PD-AAS-085
41965

SOIL SURVEY OF THE YEMEN ARAB REPUBLIC

Progress Report

March, 1980-March, 1981

DEPARTMENT OF AGRONOMY

N. Y. State College of Agriculture and Life Sciences

A Statutory College of the SUNY at Cornell

With Financial Support From the

U. S. Agency for International Development

Cornell University
College of Agriculture and Life Sciences
Department of Agronomy
Bradfield Hall
Cornell University
Ithaca, N.Y. 14853

SOIL SURVEY OF THE YEMEN ARAB REPUBLIC

Project funded by USAID Contract NE-C-1665
Land Classification and Soil Survey of the Yemen Arab Republic
Project 279-0042

PROGRESS REPORT

March 1980- March 1981
(Internal Working Document, not for Publication or Reference)

by

Cornell Yemen Soil Survey Staff

Ithaca, N.Y.
May 8, 1981

CORNELL YEMEN SOIL SURVEY STAFF

Dr. Jack King, Soil Survey Project Leader
Dr. Terry Forbes, Project Coordinator
Ralph Stuart, Technical Assistant
Merrily Dethier, Administrative Aide

TABLE OF CONTENTS

List of Figures iv
List of Tables iv
List of Maps iv

Introduction 1

PART I: TECHNICAL INFORMATION 3

Chapter 1: General Description of the Area 3
(a) Climate 3
Rainfall 3
Temperature 3
(b) Geology 3
Pre-Cambrian Shield 4
Sedimentary Rocks 5
Wajid Sandstone 5
Kohlan and Amran Groups 5
Tawilah and Medj-Zir Groups 5
Tertiary and Quarternary Volcanics 5
Yemen Volcanics 5
Quarternary Volcanics 6
Quarternary Alluvial Deposits 6
Wind Deposits 6
Fluvial Deposits 6
(c) Physiography 7
Landform Regions 7
Descriptions of Landform Regions 7
Basalt Flows (Ba) 7
Coastal Area 8
Inland Alluvium 9
Loess (L) 9
Pre-Cambrian Shield Areas (pC) 10
Sedimentary Rock Areas 10
Yemen Volcanics (Yv) 11

Chapter 2: Survey methods 11
(a) Office methods 12
(b) Field methods 12
(c) Laboratory methods 13

PART II: OPERATIONS 15
Summary of Progress 15
Outline of Staffing and Administration 15
Trips to Yemen 16
1) Dr. A. Van Wambeke 16
2) Dr. J. King 17
Search for Existing Information 17
Off-Campus Search 17
Cornell Campus Literature Search 19
Testing of Laboratory Methods 19
Preparation of Tentative Maps 19

Purchase of Satellite Imagery 19

PART III: FINANCIAL REPORT 21

Glossary of Terms 22
References 23

LIST OF FIGURES

I.1) Climatic Data of Yemen
I.2) Topographic Cross-Section of Landform Regions of Yemen

LIST OF TABLES

I.1) Landform regions of Yemen

LIST OF MAPS

I.1) Rainfall map
I.2) Generalized geology map
I.3) Landform regions map
II.1) Work areas and existing information map

INTRODUCTION

At present, only limited information is available on the soils of the Yemen Arab Republic. The few soil surveys that have been conducted are not sufficient or adequately correlated in a national or international system to serve development needs. They vary in degree of detail, and require complementary studies to respond to an increasing demand for soil resource information. This reduces their usefulness and restricts the transfer of technical knowledge from other areas with similar ecological conditions.

This project involves the mapping of soils and land resources of the Yemen Arab Republic. The study will be a part of the data base for planning the development of agriculture and urban infra-structures.

The objective of the soil survey is to produce a generalized 1:500,000 soil map based on field observations, which will be extrapolated by interpretations of satellite and air-photo imagery. The map will show associations of subgroups as recognized by USDA Soil Taxonomy.

During the initial phase, one soil surveyor with support equipment and personnel will be stationed in Yemen with base operations in Taizz. Field work will include soil profile examination and mapping. Soil analyses required to place the soils into Soil Taxonomy classification will support the field work. Up to 1500 soil samples will be taken, tested and documented throughout Yemen as part of this effort. The surveyor will be assisted by Yemeni personnel, both professional and non-professional. Soil samples will be analyzed by the FAO-assisted Agricultural Research Service in Ausseifere.

The information provided upon completion of this project will be useful in the planning of development activities in Yemen. The survey will assist in locating areas of high potential where more detailed soil information would facilitate the introduction of new technology for agricultural production.

The soil survey will map those areas of Yemen west of longitude 45 degrees, 30 minutes. It will not include islands in the Red Sea.

