
N3	1	S				
	2	R	0	5	10	Sparse under stony vegetation only along drainage lines and wadies-stunted bushes provide browse for camels. Use is only during wet season.
	Semi-Desert					
N1	1	S	0	10	20	Grass and herbs cover is only confined to underbushes and low sites receiving more moisture.
	2					
N2	1	L	0	10	20	
	2	S	0	10	20	
	3	Rock				
N3	1	S	0	5	15	Browse species are evident-soils degraded-visible bare sites are common, dunes are formed.
	2	Rock				
N4	1	R				
	2	S	0	10	15	Widely scattered bushes- soil is heavily disturbed.
N5	1	SCL	0	10	15	Patchy ground cover with widely scattered bushes.
	2	SL	0	10	15	
	3	R				
N6	1	S	0	10	15	Unstable undulating dunes.
N10	1	SCL	5	10	20	Heavy sand blowing , water courses have been reported to be buried by sand.
	2	SCL	5	10	20	
N12	1	L	5	10	20	Dense acacia bushes associated with drought resistant ground cover: spp.
	2	L	5	10	20	Extensive camel grazing, mainly browsing.
N31	1	SCL	5	10	20	Extensive browse species-acacia mellifera/drought resistant ground cover.
	2	P				

TABLE 1
ESTIMATES OF % GROUND COVER AT CRITICAL PERIOD (MAY --- JUNE)
UNDER BELOW AVERAGE, AVERAGE, ABOVE AVERAGE PPT

Comp.		Texture	Below Average %	Average %	Above Average %	Remarks
U5	1	CL	15	20	25	Low grazing pressure, dense stand of acacia senegal/balanites allesnaiec with acacia mellifera-good mixture of annual and perennial grasses. Burning is frequent.
	2	SL	15	20	25	
U6	1	C	20	25	30	Woodland savannah-acacia senegal/balanites/albizzia-dalbergia-high percent of perennials-low grazing pressure-burning is practical
	2	SC	15	20	25	
	3	C	20	25	30	
U8	1		20	25	30	Clayplain-acacia senegal/balanites alternates with open grasslands. High percent of perennials, dry season grazing area. Dense canopy cover of thorn and broad leafed trees and bushes-grass burning is practical, intensity to inform forage quality
	2		10	15	20	
	3		15	20	25	
U9	1		10	15	20	Annual grasses and herbs dominate the ground cover-dense canopy cover-more browse species, early dry season grazing.
	2		5	10	15	
	3		10	15	20	
U11	1		20	25	30	Woodlands/Thornlands used during migrations and part of the dry season.
A1	1		15	20	25	Wadi bottom and fringe of dense acacias and other browse bushes and trees, used during dry season.
	2		10	15	20	
	3		15	20	25	
A2	1		15	20	25	Wadi bottom and fringe with acacia thickest-scattered annual grasses-grazed during migrations.
	2		10	15	20	
A3	1		25	30	35	Flood plain-grazed only during the 2nd part of the dry season-green perennials predominate
	2		30	35	40	
	3		25	30	35	
L1	1		20	25	30	Flat clay plain used late in the dry season-more perennial grasses.
	2					
L2	1		20	25	30	Flat plain, high perennials percentage used during the dry season.
	2		20	25	30	

TABLE 1
ESTIMATES OF % GROUND COVER AT CRITICAL PERIOD (MAY --- JUNE)
UNDER BELOW AVERAGE, AVERAGE, ABOVE AVERAGE PPT

Comp.	Texture	Below Average %	Average %	Above Average %	Remarks
Dry Mansoon					
U2 1		20	25	30	Plateau of mixed flora with high percent of perennials-used during dry season, game animals.
2		25	30	35	
3		20	25	30	
U3 1		20	25	30	Plain of mixed flora with high percent of perennials-dry season grazing only.
2		20	25	30	
U8 1		25	30	35	Clay plain of dense acacia senegal/balanites/grasslands-high percent of perennials, dry season grazing area, burning is intensively practical.
2		15	20	25	
3		20	25	30	
U10 1		20	25	30	Clay plain with dense stands of acacia senegal/balanites, acacia mellifera cadaba cary, dry season grazing-where there are mechanized cultivated sites canopy cover is reduced.
2		20	25	30	
3		15	20	25	

TABLE 2
DATA MEASURED ON 8 DIFFERENT EXCLOSURE SITES

Exclosure Recording Site	Physiographic des of site	Soil Unit + Component	Soil Lext	Climatic Zone	Recorded PPT at the site	Vegetation Association	Grazing Pressure H.	M.	L.	Veg. Compos. D.	UN.	Ground Cover %	Production present kg/f	poten. edan	Remarks
MAZRUB	High Dunes	Q2b-1	S/LS	Arid (225-400)	280	Ac. Senegal/ lept./Ac. tortilis Erogro Cenchrus biflorus.		M		54	46	80	270	427	Dry & wet season grazing site
UM HIGLIG	Sand Sheet and low dunes	Q1b-1	S/LS	Semi-Arid (400-750)	400	Ac. Senegal, Combretum, Arist. Eragrostis	H	-	-	65	35	55	90	260	Seasona with village stock grazing
MAHBUB	Sand Sheets & low dunes	Q1b-1	S/LS		300	Albizzia, Combretum/ Dalbergia Eragrostis/ Cenchrus, Androbogan	-	-	L	58	42	70	320	340	Seasona grazing (wet season)
ENNUHUD	Sand Sheet low dunes	Q1b-2	SL/SL		400	Terminalia Short Savannah Boscia guirea/ Acacia Senegal	H	-	-	60	40	70	45	200	Year Round Grazing
Abu LAOTA	Longitudinal dunes	Q3a-1	LS/LS		360	Acacia Senegal/ Combretum, Bala/ Erogrostis/ Cenchrus	-	-	L	65	35	70	280	420	Seasona camel grazing
ELKHUWEI	Sandy Peneplain	Q6a-1	LS/LS/SCL		375	Combretum Cordofanum, Terminalia Eragrostis/ Zornia short savannah	H	-	-	93	7	85	50	]70	Year round grazing
JEBI DAGO	Northern Basin Loamy	T3a-1	LS/SL		400	Acacia Mellifera Ac. Nubica/ Boscia/Balaniles	H	-	-	97	3	50	25	338	Wet pat of dry season grazing

TABLE 2
DATA MEASURED ON 8 DIFFERENT EXCLOSURE SITES

Exclosure Recording Site	Physiographic des of site	Soil Unit + Component	Soil Lext	Climatic Zone	Recorded PPT at the site	Vegetation Association	Grazing Pressure H.	M.	L.	Veg. Compos. D.	UN.	Ground Cover %	Production present kg/f	poten. edan	Remarks
SESABAN	Dilling upland plateau	U5a-1	Cl/C		570	Acacia seyal Balanites/less perennials	-	-	L	73	27	60	900	927	Transitional zone

D stands for desirable plants (plants liked by animals)
UN stands for undesirable plants (plants rejected by animals)

H High grazing pressure
M Moderate grazing pressure
L Light grazing pressure

Production is obtained from open range
Potential Production is obtained from recording site

TABLE 3
TENTATIVE RANGE SITES GROUPING

Range Sites Groups Soil	Cl. Zone	PPT	Soil Components	General Soil Characteristics Depth	Texture	Drainage	Vegetation Associations
R	S.Desert	100-200	N1b+N2c+N31b+N3b N4a+N5c		CL-SCL/ grav.		Scattered bushes, sparse grasses and herbs, suitable for camels and other browsers.
S		100-150	N1a+N2b,N31a N4b+ N6a	SH MD-D	S/LS	E	Stunted bushes on degrad. soils, moving dunes, bare soil, devoid of ground cover. Provide poor grazing for camels in good years.
L		100-200	N2a+N3b,N5a+N5b	SH MD/D	SL-L/ grSCL	MW-W	Scattered bushes and sparse ground cover - provides poor grazing.
L		100-200	N10a+N10b+N12a+ N12b	SH MD.D	SCL/ gr,SL	MW	Heavy sand blowing, sparse scrub, acacia mellifera, Aristida camel and sheep grazing, wind erosion observed.
S	Arid	200-400	Q1a+Q1b+Q2a+Q2a+ Q3a+Q3b+Q4a+Q5a+ Q51a+Q51b+Q61b	ED	SL LS/SL	S(E)	Acacia senegal, Combretum Eragrostis - grazing seasonal, Heavy grazing in populated areas and water yards. Grazed by cattle (wet season) and all classes (dry season).
L		200-400	Q33+Q61b+Q6b	MD-D	SC-SCL / SCL	MW-W	Acacia senegal - Balanifes, Eragrostis and Cenchrus biflorus and Acacia mellifer. Combritum, Terminalia Dalbergia heavily grazed during the wet season and the dry season.
C		200-400	Q51a+Q56+Q53	VD	SC-CL / C	SWD	Sand ridges of highly reduced ground cover - Transitional grazing supports Acacia senegal, Combretum, Boscia - Acacia mellifer.
R	S.Arid	400-750	U84+L1.2	Rocky			
S			T2.2	D	S / LS	E	Acacia mellifera/Acacia nubica. Wet season grazing - overused.
S			A1.3	D	LS / SL	SE	Acacia senegal Balanites -provides browse feed.
L			T1.1,T2,U1.1,2,T2.1, T3.1,2,U2.1,2,U3.1,2, U62,U8.2,3,U9.2,U10.3, L22, A3.1,U1.3,U2.3	SH MD-D	SL-CL / gr.CL		Open savannah, Acacia/Bolonites association - pedimais vegetation flood plains, clays
C			U5.1,6.1,6.3,U8.1,9.1,9.3 10.1,2,11.1,L1.1,L2.1 A2.1,2,A3.2,3,A1.1	D	C-CL / C-LC	SP P	Acacia soya Balanites/Acacia mollifera - grass lands.

TABLE 3
TENTATIVE RANGE SITES GROUPING

Range Sites Groups Soil	Cl. Zone	PPT	Soil Components	General Soil Characteristics Depth	Texture	Drainage	Vegetation Associations
R	S.Desert	100-200	N1b+N2c+N31b+N3b N4a+N5c		CL-SCL/ grav.		Scattered bushes, sparse grasses and herbs, suitable for camels and other browsers.
S		100-150	N1a+N2b,N31a N4b+ N6a	SH MD-D	S/LS	E	Stunted bushes on degrad. soils, moving dunes, bare soil, devoid of ground cover. Provide poor grazing for camels in good years.
L		100-200	N2a+N3b,N5a+N5b	SH MD/D	SL-L/ grSCL	MW-W	Scattered bushes and sparse ground cover - provides poor grazing.
L		100-200	N10a+N10b+N12a+ N12b	SH MD.D	SCL/ gr,SL	MW	Heavy sand blowing, sparse scrub, acacia mellifera, Aristida camel and sheep grazing, wind erosion observed.
S	Arid	200-400	Q1a+Q1b+Q2a+Q2a+ Q3a+Q3b+Q4a+Q5a+ Q51a+Q51b+Q61b	ED	SL LS/SL	S(E)	Acacia senegal, Combretum Eragrostis - grazing seasonal, Heavy grazing in populated areas and water yards. Grazed by cattle (wet season) and all classes (dry season).
L		200-400	Q33+Q61b+Q6b	MD-D	SC-SCL / SCL	MW-W	Acacia senegal - Balanifes, Eragrostis and Cenchrus biflorus and Acacia mellifer. Combritum, Terminalia Dalbergia heavily grazed during the wet season and the dry season.
C		200-400	Q51a+Q56+Q53	VD	SC-CL / C	SWD	Sand ridges of highly reduced ground cover - Transitional grazing supports Acacia senegal, Combretum, Boscia - Acacia mellifer.
R	S.Arid	400-750	U84+L1.2	Rocky			
S			T2.2	D	S / LS	E	Acacia mellifera/Acacia nubica. Wet season grazing - overused.
S			A1.3	D	LS / SL	SE	Acacia senegal Balanites -provides browse feed.
L			T1.1,T2,U1.1,2,T2.1, T3.1,2,U2.1,2,U3.1,2, U62,U8.2,3,U9.2,U10.3, L22, A3.1,U1.3,U2.3	SH MD-D	SL-CL / gr.CL		Open savannah, Acacia/Bolonites association - pedimais vegetation flood plains, clays
C			U5.1,6.1,6.3,U8.1,9.1,9.3 10.1,2,11.1,L1.1,L2.1 A2.1,2,A3.2,3,A1.1	D	C-CL / C-LC	SP P	Acacia soya Balanites/Acacia mollifera - grass lands.

TABLE 4
ESTIMATES OF CARRYING CAPACITY & CONDITION AS RELATED
SOIL UNITS AND COMPONENT AT AVERAGE, BELOW AVERAGE & ABOVE AVERAGE PPT

			AVERAGE PPT.							BELOW AVERAGE PPT.							ABOVE AVERAGE PPT.						
Map Unit Symbol	Component	% Area	Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Forage Kg	C. Capacity Fed/AU/M	%	Condition Class	Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	%	Condition Class	Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	%	Condition Class
					D E S E R T																		
N3	1	90	50	25	40	10	33	20	Poor	0	0	0	0	0	0	-	150	75	50	38	8	25	Poor
	2	10	Rocky																				
		S E M I - D E S E R T																					
N1	1	30	50	25	50	12.5	26	25	Poor	-	-	-	-	-	-	-	150	75	60	45	7.3	30	Fair
	2	70	Rocky																				
N2	1	65	80	40	50	20	16.5	25	Poor	-	-	-	-	-	-	-	180	90	60	54	6.4	30	Fair
	2	25	60	30	40	12	27.5	20	-								160	80	50	40		25	Poor
	3	10	Rocky																				
N3	1	90	60	30	40	12	27.5	20	-	-	-	-	-	-	-	-	160	80	50	40	8	25	-
	2	10	Rocky																				
N4	1	80	Rocky																				
	2	20	50	25	50	12.5	26	25	-	-	-	-	-	-	-	-	150	75	60	45	7.3	30	Fair
N5	1	65	80	40	40	16	20.6	20	-	-	-	-	-	-	-	-	180	90	50	45	7.3	25	Poor
	2	30	80	40	40	16	20.6	20	-	-	-	-	-	-	-	-	170	85	50	43	7.3	25	-
	3	5	Rocky																				
N6	1	100	100	50	50	25	13.6	25	-	-	-	-	-	-	-	-	200	100	60	60	5.5	33	Fair
N10	1	65	60	30	30	9	37	15	-	-	-	-	-	-	-	-	160	80	40	32	10	20	Poor
	2	35	60	30	30	9	37	15	-	-	-	-	-	-	-	-	160	80	40	32	10	20	-
N12	1	65	100	50	60	30	11	30	Fair	-	-	-	-	-	-	-	200	100	70	70	4.7	35	Fair
	2	35	100	50	60	30	11	30	-	-	-	-	-	-	-	-	200	100	70	70	4.7	35	-

TABLE 4 (cont'd)

Map Unit Symbol	Component	% Area	AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Forage Kg	C. Capacity Fed/AU/M	Condition %	Condition Class	BELOW AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	Condition %	Condition Class	ABOVE AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	Condition %	Condition Class
N31	1	75	100	50	50	25	13.6	25	Poor	-	-	-	-	-	-	-	200	100	60	60	5.5	30	-
Q1	1	70	250	125	60	75	4.4	30	Fair	150	75	50	38	8	25	Poor	350	175	75	123	2.8	35	Fair+
	2	30	300	150	65	98	3.4	33	-	200	100	55	55	6	28	Fair	400	200	75	150	2.2	38	-
Q21	1	100	250	125	50	63	5.0	25	Poor	150	75	40	30	11	20	Poor	350	175	60	105	3.0	30	-
				A R I D		Z O N E																	
Q1	1	70	400	200	60	120	2.8	30	Fair	300	150	50	75	4.4	25	-	500	250	70	175	1.9	35	-
	2	30	180	90	65	59	5.6	32	-	80	40	55	22	15.0	28	Fair	280	140	75	105	4.4	38	-
Q2	1	100	540	270	65	175	1.0	32	-	440	220	55	121	2.7	28	-	640	320	75	250	1.3	38	-
Q4	1	100	100	50	70	35	8.1	35	-	0	0	0	0	0	0	Poor	200	100	80	80	4.1	40	-
Q5	1	70	150	75	75	56	6.0	37	-	50	25	65	16	21.0	32	Fair	250	125	85	106	3.0	40	-
	2	25	160	80	75	60	5.5	38	-	60	30	65	20	16.5	33	-	260	130	85	110	3.0	42	-
	3	5	150	75	80	60	5.5	40	-	50	25	70	18	18.0	3.6	-	250	125	90	113	3.0	45	-
Q51	1	60	200	100	70	70	4.7	35	-	100	50	60	30	11	30	-	300	150	80	120	2.8	40	-
	2	40	250	125	75	94	3.5	37	-	150	75	65	50	6.5	35	-	350	175	85	150	2.2	45	-
				S E M I		- A R	I D																
Q1	1	70	640	320	65	208	1.0	33	Fair	540	270	55	148	2.3	28	-	740	370	75	277	1.2	37	-
	2	30	90	45	75	34	9.7	38	-	-	-	-	-	-	-	-	190	95	85	80	4.1	42	-
Q3a	1	60	560	280	65	182	1.8	34	-	460	230	55	127	2.8	28	-	660	330	75	248	1.3	38	-
	2	35	500	250	70	175	1.9	35	-	400	200	60	120	2.8	30	-	600	300	80	240	1.4	40	-
	3	5	440	220	75	165	2.0	38	-	340	170	65	110	3.8	30	-	540	270	85	235	1.4	43	-
Q3b	1	60	180	90	60	54	6.0	30	-	80	40	50	20	165	25	Poor	280	140	70	98	3.5	35	-
	2	35	150	75	50	38	8.6	25	Poor	50	25	40	10	33	20	-	250	125	60	75	4.4	30	-
	3	5	200	100	60	60	5.5	30	Fair	100	50	50	25	13.2	25	-	300	150	70	105	3.0	35	-
Q5	1	70	300	150	80	120	2.8	40	-	200	100	70	70	4.7	35	Fair	400	200	90	180	1.8	45	-
	2	25	350	175	60	105	3.0	30	-	250	125	60	63	5.0	25	Poor	450	225	70	158	2.0	35	-
	3	5	250	125	60	75	4.4	30	-	150	75	50	38	8.0	25	-	350	175	70	123	2.8	35	-

Map Unit Symbol	Component	% Area	AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Forage Kg	C. Capacity Fed/AU/M	Condition %	Condition Class	BELOW AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	Condition %	Condition Class	ABOVE AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	Condition %	Condition Class
Q6a	1	70	100	50	93	46	7.0	46	-	-	-	-	-	-	-	-	200	100	98	98	3.3	49	-
	2	30	150	75	95	70	4.7	47	-	50	25	85	21	16.0	42	Fair	250	125	95	118	2.8	47	-
Q6b	1	70	600	300	70	210	1.6	35	Fair	500	250	60	150	2.2	30	Fair↓	700	350	80	280	1.2	45	Fair
	2	30	650	325	75	234	1.4	36	Fair	550	275	65	178	1.9	32	-	750	375	85	318	1.0	42	-
Q61	1	80	250	125	80	100	3.3	40	Fair	150	75	70	53	6.4	35	-	350	175	90	158	2.0	45	-
	2	20	300	150	75	113	2.9	37	Fair	200	100	65	65	5.0	33	-	400	200	85	170	1.9	43	-
T1	1	60	300	150	80	120	2.8	40	Fair	200	100	70	70	4.7	35	-	400	200	90	180	1.8	45	-
	2	40	250	125	70	88	3.7	35	Fair	150	75	60	45	7.3	30	-	350	175	80	140	2.3	40	-
T2	1	70	150	75	80	60	5.5	40	Fair	50	25	70	18	18	38	-	250	125	90	113	3.0	45	-
	2	30	200	100	85	85	3.9	43	Fair	100	50	75	38	18	38	-	300	150	95	143	2.3	48	-
T3	1	55	150	75	90	68	4.8	45	Fair	150	25	80	20	16.5	40	-	250	125	90	113	3.0	45	-
	2	45	200	100	85	85	3.9	43	Fair	100	50	75	37	8.8	37	-	300	150	95	143	2.3	48	-
U1	1	50	670	650	75	488	0.7	73	Good	570	550	65	357	0.9	63	Good↓	770	750	85	638	0.5	83	Ex.
	2	30	720	700	80	560	0.6	78	Ex.	620	600	70	420	0.8	67	Good	825	800	90	720	0.43	88	-
	3	20	695	675	80	540	0.61	78	Ex.	590	575	70	403	0.8	70	-	800	775	90	678	0.47	87	-
U2	1	50	770	750	70	525	0.63	70	Good	670	650	60	390	0.85	58	Good↓	875	850	80	680	0.48	78	Ex.
	2	35	825	800	70	560	0.6	68	Good	720	700	60	420	0.8	58	-	930	900	80	720	0.45	78	-
	3	15	800	775	65	504	0.63	63	Good	695	675	55	370	0.88	53	-	900	875	75	655	0.5	73	Good
U5	1	90	930	900	73	657	0.5	71	Good	825	800	63	504	0.65	61	-	1035	1000	83	830	0.4	80	Ex.
	2	10	980	950	80	760	0.4	78	Ex.	875	850	70	595	0.55	68	Good	1065	1050	90	945	0.34	89	-
U6	1	50	620	600	70	420	0.8	68	Good	515	500	60	300	1.1	58	Good↓	720	700	80	560	0.6	79	Ex.
	2	35	670	650	70	455	0.7	68	Good	*570	550	60	330	1.0	58	-	770	750	80	600	0.55	78	-
	3	15	620	600	70	420	0.8	68	Good	515	500	60	300	1.1	58	-	720	700	80	560	0.6	73	Good
U8	1	55	720	700	65	455	0.73	63	Good	620	600	55	330	1.0	53	-	825	800	75	600	0.55	73	-
	2	25	770	750	65	488	0.7	63	Good	670	650	55	358	0.9	53	-	875	850	75	618	0.53	70	-
	3	15	825	800	70	560	0.6	68	Good	720	700	60	420	0.8	58	-	930	900	80	720	0.45	78	Ex.
	4	5	Rocky																				

Map Unit Symbol	Component	% Area	AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Forage Kg	C. Capacity Fed/AU/M	Condition %	Condition Class	BELOW AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	Condition %	Condition Class	ABOVE AVERAGE PPT. Estimated Pot. Kg/Fed.	Est. Production Kg/Fed.	Est. Utiliz. %	Allowable Kg/Fed.	C. Capacity Fed/AU/Mon.	Condition %	Condition Class
U9	1	65	515	500	75	375	0.88	73	Good	412	400	65	260	1.3	63	-	620	600	85	510	0.65	83	-
	2	25	517	550	80	440	0.75	85	Ex.	460	450	70	315	1.0	71	Good	670	650	90	585	0.56	87	-
	3	10	620	600	70	420	0.8	68	Good	515	500	60	300	1.0	58	Good	720	600	80	560	0.6	78	-
U11	1	100	570	550	70	385	0.7	67	Good	460	450	60	270	1.2	60	Good	670	650	80	520	0.6	78	Ex.
A1	1	60	350	175	65	114	3.0	32	Fair	250	125	55	69	4.8	27	Fair	450	225	75	170	1.9	38	Fair
	2	25	400	200	75	150	2.2	38	-	300	150	65	98	3.5	33	-	500	250	85	213	1.5	43	-
	3	15	400	200	75	150	2.2	38	-	300	150	65	98	3.5	33	-	500	250	85	213	1.5	43	-
A3	1	60	720	600	80	560	0.6	78	Ex.	620	600	70	420	0.8	68	Good	885	800	90	720	0.45	88	Ex.
	2	30	670	650	75	488	0.7	73	Good	570	550	65	358	0.9	63	-	770	750	85	638	0.5	83	-
	3	10	770	750	80	600	0.55	78	Ex.	670	650	70	455	0.7	69	-	875	850	90	765	0.43	85	-
L1	1	95	770	750	80	600	0.55	78	Ex.	680	650	70	455	0.7	68	-	875	850	90	765	0.43	86	-
	2	5	Rocky																				
L2	1	90	770	750	85	638	0.5	80	Ex.	670	650	75	488	0.7	72	-	875	850	90	765	0.43	86	-
	2	10	800	775	80	620	0.53	78	Ex.	605	675	70	473	0.7	68	-	900	875	85	744	0.4	82	-
			D R Y	M O	N S O	O N																	
U2	1	50	825	800	90	720	0.44	87	Ex.	720	700	80	560	0.6	78	Ex.	930	900	95	855	0.37	92	-
	2	35	770	750	85	688	0.47	88	-	670	650	75	488	0.7	73	Good	875	850	90	765	0.43	88	-
	3	15	800	775	80	620	0.53	78	-	695	675	70	473	0.7	68	-	900	875	85	744	0.44	82	-
U3	1	65	875	850	85	623	0.53	71	Good	770	750	75	563	0.65	67	980	980	950	90	855	0.37	92	-
	2	35	850	825	80	660	0.5	78	Ex.	745	725	70	508	0.65	68	-	955	925	85	786	0.43	82	-
U8	1	55	770	750	70	525	0.63	68	Good	670	650	60	390	0.85	58	-	875	850	75	638	0.5	73	Good
	2	25	800	775	75	580	0.57	73	Good	695	675	65	439	0.75	63	-	900	875	80	720	0.45	80	Ex.
	3	15	825	800	80	640	0.5	78	Ex.	720	700	70	490	0.70	68	-	930	900	85	765	0.43	82	-
	4	5	Rocky																				
U10	1	55	720	700	85	595	0.55	83	Ex.	620	600	75	450	0.73	72	-	825	800	90	720	0.45	87	-
	2	30	720	700	85	595	0.55	83	Ex.	620	600	75	450	0.73	72	-	825	800	90	720	0.45	87	-
	3	15	745	725	90	653	0.5	88	Ex.	645	625	80	500	0.66	78	Ex.	850	825	95	748	0.43	92	-

Range Condition Classes As Related To Soil Components And Average Precipitation, Below/Above Average Precipitation

		%	Texture	Range Condition Class/Condition Trend: Average	Below Precipitation	Above Precipitation
				Desert		
N3	1	90	S	Poor	Poor	Poor
	2	10	Rocky			
				Semi-Desert		
N1	1	30	S	Poor	Poor	Fair
	2	70	Rocky			
N2	1	65	L	Poor	Poor	Fair
	2	25	S	Poor	Poor	Poor
	3	10	Rocky			
N3	1	90	S	Poor	Poor	Poor
	2	10	Rocky			
N4	1	80	Rocky			
	2	20	S	Poor	Poor	Fair
N5	1	65	SCL	Poor	Poor	Poor
	2	30	SL	Poor	Poor	Poor
	3	5	Rocky			
N6	1	100	S	Poor	Poor	Fair
N10	1	65	SCL	Poor	Poor	Poor
	2	35	SCL	Poor	Poor	Poor
N12	1	65	L	Fair	Poor	Fair/UW
	2	35	L	Fair	Poor	Fair/UW
N31	1	75	SCL	Poor	--	Fair
	2	25	Rocky			
				Fair	Poor	Fair/UW
Q1	1	70	S	Fair	Poor	Fair/UW
	2	30	L	Fair	Fair/Down W	
Q21	1	100	S	Poor	Poor	Fair
				Arid		
Q1	1	70	S	Fair	Poor	Fair/UW
	2	30	LS	Fair	Fair/Down W	Fair/UW
Q2	1	100	S	Fair	Fair/Down W	Fair/UW
Q4	1	100	S	Fair	Poor	Fair/UW
Q5	1	70	LS	Fair	Fair/Down W	Fair/UW
	2	25	CL	Fair	Fair/Down W	Fair/UW
	3	5	SC	Fair	Fair/Down W	Fair/UW
Q51	1	60	SCL	Fair	Fair/Down W	Fair/UW
	2	40	LS	Fair	Fair/Down W	Fair/UW

Range Condition Classes As Related To Soil Components And Average Precipitation, Below/Above Average Precipitation

		%	Texture	Range Condition Class/Condition Trend: Average	Below Precipitation	Above Precipitation
				Semi-Arid		
Q1	1	70	S	Fair	Fair/DW	Fair/UW
	2	30	LS	Fair	Poor	Fair/UW
Q3a	1	60	LS	Fair	Fair/DW	Fair/UW
	2	35	S	Fair	Fair/DW	Fair/UW
	3	5	SC	Fair	Fair/DW	Fair/UW
Q3b	1	60	LS	Fair	Poor	Fair
	2	35	S	Poor	Poor	Fair
	3	5	SC	Fair	Poor	Fair
Q5	1	70	LS	Fair	Fair	Fair/UW
	2	25	CL	Fair	Poor	Fair/UW
	3	5	SC	Fair	Poor	Fair/UW
Q6a	1	70	LS	Fair	Poor	Fair
	2	30	SCL	Fair	Fair/DW	Fair(S)
Q6b	1	70	LS	Fair	Fair/DW	Fair/UW
	2	30	SCL	Fair	Fair/DW	Fair/UW
Q61	1	80	SL	Fair	Fair/DW	Fair/UW
	2	20	LS	Fair	Fair/DW	Fair/UW
T1	1	60	SL	Fair	Fair/DW	Fair/UW
	2	40	SL	Fair	Fair/DW	Fair/UW
T2	1	70	LS	Fair	Fair/DW	Fair/UW
	2	30	S	Fair	Fair/DW	Fair/UW
T3	1	55	LS	Fair	Fair/DW	Fair/UW
	2	45	SL	Fair	Fair/DW	Fair/UW
U1	1	50	L	Good	Good/DW	Excellent
	2	30	L	Excellent	Good	Excellent
	3	20	SL	Excellent	Good	Excellent
U2	1	50	L	Good	Good/DW	Excellent
	2	35	SCL	Good	Good/DW	Excellent
	3	15	SL	Good	Good/DW	Good/UW
U5	1	90	CL	Good	Good/DW	Excellent
	2	10	SL	Excellent	Good	Excellent
U6	1	50	C	Good	Good/DW	Excellent
	2	35	SC	Good	Good/DW	Excellent
	3	15	C	Good	Good/DW	Good/UW
U8	1	55	C	Good	Good/DW	Good/UW
	2	25	SL	Good	Good/DW	Good/UW
	3	15	L	Good	Good/DW	Excellent
	4	5	Rocky	--	--	--
U9	1	65	C	Good	Good/DW	Excellent
	2	25	L	Excellent	Good	Excellent
	3	10	CL	Good	Good/DW	Excellent
U11	1	100	SC	Good	Good/DW	Excellent

Range Condition Classes As Related To Soil Components And Average Precipitation, Below/Above Average Precipitation

			Range Condition Class/Condition Trend			
		%	Texture	Average	Below Precipitation	Above Precipitation
A1	1	60	C	Fair	Fair/DW	Fair/UW
	2	25	LS	Fair	Fair/DW	Fair/UW
	3	15	LS	Fair	Fair/DW	Fair/UW
A2	1	50	C	Fair	Fair/DW	Fair/UW
	2	50	SCL	Fair	Fair/DW	Fair/UW
A3	1	60	SCL	Excellent	Good	Excellent
	2	30	C	Good	Good/DW	Excellent
	3	10	SCL	Excellent	Good	Excellent
L1	1	95	C	Excellent	Good	Excellent
	2	5	Rocky			
L2	1	90	SC	Excellent	Good	Excellent
	2	10	SCL	Excellent	Good	Excellent
				Dry Monsoon		
U2	1	50	L	Excellent	Excellent	Excellent
	2	35	SC	Excellent	Good	Excellent
	3	15	SC	Excellent	Good	Excellent
U3	1	65	SL	Good	Good/DW	Excellent
	2	35	SL	Excellent	Good	Excellent
U8	1	55	C	Good	Good/DW	Good/UW
	2	25	SL	Good	Good/DW	Excellent
	3	15	L	Excellent	Good	Excellent
U10	1	55	C	Excellent	Good	Excellent
	2	30	C	Excellent	Good	Excellent
	3	15	SCL	Excellent	Good/UW	Excellent

Estimated Yield of Forage in Kg Per Feddan Per Year

		Est. Pot. Kg/Fed.	Est. Prod. Kg/Fed.	Allowable Use-Fg/Fed.
DESERT	N1	50	25	12
		60	30	12
	N2	80	40	20
	N3	50	25	10
	N4	50	25	12
	N5	80	40	16
	N6	100	50	25
	N10	60	30	10
	N12	100	50	30
	N31	100	50	25
ARID	Q1	275	130	85
	Q21	250	125	65
	Q1	400	200	120
	Q2	540	270	175
	Q4	100	50	35
	05	150	75	56
	051	225	110	85
SEMI ARID	Q1	640	320	200
	03a	525	250	175
	03b	170	90	54
	Q5	300	150	120
	Q6a	100	50	40

		Est. Pot. Kg/Fed.	Est. Prod. Kg/Fed.	Allowable Use Kg/Fed.
SEMI ARID	Q6b	600	300	210
	Q61	250	150	115
	T1	300	150	120
	T2	175	100	75
	T3	175	85	75
	U1	700	680	550
	U2	800	775	500
	U5	930	900	660
	U6	650	630	440
	U8	750	760	475
	U9	525	500	450
	U11	570	550	385
	A1	350	175	115
	A2	400	200	145
	A3	720	700	560
	L1	770	750	600
	L2	770	750	630

		Est. Pot. Kg/Fed.	Est. Prod. Kg/Fed.	Allowable Use-Kg/Fed.
SEMI ARID	U2	800	775	620
	U3	875	850	625
	U8	770	750	525
	U10	720	700	595

Table For: Herbage Yield Classes*
Estimated Production (Kg/Feddan) per year

Class	Production
High	> 750
Moderate	500 - 750
Low	200 - 500
Very Low	< 200

TABLE 5
ESTIMATES OF GROUND COVER, VEGETATION COMPOSITION & FORAGE PRODUCTION OF THE SOIL UNITS & THEIR COMPONENTS UNDER

1- Average
2- Below . Average PPT
3- Above

Map Unit Symbol	Component	Texture	Ground Cover % Below Average	Ground Cover % Average	Ground Cover % Above Average	Vegetation Composition % Below D	Below U	Average D	Average UN	Above D	Above UN	Production kg/Fedd. Below Average	Production kg/Fedd. Average	Production kg/Fedd. Above Average
			D E S E R T											
N3	1	S	20	30	40	30	70	40	50	50	50	-	25	76
	2	Rock	-	-	-	-	-	-	-	-	-	-	-	-
			S E M I - D E S E R T											
N1	1	S	20	30	40	40	60	50	50	60	40	-	25	75
	2	Rock	-	-	-	-	-	-	-	-	-	-	-	-
N2	1	L	25	35	45	40	60	50	50	60	40	-	40	90
	2	S	20	30	40	30	70	40	60	50	50		30	80
	3	Rock	-	-	-	-	-	-	-	-	-	-	-	-
N3	1	S	25	35	45	30	70	40	60	50	50	-	30	80
	2	Rock	-	-	-	-	-	-	-	-	-	-	-	-
N4	1	Rock	-	-	-	-	-	-	-	-	-	-	-	-
	2	S	10	15	20	40	60	50	50	60	40	-	25	75
N5	1	SCL	15	20	25	30	70	40	60	50	50	-	40	90
	2	SL	15	20	25	30	70	40	60	50	50	-	40	90
	3	R												

1 - Ground cover } Average ±10% = Above & below average ground cover
2 - Composition } Average ±10% = % above and below average composition
3 - Production } Estimated average ±50 kgs = above & below average production

Table 5 Continued, Page 2

Map Unit Symbol	Component	Texture	Ground Cover % Below Average	Ground Cover % Average	Ground Cover % Above Average	Vegetation Composition % Below D	Below U	Average D	Average UN	Above D	Above UN	Production kg/Fedd. Below Average	Production Average	Production Above Average
N6	1	S	15	20	25	40	60	50	50	60	40	-	50	100
N10	1	SCL	5	10	15	20	80	30	70	40	60	-	30	80
	2	SCL	5	10	15	20	80	30	70	40	60	-	30	80
N12	1	L	10	15	20	50	50	60	40	30	70	-	50	100
	2	L	10	15	20	50	50	60	40	30	75	-	50	100
N31	1	SCL	30	40	50	40	60	50	50	60	40	-	50	100
	2	Rock	-	-	-	-	-	-	-	-	-	-	-	-
Q1	1	S	40	50	60	60	40	50	50	70	30	75	125	175
	2	L	50	60	70	55	45	65	35	75	20	100	150	200
Q21	1	S	40	50	60	40	60	50	50	60	40	75	125	175
			A R I D	Z O N E										
Q1	1	S	40	50	60	50	50	60	40	70	30	150	200	250
	2	LS	40	55	70	55	45	65	35	75	20	40	90	140
Q2	1	S	70	80	90	44	56	54	46	64	36	220	270	320
Q4	1	S	20	30	40	60	40	70	30	80	20	-	50	100
Q5	1	LS	40	50	60	65	35	75	25	85	15	25	75	125
	2	CL	50	60	70	65	35	75	25	85	15	30	80	130
	3	SC	55	65	75	70	30	80	20	90	10	25	75	125
Q51	1	SCL	50	60	70	60	40	70	30	80	20	50	100	150
	2	LS	50	65	80	65	35	75	25	85	15	75	125	175
			S E M I -	A R I D	Z O N E									
Q1	1	S	60	70	90	48	52	58	42	68	32	270	320	370
	2	LS	60	70	80	50	50	60	40	70	30	-	45	95
Q3a	1	LS	60	70	80	55	45	65	35	75	25	230	280	320
	2	S	50	60	70	60	40	70	30	80	20	200	250	300
	3	SC	40	50	60	65	35	75	25	85	15	170	220	270
Q3b	1	LS	30	40	50	50	50	60	40	70	30	40	90	140
	2	S	20	30	40	40	60	50	50	60	40	25	75	125
	3	SC	40	50	60	50	50	60	40	70	30	50	100	150

Table 5 Continued, Page 3

Map Unit Symbol	Component	Texture	Ground Cover % Below Average	Ground Cover % Average	Ground Cover % Above Average	Vegetation Composition % Below D	Below U	Average D	Average UN	Above D	Above UN	Production kg/Fedd. Below Average	Production Average	Production Above Average
Q5	1	LS	50	60	70	70	30	80	20	90	10	100	150	200
	2	CL	55	65	75	50	50	60	40	70	30	125	175	225
	3	SC	60	70	80	50	50	60	40	70	30	75	125	175
Q6a	1	LS	75	85	95	83	17	93	7	98	2	-	50	100
	2	SCL	75	85	95	85	15	90	10	95	5	25	75	125
Q6b	1	LS	70	80	90	60	40	70	30	80	20	250	300	350
	2	SCL	85	90	95	65	35	75	25	85	15	275	325	375
Q61	1	SL	40	50	60	70	30	80	20	90	10	75	125	175
	2	LS	30	40	50	65	35	75	25	85	15	100	150	200
T1	1	SL	40	50	60	70	30	80	20	90	10	100	150	200
	2	SL	40	50	60	60	40	70	30	80	20	75	125	175
T2	1	LS	40	50	60	70	30	80	20	90	10	25	75	125
	2	S	50	60	70	75	25	85	15	9	5	50	100	150
T3	1	LS	40	50	60	87	13	97	3	97	3	-	25	75
	2	SL	40	50	60	75	25	85	15	95	5	-	40	90
U1	1	L	70	80	90	65	35	75	25	85	15	550	650	750
	2	L	75	85	95	70	30	80	20	90	10	600	700	800
	3	SL	75	85	90	70	30	80	20	90	10	575	675	775
U2	1	L	60	70	80	60	40	70	30	80	20	650	750	850
	2	SCL	75	85	85	60	40	70	30	80	20	700	800	900
	3	SL	65	75	85	55	45	65	35	75	25	675	775	875
U5	1	CL	50	60	70	63	37	73	27	83	17	800	900	1000
	2	SL	60	70	80	70	30	80	20	90	10	850	950	1050
U8	1	C	60	70	80	55	45	65	35	75	25	600	700	800
	2	SL	70	75	80	55	45	65	35	75	25	650	750	850
	3	L	70	80	90	60	40	70	30	80	20	700	800	900
	4	Rock												
U6	1	C	50	60	70	60	40	70	30	80	20	500	600	700
	2	SC	60	65	70	60	40	70	30	30	20	550	650	750
	3	C	50	60	70	60	40	70	30	80	20	500	600	700

TABLE 6
RANGELAND PRESENT & POTENTIAL GROUND COVER & PRODUCTIVITY

Map Unit Symbol	Component	%	PPT / Growing season mm	Present G. Cover %	Pot. G. Cover %	Productivity Kg/Fedd Present	Pot.
			DESERT ZONE				
N3	1	90	100-200			25	50
	2	10	100-200				
			SEMI-DESERT				
N1	1	30	100-150	30	40	25	50
	2	70	100-150				
N2	1	65	100-150	35	45	40	80
	2	25	100-150	30	40	30	60
	3	10	100-150				
N3	1	90	100-200	35	45	30	60
	2	10	100-200				
N4	1	80	100-150				
	2	20	100-150	15	25	25	50
N5	1	65	200	20	30	40	80
	2	30	-	20	30	40	80
	3	15	-				
N6	1	100	100-200	20	30	50	100
N10	1	65	150-200	10	20	30	60
	2	35	150-200	10	20	30	60
N12	1	65	100-200	15	25	50	100
	2	35	100-200	15	25	50	100
N31	1	75	150	40	50	50	100
	2	25	150	-	-	-	-
Q1	1	70	200-400	50	60	125	250
	2	30	200-400	60	70	150	300
Q21	1	100	200-400	50	60	125	250
			ARID ZONE				
Q1	1	70	200-400	50	60	200	400
	2	30	200-400	55	65	90	180
Q2	1	100	200-400	80	90	270	540
Q4	1	100	200-400	30	40	50	100
Q5	1	70	200-400	50	60	75	150
	2	25	200-400	60	70	80	160
	3	5	200-400	65	75	75	150
Q51	1	60	200-400	60	70	100	200
	2	40	200-400	65	75	125	250
			SEMI-DESERT				
Q1	1	70	200-400	70	80	320	640
	2	30	200-400	70	80	40	80
Q3a	1	60	400-750	70	80	280	560
	2	35	400-750	60	70	250	500
	3	5	400-750	50	60	220	440
Q3b	1	60	400-750	40	50	90	180
	2	35	400-750	30	40	75	150
	3	5	400-750	50	60	100	200
Q5	1	70	200-400	60	70	150	300
	2	25	200-400	65	75	175	350
	3	5	200-400	70	80	125	250

Map Unit Symbol	Component	%	PPT / Growing season mm	Present G. Cover %	Pot. G. Cover %	Productivity Kg/Fedd Present	Pot.
Q6a	1	70	400-750	85	95	50	100
	2	30	400-750	85	95	75	150
Q6b	1	70	400-750	80	90	300	600
	2	30	400-750	85	95	75	150
Q61	1	80	400-750	50	60	125	250
	2	20	400-750	40	50	150	300
T1	1	60	400-750	50	60	150	300
	2	40	400-750	50	60	125	250
T2	1	70	400-750	50	60	75	150
	2	30	400-750	60	70	100	200
T3	1	55	400-750	50	60	75	150
	2	45	400-750	50	60	100	200
U1	1	50	400-800	80	90	650	670
	2	30	400-800	85	95	700	720
	3	20	400-800	85	95	675	800
U2	1	50	400-800	70	80	750	770
	2	35	400-800	85	95	800	825
	3	15	400-800	75	85	775	800
U5	1	90	400-750	60	70	900	930
	2	10	400-750	70	80	850	980
U6	1	50	400-750	60	70	600	620
	2	35	400-750	65	75	650	670
	3	15	400-750	60	70	600	620
U8	1	55	400-750	70	80	700	720
	2	25	400-750	75	85	750	770
	3	15	400-750	89	90	800	825
U9	1	65	400-750	60	70	500	515
	2	25	400-750	65	75	550	517
	3	10	400-750	60	70	600	620
U11	1	100	400-750	65	75	550	570
A1	1	60	400-750	50	60	175	350
	2	25	400-750	60	70	200	400
	3	15	400-750	60	70	200	400
A2	1	50	400-750	65	75	200	400
	2	50	400-750	70	80	225	450
A3	1	60	400-750	70	80	700	720
	2	30	400-750	60	70	650	670
	3	10	400-750	75	85	750	770
L1	1	95	400-750	80	90	750	770
L2	1	90	400-750	80	90	750	770
	2	10	400-750	85	95	775	800
			DRY MONSOON				
U2	1	50	400-800	80	90	800	825
	2	35	400-800	75	85	750	770
	3	15	400-800	75	85	725	800
U3	1	65	700-900	80	90	850	875
	2	35	700-900	80	90	825	850
U8	1	55	400-750	75	85	750	770
	2	25	400-750	80	90	775	800
	3	15	400-750	85	95	800	825
	4	5	400-750				
U10	1	55	400-800	80	90	700	720
	2	30	400-800	80	90	700	720
	3	15	400-800	85	95	725	745

TABLE 7

SOIL COMPONENTS %, RANGE OF RAINFALL, FOR AVERAGE, BELOW AND ABOVE AVERAGE & THE RANGE CHARACTERISTICS

Map Unit Symbol	Component	% of Comp.	Range of PPT	PPT. Below	PPT. Average	PPT. Above	Remarks
				DESERT ZONE			
N3	1 1	90 10	100-200	←	150	→	Natural vegetation consists of widely scattered bushes with or without sparse ground cover, provides poor grazing for browse animals in years of good rainfall
				SEMI-DESERT ZONE			
N1	1 2	30 70	100-150 100-150	←	125	→	Plateau of scattered bushes and sparse ground cover, highly subject to wind erosion - provides poor browsing.
N2	1 2 3	65 25 10	100-150 " " " "	← " "	125 " "	→ " "	Natural vegetation is acacia bushes and other browse spp. - provides only browsing in years of good precipitation - subject to run-off.
N3	1 2	90 10	100-200 100-200	← ←	150 150	→ →	Sandy plains, stunted bushes and sparse grass cover, supports only camels and other browsers.
N4	1 2	80 20	100-150 " "	← "	125 "	→ "	With scattered rock outcrops - unsuitable. Consists of bare sands.
N5	1 2 3	65 30 5	200 " "	← " "	200 "	→ " "	Stony, with widely scattered Acacia desert scrub - poor grazing even for camels and goats. Thirsty.
N6	1	100	100-200	←	150	→	Unstable undulating dunes, with sparse vegetation cover - provides poor grazing during migrations. Bare dunes are found.
N10	1 2	65 35	150-200 "	← "	175 "	→ "	Heavy sand blowing - most of the wadies and streams are barried with sand blown particles, supports, sparse desert scrub vegetation - Extensive camel grazing - highly subject to misuse.
N12	1 2	65 35	100-200 "	← "	150 "	→ "	Semi-desert vegetation of Acacias and drought-resistant grasses/herbs, only for extensive camel grazing. Subject to wind hazards.

Table 7 Continued, Page 2

Map Unit Symbol	Component	% of Comp.	Range of PPT	PPT. Below	PPT. Average	PPT. Above	Remarks
N31	1	75	150	←	150	→	Scattered vegetation on sands - unsuitable for grazing.
Q1	1 2	70 30	200-400 - -	←	300 "	→	Acacia tortilis - leptadenia associated with grass - mainly wet season grazing.
Q21	1	100	200-400	←	300	→	Semi-desert land/scattered bushes on sand, used during migrations
				ARID	ZONE		
Q1	1 2	70 30	200-400 " "	←	300 "	→	Acacia senegal/Acacia tortilis, leptadenia, cenchrus, Eragrostis Association used during migrations and in both wet and dry seasons grazing - Acacia senegal with Combretum Assoc. exist.
Q2	1	100	200-400	←	300	→	Fixed dunes supporting Acacia senegal, Acacia Tortilis, Balanites - Many watering sites exist heavy grazing around water sites - migratory, village and commercial stock use the unit - year round.
Q4	1	100	" "		"		Transversal dunes with scattered Acacia bushes, highly subject to wind erosion - unsuitable for agriculture and grazing.
Q5	1 2 3	70 25 5	" " " " " "		" " "		Sand ridges of highly reduced ground cover, in the proximity of urban areas - Trasional grazing - originally it was a clay plain.
Q51	1 2	60 40	" " " "		" "		Clay plain covered with sand deposits, supports Acacia senegal, combretum. Acacia mellifer and Cadaba. Seasonly grazed.
				SEMI	ARID	ZONE	
Q1	1 2	70 30	200-400	←	300	→	Heavy cultivation, continuous use on Acacia senegal, Eragrostis Association
Q3a	1 2 3	60 35 5	400-750 " " " "	←	575 " "	→	Longitudinal dunes of dunes and interdunes - Acacia senegal, Bolanites, Eragrostis, Cenchrus in dunes and Acacia mellifera - Cadaba, boscia - in interdunes :- seasonal nomadic use - overgrazing around water and villages.

Table 7 Continued, Page 3

Map Unit Symbol	Component	% of Comp.	Range of PPT	PPT. Below	PPT. Average	PPT. Above	Remarks
Q3b	1	60	400-750	←	575	→	Densely populated, overused ridges and interridges - much cultivations on the dunes - grazing is confined to fallow fields and inter clayey dunes - Acacia mellifera and Balanites
	2	35	" "	"	"	"	
	3	5	" "	"	"	"	
Q5	1	70	200-400	←	300	→	Clay plain covered by sand deposits - used during migrations - combretum, Boscia, Acacia mellifera and Balanites.
	2	25	" "	"	"	"	
	3	5	" "	"	"	"	
Q6a	1	70	400-750	←	575	→	Combretum cordofanum, Terminalia - Albizzia - Cenchrus, Eragrostis, Zornia, Heavily used by all classes of livestock during the dry seasons - perennial grasses absent.
	2	30	" "	"	"	"	
Q6b	1	70	400-750	←	575	→	Terminalia - Albizzia Association - with perennial grasses. Used during migrations - moderate use.
	2	30	" "	"	"	"	
Q61	1	80	400-750	←	575	→	Combretum - Terminalia Albizzia - Dalbergia - heavy use during wet season.
	2	20	" "	"	"	"	
T1	1	60	400-750	←	575	→	Open woodland savannaly overused early and late wet season.
	2	40	" "	"	"	"	
T2	1	70	400-750	←	575	→	Bushed grazing land (Acacia mellifera - nubica, wet season grazing - overused Many browse species in the area.
	2	30	" "	"	"	"	
T3	1	55	400-750	←	575	→	Bushed grazing land with many browse - but heavily used during the growing season. Plenty of watering sources during the rains - natural pools - eroded sites are seen.
	2	45	" "	"	"	"	
U1	1	50	400-800	←	600	→	Jebel pediment vegetation - subject to soil damage when grazed during the rains - dominant are annuals and herbs - early dry season grazing - plenty of browse species.
	2	30	" "	"	"	"	
	3	20	" "	"	"	"	
U2	1	50	400-800	←	600	→	Varying flora of broad leaved and thorny trees and bushes - much browse species - grazed only during migrations. High % of perennial grasses. Buring is heavily practiced to improve rank forage quality.
	2	35	" "	"	"	"	
	3	15	" "	"	"	"	
U5	1	90	400-750	←	575	→	Acacia seyal/Balanites with a low % of perennials - Transitionally grazed. Low grazing pressure.
	2	10	" "	"	"	"	
U6	1	50	400-750	←	575	→	Woodland savannah, of varying flora - high % of perennials - Transitional grazing - Low grazing pressure - many browse species.
	2	35	" "	"	"	"	
	3	15	" "	"	"	"	

Table 7 Continued, Page 4

Map Unit Symbol	Component	% of Comp.	Range of PPT	PPT. Below	PPT. Average	PPT. Above	Remarks
U8	1	55	400-750	←	575	→	Open wood land savannah on clay plain (Acacia seyal Assoc.) Associated with foalatable perennial grasses - more burnins is practical. Low grazing pressure - used only during migrations and dry seasons.
	2	25	" "	"	"	"	
	3	15	" "	"	"	"	
	4	5	" "	"	"	"	
U9	1	65	400-750	←	575	→	Annuals dominant Associates with Acacia seyal/Balanites/Acacia mellifera - dry season grazing and during migrations.
	2	25	" "	"	"	"	
	3	10	" "	"	"	"	
U11	1	100	400-750	←	575	→	Woodland savannah, used during migrations and dry season
A1	1	60	400-750	←	575	→	Wadi buttom and frings - provides mainly browse - Acacia spp. used during dry season.
	2	25	" "	"	"	"	
	3	15	" "	"	"	"	
A2	1	50	400-750	←	575	→	Wadi-buttom and frings - bushy with annual grasses - used during migrations.
	2	50	" "	"	"	"	
A3	1	60	400-750	←	575	→	Flood plain used during dry season - varying flora - perennials dominate - high grazing potential.
	2	30	" "	"	"	"	
	3	10	" "	"	"	"	
L1	1	95	400-750	←	575	→	Flat clay plain - open savannah, high % of perennials - used only in late dry season.
	2	5	" "	"	"	"	
L2	1	90	400-750	←	575	→	Flat clay plain - good mixture of perennials/annuals - dry season grazing.
	2	10	" "	"	"	"	
				D R Y	M O N S O	O N	
U2	1	50	400-800	←	600	→	Plateau supports mixed flora - high proportion of perennial grasses. Used during migration and dry season. Many browse species.
	2	35	" "	"	"	"	
	3	15	" "	"	"	"	
U3	1	65	700-900	←	800	→	Plain supporting woodland savannah vegetation with high % of perennials and browse dry season grazing - much burning is practiced.
	2	35	" "	"	"	"	

Table 7 Continued, Page 5

Map Unit Symbol	Component	% of Comp.	Range of PPT	PPT. Below	PPT. Average	PPT. Above	Remarks
U8	1	55	400-750	←	575	→	Clay plain of open woodland vegetation - high perennials % - dry season grazing - burning is practiced to improve forage quality. Low grazing pressure.
	2	25	" "	"	"	"	
	3	15	" "	"	"	"	
	4	5	" "	"	"	"	
U10	1	55	400-800	←	600	→	Clay plain of mixed flora - woods alternating with grasslands, high % of perennials - region for mechanizel rainfed farming. Burning - early dry season grazing.
	2	30	" "	"	"	"	
	3	15	" "	"	"	"	

TABLE 8
LAND SUITABILITY CLASSIFICATION FOR MAJOR CROPS

Map Unit Symbol	Components No.	%	Area	Slope	Depth	Texture A	Texture B	Coarse Fragments	Permeability	Internal Drainage	pH		Suitability Classes: Tr. Groundnuts Current	Tr. Groundnuts Potential	Tr. Millet Current	Tr. Millet Potential	Tr. Sorghum Current	Tr. Sorghum Potential	Modern Sorghum Current	Modern Sorghum Potential
N1	1	30	394008	5-10%	SH/MD	S	LS	3	VR	E	7.1	8.3	N	N	N	N	N	N	N	N
	2	70	919355	40	Rocky	Rocky		Rocky	Rocky	Rocky	Rocky		N	N	N	N	N	N	N	N
N2	1	65	930486	1-3	MD-D	L	CL	3	M	MW	7.2	8	N	N	N	N	N	N	N	N
	2	25	127110	2-5	D	S	LS	3	VR	E	7.6	8.4	N	N	N	N	N	N	N	N
	3	10	1150844	Rocky	Rocky	Rocky		Rocks	Rocky	Rocky	Rocky		N	N	N	N	N	N	N	N
N3	1	90	4026627	1-2	D	S	LS	1	VR	E	7.5	8.5	N	N	N	N	N	N	N	N
	2	10	454070	Scat. rocks	Rocky	Rocks		Rocks	Rocky	Rocky	Rocky		N	N	N	N	N	N	N	N
N31	1	75	1251149	2-5	MD	SCL	GSC	2	M	MW	7.6	8.8	N	N	N	N	N	N	N	N
	2	25	417050	Scat. rocks	Rocky	Rocks		Rocks	Rocky	Rocky	Rocky		N	N	N	N	N	N	N	N
N4	1	80	1683560	rocks	Rocky	Rocks		Rocks	Rocky	Rocky	Rocky		N	N	N	N	N	N	N	N
	2	20	420290	2-5	SH	S	LS	4	VR	M	6.9	8.3	N	N	N	N	N	N	N	N
N5	1	65	591009	0-5	D	SCL	SC	1	M	MW	6.6	7.9	N	N	N	N	N	N	N	N
	2	30	195850	2-4	SH	SL	GSCL	2	MR	W	7.8	8.8	N	N	N	N	N	N	N	N
	3	5	199308	Rocky	Rocks	Rocks		Rocks	Rocky	Rocky	Rocky		N	N	N	N	N	N	N	N
N6	1	100	1302608	5-15	VD	S	LS	0	VR	E	7.0	8.0	N	N	N	N	N	N	N	N
N10	1	65	1213131	0-2	MD	SCL	CL	1	M	MW	7.6	8.8	N	N	N	N	N	N	N	N
	2	35	653224	2-5	SH	SCL	GCL	3	M	MW	7.2	8.7	N	N	N	N	N	N	N	N
N12	1	65	1377877	0-1	D	L	SCL	1	M	MW	8.0	9	N	N	N	N	N	N	N	N
	2	35	741934	1-2	MD	L	GCL	2	M	MW/M	8	8.8	N	N	N	N	N	N	N	N
Q1	1	70	3747304	2-5	ED	S	LS	0	R	SE	6.8	7.6	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	30	1605988	0-2	ED	LS	SL	0	MR	W	6.8	7.5	S_3	S_2	S_3	S_2	S_3	S_3	N	N
Q2	2	100	6162814	10-25	ED	S	LS	0	VR	E	7.2	7.4	S_3	S_2	S_3	S_2	S_3	S_3	N	N
Q3	1	60	672210	5-15	ED	S	LS	0	VR	E	5.9	7	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	35	392473	2-5	ED	S	LS	0	VR	E	4.7	6.8	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	3	5	56068	0-2	MD	SC	SCL	0	MR	MW	6.8	7.8	S_3	S_2	S_3	S_2	S_3	S_3	N	N
Q4	1	100	763439	5-15	ED	S	LS	0	VR	E	7.1	7.5	N	N	N	N	N	N	N	N
Q5	1	70	76595	2-5	ED	LS	LS	0	VR	E	6.5	7.5	N	N	N	N	N	N	N	N
	2	25	273809	0-5	D	CL	C	0	MS	SWP	7	8	N	N	N	N	N	N	N	N
	3	5	54769	0-1	D	SC	C	0	MS	P	7	8	N	N	N	N	N	N	N	N
Q51	1	60	522580	0-1	D	SCL	C	0	MS	P	7	8	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	40	215053	5-15	D	LS	SL	0	R	SE	6.5	7.5	S_3	S_2	S_3	S_2	S_3	S_3	N	N
Q6	1	70	481720	1-5	D	LS	SL/SCL	0	MR	W	4	5.4	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	30	204451	0-2	D	SCL	SC	0	M	MW	3.8	4.1	S_3	S_2	S_3	S_2	S_3	S_3	N	N
Q61	1	80	368663	4-5	D	SL	SCL	0	MR	W	3.5	4	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	20	92166	2-5	D	LS	SL	0	R	R	4	6.5	S_3	S_2	S_3	S_2	S_3	S_3	N	N
Q21	1	100	1608242	10-25	D	S	S/LS	0	VR	E	7	7.5	S_3	S_2	S_3	S_2	S_3	S_3	N	N
T1	41	60	995390	2-5	D	SL	CL	0	MR	W	3.8	4	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	40	663593	1-2	D	SL	SCL	0	MR	W	4.7	5.7	S_3	S_2	S_3	S_2	S_3	S_3	N	N
T2	1	70	976342	0-2	D	LS	SCL	0	R/MR	SP/W	4.8	5.7	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	30	418432	2-5	D	S	LS	0	VR	E	4.8	5.8	S_3	S_2	S_3	S_2	S_3	S_3	N	N
T3	1	55	45310	1-2	D	LS/SL	SC	0	M	MW	5.6	8.9	S_3	S_2	S_3	S_2	S_3	S_3	N	N
	2	45	37071	0-2	D	SL/SC	SC	0	M	MW	6.2	7.8	S_2	S_2	S_3	S_2	S_3	S_3	N	N
U1	1	50	433179	1-5	SH/MD	L	GCL/GC	3	MR	W	6.5	7.2	N	N	N	N	N	N	N	N
	2	30	259907	1-2	MD/D	L/SCL	C	2	MR	MW	6.9	7.2	N	N	N	N	N	N	N	N
	3	20	173272	2-8	SH	SL	GC	4	MR	M	6.9	7.2	N	N	N	N	N	N	N	N