This progress report details the work done for the soil survey between March 1980 and March 1981. It is divided into three parts. The first describes the climate, geology and landforms of the Yemen Arab Republic and the methods to be used in making the soil survey. The second part describes the activities of the project during the first year of the project.

$

This year involved preparation for the survey field work, which has now begun in Yemen. The final section is a financial summary for the year's work. Appendicies include a glossary and a bibliography.

PART I: TECHNICAL INFORMATION

CHAPTER 1: GENERAL DESCRIPTION OF THE AREA

(a) Climate

The Yemen Arab Republic has a climate of the arid and semi-arid tropical areas. There is no freezing period. Rainfall is very seasonal and its location is dependent on the effects of the mountains. Weather and climate data are very scarce. Few continuous records are found, and those that are found are associated with projects of short duration.

Rainfall

Rainfall varies from approximately 1000 mm/yr in the Taizz area to 0 mm/yr along the coast and in the Rub Al Khali. A probable modal rainfall map is shown in Map I.1. The largest amounts of rainfall are associated with the western mountain front as humid winds off of the Red Sea are forced to rise and cool. Once past the highest mountains, the winds have dropped their moisture and rainfall decreases rapidly to the east.

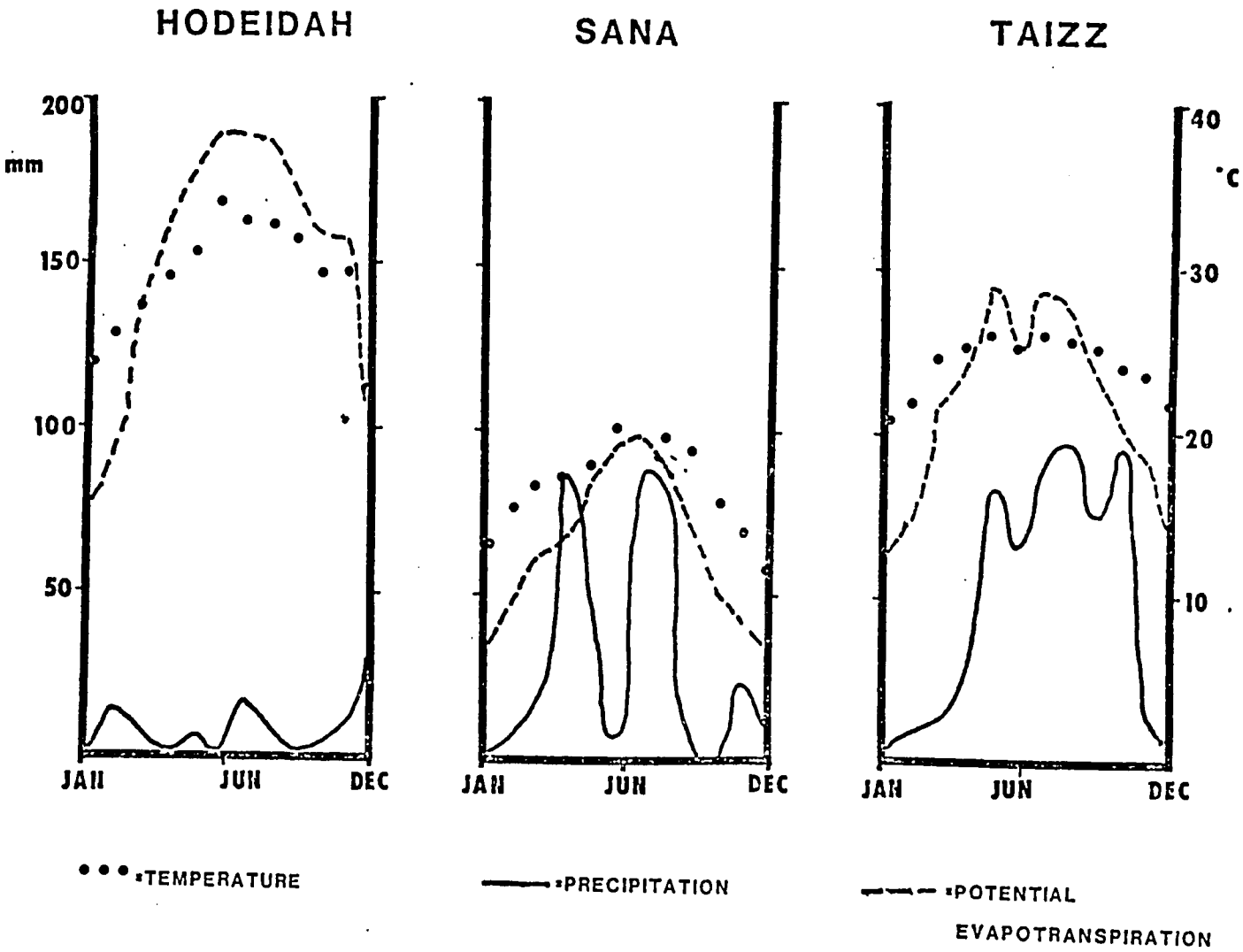
Temperature

Temperature in Yemen is also strongly influenced by elevation. The yearly average ranges from 15 degrees Celsius at Sana to 26 degrees at Hodeidah on the coast. The high temperatures result in high potential evapotranspiration rates (Figure I.1)