Table 8 Continued, Page 2

Map Unit Symbol	Components No.	%	Area	Slope	Depth	Texture A	Texture B	Coarse Fragments	Permeability	Internal Drainage	pH		Suitability Classes: Tr. Groundnuts Current	Tr. Groundnuts Potential	Tr. Millet Current	Tr. Millet Potential	Tr. Sorghum Current	Tr. Sorghum Potential	Modern Sorghum Current	Modern Sorghum Potential
U2	1	50	776494	1-3	MD	L	CL/C	1	M	MW	6.6	8.4	N	N	N	N	N	N	N	N
	2	35	45347	1-3	MD/D	SCL	C	2	M	MW/W	6	7.5	N	N	N	N	N	N	N	N
	3	15	232949	0-2	SH	SL	GSCL	1-2	MR	W	6	7.5	N	N	N	N	N	N	N	N
U3	1	65	151766	0-2	D	SL	CL/C	0	M	W/MW	5	7.5	S_3	S_3	S_3	S_3	S_3	S_3	N	N
	2	35	81720	0-3	D	SL/L	CL	0	M	W/MW	7	7.5	S_3	S_3	S_3	S_3	S_3	S_3	N	N
U5	1	90	713363	0-2	D	CL	CL/C	0-1	MS	SP/P	7	7.2	S_3	S_2	S_3	S_2	S_3	S_2	N	N
	2	10	79262	2-5	D/MD	SL	CL	0-1	MS	SP	6.8	7.2	S_3	S_2	S_3	S_2	S_3	S_2	N	N
U6	1	50	1232716	2-5	D	C	C	0	S	P/SP	6	7	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	2	35	862902	0-2	MD	SCL	CL	1	M	W/MW	5.2	6.3	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	3	15	369815	0-5	D	C	C	0	MS	VP	5.6	7.6	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_2
U8	1	55	1355143	2-5	D	C	C	0-1	MS/S	P	7.8	8.3	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	2	25	615974	1-2	D	SL	SCL	0-1	M	MW	6.5	8	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	3	15	369585	1-3	MD	L	CL	1	M	MW	6.5	7.8	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	4	5	123195	Rocky	Rocky	Rocky		Rocky	Rocky	Rocky	Rocky		S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
U9	1	65	454300	2-5	VD	C	C	0-1	MS/S	P	7	8.8	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	2	25	174731	1-2	VD	L	CL	0	M	MW	6.5	8.8	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	3	10	89392	1-3	D	CL	Sic	0	M/MS	SP	7	8.7	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
U10	1	55	1484406	2-5	VD	C	C	0-1	MS/S	SP/P	7	8	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	2	30	809676	.5-1	VD	C	C	0	S	P	7	8.5	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
	3	15	404838	1-2	MD/SH	SCL	CL	1-2	M	MW	5	6.5	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
U11	1	100	399384	0-2	D	SC	C	0-1	MS	SP	7	8	S_3	S_3	S_3	S_3	S_3	S_3	S_2	S_2
L1	1	95	3630715	0-2	VD	C	C	1	MS	SP	8.2	8.8	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3
	2	5	191090	Rocky	Rocky	Rocky		Rocky	Rocky	Rocky	Rocky		S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3
L2	1	90	193548	0-2	VD	SC/C	C	0	S	P	5.9	6.5	S_3	S_3	S_3	S_3	S_3	S_3	N	N
	2	10	21505	1-3	MD	SCL	CL	0-1	MS/M	M	5.1	5.3	S_3	S_3	S_3	S_3	S_3	S_3	N	N
A1	1	60	847925	0-.5	VD	C	C	0	VS	VP	5.6	7	N	N	N	N	N	N	N	N
	2	25	353302	0-1	D	LS	CL/SC	0-1	MS	SP	5.6	7.2	N	N	N	N	N	N	N	N
	3	15	211981	1-2	D	LS	SL	1	MR	SE	4.5	5.3	N	N	N	N	N	N	N	N
A2	1	50	13825	0-.5	VD	C	C	0	S	P	5.9	7.5	S_3	S_3	S_3	S_3	S_3	S_3	N	N
	2	40	11060	0-1	D	SCL	CL/C	0-1	MS	SP	5.5	7.5	S_3	S_3	S_3	S_3	S_3	S_3	N	N
A3	1	60	385253	0-1	VD	SCL	CL/SCL	0	MS	MS/M	6.5	7.2	S_3	S_3	S_3	S_3	S_3	S_3	N	N
	2	30	192626	0-.5	VD	C	C	0	S	S	6.2	7.6	N	N	N	N	N	N	S_3	S_2
	3	10	64088	0-2	VD	SCL	SC	1	MS	M	6.5	7.2	N	N	N	N	N	N	S_3	S_2
RN	1	85	130569	1-2	VD	CL	C	0	S	MW	7	8	S_3	S_2	S_3	S_2	S_3	S_2	S_3	S_2
	2	15	23042	0-1	VD	C	C	0	VS	P	6	7.2	S_3	S_2	S_3	S_2	S_3	S_2	S_3	S_2
RT	1	100	855605	1-3	D/VD	C	C	0	S	P	7	8.8	S_3	S_2	S_3	S_2	S_3	S_2	S_3	S_2
HM	1	100	1978490	Mountain	Rocky	Rocky		Rocky	Rocky	Rocky	Rocky		N	N	N	N	N	N	N	N

TABLE 9
EVALUATION OF SOIL COMPONENTS FOR MAJOR CROPS

Kind of Soil	Components No.	Components %	Fed.	Yield Lg./Fed. Millet Tr.	Millet Mod.	Sesame Tr.	Sesame Mod.	Peanuts Tr.	Peanuts Mod.	Cotton Tr.	Cotton Mod.	Sorghum Tr.	Sorghum Mod.	Presently Cultivated Area	Potential for Cultivation Traditional %	Traditional Fed.	Modern %	Modern Fed.	Suitability for Modern Sorghum	Remarks
N1	1	30	394008	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Low rain and poor soil
	2	70	919353	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	Rocky
N2	1	65	2940386	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Low rain
	2	25	1127110	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" "
	3	10	4508440	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" "
N3	1	90	486627	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Low rain
	2	10	154074	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" "
N31	1	75	1251149	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Low rain
	2	25	417050	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" "
N4	1	80	1683560	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Rocky and dissected
	2	20	420890	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" " "
N5	1	65	2591009	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Shallow and stony
	2	30	1195850	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" " "
	3	5	199308	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" " "
N6	1	100	1302608	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Low fert. and erosion hazard
N10	1	65	1213131	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	Dry, shallow and erosion hazard
	2	35	653224	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	
N12	1	65	1377877	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	" " " "
	2	35	741936	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	" " " "
Q1	1	70	37477[illegible]	[illegible]	213	102	306	130	390	Nill	Nill	185	555	473,210	10	374730	11	412,203	N-Poor	Low fertility and low moisture and erosion hazard
	2	30	1605[illegible]	[illegible]	[illegible]	100	300	125	375	"	"	180	540	150,000	9	144539	10	160,599	N-Poor	
Q2	1	100	616[illegible]	[illegible]	[illegible]	95	285	123	369	Nill	Nill	175	525	431,160	11	677910	12	739,538	N-Poor	" " " " " " "
Q3	1	60	642[illegible]	[illegible]	237	119	347	202	606	Nill	Nill	205	615	350,000	12	77137	20	128,562	N-Poor	Low moisture and low fertility
	2	35	332473	85	255	132	396	194	582	Nill	Nill	230	690	243,000	14	46546	22	73,144	N-Poor	" " " " "
	3	5	56068	85	255	132	396	185	255	Nill	Nill	200	600	12,000	13	7289	21	11774	N-Poor	" " " " "
Q4	1	100	763439	Uncultivated											-		12	91613	N-Poor	Low moisture, unfertile and erosion hazard.
Q5	1	70	766655	82	246	115	145	208	624	Nill	Nill	190	570	200,000	15	15,000	20	153333	N. Poor	Low moisture and low fertility
	2	25	273809	85	255	138	414	178	534	Nill	Nill	200	600	121,168	16	43809	22	60238	N-Poor	" " " " "
	3	5	54162	88	264	145	435	152	456	Nill	Nill	190	570	30,000	18	9749	24	12999	N-Poor	" " " " "
Q51	1	60	522580	Uncultivated																Poorly drained
	2	40	215053	77	231	137	411	166	498	Nill	Nill	184	552	71700		25806	35	75269	N. Poor	Moderately drained
Q6	1	70	481720	71	211	112	336	141	423	Nill	Nill	130	390	160,527		72258	20	96344	N-Poor	Low fertility and low moisture
	2	30	204451	75	225	114	342	127	381	Nill	Nill	128	374	80,000		32712	21	42935	N-Poor	" " " " "
Q61	1	80	368663	70	210	111	333	133	399	Nill	Nill	123	369	125,460		62672	22	81106	N-Poor	" " " " "
	2	20	92166	68	204	108	324	131	393	Nill	Nill	120	360	25,000		14747	21	19355	N-Poor	" " " " "
Q21	1	100	608292	62	186	94	-	-	Nill	Nill	Nill	Nill	Nill	82,300		72995	14	85161	N-Poor	" " " " "
T1	1	60	995390	66	198	-		68	204	Nill	Nill	192	576	121,526		119447	40	398,156	S_3 Marginal	
	2	40	663593	62	188	-		66	198	Nill	Nill	185	555	121,202		92902	42	278798	"	
T2	1	70	976342	70	210	61	183	60	180	Nill	Nill	186	558	16640		97634	40	390537	"	
	2	30	418432	67	204	57	171	66	198	Nill	Nill	176	528	5946		37659	38	159004	"	
T3	1	55	45310	76	228	59	177	64	192	Nill	Nill	169	507	45202		6797	45	20390	"	
	2	45	37071	79	237	66	198	68	204	Nill	Nill	180	540	72378		5931	46	17053	"	
U1	1	50	433179	54	162	54	162	52	156	Nill	Nill	110	330	1143		8664	10	43318	N-Poor	
	2	30	259907	55	165	46	138	53	159	Nill	Nill	115	345	947		7797	12	31189	"	
	3	20	172272	58	174	53	159	50	150	Nill	Nill	120	360	503		1723	8	13781	"	
U2	1	50	776494	59	177	57	171	53	159	Nill	Nill	125	375	1386		69884	25	194124	S_2-Suitable	
	2	35	543547	57	171	55	165	51	153	Nill	Nill	115	345	567		38048	22	119580	"	
	3	15	232949	54	162	49	137	48	144	Nill	Nill	108	324	277		13977	20	46590	"	
U3	1	65	151766	92	368	88	352	102	408	Nill	Nill	220	880	19347		22765	35	53118	"	
	2	35	81720	94	376	87	348	99	396	Nill	Nill	216	864	7459		11441	34	27785	"	
U5	1	90	713363	84	336	82	328	91	364	Nill	Nill	200	800	20,242		142672	30	214009	S_3-Marginal	
	2	10	79262	81	324	79	316	90	360	Nill	Nill	202	808	986		15060	29	22986	"	

Table 9 Continued, Page 2

Kind of Soil	Components No.	Components %	Fed.	Yield Lg./Fed. Millet Tr.	Millet Mod.	Sesame Tr.	Sesame Mod.	Peanuts Tr.	Peanuts Mod.	Cotton Tr.	Cotton Mod.	Sorghum Tr.	Sorghum Mod.	Presently Cultivated Area	Potential for Cultivation Traditional %	Traditional Fed.	Modern %	Modern Fed.	Suitability for Modern Sorghum	Remarks
U6	1	50	123276	93	372	108	432	91	364	180	720	220	880	150,480	24	295852	55	677993	S_2-Suitable	
	2	35	862902	90	360	104	416	99	396	175	700	211	844	107,115	25	215726		517741	"	
	3	15	369315	87	348	101	404	94	376	177	708	195	780	63125	20	73963		184908	"	
U8	1	55	1355143	100	400	110	440	97	388	185	740	225	900	60326	18	243926	45	609814	"	
	2	25	615974	105	420	112	448	100	400	190	760	227	908	45186	20	123195	50	307987	"	
	3	15	369585	100	400	107	428	96	384	183	732	221	884	14758	19	70221	48	177401	"	
	4	5	123195	Uncultivated				Rocky		Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	N. Poor	
U9	1	65	454300	80	320	75	300	82	328	182	728	215	860	24527	13	59059	37	168091	S_2-Suitable	
	2	25	174731	75	300	74	296	81	324	178	712	212	848	13972	15	26210	40	69892	"	
	3	10	69392	75	300	73	292	80	320	177	708	210	840	5477	14	9715	38	26369	"	
U10	1	55	1484406	100	400	112	448	96	384	187	748	232	928	721360	10	148441	45	667983	"	
	2	30	801676	100	400	110	440	95	350	195	780	231	924	257907	9	72871	44	356257	"	
	3	15	404838	95	380	109	436	93	372	193	772	230	920	221186	8	32387	44	178129	"	
U11	1	100	339384	95	380	105	420	91	364	190	760	225	900	35,834	18	71889	44	219661	"	
L1	1	95	3630715	90	360	85	340	90	360	195	780	210	840	730820	20	764360	51	1949120	"	
	2	5	191090	Uncultivated			Rocky							Nill	Nill	Nill	Nill	Nill	Nill	
L2	1	90	193548	Uncultivated poorly drained											15	29032	60	116129	S_3-Suitable	
	2	10	21505	Uncultivated Poorly drained								190	255	327	16	3441	62	13333	"	
A1	1	60	847925	V. Poorly drained										Nill	Nill	Nill	Nill	Nill	N-	
	2	25	353302	V. Poorly drained										Nill	"	"	"	"	"	
	3	15	211981	V. Poorly drained										Nill	"	"	"	"	"	
A2	1	50	13225	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	S_3-Suitable	
	2	40	11060	"	"	"	"	"	"	"	"	"	"	"	"	"	15	1659	"	
	3	10	2765	"	"	"	"	"	"	"	"	"	"	"	"	"	Nill	Nill	"	
A3	1	60	325253	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	Nill	15	57788	"	
	2	30	192626	"	"	"	"	"	"	"	"	"	"	"	"	"	Nill	Nill	"	
	3	10	64028	"	"	"	"	"	"	"	"	"	"	"	"	"	10	6409	"	
PN	1	85	130560	"	"	"	"	"	"	"	"	"	"	"	Nill	Nill	Nill	Nill	N-Poor	Only on flood recession it is cropped with vegetables.
	2	15	23042	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	
RT	1	100	855605	Undermechanized cotton							750				"	"	"	"	S_3-Suitable	
HM	1	100		Uncultivated Hills											"	"	"	"	N-Poor	Uncultivated Hilly Land

Table 10. Criteria Used In Evaluating Soil Blowing Hazard

1. Soil Properties Influencing Soil Blowing

Surface Soil Properties	Soil Erodibility Factor
Coarse Fragments (over 50% cover)	0
Wet Soils (permanent)	0
Cracking Clay Soils	1
Medium & Fine Textured Soils (other than cracking clays)	2
Coarse Textured Soils Sandy Loams	4
Loamy Sands	7
Dry Sands	10

2. Amount of Plant Residues on Surface Soil

(Percent of Soil Cover During Critical Period)

Class	Percent of Cover
V. Good	More than 40% soil cover
Good	25-40% soil cover
Fair	15-25% soil cover
Poor	Less than 15% soil cover

Soil Erodibility Factors for Surface Cover

V. Good - 1
Good - 3
Fair - 7
Poor -10

3. Length of Critical Soil Blowing Period

Class	Length Time	Erodibility Factor
Short	Less than 20 days (dry monsoon)	1
Moderate	20-50 days (semi-arid)	4
Long	50-90 days (arid)	7
Very Long	Over 90 days (desert-semidesert)	10

4. Barriers That Reduce Wind Velocity

(Evaluation of Landscapes and Vegetative Barriers)

Class	Description	Erodibility
High	Mountains-Dense Forest-Wet & moist >40% canopy	0
Moderate	Level to undulating-Frequent trees-Shrubs 20-40% canopy; Rolling to hilly-moderate amt. tall veg. 15-25% canopy	3
Low	Rolling to hilly-occasional to sparce tall veg. 5-15% canopy; Level to gently sloping-occasional to moderate amt. tall veg. 10-20% canopy	7
None	Level to gently sloping; none to sparce low veg. <5% canopy	10

Soil Blowing Hazard Rating

Class	Erodibility Factor
None to slight	0-15
Moderate	16-27
Severe	28-33
Very severe	34-40

TABLE 11
FACTORS AFFECTING SOIL BLOWING IN CLIMATE ZONE 1.2 "DESERT"

Map Units	Soil Components No.	Soil Components %	Surface Texture	Critical Period Soil Moisture Precipitation Below	Critical Period Soil Moisture Precipitation Average	Critical Period Soil Moisture Precipitation Above	Plant Residues Surface Cover Precipitation Below	Plant Residues Surface Cover Precipitation Average	Plant Residues Surface Cover Precipitation Above	Critical Period Soil Blowing Hazard Precipitation Below	Critical Period Soil Blowing Hazard Precipitation Average	Critical Period Soil Blowing Hazard Precipitation Above	Soil Blowing Hazard: Soil Erodibility Factors: Soil Properties	Soil Blowing Hazard: Soil Erodibility Factors: Surface Cover	Soil Blowing Hazard: Soil Erodibility Factors: Length Blow Period	Soil Blowing Hazard: Soil Erodibility Factors: Wind Barrier	Soil Blowing Hazard: Hazard Class
N3	1	90	Coarse	V.Dry	V. Dry	V.Dry	Poor	Poor	Poor				10	10	10	10	VS
	2	10	Rocky	"	"	"	"	"	"				0	10	10	3	M
FACTORS AFFECTING SOIL BLOWING IN CLIMATIC ZONE 1-2.2 "Semi-Desert"																	
N1	1	30	Coarse	V.Dry	V.Dry	V.Dry	Poor	Poor	Fair				10	10	10	10	VS
	2	70	Rocky	"	"	"	"	"	Poor				0	10	10	3	M
N2	1	65	Medium	"	"	"	"	"	"				2	10	10	10	S
	2	25	Coarse	"	"	"	"	"	"				10	10	10	10	VS
	3	10	Rocky	"	"	"	"	"	"				0	10	10	3	M
N3	1	90	Coarse	"	"	"	"	"	"				10	10	10	10	VS
	2	10	Rocky	"	"	"	"	"	"				0	10	10	3	M
N4	1	80	Rocky	"	"	"	"	"	"				7	10	10	3	S
	2	20	Coarse	"	"	"	"	"	"				10	10	10	7	VS
N5	1	65	Medium	"	"	"	"	"	Fair				2	10	10	10	S
	2	30	Coarse	"	"	"	"	"	"				7	10	10	10	VS
	3	5	Rocky	"	"	"	"	"	Poor				0	10	10	3	M
N6	1	100	Coarse	"	"	"	"	"	Fair	Severe	Severe	Severe	10	10	10	7	VS
N10	1	65	Medium	"	"	"	"	"	"	"	"	Medium	2	10	10	7	S
	2	35	Medium	"	"	"	"	"	"	"	"	"	2	10	10	7	S
N12	1	65	Medium	"	"	"	"	"	"	"	"	"	2	10	10	10	S
	2	35	Medium	"	"	"	"	"	"	"	"	"	2	10	10	10	S
N31	1	75	Medium	"	"	"	"	"	"	"	"	"	2	10	10	7	S
	2	25	Rocky	"	"	"	"	Poor	Poor				-2	10	10	3	M
RN	1	85	Fine	Moist	Moist	Moist	Fair	V.Good	V.Good				0	1	7	3	N
	2	15	Fine	"	"	"	"	"	"				0	1	7	0	N
H	1	100	Rocky	V.Dry	V.Dry	V.Dry	Poor	Poor	Poor				0	10	-7	0	M
Q1	1	70	Coarse	"	"	"	Fair	Fair	Good				10	7	7	10	VS
	1	30	Coarse	Dry	Dry	Dry	Poor	Fair	Fair				7	7	7	10	S
Q21	1	100	Coarse	V.Dry	V.Dry	V.Dry	"	"	"				10	7	7	7	S
FACTORS AFFECTING SOIL BLOWING IN CLIMATIC ZONE 1.2.3 "Arid"																	
Q1	1	70	Coarse	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair	Severe	Severe	Severe	10	7	7	7	S
	2	30	Coarse	Dry	Dry	Dry	"	Poor	"	"	"	"	7	10	10	10	
Q2	1	100	Coarse	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair				10	7	7	3	M
Q4	1	100	Coarse	"	"	"	"	Poor	Poor	Severe	Severe	Severe	10	10	7	7	VS
Q5	1	70	Coarse	"	"	"	"	Fair	Fair	"	"	"	7	7	7	7	S
	2	25	Fine	Moist	Moist	Moist	Fair	Fair	Good				2	7	7	10	M
	3	5	Medium	"	"	"	Poor	"	Fair				2	7	7	10	M
Q51	1	60	Medium	Moist	Moist	Moist	Poor	Poor	Fair	Severe	Severe	Severe	2	10	7	10	M
	2	40	Coarse	V.Dry	V.Dry	V.Dry	"	"	"				7	10	7	7	S
RN	1	85	Fine	Moist	Moist	Moist	Fair	Good	Good				0	3	7	3	N
	2	15	Fine	"	"	"	"	"	"				0	3	7	3	N
RT	1	100	Fine	V.Dry	V.Dry	V.Dry	Poor	Fair	Good				0	7	7	0	N
H	1	100	Rocky	"	"	"	"	Poor	Poor				0	10	7	0	M
FACTORS AFFECTING SOIL BLOWING IN CLIMATIC ZONE 1.2.4 "Semi-Arid"																	
Q1	1	70	Coarse	V.Dry	V.Dry	V.Dry	Poor	Poor	Fair	Severe	Severe	Severe	10	10	4	10	VS
	2	30	Coarse	Dry	Dry	Dry	"	"	"	"	"	Medium	7	10	4	10	S
Q3	1	60	Coarse	"	"	"	Poor	Poor	Fair	"	"	"	7	10	4	7	S
	2	35	Coarse	"	"	"	"	Fair	Fair	"	Medium	"	10	7	4	7	S
	3	5	Medium	"	"	"	Fair	Fair	Good	Medium	Medium	Low	2	7	4	10	M

Table 11 Cont'd, Page 2

Map Units	Soil Components No.	%	Surface Texture	Critical Period Soil Moisture Precipitation Below	Average	Above	Plant Residues Surface Cover Precipitation Below	Average	Above	Critical Period Soil Blowing Hazard Precipitation Below	Average	Above	Soil Blowing Hazard: Soil Erodibility Factors: Soil Properties	Surface Cover	Length Blow Period	Wind Barrier	Hazard Class
Q5	1	70	Coarse	V.Dry	V.Dry	V.Dry	Poor	Fair	Good				7	7	4	10	S
	2	25	Fine	Dry	Dry	Dry	Fair	Fair	Good				2	7	4	10	M
	3	5	Medium	Dry	Dry	Dry	Fair	Fair	Good				2	7	4	10	M
Q6	1	70	Coarse	V.Dry	V.Dry	V.Dry	Fair	Good	Good				7	3	4	10	M
	2	30	Medium	Dry	Dry	Dry	Fair	Good	Good				2	3	4	10	M
Q61	1	80	Medium	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair				2	7	4	10	M
	2	20	Medium	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair	Medium	Medium	Low	2	7	4	10	M
T1	1	60	Medium	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair	Medium	Medium	Low	4	7	4	3	M
	2	40	Medium	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair	Medium	Medium	Low	4	7	4	10	S
T2	1	70	Coarse	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair	Medium	Medium	Low	7	7	4	7	M
	2	30	Coarse	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair	Medium	Medium	Low	10	10	4	10	VS
T3	1	55	Medium	V.Dry	Dry	Dry	Poor	Fair	Fair				7	7	4	3	M
	2	45	Medium	V.Dry	Dry	Dry	Poor	Fair	Fair				4	7	4	7	S
U1	1	50	Medium	V.Dry	V.Dry	V.Dry	Fair	Good	Good				2	3	4	7	M
	2	30	Fine	Dry	Dry	Dry	Fair	Good	Good				2	3	4	10	M
	3	20	Medium	V.Dry	V.Dry	V.Dry	Fair	Fair	Good				4	7	4	10	M
U2	1	50	Medium	V.Dry	V.Dry	V.Dry	Poor	Good	Good				2	3	4	10	M
	2	35	Medium	V.Dry	V.Dry	V.Dry	Fair	Fair	Good				2	7	4	10	M
	3	15	Coarse	V.Dry	V.Dry	V.Dry	Poor	Fair	Fair				4	7	4	7	M
U5	1	[illegible]	Fine	Dry	Dry	Dry	Fair	Fair	Good				2	7	4	10	M
	2	10	Medium	Dry	Dry	Dry	Fair	Fair	Good				4	7	4	7	M
U6	1	50	Fine	Dry	Dry	Dry	Fair	Good	Good				0	3	4	7	N
	2	35	Medium	V.Dry	Dry	Dry	Fair	Fair	Good				2	7	4	10	M
	3	15	Fine	Moist	Moist	Moist	Fair	Good	Good				0	3	4	10	M
U8	1	55	Fine	Dry	Dry	Dry	Fair	Good	Good				0	3	4	7	M
	2	25	Coarse	V.Dry	V.Dry	V.Dry	Fair	Fair	Fair				4	7	4	7	M
	3	15	Medium	V.Dry	Dry	Dry	Fair	Fair	Good				2	7	4	7	M
	4	5	Rocky	V.Dry	V.Dry	V.Dry	Poor	Poor	Poor				0	10	4	4	M
U9	1	65	Fine	Dry	Dry	Dry	Poor	Fair	Fair				0	7	4	7	M
	2	25	Medium	V.Dry	V.Dry	V.Dry	Poor	Poor	Fair				2	10	4	10	M
	3	10	Fine	V.Dry	Dry	Dry	Poor	Fair	Fair				2	7	4	10	M
U11	1	100	Medium	Dry	Dry	Dry	Fair	Good	Good				2	3	4	10	M
A1	1	60	Fine	Moist	Moist	Moist	Fair	Fair	Good				0	7	4	0	N
	2	25	Coarse	Dry	Dry	Dry	Poor	Fair	Fair				7	7	4	3	M
	3	15	Coarse	V.Dry	Dry	Dry	Fair	Fair	Good				7	7	4	7	M
A2	1	50	Fine	Moist	Moist	Moist	Fair	Fair	Good				0	7	4	0	N
	2	40	Medium	Dry	Moist	Fair	Poor	Fair	Fair				2	7	4	10	M
A3	1	60	Medium	Dry	Dry	Dry	Good	Good	Good				2	3	4	10	M
	2	30	Fine	Dry	Moist	Moist	Good	Good	Good				0	3	4	10	M
	3	10	Medium	Dry	Dry	Dry	Good	Good	Good				2	3	4	10	M
L1	1	95	Fine	Dry	Dry	Dry	Fair	Good	Good				0	3	4	10	M
	2	5	Rocky	V.Dry	V.Dry	V.Dry	Poor	Poor	Poor				0	10	4	3	M
L2	1	90	Fine	Dry	Dry	Dry	Fair	Good	Good				2	3	4	3	N
	2	10	Medium	V.Dry	V.Dry	V.Dry	Fair	Good	Good				2	3	4	10	M
RN	1	85	Fine	Moist	Moist	Moist	Fair	Good	Good				0	3	4	3	N
	2	15	Fine	Moist	Moist	Moist	Fair	Good	Good				0	3	4	3	N
RT	1	100	Fine	V.Dry	V.Dry	V.Dry	Poor	Fair	Good				0	7	4	0	N
W	1	100	Rocky	V.Dry	V.Dry	V.Dry	Poor	Poor	Poor				0	10	4	0	N

Table 11 Cont'd, Page 3

Map Units	Soil Components No.	%	Surface Texture	Critical Period Soil Moisture Precipitation Below	Average	Above	Plant Residues Surface Cover Precipitation Below	Average	Above	Critical Period Soil Blowing Hazard Precipitation Below	Average	Above	Soil Blowing Hazard: Soil Erodibility Factors: Soil Properties	Surface Cover	Length Blow Period	Wind Barrier	Hazard Class
FACTORS AFFECTING SOIL BLOWING IN CLIMATIC ZONE 1.2-5.1 DRY MONSOONS																	
U2	1	50	Medium	V.Dry	V.Dry	V.Dry	Fair	Good	Good				2	3	1	10	M
	2	35	Medium	V.Dry	V.Dry	V.Dry	Good	Good	Good				2	3	1	10	M
	3	15	Coarse	V.Dry	V.Dry	V.Dry	Good	Good	Good				4	3	1	10	M
U3	1	65	Coarse	V.Dry	Dry	Dry	Fair	Good	Good				4	3	1	10	M
	2	35	Medium	V.Dry	Dry	Dry	Fair	Good	Good				2	3	1	10	M
U8	1	55	Fine	Dry	Dry	Dry	Good	Good	Good				0	3	1	7	N
	2	25	Coarse	V.Dry	V.Dry	V.Dry	Fair	Fair	Good				4	7	1	7	M
	3	15	Medium	Dry	Dry	Dry	Fair	Good	Good				2	3	1	7	N
	4	10	Rocky	V.Dry	V.Dry	V.Dry	Poor	Poor	Poor				0	10	1	4	N
U10	1	65	Fine	Dry	Dry	Dry	Fair	Good	Good				0	3	1	7	N
	2	30	Fine	Moist	Moist	Moist	Fair	Good	Good				0	3	1	10	N
	3	15	Medium	V.Dry	V.Dry	V.Dry	Fair	Good	Good				2	3	1	10	M
H	1	100	Rocky	V.Dry	V.Dry	V.Dry	Poor	Poor	Poor				0	10	1	0	N

TABLE 12

WIND SPEED IN M.P.H. AT THE CENTER OF THE STUDY AREA "ELOBEID TOWN"

Month	Annual Average	Maximum	Maximum Gust	Critical Periods *	Predicted Speed at Critical Period
January	9.1	23	32		
February	9.5	25	35		
March	10.1	29	47	Whole of March	24
April	7.1	26	40		
May	7.0	24	61	Mid May to	
June	8.8	30	69	Mid June	25
July	10.4	27	74		
August	7.9	28	67		
September	5.5	25	58		
October	6.5	23	51		
November	7.8	25	32		
December	8.7	21	33		

*1 At these periods serious erosion occurs because of high wind speed, drought and poor vegetative cover.

2 All soils in the different climatic zones within the study area are subject to erosion hazards at these same critical periods.

MAPPING AND LOCATING AEOLIAN FEATURES (SAND DUNES) AND AREAS OF HIGH WIND POTENTIAL USING LANDSAT DATA

Abbas Doka M. Ali*

ABSTRACT

Sand dunes and other aeolian features in central Sudan (Qoz lands) are the result of interactions between the wind and earth's surface. Landsat is a very useful tool in locating and mapping aeolian geomorphic features. These features with other topographic features can be used to infer wind directions and other wind characteristics. Interpretations of Landsat show the presence of: (1) a wide natural barrier; the plateaus and the mountains at the northern part of north Kordofan; (2) three "wind corridors" across this natural barrier; (3) smaller wind channels within and around these corridors, and; (4) very distinct shapes of other aeolian features within these corridors.

A recent study in the USA determined that the source area of many sand dunes is located where stably-stratified air flows over a blocking topographic barrier, accelerates to supercritical speed, near the downwind base of the barrier, and then experiences a hydraulic jump. In the hydraulic jump area, the strong turbulence erodes the soil material for deposit downstream as dunes. Deflation occurs in the area of the hydraulic jump (Ronald W. Marrs and et al. 1977).

Interpretations of Landsat imagery revealed that most of the dunes in this area are most probably created due to the wind blowing across the natural barrier a long time ago. Most of these dunes are now stabilized with the exception of some areas of active dunes due to their location along the

* Soil Survey Administration, Wad Medani. Report prepared while in training at the VISP at RSI.

"wind corridors" (Hamrat El Wozz, El Obeid and Rahad) or due to man's abuse of land in some localized areas.

Integrated studies utilizing the combination of image analysis, aircraft data, meteorological data and field observations are recommended for this area to determine different wind characteristics, sand flow patterns and horizontal wind movement so as to locate areas which need urgent conservation measures.

INTRODUCTION

This study demonstrates the application of remote sensing techniques to locate areas affected by desertification in central Sudan. Some projects were established in this area either to study land degradation in certain areas or to demonstrate some conservation practices and some of their schemes are meant for the settlement of the nomads. In recent years, land degradation and/or desertification severely affected the natural resources in central Sudan, making life very difficult for the large number of people in the area.

A new tool is needed that can help in locating different geomorphic aeolian features and to indicate sites of high wind energy or active dunes over all the region. Landsat imagery has been suggested for monitoring and mapping the processes of desertification. By interpretation of Landsat in this study we can assess the magnitude of the problem and conclude many inferences, however, some other field observations are needed to confirm these results. Repetitive coverage and uniformity over time are the main valuable characteristics of Landsat that enable to a great extent the study of desertification which is a gradual phenomenon. Present techniques (e.g. photographic enhancement, digital analysis, etc.) should be tried in studying this problem.

Besides the interpretation of Landsat imagery for locating and mapping the sand dunes, a study based on the repetitive coverage of Landsat was carried out to detect the horizontal movement of the sand dunes at Abu Habil area. The methods used to measure sand encroachment at this area were not sophisticated because at this stage we are thinking of direct methods to test the applicability of Landsat data for this study. Later on, more complicated methods are most probably needed for detailed studies.

This area is considered one of the largest potential areas in the Sudan affected by desertification, so it was taken as a first priority. Some other areas in eastern, western and northern Sudan are also affected by desertification and the studies can be extended to cover these areas. The goal of the work reported in this paper was to investigate (1) the applicatility of Landsat imagery for locating and mapping areas affected by desertification in central Sudan; and (2) the possibility of studying the magnitude of the horizontal movemement of the dunes (desert encroachment) through time.

Future studies for the assessment of desertification in the northern and central part, should be based on the soil map. By studying the relationship between land cover types, soil moisture and wind velocity for each soil, we can determine soil blowing, or the susceptibility of the fragile soils to soil blowing. An interpretive soils map showing the susceptibility of the different soil units to wind erosion could easily be drawn from such results. Carrying capacity for different soil units can also be investigated. I think this is the most practical way towards identifying areas which need urgent conservation measures.

PROCEDURES

Mapping, Locating Sand Dunes and Aeolian Features:

Many depositional and deflational aeolian features are being mapped from Landsat imagery. Field observations provide a check of the interpreted features and relationships. These interpretations should provide an estimate of the regional occurence of such features, and allow a determination of whether or not aeolian are typical of high wind areas under various physiographic and climatic conditions.

Sand areas could easily be delineated on Landsat imageries. The sandy areas appear as yellowish white tones separated by dark green interdunal areas on the false color composite. Longitudinal and Transversal sand dunes could be easily located by their very distinct alignment. The wind corridors or the gaps within the natural barrier are very clear, through which wind blown materials are carried by the wind into the area. Some aeolian features are very clear within these wind corridors (El Obeid scene, Kagmar and Sodri scenes). Small wind channels could easily be seen and mapped. Water channels, and intensive land use on some places could easily be detected.

Fine textured and/or deflation areas were easily mapped as many seasonal water courses are confined to these areas. Hills in the north and center of the area which are rocky and particularly bare, have dark green to blackish color tones.

Investigating the Possibility of Measuring Desert Encroachment Using Landsat Data

Step 1 55.8 mm transparency chips, band 5 and 7 of Landsat image 1108-07482, 8 Nov. 1972 and 2374-07335, 31 Jan. 1976 of Khor Abu Habil

area (figure 1) were selected to investigate the above mentioned objective using the "additive color viewer" (I^2S) for better enhancement and to compare if there was any horizontal movement within the longitudunal sand dunes in these areas during the time indicated on the two scenes (three years). The two scenes were not scanned in the same month and although this was undesirable, it could not be avoided given the data available. Bands 5 and 7 were chosen because the unconsolidated sandy materials with nearly flat relief (northern sandy plains) give a high reflectance on these bands and are easily separated from residual parent materials of erosional landscape (northern pediplains) consisting of broad basins, scattered ridge tops and seasonal stream courses, which appear as darker zones (Pacheco & Hashim SSA Report No. 81, 1976).

Step 2 Two positive transparencies (scale 1:3,369,000) of the two dates of the same scene were obtained from EROS Data Center in Sioux Falls. These 70 mm chips were displayed on the color additive viewer. By doing so, we were able to enlarge the scale of the chips from 1:3,369,000 to 1:500,000. These enlargements were carried out to aid in detecting small changes in the longitudinal dunes, if any.

Step 3 The positive transparencies (18.5 x 18.5 cms.) of scale 1:1,000,000 were used in this step. A portion of these transparencies was fitted into a projector (m-354 transparency cartridge projector) and displayed on the wall with 15X enlargement. This enlargement was controlled by drawing vertical and horizontal lines 1 cm x 1 cm on a blank transparency and inserting it with Landsat chips in the cartridge. When displayed on the wall, we measured the distances to

E030-001 E030-301 E031-001
31JAN76 C N12-59/E030-40 N N12-57/E030-43 MSS 5 R SUN EL40 AZ127 188-5209-A-1-N-D-2L NASA ERTS E-2374-07335-5 02

Fig. 1. Landsat image No. 2374-07335 band 5 showing Abu Habil Stream affected by sand dunes and Bara area affected by active dunes. 1 - El Obeid, 2 - Rahad, 3 - Umm Rawaba, 4 - Bara, D - longitudinal dunes, the arrow indicating wind direction, B - Some plain, C - clay soils, L - agricultural lands (sands), J - Jebel El Dair, A - active sand dunes.

15 cm x 15 cm. The scene should be displayed accurately by checking and adjusting the vertical and horizontal distances on the wall. The wall was used because it is stable if compared with the conventional screen. The projector was stopped for some minutes during the display to eliminate the expansion within the projector due to the high temperature which will lead to enlarging the displayed figure by a few millimeters than the adjusted one at first. Example interpretations are provided in Figures 2, 3, and 4.

Step 4 Using the CCT of the same scene (ID No. E-1108-07482, 1972) a small area of longitudinal sand dunes was chosen for preparing a digital map showing the longitudinal sand dunes and the background features.

RESULTS

1. A map was prepared showing the location of different aeolian features and active sand dunes. (Fig. 5)
2. A map was prepared showing the "wind corridors" and the active sand dunes areas within the central potential areas (Fig. 6).
3. No horizontal movement was detected within the longitudinal sand dunes, however, some other changes (burning, some new sandy islands inside Abu Habil stream) were detected.
4. The longitudinal sand dunes were very clear in the digital map prepared by the Computer Compatible tapes (CCT).

CONCLUSIONS

1. Landsat imagery has proven to be very useful in locating and mapping dunes and other aeolian features. Color composite images combining bands 4, 5 and 7 are most useful for mapping dunes because of the color distinction between the active dunes, alluvium, pediments, clouds and surrounding rock formations.

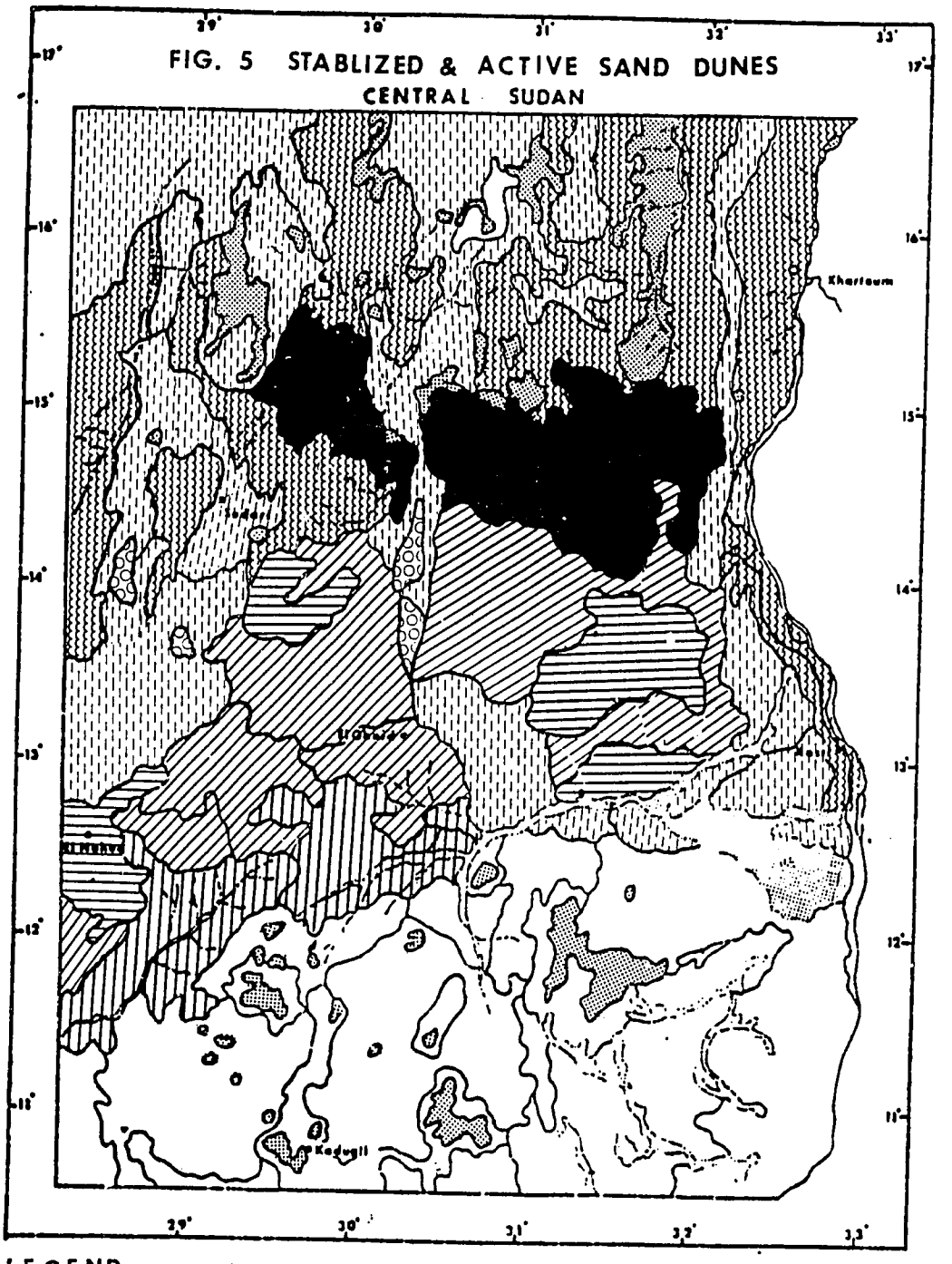
Fig. 2. Landsat image No. 2357-07392 band 7 showing the northern natural barrier and two wind corridors. 1 - Sodari, 2 - Hamrat El Wazz, W - wind corridor, the arrows indicating wind direction, T - transversal dune, A - active dunes, H - rocky area of the natural barrier, S - small wind channels, X - isolated barriers (hills). C - clay soil protected by the barrier. L - agricultural lands.

Fig. 3. Landsat image No. 2319-07281 band 5 showing the area west of the White Nile. 1 - El Dueim, 2 - Wad Medani, N - White Nile, B - Blue Nile, G, M - Gezira and Managil schemes, A - Riverain lands, W - wind corridor, the arrow indicating wind direction, R - rocky and gravelly areas, S - sand dunes affecting agricultural lands.

E031-301 E032-001 E032-301
07DEC75 C N13-06/E032-14 N N13-05/E032-16 MSS 5 R SUN EL41 AZ137 189-4442-A-1-N-D-2L NASA ERTS E-2319-07284-5 01

Fig. 4. Landsat image No. 2319-07284 band 5 showing Khor Abu Habil Delta affected by sand dunes from the north. 1 - Kosti, 2 - Rabak, 3 - Tendalti, S - sand dunes with wind direction, E - effect of dunes on Abu Habil drainage system, N - White Nile, A - sands carried with water to the delta. Area of extensive grazing, and bare soils around the villages.

FIG. 5 STABLIZED & ACTIVE SAND DUNES
CENTRAL SUDAN



LEGEND

30 0 30 60 90 120
Km

ACTIVE SAND DUNES

TRANSVERSAL SAND DUNES

TRANSITIONAL ZONE (STABLIZED)

WIDE VALLEYS (WADI)

CRACKING CLAY SOILS

PEDIMENTS & WIND BLOWN SAND

SAND SHEET

HIGH SAND DUNES

HILL & ROCK OUTCROPS

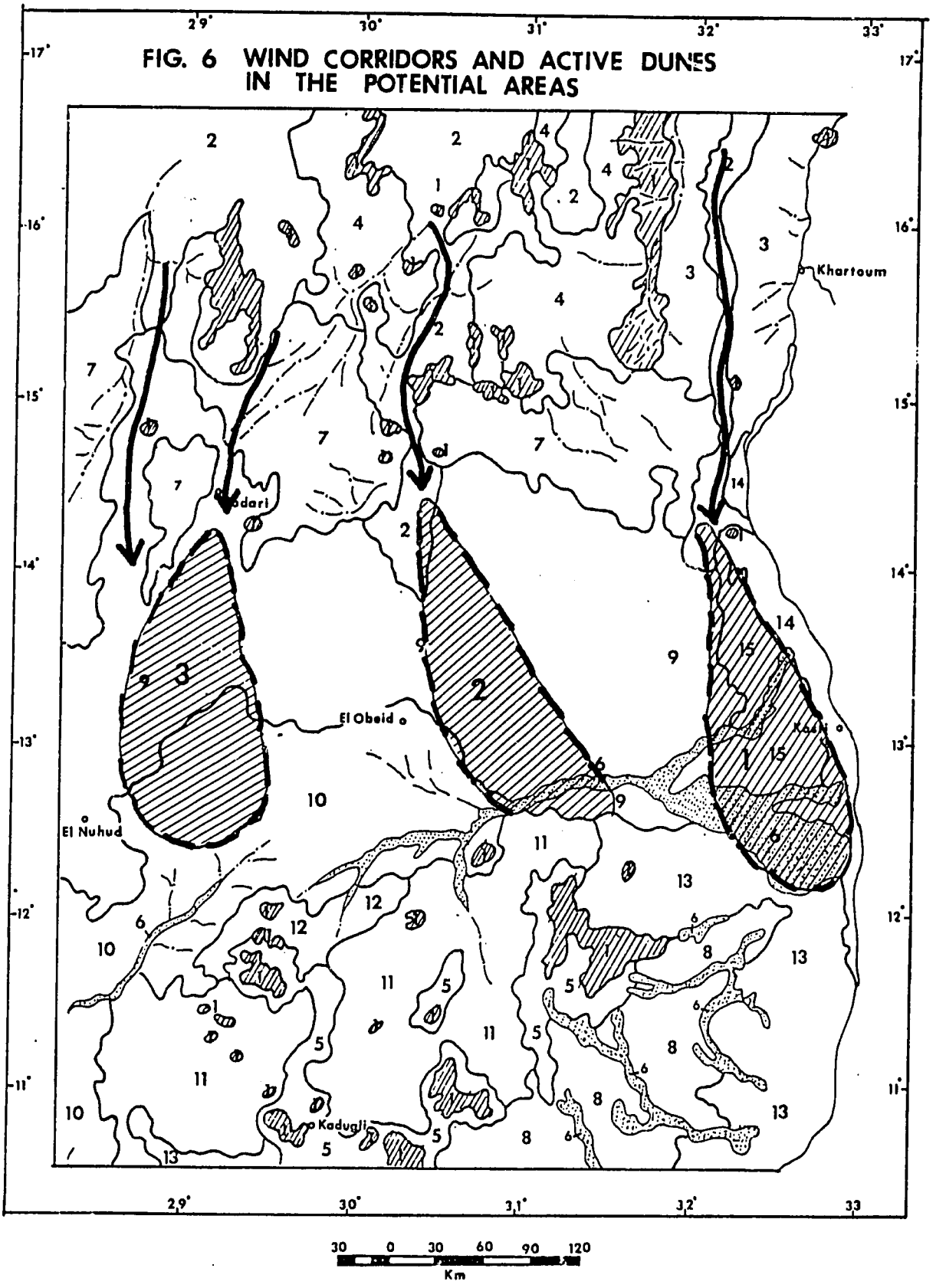


FIG. 6 WIND CORRIDORS AND ACTIVE DUNES IN THE POTENTIAL AREAS

2. Landsat data have greatest advantages over all other data forms regarding their availability and its ability to display on a broad regional scale, such features as dunes, field shape, size and relationship to regional topography and wind characteristics.
3. Small scale characteristics are difficult to distinguish from Landsat. Accurate measurement of dune size, spacing and their changes through time is difficult for many areas of small dunes with minor changes.
4. Other sophisticated methods should be used with Landsat imageries within long periods (6 years or more) to measure the horizontal changes or sand encroachment.
5. Three "wind corridors" and areas of active dunes were located in the area.
6. Different aeolian features are indirect indicators of wind characteristics.
7. Shapes and distribution of some dunes are controlled by geologic outcrop patterns and others appear to be dominantly controlled by wind pattern.
8. Aeolian features are found in areas of high wind, but are not solely a function of wind. Topography, surface materials, vegetation, land use, temperature, precipitation and other factors also influence their development.
9. Future investigations should utilize the combination of image analysis, air-reconaissance, field observations and other studies on geology (e.g. sand mineralogy) and meteorology (e.g. wind characteristics), etc. in studying the characteristics of aeolian features and their effects on the area.

10. The characteristics of Landsat justify its use as a regional tool to be applied in natural resources studies.

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HYDROLOGY AND DESERTIFICATION STUDY OF CENTRAL SUDAN

A/Rahim A/Aziz Mohamed*

INTRODUCTION

Sudan is the largest country in Africa with an area of 2.5 million square kilometers. Its population is about 15 million. It has common borders with Uganda, Zaire, Kenya, Ethiopia, Egypt, Libya, Chad and the Central African Empire (Fig. 1).

The northern parts of Sudan have insufficient rainfall in many parts of the country is compensated to some extent by the White Nile which originates from Lake Victoria in Uganda, and the Blue Nile which originates from Lake Tana in Ethiopia. The two Niles join at Khartoum, the capital, to form the River Nile which flows northward to Egypt. The area lying between the White and Blue Nile is considered the most productive area for irrigated cotton production. The topography of the country is mainly flat with the exception of a few mountainous areas over 3,000 meters above mean sea level.

Estimated censuses show that the population has grown from 10.3 million in 1955 to 14.1 million in 1973, at a growth rate of about 2% per year during the last 18 years. The population is mainly agricultural and the majority of the people live in rural areas.

Desert Encroachment:

In Sudan, man has played a great part in speeding up desert encroachment. Among the many factors affecting desert encroachment, the following are considered to be the major ones:

1. Highly variable and unpredictable rainfall with extended periods of drought.

* Rural Water Corp.: Ministry of Agriculture, Food and Natural Resources, Khartoum. Report prepared while in training at the VISP at RSI.

Fig. 1. The Sudan within Africa

2. The thunderstorm characteristic of the rainfall with unbalanced distribution over time.

3. Overpopulation and overcultivation with subsequent lowering of the water table.

4. The non-uniform distribution of watering points creates overgrazing around them.

5. Burning of shrublands, grasslands and forests.

6. Irrational cultivation and cultivation in marginal areas.

7. Uprooting shrubs for cultivation.

8. Woodcutting and deforestation.

A UNEP/UNESCO reconnaissance team reported that sand from the extensive Libyan desert and Jebal Abyan Plateau is being blown southward in a broad point by the steady northern winds. A typical example, Wadi Howar, which flows in a northeastern direction from Darfur Province to the loop of the Nile in the Northern Province, is being buried over its whole length and large portions have already been transformed into sandy deserts. The whole length of the Nile between Delgo and Karima (that is the greater part of the east-west loop) is subject to serious sand encroachment along the north facing bank. Even large areas of irrigated agricultural land on alluvial soil have been abandoned due to sand accumulation, with an average depth of 7 cm. This phenomenon of buried wadis and khors due to moving sand dunes will be discussed more elaborately later.

General Objectives of the Program as Outlined By the Sudanese Technical Committee for Desert Encroachment Control:

In Sudan, before coming to participate in the training program at the Remote Sensing Institute, Brookings, South Dakota, U. S. A., the Sudanese Technical Committee for Desert Encroachment Control outlined the

proposed program as follows:

The major objective of this proposed program, in addition to training the selected participants in interpretation of imageries, is for monitoring desert encroachment in order to determine its progress. More importantly, it is to quantify desert encroachment in terms of past and current land resources and water losses, and to develop an identification index of different imagery patterns so that the technique can be used to sustain an overall inventory of the western savannah, still considered a "gap" in our present Sudan resource inventory.

The results of this training were expected to be the following:

1. Develop vegetation, soil, hydrological and landuse maps of areas selected and, if possible, the adjoining areas.
2. Quantitatively monitor desert encroachment.
3. Determine areas lost to the desert.
4. Delineate areas currently affected by the problem of sand dune movement.
5. Estimate the change in drainage systems in the area due to sand dune movement.

Objectives of the Program as Outlined by the Author:

From the author's point of view, the project under consideration has two broad objectives:

1. First objective: It is worth mentioning that until now, no attempt has been made to renew the topographical maps of rural areas in the Sudan. Rural water resources people on their everyday surveys and investigations for water sources mainly rely on the topographical maps which are based on triangulation surveys carried out in 1936.

The only renewal achieved in this field was carried out by the United Nations Special Fund during the period (1961-1965). The United Nations Special Fund Project, executed by FAO, helped the Sudan Government develop data on the land and water resources of the Kordofan Province Savannah Belt. The area covered by the aerial photo survey is only 66,000 square kilometers. This is a small percentage compared with the total area of the country amounting up to 2.5 million square kilometers.

The ultimate goal of the study is to map surface drainages, watersheds and depressions for the erection of necessary water points: Hafirs, reservoirs, and water spreading structures, etc. As a consequence of the above mentioned mapping, delineation of surface drainages and depressions will give many clues to the evaluation of groundwater, especially in the basement complex formations. These maps will be produced from the interpretation of 1972 Landsat I imageries.

2. Second objective: A second interpretation will be made from the 1976 imageries of Landsat 1 and 2 to produce hydrological maps of the same selected area. Then a comparison will be attempted between the 1972 and 1976 maps so as to quantify desert encroachment in terms of past and current water resources and water losses. This second objective is mainly meant to satisfy the fourth and fifth objectives outlined by the Technical Coordinating Committee for Desert Encroachment Control.

The Geography of the Study Area

Location:

The Study Area lies between latitude 11° 52' 30" and 17° 00' 00" N, and traverses the Sudan beginning at the White Nile on the east and ending at longitude 28° 15' 00" to the west. An additional strip at the south western corner of the Study Area was added so as to include the remainder of Wadi El Ghalla watershed left outside the Study Area. The Study Area is covered by ten Landsat imageries and consists of approximately 342,250 km^2.

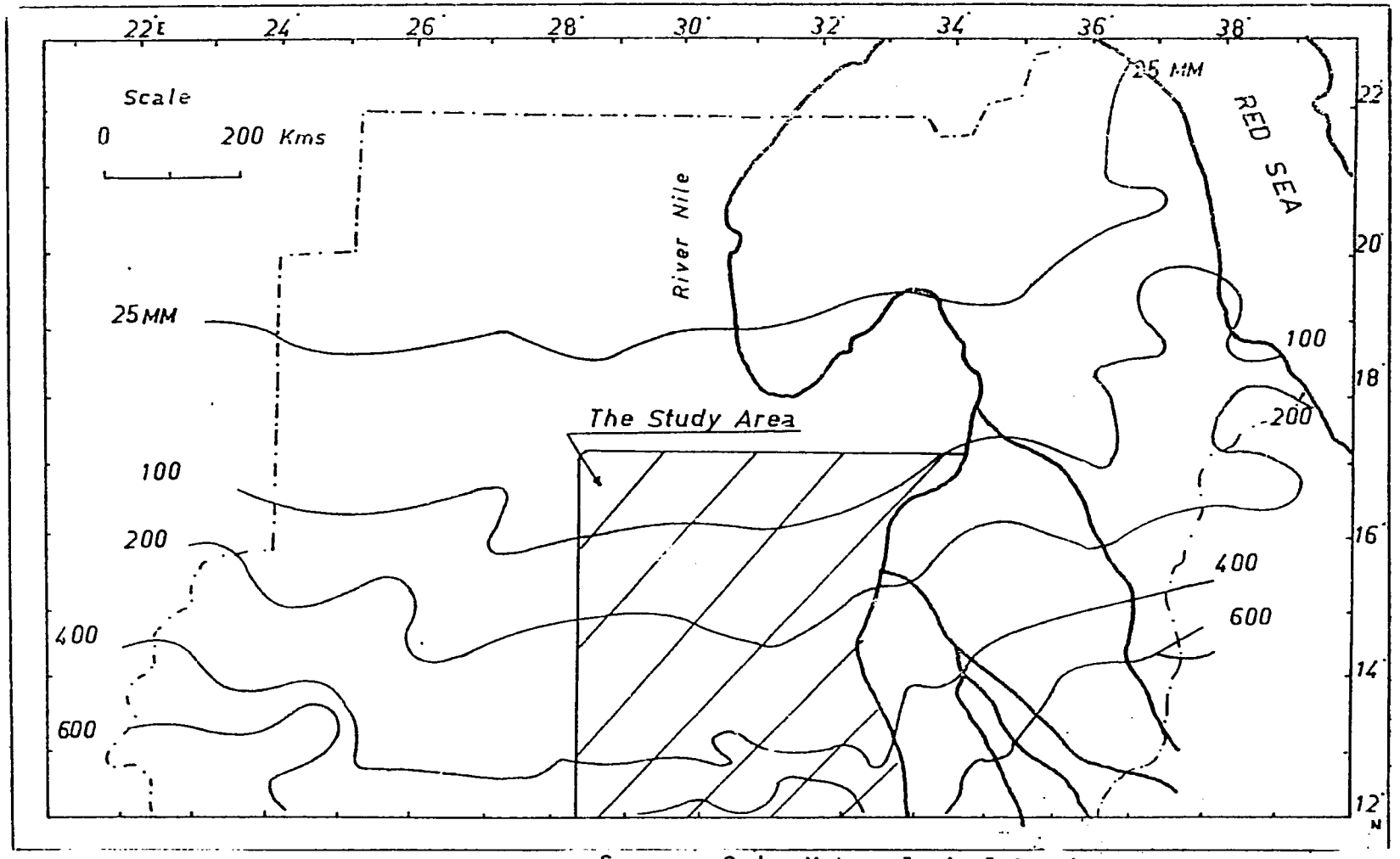
The Area comprises the provinces of Northern Kordofan, Khartoum, the northern portions of the Southern Kordofan, the White Nile, and the Southern portion of the Northern Provinces.

Climate:

Rainfall over the Study Area is characterized by marked seasonality, wide variability, and general unreliability.

Average annual rainfall ranges between 100 mm. in the extreme norther portion of the area, to about 500 mm. in the southern portion. Rainfall isohyets run from east to west following the latitudinal pattern (Fig. 2).

Rainfall is controlled by the nature and behaviour of the Inter-Tropical Convergence Zone (I.T.C.Z.), which itself is controlled by the atmospheric pressure conditions over and in the vicinity of the African Continent. All rains occur when the I.T.C.Z. is lying either within or to the north of the project area. However, due to the nature of the I.T.C.Z., variations in rainfall exist over the northern part



Source: Sudan Meteorological Service 1931-1960 Average

Fig: 2 The Study Area and its Average Annual Rainfall (MM)

of the area. Consequently, the rainy season of the southern parts of the area occurs from July to September, while August is considered the rainy month of the extreme northern parts. These months receive more than 75% of the mean annual rainfall, a reflection of the very marked seasonality of rainfall over this part of the Sudan. The monthly average rainfall during this period varies between 150 mm in the extreme south to less than 25 mm in the extreme north. The coefficients of variation of the annual rainfall means vary between 20% in the south to more than 150% in the north. For the largest part of the area, the annual coefficients of variation range between 100% and 150%, clearly indicating the variable nature of annual rainfall which is illustrated in Fig. 3.

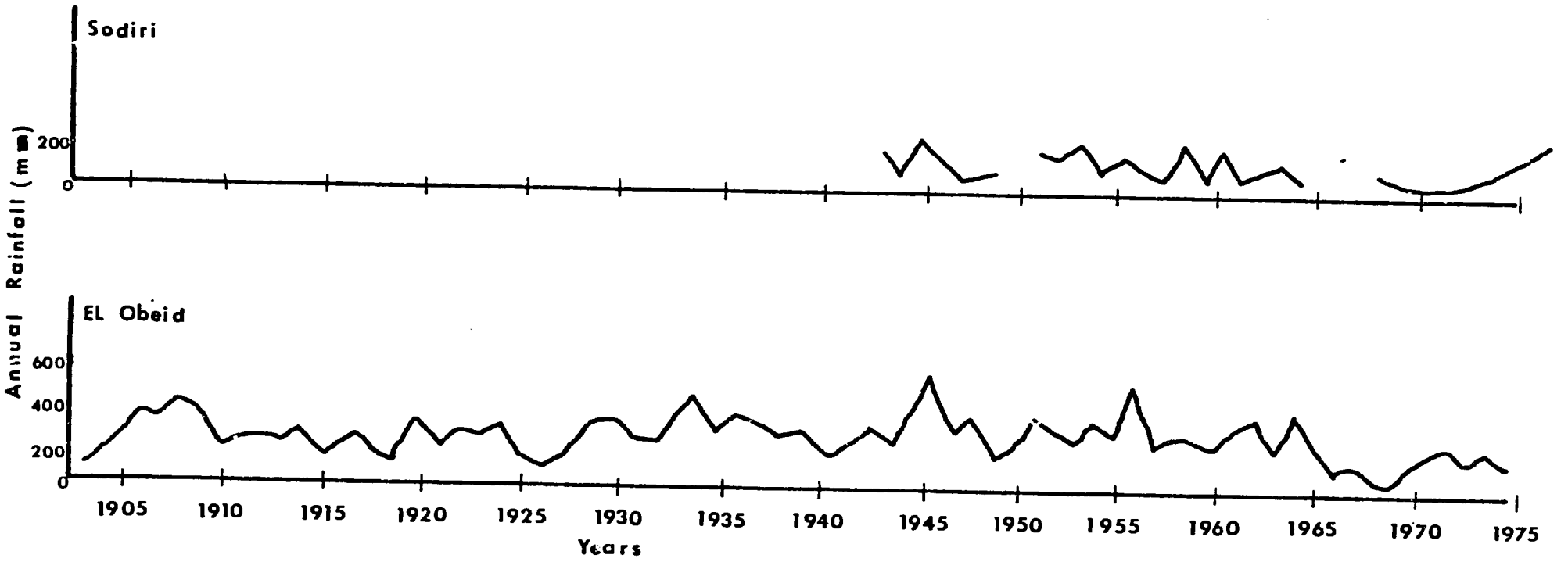
Using Penman's formula for determining potential evapotranspiration, the annual evapotranspiration was estimated as 1,900 mm over the extreme southern part of the region and increases rapidly northward to a maximum of over 2,500 mm in the extreme northern part.

The entire region suffers from a large water deficit which tends to increase from south to north. The mean annual water balance is minus 2,250 mm over the extreme northern part of the region. Also, large water deficits characterize the entire region except perhaps for the extreme southern margin where a temporary monthly balance may be achieved between water supply in the form of rainfall and water loss in the form of potential evapotranspiration.

Water Resources:

Topographically, the Study Area lies in the Nile Basin. It is a wide open plain with occasional rocky inselbergs standing up from it.

FIGURE 3. Annual Rainfall at Selected Stations in the Study Area
Source: Sudan Meteorological Service



water potentialities can be divided into two broad divisions:

(1) Surface water resources and,

(2) Ground water resources.

(1) Surface Water Resources:

The surface drainage of the Study Area is essentially internal.

Except for the occasionally scattered "regebat" which are channels having no appreciable flow, the whole Study Area is mainly divided into the following four basins; Wadi El Ghalla, Wadi Shelengo, Khor El Berdab, and Khor Abu Habil.

The interpretation and mapping of the above mentioned basins were carried out using the 1972 Landsat I imageries. The following factors were considered during the procedure of the interpretation:

1. Water courses are best mapped from the Multi-Spectral Scanner (MSS) - Band 7 - black and white imageries with occasional consulting of the color composite imageries.

2. Water bodies are best mapped from the Multi-Spectral Scanner (MSS) - Band 7 - black and white imageries.

3. Many alternatives were discussed to select the best time for mapping water courses and bodies from the different multi-date satellite imageries. Imageries of November 8, 1972 proved to be the best because they were cloud-free and at the same time represented the end of the rainy season.

(1) Wadi El Ghalla Basin:

Wadi El Ghalla Basin was interpreted and mapped from the MSS - Band 7 - black and white 1:500,000 Landsat - I mosaic (the mosaic comprises the following imageries: Alnuhud of Path 188 - Row 51 and El Fula of Path 188 - Row 52).

The effective catchment of the Wadi El Ghalla is estimated to be only 10,700 sq. km. The Wadi flows sluggishly southwestward in a

shallow valley skirting the edge of the sandy pediplain around Alnuhud. Drainage of the right (west) bank is essentially internal and most of the runoff reaching the main channel originates from the gravelly jebel pediment southeast of Abu Zabad. The flow contributed by Knor Agak is completely absorbed by storage in the turda at Abu Zabad. Doxiadis Associate (1966) has assessed the storage of this turda to be about one million cubic meters.

No flow is detected to pass downstream of Abu Zabad Turda. The continuity of the Wadi El Ghalla is maintained by the discharge of several large alluvial tributaries mainly originating from the left (east) bank. The regime of this middle reach is controlled by the lithology of the Basement Complex which outcrops at Es Sinut, Es Sumeita, Toto, Kutna and Burdia to form shallow basins. Runoff accumulated in these basins persists on the surface at least until the end of November, after which wells are dug in the clayey alluvial bed.

The Wadi El Ghalla turns west downstream of Burdia and flows through a Nubian Sandstone terrain in which it receives little inflow from its tributaries on either bank. South of El Fula, the Wadi stagnates in an 8000 hectare clay basin.

Downstream of Izz ed Din, the Wadi El Ghalla meanders across a buried ridge of Basement complex rocks in a shallow clay channel between sandy clay banks. After 30-40 km, the Wadi enters a complex of narrow incised basins and traverses westwards to enter the lower reach of a degenerate watercourse rising in the vicinity of El Odaiya.

Below Suneitaya the Wadi disperses in a delta, known as El Muglad (after the reddish sandy clay soil which predominates in the area). The delta also receives diffuse runoff from the goz terrain around Babanuse and Tibun.

In the semi-arid climatic conditions of the area, surface water retained in shallow basins is subject to high evaporation losses. Water infiltration to deep sub-surface storage beneath the essentially impermeable clay bed of the Wadi is not likely to be very great.

The following Table 1 shows the discharges records at the three existing hydrometric stations.

Table (1): Wadi El Ghalla Flow Records

Records are listed in downstream order of the prior drainage.

Wadi El Ghalla at Es Sinut (2,300 sq. km.)

Year	No. of Floods	Flood Discharges (m^3)	Average Flood (m^3)	Max. Flood (m^3) & its Duration	Max. Discharge (m^3/sec) & its Duration
1967	21	2,666,000	127,000	500,000 (15-17 Aug.)	4.21 (15-17 Aug.)
1968	24	13,281,000	553,000	1,910,000 (26 July - 4 Aug.)	12.25 (22-23 July)
1969	36	12,987,000	360,000	1,767,000 (29 Aug. - 2 Sept.)	8.96 (16-19 Sept.)
1970	27	21,031,000	962,000	6,301,000 (18-27 July)	13.83 (31 July - 2 Aug.)
1971	56	16,072,000	287,000	2,954,000 (1 Aug.)	10.10 (31 July)
1972	30	27,056,000	902,000	11,424,000 (12-22 July)	59.60 (12-22 July)
1973	28	5,824,000	208,000	1,040,000 (20-30 Aug.)	13.86 (25 July)

Wadi El Ghalla at Abu Tulu (5,800 sq. km.)

1972	25	94,973,000	3,799,000	11,305,000 (6-8 Aug.)	81.16 (6-8 Aug.)
1973	23	30,177,000	1,312,000	6,366,000 (22-25 July)	72.09 (8-11 Aug.)

Wadi El Ghalla at Suneitaya (6,350 sq. km.)

1973	45	6,335,000	141,000	-	9.75

Source: Reference No. 1

Comments:

The following comments consider El Fula Imagery (Path 188 - Row 52) in which Wadi El Ghalla predominates:

1) For the color composite imagery:

All water bodies including Lake Keilak appear in dark tone except:

a. Miri Barra Reservoir whose water appears in blue tone.

b. A water body, having a crescent shape and at a distance of 25 kms. north of Miri Barra Reservoir, appears in a greenish tone.

2) For MSS Band 7 Black and White Imagery:

a. All water bodies have a dark tone.

3) For MSS Band 5 Black and White Imagery:

All water bodies appear in dark tone except:

a. Miri Barra Reservoir where water appears in a pale white tone.

b. The water body mentioned in 1-b does not show at all.

Conclusion:

1. All water bodies having a dark tone in 1, 2, 3 imageries are considered to be clear water.

2. Miri Barra Reservior is considered to be turbid (silted) water because it shows in whitish tone in MSS Band 5 Black and White imagery as well as the water body mentioned in 1-b.

(2) Wadi Shelengo - Watershed:

The Wadi Shelengo drains an area of 8450 sq. km. The watershed is situated on the western flank of the Nuba Jebels and extends SSW through a sandstone ridge to discharge into a delta region of approximately 2200 sq. km.

The discharge of Wadi Shelengo is gauged by three gauging stations equally distributed along the Wadi. In addition, there is a fourth gauging station located at the north of Khor El Far, which is one of the major tributaries of Wadi Shelengo. The Khor El Far drains the pediment south of the Katla Jebels. In order to assess yield and spillway capacity of the proposed dam at Ugheibish, the flood runoff was recorded there from 1968 to 1973 (Table 2).

The three stream-gauging stations are the following:

a. Nabuk stream-gauging station:
Located 1.5 km downstream of the confluence (el melemm) of the upper Shelengo and the Khor El Far which drains areas of 1300 and 1200 sq. km. respectively. The Wadi, upstream of the confluence, drains the pediment west of the Katla Jebels. Comparing the 1972 and 1973 floods at Nabuk and Ugheibish, it is clear that over 50% of the floods recorded at Nabuk originated entirely from the upper Shelengo.

b. Debekaya stream-gauging station:
The Debekaya gauge is recording the runoff from 5400 sq. km. of Selengo basin. Between Debekaya and El Arak, the Shelengo is joined by a number of both left and right bank minor tributaries.

Just above Debekaya, the main channel of Wadi Shelengo retains much of the character of its tributaries although the flatter gradients and lower velocities result in a more stable regime with the bed load decreasing downstream.

c. Kulushabi stream-gauging station:
In terms of catchment area, the largest tributary of the Shelengo is the Khor Abu Likri which drains a basin of 1450 sq. km. The Kulushabi stream-gauging station, just downstream of the month of the Khor Abu Likri, monitors the flood runoff from 86% (7250 sq. km.) of the Shelengo basin. The channel and floodplain storage along the sluggish middle reaches of the Khor Abu Likri probably attenuates the discharge reaching the Wasi Shelengo. However, near its mouth the Khor is steeper and its narrow channel (about 5 m.) lies in a deeply incised valley.

(3) Khor El Berdab Basin:

The Khor El Berdab catchment is formed mainly of two khor-systems:

Table (2): Wadi Shelengo Flow Records

Records are listed in downstream order of the prior drainage.

(i) Khor El Far at Ugheibish (1000 sq. km.)

Year	No. of Floods	Flood Discharges (m^3)	Average Flood (m^3)	Max. Flood (m^3) & its Duration	Max. Discharge (m^3/sec) & its Duration
1968	8	8,723,000	-	-	-
1969	10	11,650,000	-	-	-
1970	23	17,910,000	779,000	5,573,000 (20-23 July)	41.18 (9-11 Sept.)
1971	20	14,834,000	742,000	3,618,000 (28-29 July)	53.53 (28-29 July)
1972	29	14,304,000	493,000	1,993,000 (2 Aug.)	-
1973	24	10,345,000	431,000	1,137,000 (5 Aug.)	43.53 (8 Aug.)

(ii Wadi Shelengo at Nabuk (2,550 sq. km.)

1972	41	31,517,000	750,000	3,120,000 (13 July)	-
1973	44	54,166,000	1,231,000	5,136,000 (10 Aug.)	60.53 (10 Aug.)

(iii) Wadi Shelengo at Debekaya (5,400 sq. km.)

1973	9	16,497,000	-	-	-
N.B.: August & September records are not available					

(iv) Wadi Shelengo at Kulushabi (7,250 sq. km.)

1973	33	99,324,000	3,010,000	23,042,000 (7-18 Aug.)	42.85 (22-31 July)

Source: Reference No. 1

a. Mainstream of Khor El Berdab and, (see Table 3)

b. Khor El Kiddi.

a. Khor El Berdab: Khor El Berdab is considered to be the largest of the Kheiran draining the central jebels. It rises on the jebel pediments 20 km. south of Dilling and flows southwards through the Miri Jebels, about 20 km. west of Kadugli. In 1967/68, a 4.5 million cubic meters reservoir was built at Miri Barra, which lies midway along the Khor. South of the jebels, the khor disperses into a delta just east of Lake Keilak. Lake Keilak is the terminal sump for most of the discharge of a 2200 sq. km. catchment which includes that of the Khor El Batha and a number of small kheiran draining the pediments of the southern jebels. Spillage into the lower reach of the Khor El Berdab is partially obstructed by the delta alluvium deposited by Khor El Berdab south of Kanga. In spite of that, when the lake reaches its maximum area of 750-800 hectares, some spillage occurs through a 70 m. wide channel.

b. Khor El Kidi: It is the major tributary to Khor El Berdab at its origin. Altogether, parallel with the mainstream of Khor El Berdab, it drains through the narrowest part of the catchment. One of the four stream-gauging stations was erected across Khor El Kidi to assess its contribution to Miri Barra Reservoir.

Another small catchment of Khor El Batha flows parallel and to the west of Khor El Berdab catchment. The discharge of Khor El Batha is measured at Umm Adara, just upstream of where the khor enters the alluvial reach terminating in Lake Keilak.

(4) Khor Abu Habil Basin:

The Abu Habil Basin is interpreted and mapped from the MSS - Band 7 - black and white 1:500,000 Landsat - I mosaic. The mosaic comprises the following imageries: Kosti of Path 186 - Row 51; El Obeid of Path 187 - Row 51; En Nahud of Path 188 - Row 51; El Fula of Path 188 - Row 52.

Khor Abu Habil flows partly from the west, originating near Dilling and partly from the southern Nuba Mountains area. When it reaches Rahad Turda, the Khor Abu Habil swings eastward. It runs past Semeih to Umm Ruwaba and then flows on to Sherkeila and Tendelti; just beyond

Table (3): Khor El Berdab Flow Records

Records are listed in downstream order of the prior drainage.

(i) Khor El Kidi (145 sq. km.)

Year	No. of Floods	Flood Discharges (m3)	Average Flood (m^3)	Max. Flood (m^3) & its Duration	Max. Discharge (m^3/sec) & its Duration
1973	4	1,810,000	453,000	967,000 (22 Aug.)	19.61 (22 Aug.)

(ii) Khor El Berdab at Berdab (980 sq. km.)

1972	30	109,630,000	3,654,000	17,893,000 (8 Sept.)	-
1973	34	27,014,000	795,000	3,459,000	20.79 (7-9 Sept.)

(iii) Khor El Berdab at El Koufa (1475 sq. km.)

1972	8	4,399,000	550,000	1,556,000 (31 Aug. - 4 Sept.)	6.40 (31 Aug. - 4 Sept.)

(iv) Khor El Batha at Umm Adara (856 sq. km.)

1972	14	9,622,000	687,000	1,925,000 (1-3 Aug.)	52.40 (1-3 Aug.)
1973	17	10,301,000	606,000	2,140,000 (-)	76.13 (-)

Source: Reference No. 1

Tendelti of the stream dries out. The dried-out valley runs on to the Nile. In an earlier geological age it was an active tributary to the Nile. The basin which feeds the Khor Abu Habil at its state near Rahad is 18,250 km.^{2} with an average rainfall of 610 mm.

There is a record of water levels in the Khor extending for a number of years in the past. This record consists of a three-times daily recording of the water level on the downstream gauge of the Rahad regulator, as from 1958 data presented in Table 4.

Table (4): Khor Abu Habil Flow Record at Er Rahad Cross - Regulator:

Year	Discharge $10^6.m^3$
1958	37.4
1959	193.0
1960	41.7
1961	193.0
1962	27.1
1963	93.4
1964	175.3

Within the catchment of Abu Habil lies Khor lies Khor Tagerger, which drains a sub-basin of an area 4,100 km.^{2} with an average rainfall of 375 mm. between El Obeid and Er Rahad. Khor Tagerger flows from the northwest into Er Rahad Turda (a natural depression) feeding it with 4 million cubic meters.

In 1968, the depression of Er Rahad Turda was excavated to a volume

of 56 million cubic meters. Consequently, a feeder canal was diverted from Khor Abu Habil to feed the remaining 52 million cubic meters to the Rahad Turda.

Additional Remarks:

As a result of comparison done between imageries of dates November 8 of 1972 and 1976, the following remarks are deduced:

1. The construction of a new reservoir (Baggara Reservoir) during the period 1973-1975 was clearly identified in the imagery of 1976.

2. In 1970, eleven check dams were constructed on Khor Mulbas upstream of village Bangadeed. These check dams were intended to protect the gardens downstream from the erosion created by the khor and its tributaries.

   The eleven check dams were clearly identified on the imagery of November 8, 1972. Due to the complaints arising from the natives of village Bangadeed about the destruction of the check dams during the rainy season of 1975, I personally paid a visit to the check dams and their destruction was clearly noticed. For this reason, the reservoirs created by the dams are not seen on imagery of January 31, 1976.

(B) Ground Water Resources:

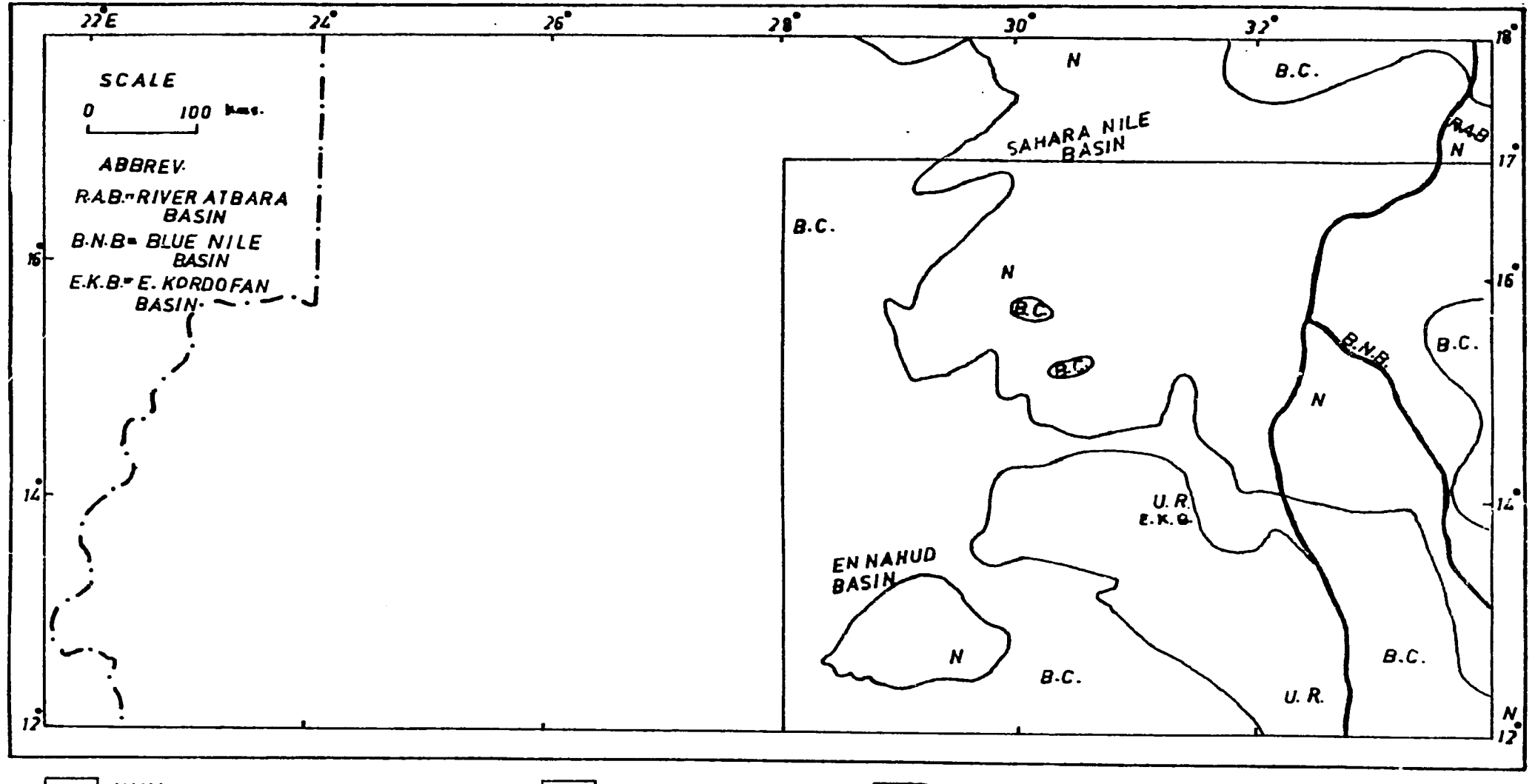
In the Study Area there are three main groundwater basins which are associated with the following geological formations:

Basins		Type of Formation
1. Eastern	Kordofan Basin	Umm Ruwaba Formation
2. Sahara	Nile Basin	Nubian Sandstone Formation
3. Nahud	Basin	Nubian Sandstone Formation

To have a clear understanding of the three water basins, some basic information about the geological formations is depicted in Fig. 4.

Umm Ruwaba Formation:

The Umm Ruwaba formation covers about 20% of the area of the Sudan.



U.R. UMM RUWABA FORMATION

N NUBIAN SANDSTONE FORMATION

B.C. BASEMENT COMPLEX

Source: Reference no. 3

Fig 4: GROUND WATER BASINS OF THE STUDY AREA

It is predominantly unconsolidated and poorly stratified intercalations of sands, silts and clays and constitutes an important source of ground water in the Sudan. The ground water occurs in lenticular sand layers embedded within clayey media generally under semi-artesian conditions. The water quality is generally good with salinity ranging from 300 to 23,000 ppm.

Nubian Sandstone Formation:

The Nubian Sandstones cover about 25% of the area of the Sudan and occur mainly in Kordofan, Darfur, Northern and Khartoum provinces. The origin of the Nubian formation is still a matter of controversy, but it is believed that it has been deposited in fresh water environments. This is supported by the presence of current bedding, ripple marks, and some fresh water fossils.

The Nubian formation as a whole is a water bearing formation and represents the best regional source of ground water in the Sudan. The water quality is generally good with average total salinity of 600 ppm. Water is generally tapped in sufficient quantities from the sandy and pebbly layers due to the fact that the Nubian formation has been deposited over the irregular surface of the Basement Complex rocks. The formation has an irregular thickness.

Ground Water Basins:

1. Eastern Kordofan Basin

It covers the area extending from north of El Obeid to the White Nile with a surface area of 68,392 km^2. The velocity of the water is very slow (0.1 to 0.3 m/year) due to the poor nature of permeability and water levels that range from 50 to 70 meters.

2. Sahara Nile Basin

It covers an area of 273,980 km.^{2} which included the northern part of Northern Kordofan province and extends from north of Khartoum to the Egyptian borders.

The general ground water movement is from south to north, with velocity ranging from 0.44 to 1.46 m/year. The water levels are usually 10 m. near the Nile and fall rapidly reaching a maximum depth of 25 m. in the central part.

3. Nahud Basin

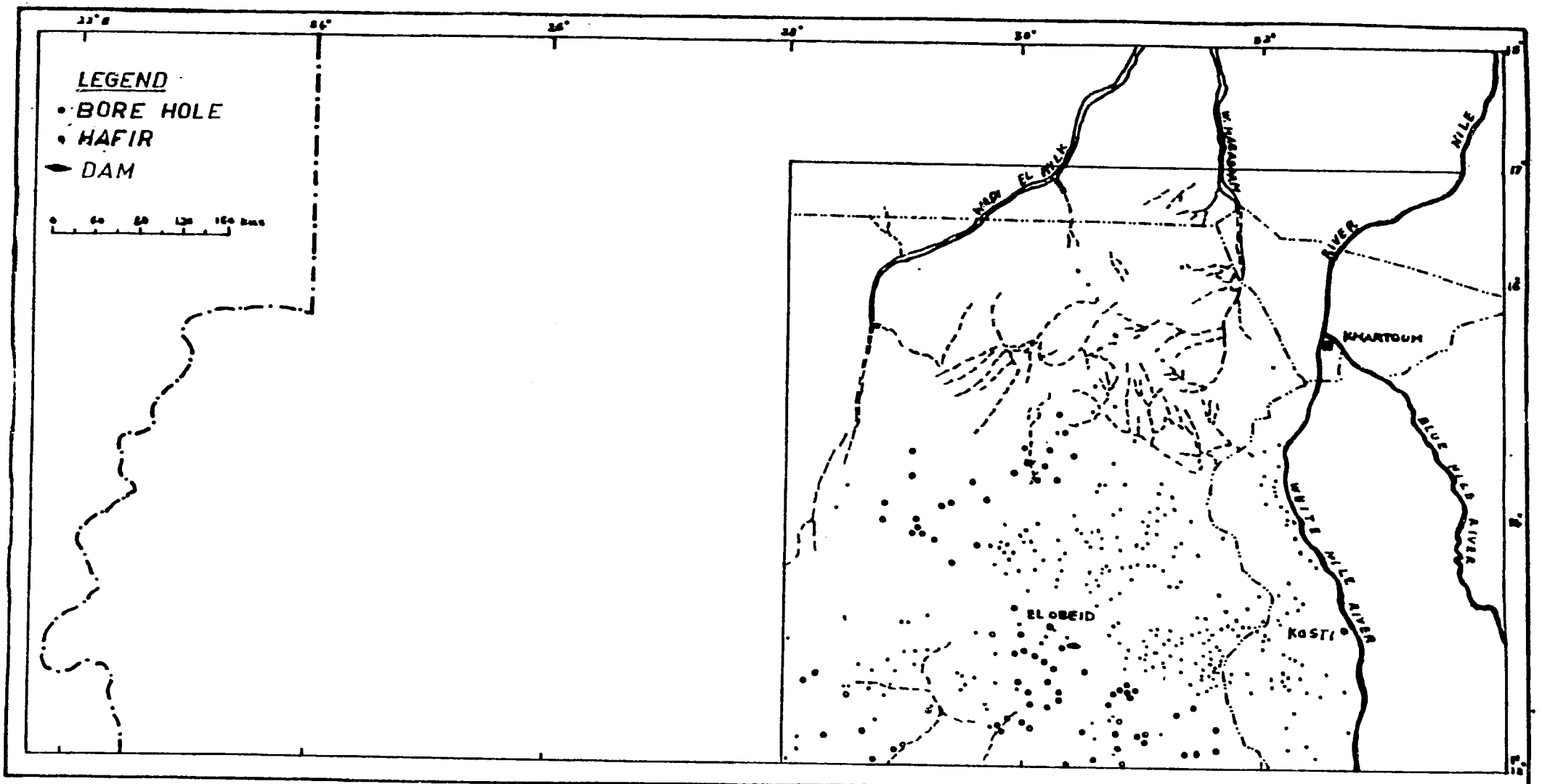
It is an isolated outline of Nubian sandstone with an area of 6,793 km.^{2} around El Nahud. The ground water flow is from west to east with velocities of 1 to 2.75 m/year and water levels ranging from 75 to 120 m.

A summary of the water resources of the various basins is given in Table 5 and Fig. 5.

Table (5): Hydrogeological Data of Ground Water Basins

Name of Basin	Under-flow $M.m^3$	Recharge $M.m^3$	Storage $M.m^3$	Abstraction $M.m^3$	% of Abstraction to Recharge	Present State of Develop.	Manage-ment State	Future poten-tialities	Areas for Development and Detailed Studies
Eastern Kordofan	2.32	15.8	1,710	4.5	28.3	Dev.	Required	Poor	-
Sahara Nile	30.7	136	5,500	7.4	5.44	Under-dev.	Required	Excellent	Wadi El Oaab Wadi El Khuwei Wadi El Mugga-dam
Nahud	1.46	15.4	136	2.54	16.5	Dev.	Very Es-sential	Good	Heidob well field

Source: Reference No. 3



SOURCE: RURAL WATER CORPORATION'S RECORDS, KHARTOUM, SUDAN.

Fig 5: Map showing water supply points

Conclusions & Recommendations

Conclusions:

1. The interpretation and mapping of water resources were carried out using the 1972 Landsat I imageries. The following results were obtained:

   a. Many alternatives were discussed to select the best time for mapping water courses and bodies from the different multi-dates satellite imageries. The imageries of November 8, 1972 proved to be the best because they were cloud-free and at the same time represented the end of the rainy season.

   b. Water courses are best mapped from the Multi-Spectral Scanner (M.S.S.) - Band 7 - black and white imageries with occasional consultation of the color composite imageries.

   c. Water bodies are best mapped from the MSS - Band 7 - black and white imageries.

2. Considering all the land resources affecting desertification such as: overgrazing, deforestration, etc. water is the key factor to full exploitation of these land resources. Since 1957, the Government has spent large sums of money on water development by constructing hundreds of water reservoirs, water spreading schemes, dams and more than a thousand water yards. This, plus the consequent increase in animal numbers, is causing a great grazing pressure on the range surrounding existing water centers. Desert encroachment, particularly in the low rainfall savannah, is mostly confined to the perimeter surrounding these centers.

The development of surface and groundwater in the Study Area has received very little attention with the exception of developing drinking water. Full exploitation of these sources of water could contribute to the reclamation of deserts. For example, to lessen grazing pressure on

the adjacent range lands, fodder is to be produced where water is available.

Water spreading schemes are another means of arresting desert encroachment. This can be achieved through construction of embankments and earth dams across intermittent and ephemeral streams so as to allow water to spread over a larger area and to plant such areas with fodder crops.

Recommendation:

In order to satisfy the second objective as outlined previously by the author, a second interpretation should be made from the 1976 imageries of Landsat 1 and 2 to produce a drainage map of the Study Area. Then a comparison will be made between the 1972 and 1976 maps so as to quantify desert encroachment in terms of past and current water resources and water losses. So it is recommended that the November 1976 Landsat imageries should be made available.

Plate 3. Drainage System Map of Central Sudan. Original scale of 1:500,000 covering region between 11°00'N - 17°00'N latitudes and 28°30'E - 33°30'E longitudes.

An example area of the map at the original scale is on the following page. The original map is available from the author. The map Legend is:

MAIN CHANNEL OF THE STREAM

STREAMS AND TRIBUTARIES

CLEAR WATER

TURBID WATER

PONDS

ROCK OUTCROPS

ROADS (ALL SEASON)

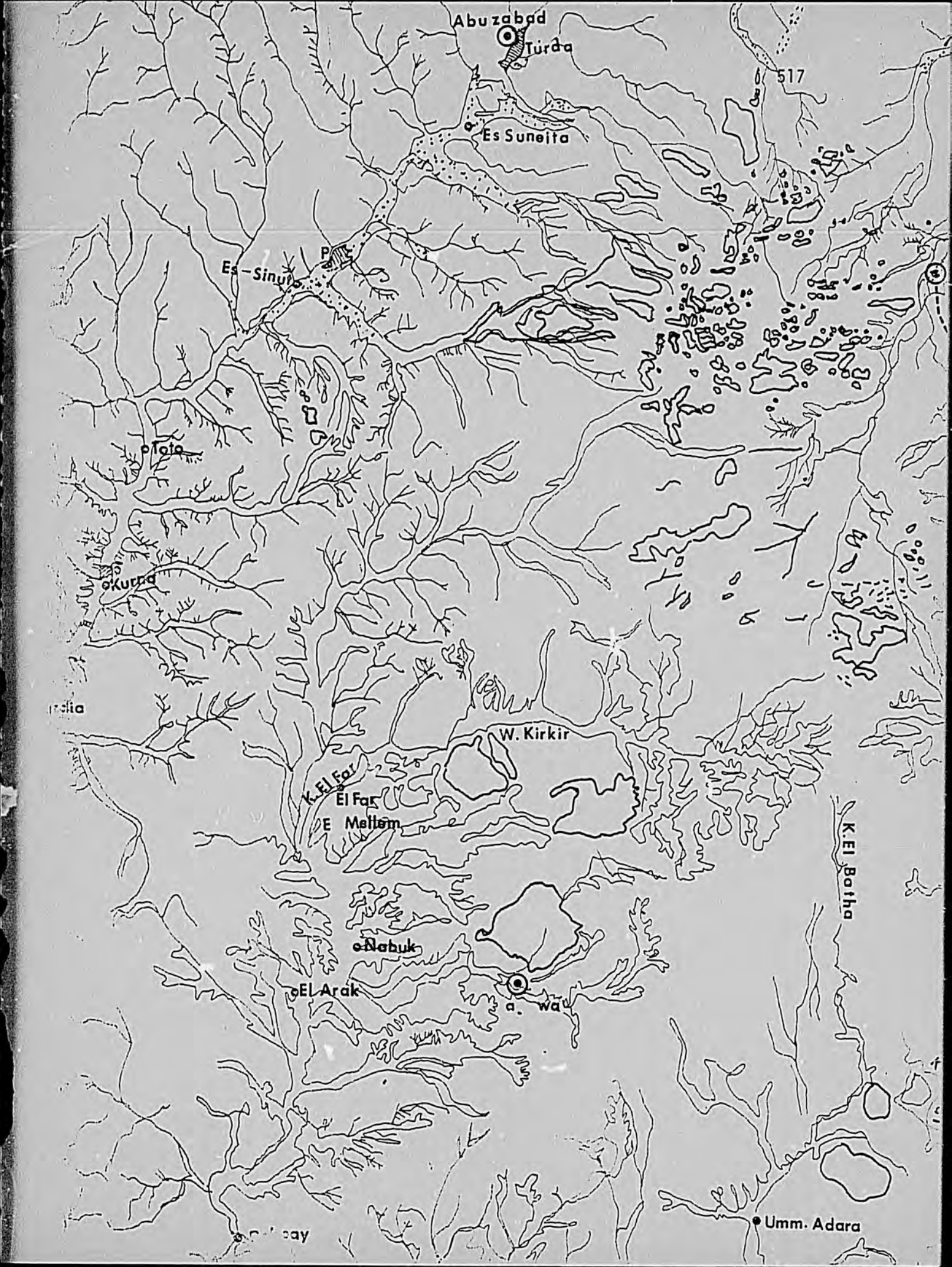
ROADS (DRY SEASON)

FLOOD PLAIN

VILLAGE

TOWN/CITY

DECEMBER 1978


Abuzabad
Turda
517
Es Suneita
Es-Sinut
Tato
Kurna
W. Kirkir
K. El Far
El Far
E Mellem
K. El Batha
Nabuk
El Arak
a. wa
Umm. Adara

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2 - Doxiadis Associates (1966) — Hydronomic Investigation UNSF/FRO, Land & Water Use Survey in Kordofan Province, document DOX-SUD-A51.

3 - Sudan's Desert Encroachment Control Rehabilitation Programme (D.E.C.A.R.P.) — Ministry of Agriculture Food & Natural Resources. National Council for Research.

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A/RAHIM A/AZIZ MOHAMED

INTEGRATED GEOLOGY OF CENTRAL SUDAN

Shadul Ahmed Shadul*

ABSTRACT

The "Central Sudan" is located between Lat. 11°00' - 16°00' N and Long. 28°00' - 33°30' E and covers about 1/10 the area of the Sudan. The area can be divided physiographically into three regions: the central plain which is flat-lying, fertile land on the eastern side, the northwestern region which is the southern extension of the Sahara Desert, and the Nuba Mountains which are topographically highland in the southwestern part of the area. The central Sudan extends from the poor to the rich savanah belt. The area is drained by the Nile River and its tributaries, and the seasonal streams of Abu Habl and Wadi el Ghulla.

Geologic investigation in the area started as early as the beginning of this century but very little systematic work was accomplished. The area under consideration was mapped by interpretation of Landsat imageries and by using published and some unpublished maps and reports as ground truth. Twelve Landsat scenes at a scale of 1:500,000 cover this area. The visual interpretation was done using black and white prints of bands 4, 5 and 7 and a false color composite of bands 4, 5 and 7. Other remote sensing instruments and techniques such as digital processing, the color additive viewer, the reflecting projector, light magnifying lens and the "Image - 100" system were found to be very helpful in interpretation. Keys for interpretation were developed to aid in the organization of the information contained in the present image.

* Director, Geological Survey Administration, Geological and Mineral Resources, Ministry of Energy and Mining, Khortoum, Sudan Report prepared while in training at the VISP at RSI.

The central Sudan is covered by three main rock types: the Basement complex of pre-cambrian age, the Cretaceous Nubian Sandstone, and the Umm Ruwaba sediments of the Tertiary Age. The recent deposits are the sand dunes and alluvial deposits.

The Basement complex is the oldest rock in the area and it consists of schists, granite, gneisses, and younger granite intrusives. The lower basal schists are of chlorite and hornblende with mica-rich bands while the upper schists are carbonaceous metasediments which consist of marble bands and graphitic schists. The granitic gneiss and augen gneisses are of batholithitic nature. The younger granite intrusives are mainly soda granite and syenite.

The Cretaceous Nubian Sandstones lie unconformably on the Basement complex rocks. The Nubian Sandstone consists of two formations: the lower basal conglomerate and the upper sandstone. The basal conglomerate is composed of subrounded to ellipsoidal pebbles, and mudstone and siltstone conglomeratic fragments. It is grey to brown in color, poorly sorted and uncompacted. The upper sandstone formation is coarse to medium-grained quartz sandstone. It contains a thick layer of multicolored mudstone. This formation has nearly horizontal, well-developed graded bedding with ripple marks. The thickness of the Nubian sandstone varies from 500 ft to 1500 ft. The evidence available for both the basal conglomerate and the upper sandstone formation of the Nubian sandstone support the shallow water environment of deposition.

The formation of the Dilling pediment may have taken place after the Nuba Mountain uplift and before the deposition of Umm Ruwaba sediments.

The Umm Ruwaba and the Gezira sediments are flat-lying, unconsolidated sands, silts and clays with some gravels. It is buff to dark grey in color. They are younger than the Nubian sandstones and older than the aeolian sands. They are believed to be of Plio-Pleistocene in age. The author believes that the Umm Ruwaba and the Gezira sediments were deposited by the Nile River and its tributaries. This is supported by the discovery of the old buried channel of the Nile as shown in Plate 1 and the old delta of Abu Habl near Umm Ruwaba. The difference in the grain size of the sediments of Umm Ruwaba and the Gezira is due to the source and the distance of the derived materials. The thickness of sediments varies from a few feet to 365 ft in the Gezira area, and reaches up to 800 ft. at Umm Ruwaba town. It is suggested here that both the Umm Ruwaba and the Gezira alluvial deposits should be renamed as "the Nile formation". This new name would indicate the source and environment of deposition as well as the age of the formation.

The Qoz deposits (stabilized dunes) consist of the longitudinal and transverse sand dunes and sand sheets. The sand dunes are bounded on the east by the White Nile and on the south by khor Abu Habl. The northern and western boundaries lie beyond this area. The height of the longitudinal and transverse dunes reach up to 140 ft and 50 ft, respectively. The Qoz sand is generally rounded quartz sand and has

buff to reddish color. The trend of the longitudinal dune may indicate the effect of the northerly winds. The Qoz deposit is believed to be of Pleistocene to recent in age. The alluvial deposits of the Nile River and the seasonal streams are also of recent age.

The structural features in the central Sudan are generally described as part of the broad structural elements revealed from the geological setting of outcrops on the geological map of the Sudan. The regional trend of schistosity of the basal schists in the Nuba Mountains is north-northeast, south-southwest. This trend affected the younger rock type. The matasediment bands and the shear zone east of Rashad attained the same regional trend as the basal schists. Some of the younger granite intrusives are also aligned along the north-northeast trend. The older granite gneisses are circular in shape and follow the northwest to southeast trend. There are two fault systems: one has a north-northeast attitude and the other follows the northeast trend. Except for surface water supplied by the Nile River and some tributaries, ground water is the main source of water supply in the central Sudan area. The main water-bearing formations in the area in increasing order of their importance are: a) the Nubian sandstone aquifer; b) Umm Ruwaba and the Gezira aquifers; and c) recent deposits.

The thickness of the Nubian sandstone ranges from a few feet to 1500 ft in Khartoum. The average saturated zone ranges from 140 ft at the Gezira area to 1000 ft at En Nahud outlier. Depth to water table away from the Nile basin varies from 80 ft at Soba to 400 ft at En Nahud outlier. The quality of ground water in the Nubian sandstone aquifer is generally good.

Umm Ruwaba sands are very thin in eastern Kordofan area while they reach up to 834 ft near Umm Ruwaba town. The depth to the water table varies between 300 - 400 ft below the surface. The yield and quality of water is highly variable. The average saturated zone of the Gezira aquifer is 70 ft and the depth to water table varies from 20 ft near the Nile to 148 ft in the central region. The yield and quality is also variable.

The recent deposits of Qoz sands and the valley fills in the Basement complex area are of local nature and relatively poor water producers. The water quality is generally good.

Most of the minerals occur in the Basement complex rocks. The major deposit in the Nuba Mountain area is the Abu Tulu iron ore. The iron ore is mainly hematite and the reserves are estimated at 35 million tons with average iron content of 60% Fe. Gold of Jebel Sheibun, of the Nuba Mountains, is known for over 200 years. Other occurrences of gold are reported at Jebel Tira Mardi and Umm Gabralla Hills. Graphite schist and marble bands are located at Rashad area. Jebel ed Dair is known for its fluorspar and carbonatite deposits. Lead and zinc deposits are reported from Dilling area. Tin, tungsten (wolfram), copper and molybdenum are also known to occur at El Qroon el Zurug of the Sabaloka ring complex.

INTRODUCTION

Background

The "Central Sudan" covers most of Khartoum, El Gezira, White Nile, and North- and South-Kordofan Provinces. The area of Central Sudan occupies about one-tenth the total area of the Sudan which is 2,496,138 km^2. Within this area lies the Gezira and Managil extension agricultural schemes. This scheme consists of 1,800,000 irrigated acres where long-fibre cotton, wheat, groundnuts, rice, and sorghum are produced which form the backbone of the economy of Sudan. The gum-arabic production in North Kordofan constitutes about 70% of the world gum production. Rain-fed farming for sorghum, millet, groundnuts, and sesame is vastly practiced in North- and South-Kordofan Provinces. A dense livestock population is grazed in the western area, mainly camels in Northern Kordofan and cattle in Southern Kordofan. The White Nile irrigated farms are mainly cultivated for cotton. At present desert creep, particularly in North Kordofan and the White Nile provinces, endangers some of the cultivated land.

The Central Sudan has been investigated for groundwater to support the irrigation schemes. North Kordofan is well known for being a hardship area due to the lack of an adequate source of both surface and groundwater. Mineral investigations for gold in the Nuba Mountains started as early as the beginning of this century. A few occurrences were recorded but no mining operations have been carried out. Discovery of Jebel Abu Tulu iron ore deposits in South Kordofan of about 35 million tons with an average iron content of about 65% did not invite many investors due to the

lack of infrastructure and the high cost of transportation. No energy source is presently available locally for processing.

Purpose

The Geological and Mineral Resources department of the Sudan has submitted a project, in the six-year plan, for detailed mapping and mineral prospecting of the Nuba Mountains area.

This report is intended to integrate the geology of Central Sudan and to serve as a base for the proposed detailed geologic work in the Nuba Mountains area.

Location

The area of study is located in Central Sudan. Its four corners are:

N.E. Corner Lat. 16°30' N Long. 33°30' E,

S.E. Corner Lat. 11°00' N Long. 32°30' E,

S.W. Corner Lat. 11°00' N Long. 28°00' E,

N.W. Corner Lat. 15°30' N Long. 29°00' E.

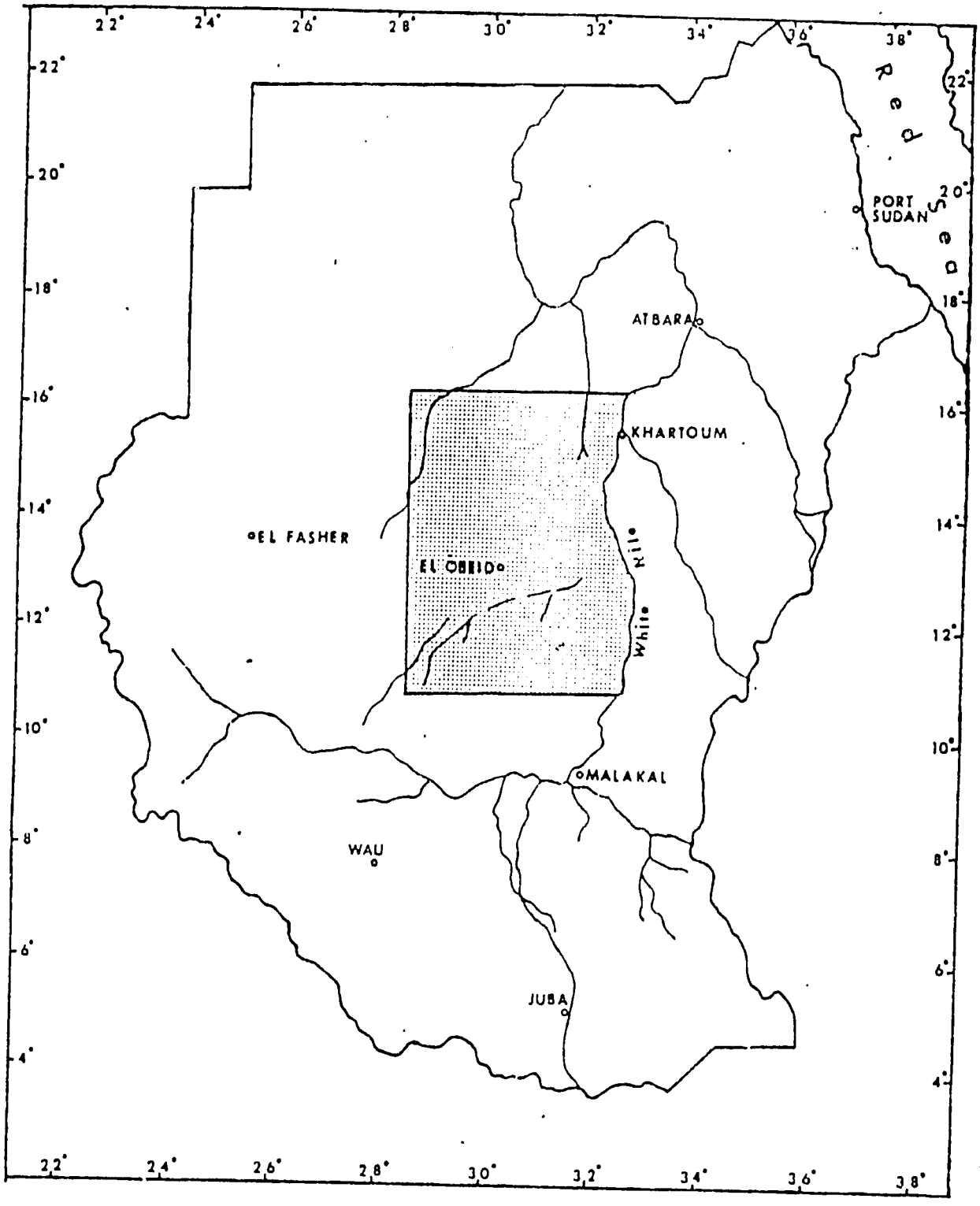
The area studied is about 260,000 sq. km. and is shown in Fig. 1.

PHYSIOGRAPHY AND CLIMATE

Topography

The Central Sudan can be divided into three main regions: a) The northeastern region (Sudan central plain) which covers most of the Gezira, White Nile, Khartoum and the eastern parts of North and South Kordofan Provinces. This central plain is a flat-lying land ranging in altitude from 300 m to 400 m above mean sea level (msl) with a very gentle slope

LOCATION MAP OF STUDY AREA
CENTRAL SUDAN



0 100 200 300 400 500 600
Km

Figure 1

northwards. b) The northwestern region is flat lying and constitutes the southern boundary of the great Sahara desert. It is covered mainly by sand dunes and sand sheets. The region ranges in altitude from 400 m to 500 m (msl) with a gentle slope north-northeast. c) The Nuba Mountains region lies in the southwestern part of the area. It is a topographic high ranging in altitude from 400 m to 800 m (msl). It has a northeast slope towards the White Nile and a southwest slope towards Bahr el Arab.

Climate

The area has an average annual rainfall varying from 150 mm in the north to 800 mm in the south. The rainfall typically starts from May in the south to mid-July in the north and ends in mid-September with a maximum in August. The daily temperature varies from 18° C to 28° C in winter and from 35° C to 42° C during summer.

Drainage

The north-flowing White and Blue Niles are the main tributaries of the River Nile which is the major drainage system of the Sudan. Khor Abu Habl is a seasonal stream which drains the northern area of the Nuba Mountains northeastwards conforming with the slope of the area and forming a large delta west of the White Nile near Kosti. Wadi El Ghalla is the other seasonal stream which drains the west and northwest slopes of the Nuba Mountains southwestwards. Many small seasonal streams such as El Bardab and Shillingo drain the Nuba Mountains southwards. The area of the northwestern plain is drained by small seasonal streams which disappear into the sand sheets. Surface drainage is limited in the sand dunes (Qoz) as

compared to the silty clayey depressions where shallow seasonal lakes (locally called "rahads" and "fulas") are formed.

PREVIOUS WORK

Mapping

Although geologic information has been recorded during the period 1905-1947 regarding mineral occurrences, water supply, and soil classification, yet no geological map was published until 1947. The first geological map of the Sudan was published by Andrew in 1947 at a scale of 1:4,000,000, followed by the second edition in 1949. Andrew gave only a very general description of the geology of the Sudan in Tothill's book, "Agriculture in the Sudan - 1948". This report was accompanied by a regional map at a scale of 1:10,000,000. The Geological Survey Department of Sudan in 1964, now called the Geological and Mineral Resources, published a geological map of the Sudan at a scale of 1:4,000,000 compiled from adjusted quarter million geologic maps. At present, the Geological and Mineral Resources department is updating the 1964 geologic map at a scale of 1:2,000,000. Vail (1969-1973) compiled a geological map at a scale of 1:2,000,000 from interpretation of aerial photographs and satellite imagery. No memoir accompanied the map. The Rural Water and Development Corporation published a hydrogeological map at a scale of 1:2,000,000 compiled from the data collected from groundwater bore holes.

Delany in 1951 compiled the Eastern Khartoum geologic map at a scale of 1:250,000 and published in 1953. Hunting Technical Services in 1964 published four geological maps of El Obeid (55-I), Jebel Ed Dair (55-M),

Iyal Bakhit (54-L), and Abu Zabad (54-P) at scales of 1:250,000 for the Land Use and Rural Water Development department of Sudan. Mansour and Samuel (1957) published a memoir about the geology and hydrology of Rashad (66-A) and Talodi (66-E) sheets. Most of the area of Central Sudan is geologically mapped at a scale of 1:250,000 except the northern part of North Kordofan Province (north of Lat. $15^{0}00'$). It is worth noting that most of this work is unpublished, and some of the open file reports are missing or were never completed. Previous work was carried out by different geologists, so the geological boundaries do not match at some places. The Geological Survey Administration of the Geological and Mineral Resources department, realizing this situation, has started to do the necessary corrections for the compilation of these separate maps into one in the future.

Review of Literature

The geological investigations in the Central Sudan area were carried out in Khartoum and the Gezira regions by Abdul Wahab, O., in 1963 during his drilling for the Shambat bridge site across the River Nile at Khartoum; Kheiralla in 1966 during his thesis work about the Nubian Sandstone Formation of the Nile Valley with reference to groundwater geology; and Abdul Salam in 1966, also for his thesis about the groundwater geology of the Gezira. Both Delany, in the period 1949-54 in Khartoum area with special reference to the Sabaloka ring structure; and Almond, in 1964 gave preliminary accounts of the geology of Sabaloka. This was followed in 1967 by the reporting of a tin-tungsten mineral occurrence at Sabaloka ring

structure. Tagoog Mining Company was permitted to prospect for the tin-tungsten deposit in 1968-69, but with little success.

The geological investigation in North and South Kordofan was carried out by Mansur and Samuel in 1957 during their geological and hydrogeological survey at Rashad and Talodi areas of Nuba Mountains. They gave a detailed account on the basement complex rocks with some reference to mineral occurrences. Mansur and Iskander in 1960 studied the Abu Tulu iron ore deposit near El Fula of the Nuba Mountains. Mansur in 1961 gave a short account on the source of water supply as related to geology in Kordofan Province. Rodis, Hassan, and Wahadan in 1963 investigated the availability of groundwater in the Kordofan Province. A more detailed study was carried out by Rodis and Iskander in 1963 on the Nubian Sandstone outlier at En Nahud area. Several annual reports of general nature were written by Andrew before 1953 and others by Abdalla in the period 1953-60. Whiteman (1971) in his book "The Geology of the Sudan Republic" gave a detailed account of the geological work carried out all over the Sudan with some reference to the adjacent countries. Shadul in 1973 submitted a technical paper about the geology of western Sudan in Arkawit conference held in Taggat, Sudan.

METHODOLOGY

A six months training program at the Remote Sensing Institute, South Dakota State University in Brookings, sponsored by Technical Assistance, Office of Science and Technology, U.S. Agency for International Development, Washington, D.C. was attended. During the training program, this study was carried out as a practical application of remote sensing techniques.

Materials Used

The Central Sudan is covered by twelve Landsat scenes which lie along the three paths 186, 187 and 188, and the four rows 49, 50, 51 and 52. The interpretation was done on Landsat prints at a scale of approximately 1:500,000. Three black and white prints of bands 4, 5 and 7, and a false-color composite of bands 4, 5 and 7 were prepared for each scene. Note that bands 4, 5, and 7 are the spectral regions 0.5-0.6 μm, 0.6-0.7 μm, and 0.8-1.1 μm, respectively. A false-color Landsat mosaic at scale of 1:1,000,000 was also prepared for interpretation. The first Landsat prints produced from the standard transparencies were of poor quality and lacked tonal contrast. Therefore, contrast stretching of the transparencies was made to increase tonal contrasts for ease of interpretation. To avoid any cloud cover, the following dates for Landsat scenes were requested: Oct. 22, and Nov. 8, 1972; Jan. 13, 1973; Dec. 7, 1975; and Jan. 14, 1976. The different periods of Landsat scenes seemed to be useful for interpretation and fit best the other Sudanese professional trainees from different disciplines within the Natural Resources. A systematic detailed individual half-a-million Landsat imagery was analyzed and interpreted visually on a mylar overlay. A hand lens and sometimes light magnifying lens were found helpful for some identification. A reflecting projector was used for the compilation of the twelve frames and to adjust the scale of the Landsat scenes.

Very limited interpretations were made using the International Imaging System Color Additive Viewer (I^2S). Symbol overstrike maps for the Sabaloka ring dyke area were generated using the South Dakota State University's IBM 370/148 computer system. A histogram equilization

technique was used to slice the computer compatible tape (CCT) data into six levels of gray (Fig. 2). The General Electric Image 100 system at the EROS Data Center was used for the analysis and digital enhancement of two subscenes from the Khartoum frame (ID 2319-07275). The first subscene was the Sabaloka area which was classified as follows: (a) ring dyke, (b) rhyolite, (c) weathered Nubian Sandstone, (d) pediment, (e) River Nile water, and (f) surficial materials (Fig. 3). The second subscene was the area between Merkhiyat and the green belt. This subscene was classified as follows: (a) the consolidated Nubian Sandstone at Merkhiyat, (b) the "green belt", (shelter belt for Khartoum for sandstorm protection) (c) the Gezira soil, (d) the weathered Nubian Sandstone, (e) the White Nile water, (f) the Blue Nile water, (g) the River Nile water, and (h) flood plains (Fig. 4).

Image Interpretation Keys

Image interpretation keys often help the interpreter to organize the information present in image form and guide him to reliable feature identification. Identification by selection or by elimination were both applied. The following interpretation keys were developed for the study area.

Visual Illusion: The guiding keys used to recognize the topography are: (a) the streams flow from high land to low land and are bordered by alluvial land, (b) compacted, highly resistant rock outcrops usually form the high relief area, whereas weathered soft rocks form low relief areas, (c) villages are located at the top of fixed sand dunes, rather than in the silty clay depressions between the sand dunes (this is best represented in

Fig. 2. Computer MSS 7 lineprinter maps of the Sabaloka area from Landsat scene 2319-07275. The brightness value intervals for each of the six greytones on the map were selected by analysis of the histogram information for maximum contrast.

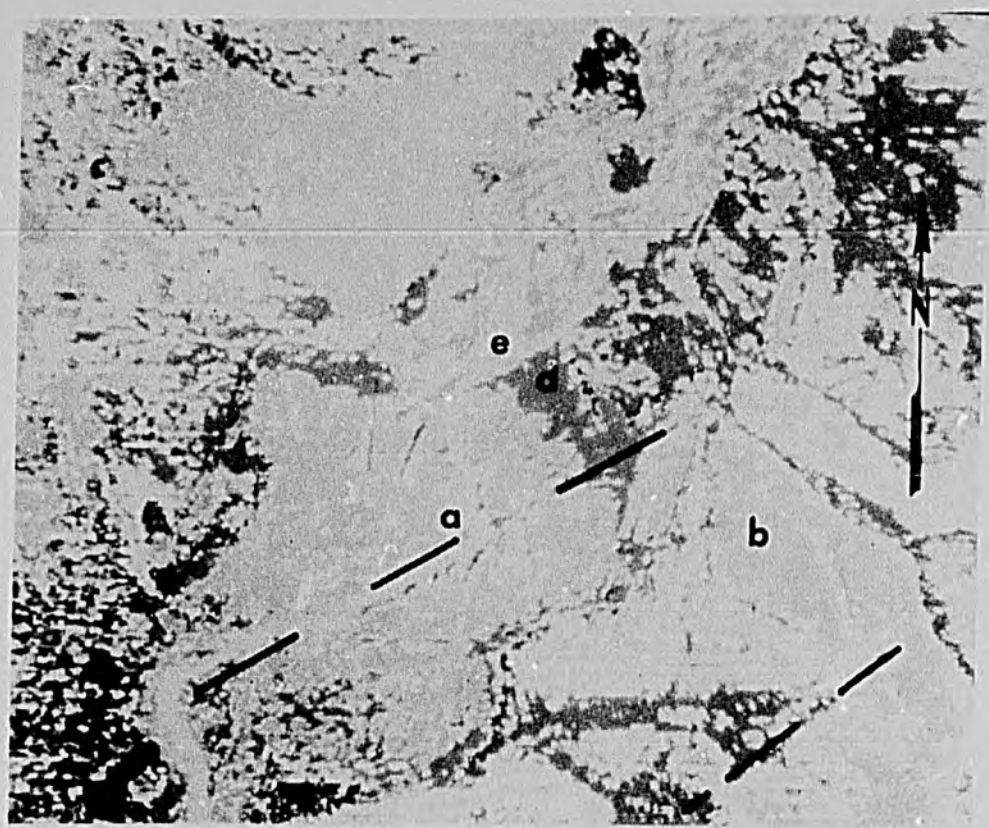


Fig. 3 Sabaloka subscene classification using "Image 100" from the CCT of Khartoum scene no. 2319-07275 showing different classes: a) ring dyke, b) rhyolite, c) weathered Nubian sandstone, d) pediment, e) River Nile, and f) surficial materials. Approx. scale 1:220,000. Original in color.

Fig. 4 Khartoum subscene classification using "Image 100" from the CCT of Khartoum scene no. 2319-07275 showing different classes of: a) Nubian sandstone at Merkhiyat, b) green belt for Khartoum, c) Gezira soil, d) weathered Nubian sandstone, e) White Nile, f) Blue Nile, g) River Nile, and h) flood plains. Approx. scale 1:220,000. Original in color.

the area around Umm Ruwaba town), (d) vigorous green vegetation may indicate water courses, high water tables, depressions and sometimes flat areas. (Actually the latter is sometimes misleading, especially where dense forests are found on slopes or at the top of high relief areas. An example of this is the area around Kadugli town in the Nuba Mountains.)

Drainage Pattern: Drainage pattern creates a texture, or a certain reflection of the underlying geologic formations (Fig. 5). In this area it is noticed that: (a) the drainage is well developed in the basement complex area (hard, crystalline rocks), and has sharp well-defined boundaries; (b) in the consolidated Nubian Sandstone region the drainage is not well developed and has wide undefined water courses (flood plain), i.e., En Nahud outlier; (c) in the loose coarse to medium-grained sand of Umm Ruwaba and sand sheets, there is no drainage pattern, because most of the rainfall infiltrates into the porous sands; (d) drainage patterns may follow certain geologic structures, and (e) the dentritic pattern of the small tributaries may indicate the schistosity plane, as can be seen in Wadi el Ghalla.

Association: Some objects are so commonly associated with other objects that one tends to confirm photointerpretation methods. The characteristics of the weathering of "younger" intrusives (soda granite and syenite) are good examples in this area, i.e. Jebel Ed Dair and Jebel Dambeir and Jebel Atshan. The circular shape of the pediments surrounding the steep rock outcrop with their tonal variations are clearly identifiable (Fig. 6).

Size, Shape and Texture: The size, the circular shape and the impression of roughness are good clues to identify the batholith- or stock-like features of Jebel Limon and Jebel Kadugli of the Nuba Mountains (Fig. 7).

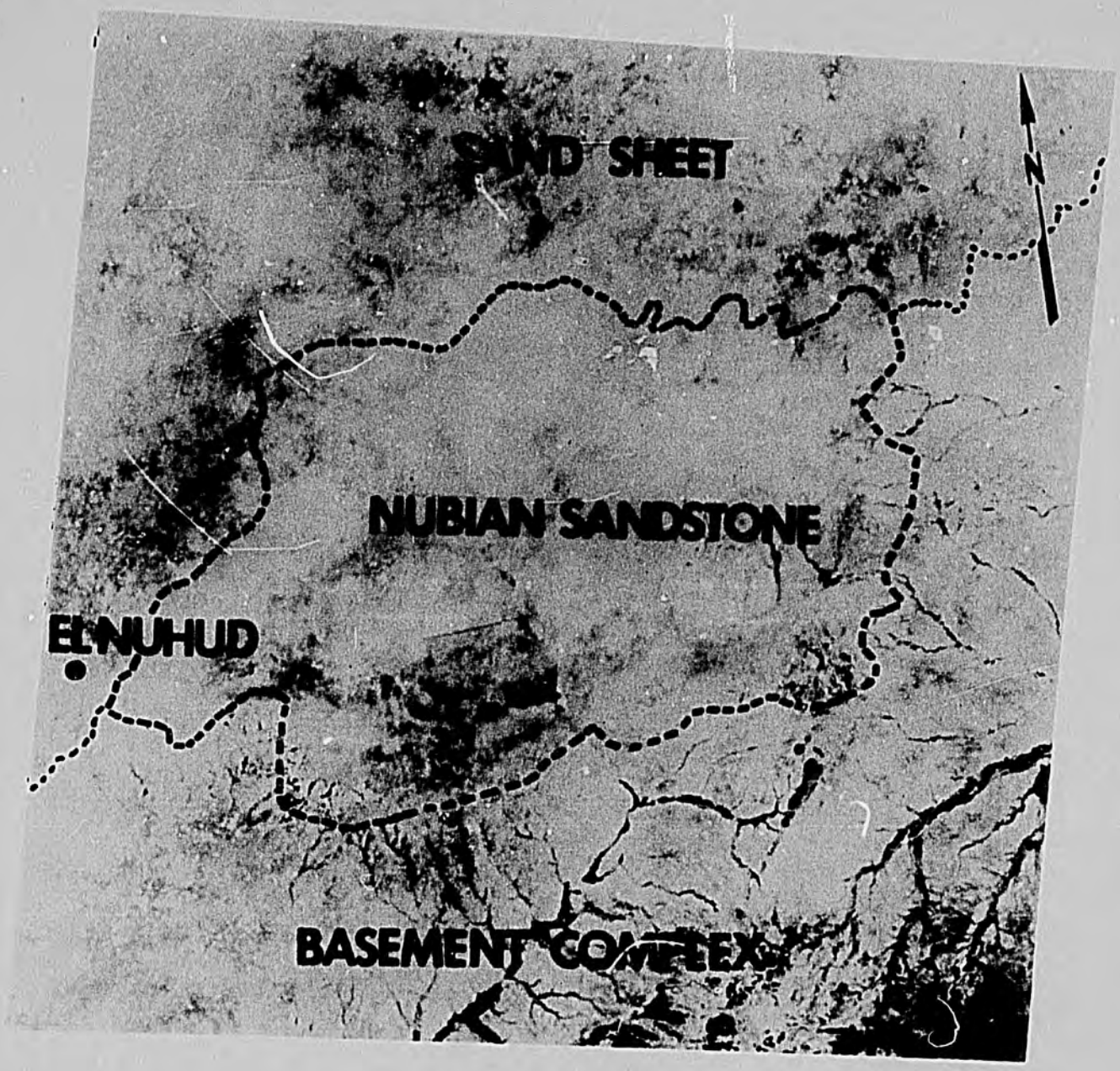


Fig. 5. Landsat scene no. 1109-07540, band 5 for the area east of El Nuhud, showing the drainage pattern well developed in the Basement Complex area, poorly developed in the Nubian Sandstone outlier, and none in the sand sheet area. Approx. scale 1:1,150,000.

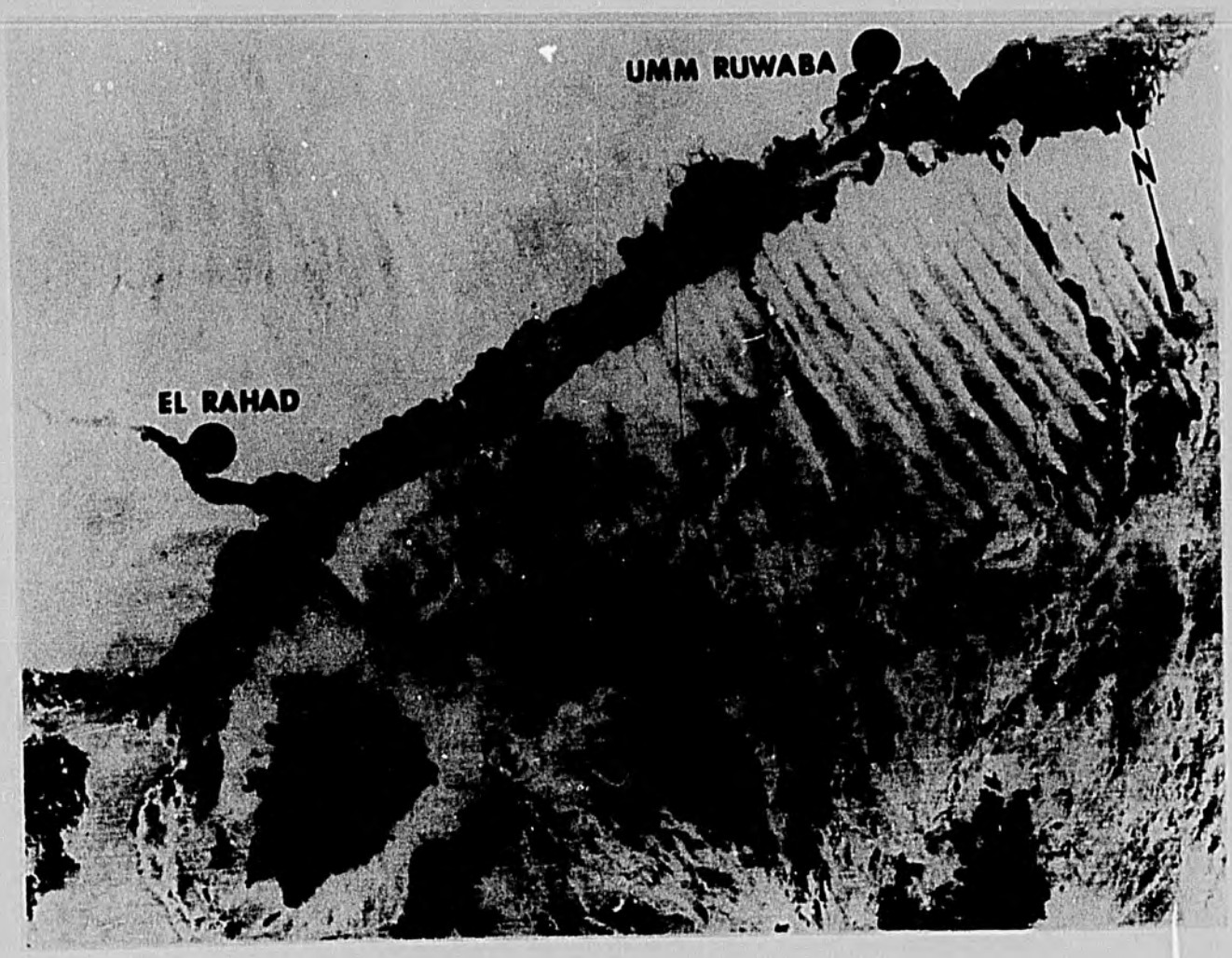


Fig. 6. Part of Landsat scene no. 1216-07484 in band 5 showing the subcircular pediment around the foot of Jebel Ed Dair, an example of weathering characteristic associated with younger intrusives. Also, the longitudinal sand dunes can be seen on both sides of Khor Abu Habl which approximately marks their southern limit. Approximate scale 1:600,000.

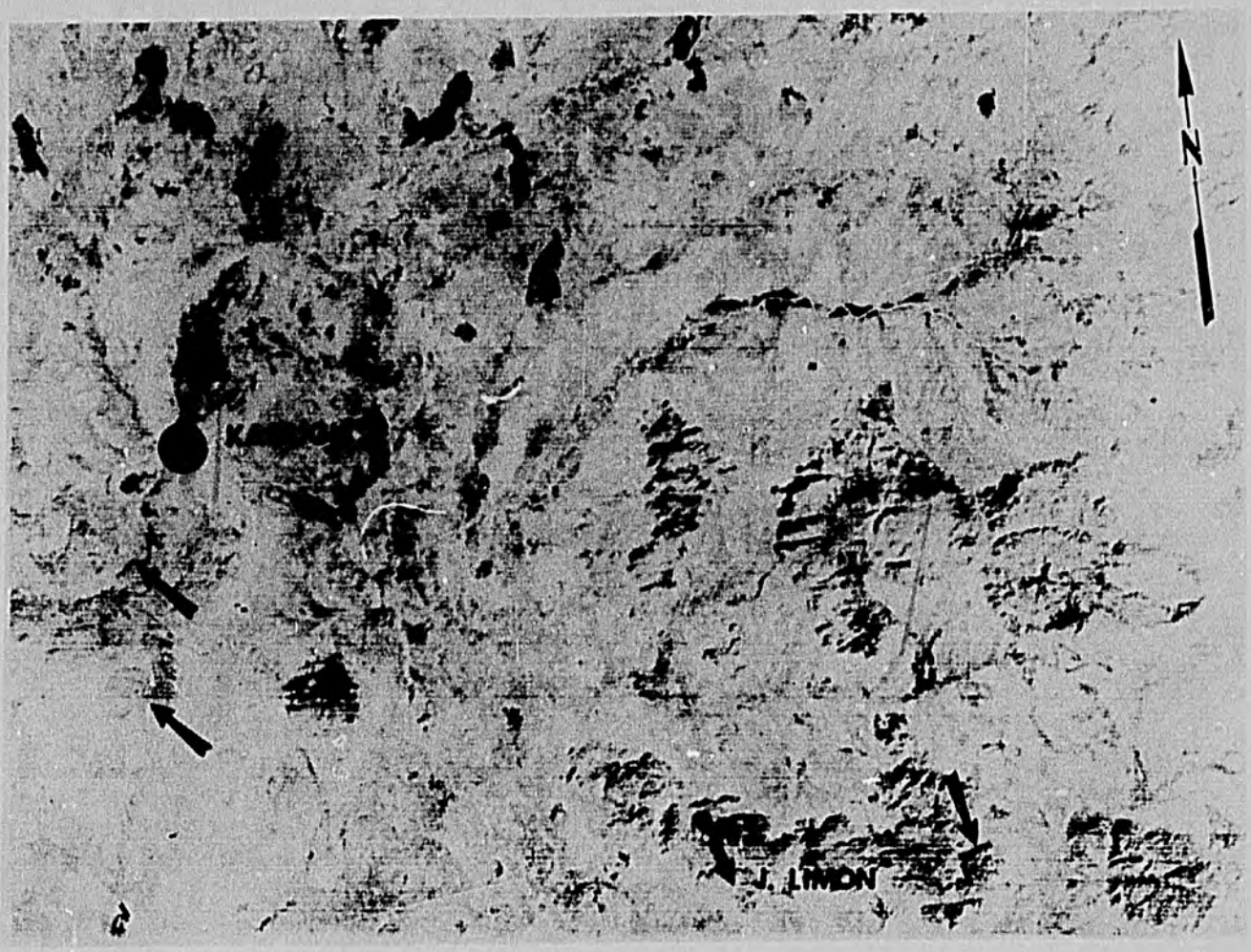


Fig. 7. Part of Landsat scene no. 1108-07484 in band 5 showing the batholith-like structure, the circular shape and rough surface, of Jebel Limon and Jebel Kadugli. Approximate scale 1:536,000.

Enhancement: Vegetation may enhance geologic lineaments. In this area the thin cover of wind blown sand sometimes enhanced the structural lineament of the underlying schist. This is well illustrated in the Sabaloka area where the vegetation enhanced the northeast probably structural lineament parallel to the joints of the crystalline rock of Sabaloka ring dyke (Fig. 3).

Available Data

The author has studied the geology of the Sudan for over ten years and is familiar with the geology of the study area. He made short visits to the Nuba Mountains area in 1974 and 1975, and submitted a paper in 1973 about the geology of western Sudan in Arkawit conference. The author used the unpublished geologic maps covering the Nuba Mountains as ground-truth. He also consulted the four geologic maps published by Hunting Technical Services (1964) and J.R. Vail's (1:2 million) geologic map of Sudan. The literature cited and in particular the Geology of the Sudan Republic by Whiteman (1971) were referred to in the text.

THE BASEMENT COMPLEX

The term "Undifferentiated Basement Complex" is widely used in the Sudan by geologists to describe the metamorphic, igneous, and sedimentary rocks of presumably Pre-Cambrian age. In the absence of isotopic age determination for the Basement complex rocks, only speculation about the relative age of these rocks can be correlated to similar geologic formations in neighboring countries. Potassium-argon data for the Sabaloka ring dyke recently obtained by Whiteman (1971), and isotopic data obtained by Vail

for the biotite-granite of the Ingassana Hills, showed that the younger granites are of Late Pre-Cambrian to Early Cambrian age. These findings did not solve the age problem because some geologists assigned the younger granite to the late Cretaceous-Early Tertiary period for their effect upon the Cretaceous Nubian Sandstone.

A generally accepted evidence of relative age is that the Basement complex rocks are older than the horizontal and subhorizontal Palaeozoic and Mesozoic sedimentary rocks at the NW boundary of the Sudan. Field relations between the Basement complex rocks and the overlying Palaeozoic sedimentary rocks proved to have very insignificant importance on age determination. The erosional and deformational phases that took place during the Cambrian to Jurassic time is unknown in the Sudan due to the missing formation except for a small Palaeozoic sandstone outcrop. The Palaeozoic sandstone is located in a remote, inaccessible area, so it has not been geologically explored or studied in detail. In the Central Sudan area, there is no Paleozoic outcrop on the surface. The only remaining evidence is that Cretaceous Nubian sandstone unconformably rests on the Basement complex rocks.

Most of the detailed work in the Basement complex rocks was carried out in the Red Sea Hills area and eastern Sudan. A correlation chart was published for those areas. The local names, type locality, and terminology used on the correlation chart has complicated to some extent the geology of the Basement complex rocks.

In Central Sudan, the Basement complex crops out mostly in Kordofan Provinces. It is difficult at this stage to correlate the Basement complex rocks of the area to those of other areas. The main effort will be to

define the undifferentiated Basement Complex rocks in this area to mappable small units.

The Basement complex rocks are covered by relatively thick layers of quaternary clays and wind blown sands. The fire burns practiced by farmers to clear the land from grass before cultivation, which is called locally "harig cultivation", are generally practiced in western Sudan. These fire burns mask the rock outcrops from detection on Landsat imagery. The scattered isolated Basement complex outcrops in the area, with all the above mentioned factors, makes it hard for investigators to subdivide the Basement complex rocks.

The author, after careful study, was able to divide the Basement complex of Central Sudan into three main rock types, namely: The Younger intrusive granites, the granite gneiss, and the schists (See Plate No. 1.)

The Schists

There are two main types of schists which are considered the oldest rocks of the Basement complex in the area.

Basal schists

They cover most of the north, central, and northwestern parts of the Nuba Mountains area and consist of chlorite, hornblende-bearing rocks, and mica-rich bands. Gabbro is reported east of Rashad area. Early granite intrusions and acid dykes have had some effect on the basal schists. Interfingering with metasediments is observed at the southern parts of the Nuba Mountains. The schists are trending NNE-SSW, which is the dominant regional trend in the area. This schist trend seems to control the shear zone and the structural lineaments in the area. The Salara hill near

Dilling has an east-west trend. This may be attributed to the fault shown on the map (Plate 1).

Metasediment (carbonaceous) schists

The metasediment schists occupy the northeastern parts of the Nuba Mountains east of Rahad and Abu Gebeiha. They are composed of quartzite, marble bands, and graphitic schists. Calcareous mudstones and slates have been recorded. The Landsat imagery showed greasy graphite-rich bands. These have been identified as outcrops about four kilometers wide and over 100 kilometers long, trending north-northeast east of Abu Gebeiha. This graphite band follows the regional trend. Marble bands near Abu Gebeiha have been reported. These marble bands may be the same as those near Rabak. The metasediment schists may correlate to the Nafardeib series of the Red Sea Hills.

Granite Gneisses

These rocks are mainly of foliated, hornblende, grey to pink granitic gneiss and grano-dioritic gneiss. Fine to medium grain matrix enclosing phenocrysts (augen gneiss) is common. Foliation generally follows the trend of the schists.

Most of these granitic gneisses are located in the northwest-southeast along Lagawa-Kodogli-Talodi areas of the Nuba Mountains. The granite gneisses occur in a form of subcircular to elliptical shape. They are batholiths of three to six kilometers in diameter. The foliation trend, the structural lineament, and the microcline present may suggest that the granite gneisses were subjected to at least one cycle of metamorphism. These gneisses can be correlated to the batholitic granites of the Red Sea Hills area.

Younger Granite Intrusives

The younger granites were first grouped as a subdivision of the Basement complex rocks in the Sudan by Andrew (1948). They are unfoliated soda-granite and syenite fine-grained intrusives. Dark minerals such as biotite and hornblende may be considered as accessories.

These younger intrusives have a circular to oval base and they form high-angle cones. The pediments, or tallus debree surrounding them, are weathered products of these intrusives. They form a distinguishable feature on Landsat imagery (Fig. 6). They have more or less sharp and defined boundaries.

The younger intrusives follow two major structural lineaments in the area. One group follows the northeast-southwest regional trend of the country rock. These are located between Habilla and Jebel ed Dair, and between Soderi and Hamarat el Wazz (Jebel Hadid). The second group of younger intrusives follow the NW-SE trend between Jebel Atshan-Jebel ed Dair-Jebel Abu Haraz. Very prominent structural lineaments follow the same northwest-southeast trend as shown in Plate 1.

There are many isolated younger intrusives scattered in the area. These intrusives are shown in Plate 1. The younger granites are believed to be the younger rock unit of the Basement complex rocks. Sabaloka ring complex was dated as early as 540±25 million years. This was based on Almond's (1967) potassium-argon age determination of a microgranitic and mica-granite of Sabaloka area which resulted in 540±25 and 476±25 M.Y., respectively. It is postulated that the younger intrusives have the same age and probably the same origin as the Sabaloka ring dyke.

Investigators became interested in the younger granites in the Sudan after the discovery of traces of copper, molybdinum and wolfram at Sabaloka. The similarity of petrography and structure of the younger intrusives in the Sudan to those of west and east Africa, where concentrations of tin and tungsten resulted from mineralization, encouraged prospecting for minerals at the Sabaloka ring complex area.

THE NUBIAN SANDSTONE

According to Whiteman (1971, pp. 54-42) the term Nubia or Nubian Sandstone was introduced into Egyptian stratigraphy by Russeger in 1937, and was first used in the Sudan by Beadnell as Nubian Series in 1909, and adapted by Sandford in 1935.

The consolidated, brown to yellowish, subhorizontal bedded sandstones in the northwestern parts of the Sudan, which is a continuation to those of Egypt and Libya, are described by many geologists in the Sudan as the Nubian Sandstone or Nubian series of Cretaceous age. Similar formations in Kasala, Sennar, and En Nahud were considered part of the Nubian Sandstone. The Nubian Sandstone lies unconformably on the Basement Complex rock of the Pre-Cambrian age.

The Cretaceous age of the Nubian Sandstone determined in Egypt and Libya was accepted by geologists in the Sudan. The majority of the fossil specimens found in the Sudan are referred to as the genus Dadoxylon. Fossils such as Weichselia recteulata, fern fragments, and frenelopsis hoheneggeri were collected from Jebel Dirra, 75 kilometers east of El Fasher, North Darfur Province, and were identified by Edwards (1926) as early Cretaceous age. Near Jebel Umm Marrahi, 30 km north of Khartoum, a silicified forest covering some acres was discovered. Specimens up to 16 meters long were found. The marine strata intercalated with the Nubian Sandstone was reported by Delany in 1952 at El Bab, Khor Langeb ($17^{o}15'$ N, $36^{o}38'$ E). She recognized the Nubian Sandstone which lies east of both Jebel Ohara ($17^{o}13'$ N and $36^{o}34'$ E) and Jebel Halli ($17^{o}25'$ N and $36^{o}35'$ E). The outcrop is about 1-2.5 km wide and 2.2 m thick. It is a yellow dolomite, brown to reddish limestone, and Marl and contains gastropods

and plant fossils. The Nubian Sandstone in the Northern Province was found to enclose coal beds (lignite) of 0.10 to 0.65 m thick and about 9 m below the surface at Tangassi, Hamour, and Dongola. Coal beds (lignite) were also found at Wad Kaba in Gedarif area.

Key information about the palaeontological evidence, related to the age and environment of deposition of the Nubian Sandstone, is beyond the scope of this investigation. Lithology of the Nubian Sandstone in Khartoum and part of the White Nile Provinces was described by Kheiralla (1966). Rodis and others in 1963, and B.G. Karkanis in 1965 gave a short account about the Nubian Sandstone in Kordofan Provinces.

Kheiralla in 1966 divided the Nubian Sandstone into five members (from oldest to youngest): (1) Pebble conglomerate (2) Intraformational conglomerate (3) Merkhiyat Sandstone (4) Quartzose sandstone and (5) Mudstone.

Pebble Conglomerate:

This is the basal member which caps the Basement complex rocks, i.e. jebel Rawiyan, Sabaloka. It consists of black phyllite, quartz pebbles, and banded quartzite. The pebbles are disc-shaped, rounded, rod-like, and ellipisoidal shape. The conglomerate member is poorly sorted and varies in size from granulatesto pebbles with some fine sands. It is light to dark brown and chocolate to red in color. The reddish color of this member depends upon the iron oxide content. It is not well compacted and the cementing material is mostly iron solution and silica.

Intraformational Conglomerate:

This member is composed of mudstone, siltstone, and some pebbles embedded in a coarse sandy matrix. The particles vary in shape from plates to rounded fragments and from a fraction of a centimeter to several centimeters in diameter. The color varies from grey to purple and some vary from buff to dark brown. It is poorly sorted.

Merkhiyat Sandstone:

Kheiralla (1966) recognized the following characteristics for Merkhiyat sandstone: (a) high clay-silt content, (b) abundance of white clayey specks, (c) pebbly nature, (d) well-developed cross stratification, and (e) abundant fossils.

The Merkhiyat member consists of coarse to medium sandstone with 30% fine material and some pebbles up to three cm in diameter. It is mainly yellowish to brown but some grey to buff colors are noticed. The member is fairly to poorly sorted. Highly silicified layers occur in many localities but in general the Merkhiyat member is poorly cemented. Graded bedding is exceptionally well developed and cross stratification is common in this member. Kheiralla mentioned that the thickness of Merkhiyat sandstone is highly variable but a maximum thickness of 237 m is reported in SGS borehole number 1517 (El Marrikh Club - Omdurman).

Quartzose Sandstone:

It contains mainly medium to fine grained quartz sands. It is well sorted with about 6% fine clay-silt. The color varies from pale pink to yellowish brown, and at some places a violet to reddish color is noticed.

This member has a flat, well-developed bedding. Fossil ripple-marks are common and indicate a southeast current direction. Binding materials are iron solution and silica.

Mudstone:

The mudstone member consists mainly of clay mineral of Kaolinite group with quartz, mica, sericite, and they are occasionally pyriteous and carbonaceous. It has a grey to chocolate color. Yellowish-brown to violet is common where iron solution is of relatively high concentration.

Rodis, Hassan, and Wahadan (1965) described the Nubian Sandstone of Kordofan. It consists of sandstone, conglomerate, and mudstone with hard ferrugenous and siliceous layers. The strata are generally flat-lying or dip gently northwards. The sandstone grains are subangular to rounded with clay silt matrix. Facies changes in lithology are common in this member. The thickness of the Nubian Sandstone in the area varies from 164 to 558 m. with 500 m at En Nahud outlier.

B.G. Karkanis in 1965 divided the Nubian Sandstone in western Sudan into basal, middle and upper series.

Basal Series

It consists of an alteration of light brown, coarse to very coarse-grained silicified sandstone and conglomeratic beds. It is hard and resistant to weathering and erosion due to the silica cement. Where exposed, it forms mesas of basal conglomerate capping hills of Basement complex rocks.

Middle Series

It contains mudstone and quartzitic sandstone of coarse to very fine grain. It is of multicolor and poorly cemented. The mudstone is dominant and the clay has a bentonitic character.

Upper Series

It is medium to fine quartzitic sands with silts and clays. It has a brown to buff color and is poorly sorted. The sandstone is poorly cemented. The maximum thickness of the Nubian Sandstone may exceed 1500 ft. in the Central Sudan area.

Many geologists have postulated the origin of the Nubian Sandstone in the Sudan. The investigators suggested one of the following major four depositional environments: marine, aeolian, near-shore, and freshwater deposits.

The presence of the rounded boulders in the basal conglomerate, the graded sands to mudstone, some of the marine fossils found, and the ripple marks made some of the geologists believe that the Nubian Sandstone was deposited in a marine environment. Other investigators considered the Nubian Sandstone as a gigantic fossil desert due to the lack of marine fossils and the nature of deposition.

Rodis (1964) suggested a continental and/or near-shore environment. B.G. Karkanis (1965) pointed out that the saline water in the Nubian Sandstone is connate water which may be an indication of marine origin. Kheiralla (1966) postulated a river deposit for the origin of the Nubian Sandstone. He believed that the presence of the large pebble conglomerates, the intraformational conglomerates, the ripple-marks, the graded bedding,

and the lens-shaped forms of the pebble conglomerate bodies indicate channel deposit. Whiteman, (1971, p. 64) suggested that the Nubian Sandstone in the Sudan was deposited in a great series of fans and playa (rahad) separated by low isolated jebels (hills).

The author believes that the information now available about the Nubian Sandstone in Central Sudan is not adequate to postulate the origin of the Nubian Sandstone. Better understanding of the environment of deposition may result from the compilation and analysis of all the scattered pieces of information about the Nubian Sandstone. The writer observed, during his Landsat image interpretation, that a continuous exposed section of the Nubian Sandstone extends from the basal conglomerate at Jebel Merkiyat, Omdurman, and continues northwards just west of Wadi el Mugadam to ed Debba and El Khandag, where it is capped by Hudi chert. A study of jebel Abyad plateau ($18^{o}30'$ N and $29^{o}00'$ E), which is about 160 km west of El Khandag, reportedly found gypsum (or anhydrite) in the Nubian Sandstone, and study may indicate a lagoonal environment for the gypsum deposit. The concentration of gastropods fossils of recent wash observed near el Golid may be derived from nearby area.

The author is of the opinion that the Nubian Sandstone consists of two distinct and well defined formations: the lower basal conglomerate and the upper sandstone.

Lower Basal Conglomerate:

It consists of rounded, subrounded, ellipsoidal, disc-shaped and rod-like pebbles. It contains mudstone and siltstone conglomeratic fragments. This formation has grey to brown color with some units having a buff to

chocolate color. The pebbles vary in size from a few centimeters in diameter to only a fraction of a centimeter. The matrix is coarse sands with some silts and fine material. The formation is poorly sorted and uncompacted. The cementing materials are iron solution and silica.

Upper Sandstone

The upper sandstone is coarse to medium quartz sandstone with some pebbles of up to two centimeters in diameter. It contains a thick layer of mudstone. This formation has nearly horizontal well developed graded bedding. Ripple-marks are common, especially at the top part of the formation. The color and cementing depends to a great extent upon the silica and iron solution. The formation ranges from well sorted to poorly sorted.

The thickness varies from 150 m in Kordofan to 450 m in Khartoum, where the maximum thickness was reported in the north of North Darfur. The environment of deposition was subaqueous in both formations due to the large pebbles in the lower basal conglomerate, and the ripple marks in the upper formation.

DILLING PEDIMENT

The Dilling pediment is located southwest of Dilling. It is an extensive pediment which is about 30 km long and 12 km wide. It is trending north of northeast. It is bounded by a fault on the western side. The age of the Dilling pediment is uncertain but Whiteman (1971, p. 165) postulated its age to the late Cretaceous-early Tertiary age. The formation of the Dilling pediment must have taken place after the Nuba Mountain uplift.

UMM RUWABA AND GEZIRA FORMATION

(NILE FORMATION)

Umm Ruwaba Formation

Andrew and Karkanis (1945, p. 163) proposed the name "Umm Ruwaba series" for the thick superficial deposits that occur on the central plain surrounding the Nuba Mountains.

The Umm Ruwaba formation is composed of flat-lying unconsolidated sands. It consists of medium-grained sands with sometimes gravelly and clayey sands. It is buff to greyish-white in color and is unsorted. Rapid facies and bedding changes in short distances are the general characteristics of the formation.

Some fossils have been found, such as fragmentary teeth, reptiles, mammal bones, large spines of fish and a molar belonging to species Hylochoerus grabhami, which are said to resemble present Nile forms. The Umm Ruwaba age is postulated as Tertiary to Pleistocene.

The Umm Ruwaba sediments were described as fluviatile and lacustrine. Some geologists suggested that the Umm Ruwaba continental deposits were laid down in a depression formed at the same time as the uplift of the Nuba Mountain. Others believed in a presence of a lake Sudd covering an area as far as the rock sill at Sabaloka, which acted as a regulator for the Nile Valley. Whiteman (1971, p. 89) suggested that the Umm Ruwaba deposits were probably laid down in a series of land deltas like the deposits of the Gash delta, near Kassala. Standing water lakes existed from time to time, depending on the relationship between evaporation, transportation, precipitation, date of integration of the river system, river flow, etc.

The thickness of the Umm Ruwaba formation is highly variable as the formation rests unconformably on the Basement complex and the Nubian Sandstone with irregular shapes of basins. Rodis (1964, p. 35) stated that the formation attains a thickness of more than 335 m in eastern Kordofan.

Gezira Formation

Gezira is an arabic word meaning "island". The Gezira lies between the Blue and White Niles confluence at Khartoum extending southward to Sennar and Kosti.

The Gezira sediments are unconsolidated clays, silts, sands, and gravels. At the base of the formation is a gravelly sand layer 9m thick, followed by 35 m of clayey sand. The top layer is 17 m of dark clay and silt known locally as Gezira clays or cotton soil. The Gezira formation rests unconformably on the Nubian Sandstone.

Some fossils such as gasteropods, elephant teeth, fish bones, and spines of species now living in the Nile have been recorded. Gezira sediments are probably of Plio-Pleistocene age.

Andrew (1948, p. 107) suggested that the clays of the central plain are probably post-lower Palaeolithic but pre-Neolithic in age. Whiteman (1971) pointed out that field relationships indicate the Gezira formation may be both late Tertiary and Pleistocene in age. The Khor Abu Anga gravels may be considered as a facies of part of the Gezira formation. Whiteman (1971, p. 125) considered that the two formations of the Gezira and Khor Abu Anga were laid down by two separate river systems. The thickness of the Gezira formation varies from a few meters to 111 m.

The author believes that Umm Ruwaba and the Gezira sediments were deposited by the Nile and its tributaries. This is supported by the interpretation of an old buried channel of the Nile as shown in Fig. 8. The old buried channel lies about 40 km west of the White Nile at Khartoum. The buried channel is clearly connected to the present channel. The western extension of Umm Ruwaba sediments includes the old delta of Abu Habl at Umm Ruwaba (Fig. 9).

The difference in the grain size of the sediments of Umm Ruwaba and the Gezira is due to source and the distance travelled by the derived materials. The Gezira sediments were derived from the volcanic rocks of the Ethiopian plateau and from the Basement complex rocks and Nubian Sandstone in the Sudan. The finer clayey sand materials are predominant in the northern part (near Soba), while the coarse sandy materials were deposited in the central and the southwestern areas. The Umm Ruwaba sediments were transported for a short distance from the surrounding Basement complex and Nubian sandstone rocks. The fossil forms in both Gezira and Umm Ruwaba sediments are similar to the present Nile species.

The section of Umm Ruwaba sediments at Umm Ruwaba town represents a deltaic environment and may not be representative of the whole area. Drilling for oil in the areas of El Muglad, Baraka, and Bentiu may result in a better understanding of the origin of the sediments.

The author believes that the Gezira and Umm Ruwaba sediments are clearly alluvial deposits. They were laid down by the Nile and its tributaries. Both sediments are younger than the Nubian Sandstone and older than aeolian Qoz sands. The age of the sediments is probably Pliocene-Pleistocene.

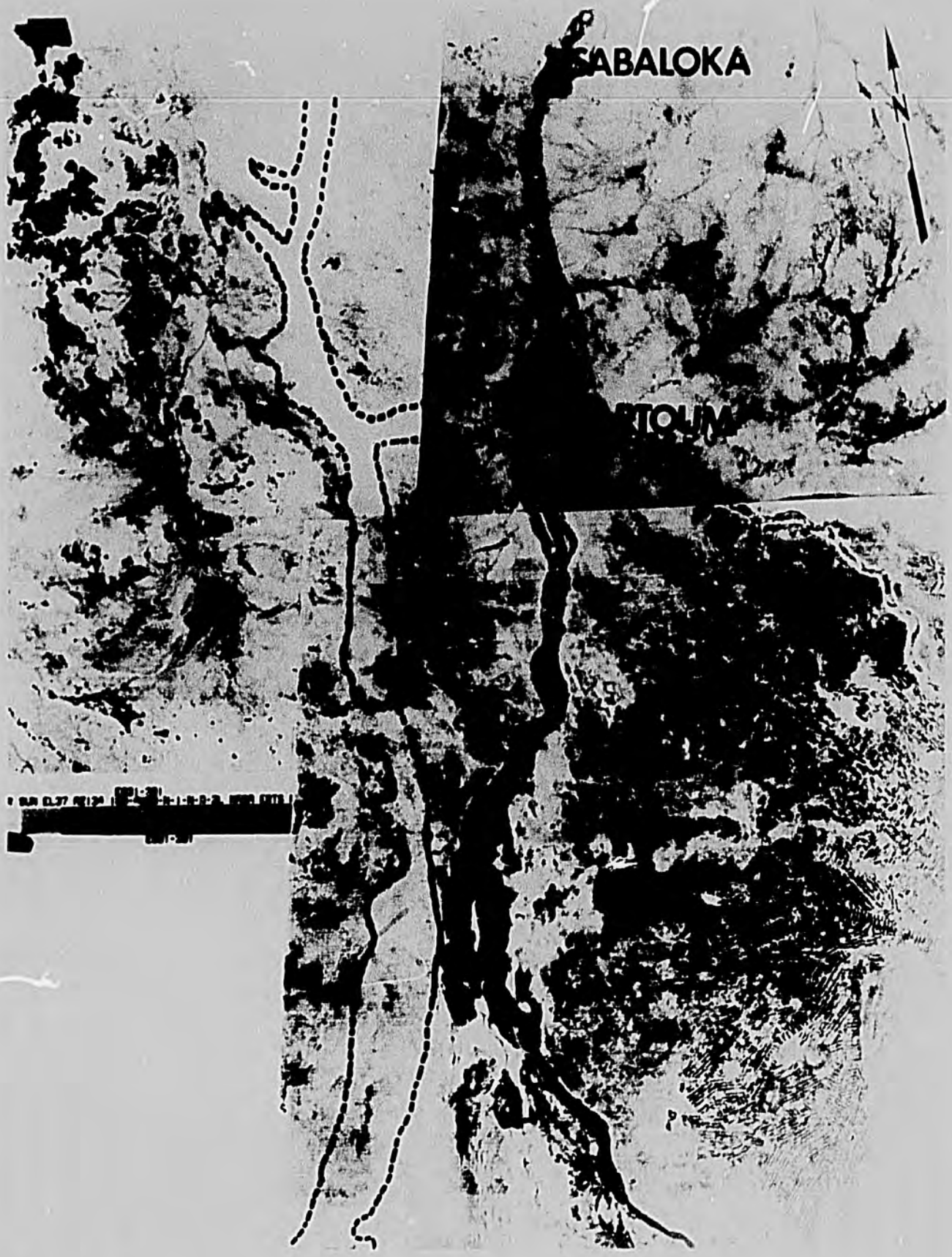


Fig. 8. Mosaic of Landsat scenes no. 1071-07410 (Khartoum) and 2319-07281 (S. of Khartoum) and 2356-07331 in band 5 showing a feature interpreted to be the old buried channel of The River Nile. It is locally known as Qoz Abu Dulu. Approx. scale 1:1,340,000.

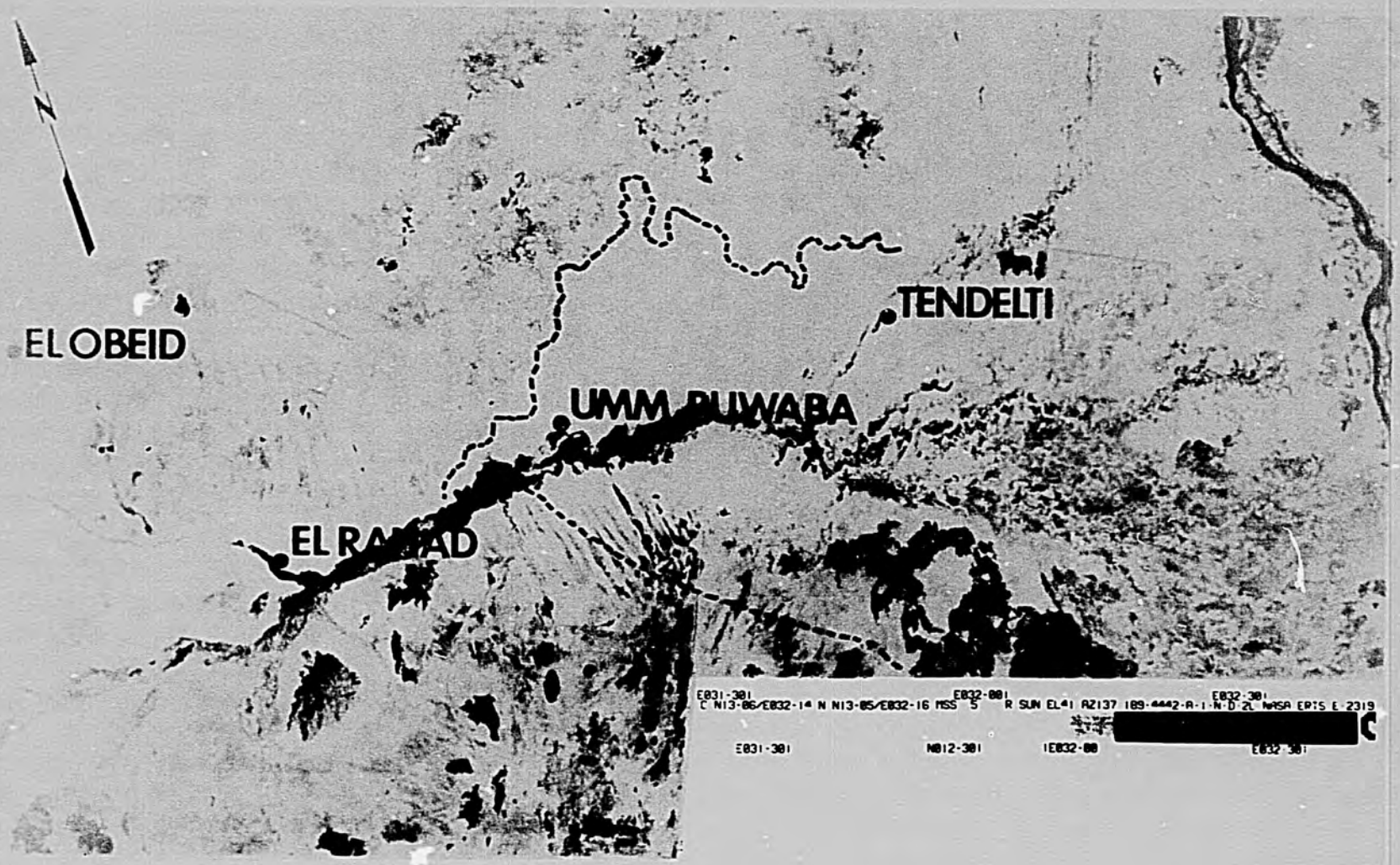


Fig. 9. Mosaic of Landsat scenes no. 2374-07335 (El Obeid) in band 7 and 2319-07284 (Kosti) in band 5 showing the old delta of Abu Habl at Umm Ruwaba and extending northeastwards. Approx. scale 1:1,360,000.

It is worth noting that the old terrace referred to in the literature as the extension of the Lake Sudd was actually the flood plain of the old buried channel. Whiteman (1971, p. 125) suggested that Khor Abu Anga and the Gezira sediments were laid down by two separate river systems. The writer is of the opinion that both sediments were laid by the old river system, but the present Khor Abu Anga is eroding the banks of the old buried channel.

The author suggests that the Gezira and Umm Ruwaba sediments may be renamed as "The Nile Formation" which indicates the source of deposition and age.

RECENT DEPOSITS

Qoz Deposits (Sand Dunes)

The symbol "Qoz" is widely used in the Sudan and means heap. In Kordofan and Darfur, it is often used to mean sand dune. In this report, the Qoz deposits refer to longitudinal, transverse dunes and sand sheets.

Special attention was given to these sand dunes in the Sudan by the Ranch Management department due to their encroachment onto the fertile cultivated lands. They form the front line of the desert creep.

In Central Sudan, the White Nile is the eastern limit of the sand dunes, and Khor Abu Habl from er Rahad to Kosti may be considered as the southern limit of the dunes as shown in Fig. 9. The northern limit of the sands extends beyond the mapped area.

Longitudinal sand dunes

There are three major areas of longitudinal sand dunes: (a) the area between Hamarat et Wazz to Kagmar forms a gap where longitudinal dunes are

formed and trend NNE-SSW, (b) the second area lies between El Obeid and Umm Ruwaba where they trend NNW-SSE (Fig. 6), (c) the third area of longitudinal sand dunes lies west of the White Nile and extends from Wad ez Zaki to Ed Dueim. They are trending nearly N-S.

The Transverse Sand Dunes

The major transverse sand dune area lies at El Kheiran north of El Obeid. The other areas lie west and southwest of Kagmar (Fig. 10).

Sand Sheets

Sand sheets cover most of the area which lies between El Obeid, Soderi, and En Nahud Nubian Sandstone outlier. The sand dunes consist of well-rounded quartz sands of buff to deep red in color. Their color is mainly due to iron oxide staining. According to Whiteman (1971, p. 136) the longitudinal sand dunes are often up to 40 m high and the transverse dunes are up to 15 m high.

The degree of sorting of the sand dunes, the trends shown by the deposits, and the wind shadow indicate that the Qoz deposits (sand dunes) are formed by wind blown materials. The trends, sharp topography, and the slight modification may suggest that the effect of the northerly winds upon these deposits is great.

Dr. Perry Rahn, of South Dakota School of Mines and Technology (personal communication), pointed out that world-wide maximum erosion rates take place where the average annual precipitation is about 300 mm. It is noticed that the Qoz deposits (sand dunes) were stabilized naturally by the thin

Fig. 10. Part of Landsat scene no. 2357-07392 in band 5 showing the transverse dunes west of Kagmar. Approx. scale 1:430,000.

iron stained cover, and sometimes by thin layers of fine silt and clay. The thin vegetation cover serves to reduce wind speed at the ground surface, thus fixing the dunes.

Alluvial Deposits

The silty clays and sandy channel fill of the River Nile, Abu Habl, and Wadi el Ghalla form the alluvial deposits of Recent Age. The thickness of recent alluvial deposits varies from a few centimeters to several meters.

STRUCTURES

In general there is no major structure shown on the published geologic maps of the Sudan. Only a few minor structures are mapped. The structural features in the Central Sudan area are generally described as part of the broad structural elements revealed from the geological setting of outcrops on the map. It is suggested that the Nubian Sandstone in the Gezira area and at En Nahud outlier were laid down in synclinal basins which trend northwest-southeast. Umm Ruwaba sediments are also believed to be deposited in the depression that runs from Malakal to Kosti which was occupied by the Nile Valley. The Nuba Mountains uplift seems to have taken place after the deposition of the Cretaceous Nubian formation and probably before the Umm Ruwaba formation. The Dilling pediment was formed during late-Cretaceous to early Tertiary.

The regional trend of the basal schists in the Nuba Mountains is north-northeast to south-southwest. This trend affected the younger formations. The meta-sediments bands and shear zones east of Rashad town have attained the same regional trend of the basal schists. Some of the

younger granite intrusives are aligned along the north-northeast trend. Other younger granite intrusives and the old granite gneisses (batholiths) follow the northwest-southeast trend. The major inferred faults in this area are trending northwest-southeast as shown in the accompanying map (Plate 1). The north-northeast to south-southwest faults seem to be the older fault system in the area. The northeast-southwest fault, between Dilling and Rigl el Fula, seems to be younger, as it displaced the older fault system. The east-west fault just north of Dilling seems to be the youngest.

GROUNDWATER

Groundwater is the main source of water supply in most of the Sudan. Surface water other than the River Nile and its tributaries, carried by seasonal streams, is conserved in natural depressions (called locally turda, hafir, rahad or fula) and man-made reservoirs. Hand-dug wells are the old type of water points which still supplement the other water supply sources. Open wells (hand-dug) are limited to very small villages due to their low yield.

Due to the high evaporation rate in Central Sudan, the long dry hot season, and the erratic nature of streams in regard to flood intensity and duration, the efficiency of surface water reservoirs is highly reduced.

Abdul Salam (1966) in his thesis gave detailed information about the groundwater geology of the Gezira area. Said (1975), in his doctoral thesis about the geology and groundwater of Khartoum, did a comprehensive work in the area. Kheiralla (1966) referred to the groundwater in the Nubian sandstone.

Rodis, Hassan, and Wahadan (1963), and Rodis and Iskander (1964), published a detailed work about the availability of ground water in Kordofan Provinces. Asaad (1967) in his article dealing with "hafirs" in the Sudan, showed the location, distribution and water capacities of surface water reservoirs throughout the country. Doxiadis and Associates (1964-66) gave an account of ground and surface water potential and its use in Kordofan.

The main water-bearing formations in the area arranged according to their importance are: a) the Nubian formation, b) Umm Ruwaba formation, c) Gezira formation, d) Recent deposits, and e) the Basement complex.

The Nubian Sandstone Aquifer:

Groundwater in Khartoum area is commonly found in the pebbly conglomeratic horizon, and sometimes in the quartzose sandstone. The water table lies between 15 to 45 m below the surface.

The maximum thickness of the Nubian formation in El Gezira area is 240 m at Soba, southeast of Khartoum. The water bearing beds are sandstone and conglomeratic sandstone. The average saturated thickness is 45 m. According to Abdul Salam (1966) the depth to static water level is variable, and the depth to the top of the saturated zone varies from 24 m at Soba to 58 m at Amarat es Sheikh Hagu.

The study of the Nubian sandstone outlier at En Nahud by Rodis and Iskander (1964) showed the maximum thickness of the saturated zone is about 300 m. The depth to the water table ranges from 60 to 120 m. They found that the water is under slight artesian pressure. No draw down in water table was noticed while pump testing.

The groundwater of the Nubian sandstone aquifer is generally good and frequently clear, odorless and has low mineral content. A yield of 1000 gallons per hour (g/h) on the average is typical.

Umm Ruwaba Aquifer:

The Umm Ruwaba formation is thin over the Basement complex in east Kordofan and as a consequence little or no water is found. The thickness of Umm Ruwaba sands varies from 29 m west of the west bank of the White Nile near El Jebelein to 278 m near Umm Ruwaba. The water table lies between 90-120 m below the surface. The yield is highly variable and the water is sometimes saline. The yield and the chemical quality of water from the old delta of Abu Habl near Umm Ruwaba is exceptionally good.

Gezira Aquifer:

The water-bearing strata consists of fine, medium, and coarse grained sands. The best producing horizons are the gravelly sands. The average saturated thickness of the aquifer varies from 18 to 25 m. The depth to the water table varies from 7 m near the Blue Nile to 45 m half way between the Blue Nile and the White Nile. The yield is highly variable ranging from 500 to 10,000 g/h. The quality of groundwater of the Gezira aquifer varies from good to very poor.

Recent Deposits:

The water in Qoz sands (sand dunes) are of local nature and the deposits are generally poor producers.

The Basement Complex:

The water obtained from the Basement Complex area is generally found in the valley fill. The valley fill is gravelly to bouldery and generally shallow. Well yields are typically small but of a good quality.

MINERAL DEPOSITS

Most of the minerals occur in the Basement complex rocks. The minerals are located in the southern part of Nuba Mountains area. The major deposit in the area is the Abu Tulu iron ore deposit. Several gold occurrences were reported in Kadugli-Talodi area. Graphite schist and marble bands are located around Rashad area. Jebel ed Dair is known for its fluorspar and carbonatite deposits. A lead-zinc deposit was reported from the Dilling area. The recently discovered deposits of tin-tungsten (wolframite), copper, and molybdenum are associated with the ring complex of Sabaloka, north of Khartoum.

According to Whiteman (1971, p. 229), the gold occurrence of Jebel Sheibun of the Nuba Mountains has been known to the Arabs of Darfur since 1788. In 1845 Mohammed Ali Pasha, the ruler of Egypt, sent a mission to the Sheibun area in search for gold, but with little success. Panning for gold in the alluvial deposits by the natives in the Nuba Mountains area started over 200 years ago. The "Sudan Territories Exploration Syndicate", which was later changed to "Egyptian-Sudan Exploration Company", held a prospecting license for gold in the Nuba Mountains during the period 1900-1903. Only traces of gold were found and the prospecting was abandoned in 1903. The main gold localities in the Nuba Mountains known are Jebel Tira Mandi, Jebel Sheibun, and Umm Gabralla Hills.

Jebel Tira Mandi:

The gold occurs in the sand and gravels of the channel fill. Quartz boulders, embedded in a reddish clay were also processed for gold. Mansur and Samuel (1957) described the gold locality at Mandi as a small hill at the southern end of Jebel Mandi. Numerous closely packed quartz veins, trending northeast, and dipping 50° west were invading the country-rock schists. No assay analysis was made for the gold content.

Jebel Sheibun:

The fine-grained, grey to pink granite of Jebel Sheibun is dissected by small quartz veins of about 15 cm thick. According to Mansur and Samuel (1957) the gold works are confined to a zone of coarse shallow soil about one to three meters thick.

Umm Gabralla Hills:

The gold is found in milky white quartz veins, and sometimes in smoky quartz veins. These veins follow the trend of the schists which is north-northeast. They are relatively thick veins of over two meters thick.

The gold in the alluvial deposits in Tira Mandi was worked as a spare-time job by natives. The profit was found to be very low and depended mainly on a very low labor cost.

Abu Tulu iron ore deposit:

Jebel Abu Tulu is located at lat. $11^{o}41'$ N and long. $28^{o}40'$ E and lies about 30 km northeast of Rigl El Fula. The iron ore deposit consists of two main conical hills of 80 and 65 meters high above the surrounding plain

level. The ore is mainly hematite. Mansur and Iskander (1960), calculated the iron ore reserves as 35 million tons with an iron content ranging from 55% to 65% Fe.

El Qroon el Zurug, Sabaloka:

According to Almond (1967), the mineralized stockwork forms a hill in the Sabaloka area about 2½ kilometers north-northeast of Abu Dom. The stockwork hillock rises about 22 m. above the surrounding pediment and cuts into the Basement Complex. The mineralized zone is closely associated with the contact of a porphyritic fine granite of the ring dyke. Almond (1967) believed that the mineralization may have originated from a nearby mass of biotite-muscovite granite.

The following minerals have been found within the veins: quartz, mixed hematite, black manganese oxide (after wolframite), wolframite, cassiterite, goethite, limonite, chalcedony, zinnwaldite, jarosite, powellite, galena, fluorite, molybdenite, scheelite, calcite and malachite (Whiteman - 1971, p. 236). Tin tungsten (or wolfram), copper (malachite), and molybdenum (molybdenite) had attracted a lot of investigators and mineral prospecting companies to carry detailed works in the Sabaloka area. Poor results were obtained, as most of the minerals were found to be just traces.

CONCLUSION

The Landsat imagery interpretation as a remote sensing tool proved to be very useful for the survey of natural resources in general and geological survey in particular. It is a quick type of survey, fairly accurate and less expensive compared with the traditional method. It requires very short training to master the technique.

The scattered pieces of geological information in the form of maps at different scales and with a big variety of details, and the geological reports, make the Landsat imagery most fit for the Sudan to integrate such work and to extrapolate this work for other unsurveyed parts.

During the three months period of interpretation of Landsat imageries for Central Sudan, the results obtained may contribute to the geology of the Sudan. Some of the results obtained are:

a) The discovery of the buried channel of the old Nile River.

b) The discovery that the borehold is not a good representative as type locality of Umm Ruwaba formation since it is deposited in a deltaic environment of Abu Habl.

c) The location of the old delta of Abu Habl.

d) The suggestion of renaming Umm Ruwaba formation and the Gezira sediments as the "Nile Formations" since they are both deposited by the Nile River and its tributaries.

e) The identification of additional younger granite intrusives in the area.

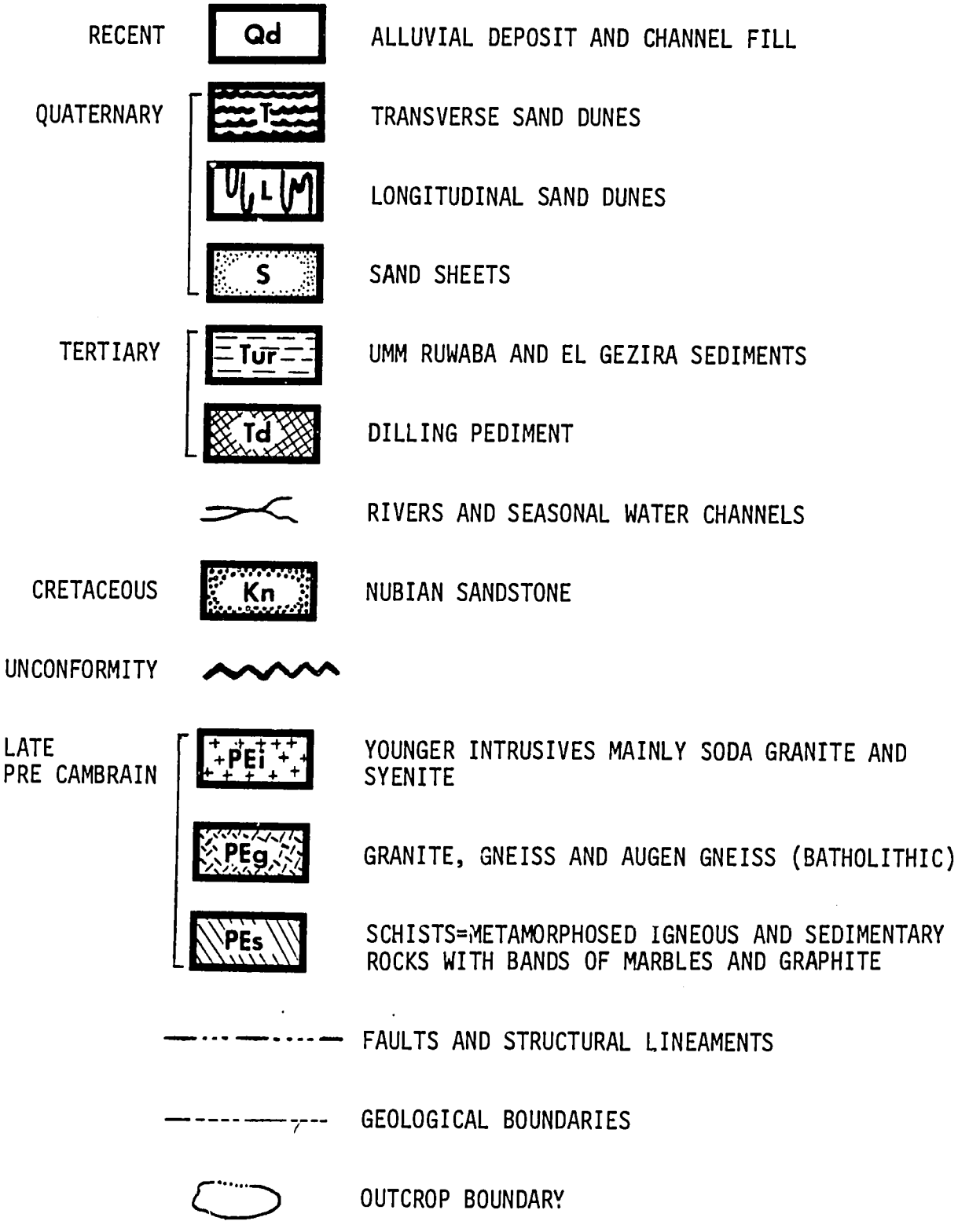
f) The clearly shown structural lineaments and their effect on the different rock types.

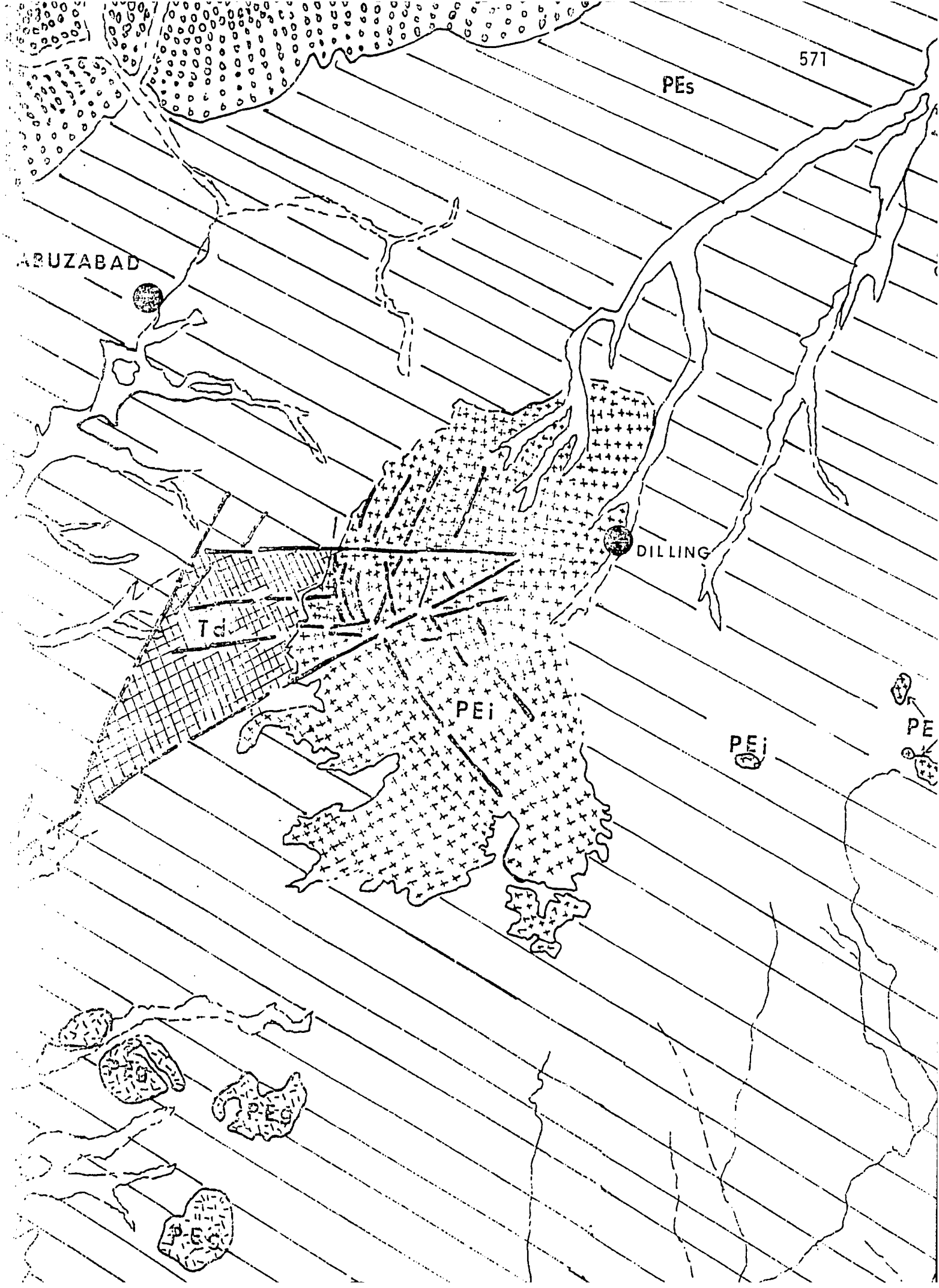
g) The suggestion that the intersection of these structural lineaments at Jebel ed Dair is a favorable environment for mineralization.

h) The location of the longitudinal and transverse sand dunes and sand sheets and their extension which may help in solving the sand encroachment and desert creep problem.

Plate 1. Landsat Photointerpretation of Geologic Features of Central Sudan. Original scale of 1:500,000 covering region between 11°00'N - 17°00'N latitudes and 28°30'E - 33°30'E longitudes.

An example area of the map at the original scale is on the following page. The original map is available from the author. The map Legend is:

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