(b) Geology

The Yemen Arab Republic includes four major geologic provinces: the pre-Cambrian shield areas, sedimentary rocks of Paleozoic and Mesozoic ages, Tertiary and Quarternary volcanics, and Quarternary alluvial deposits. A generalized

Figure I.1: CLIMATIC DATA FOR YEMEN

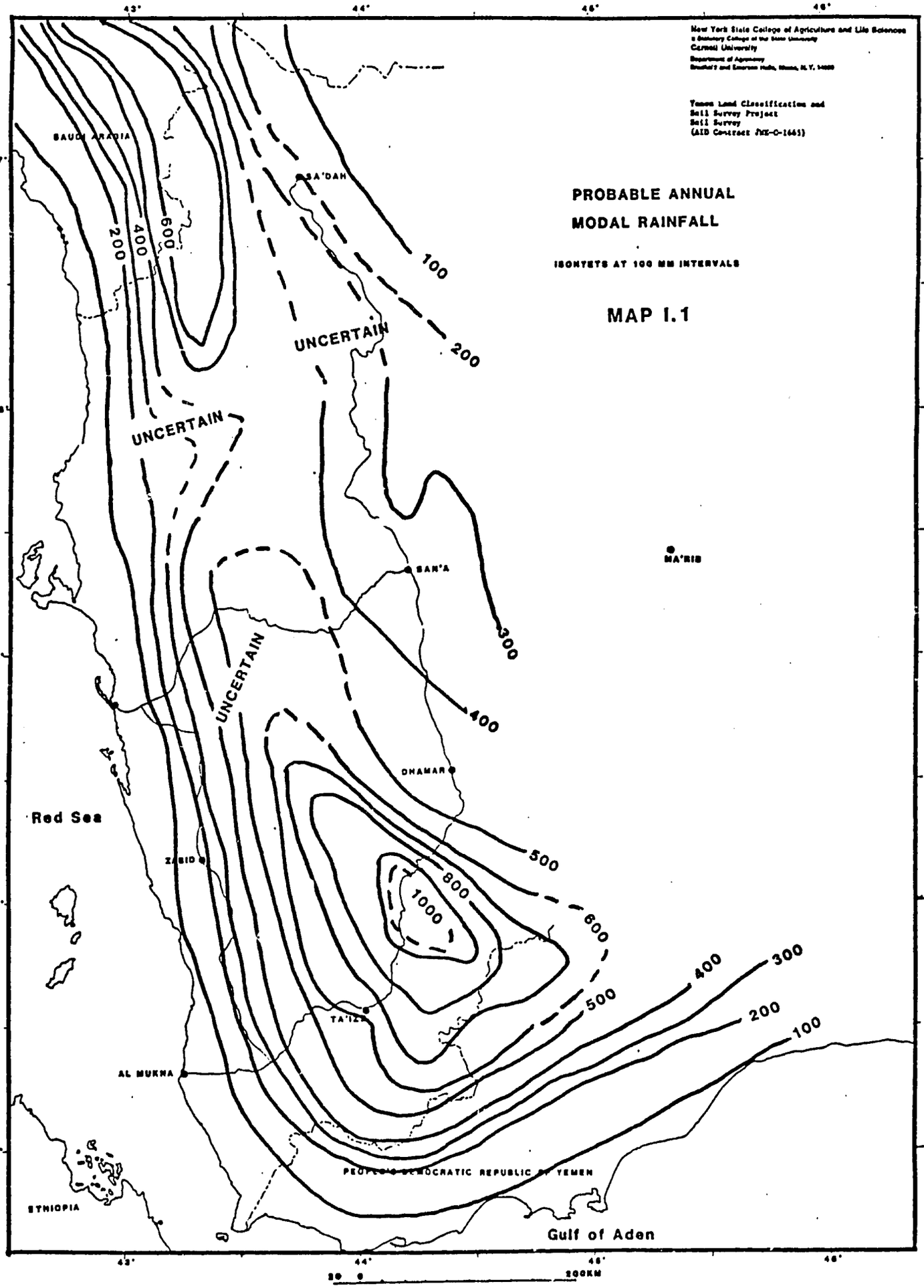


geologic map is given in Figure I.2.

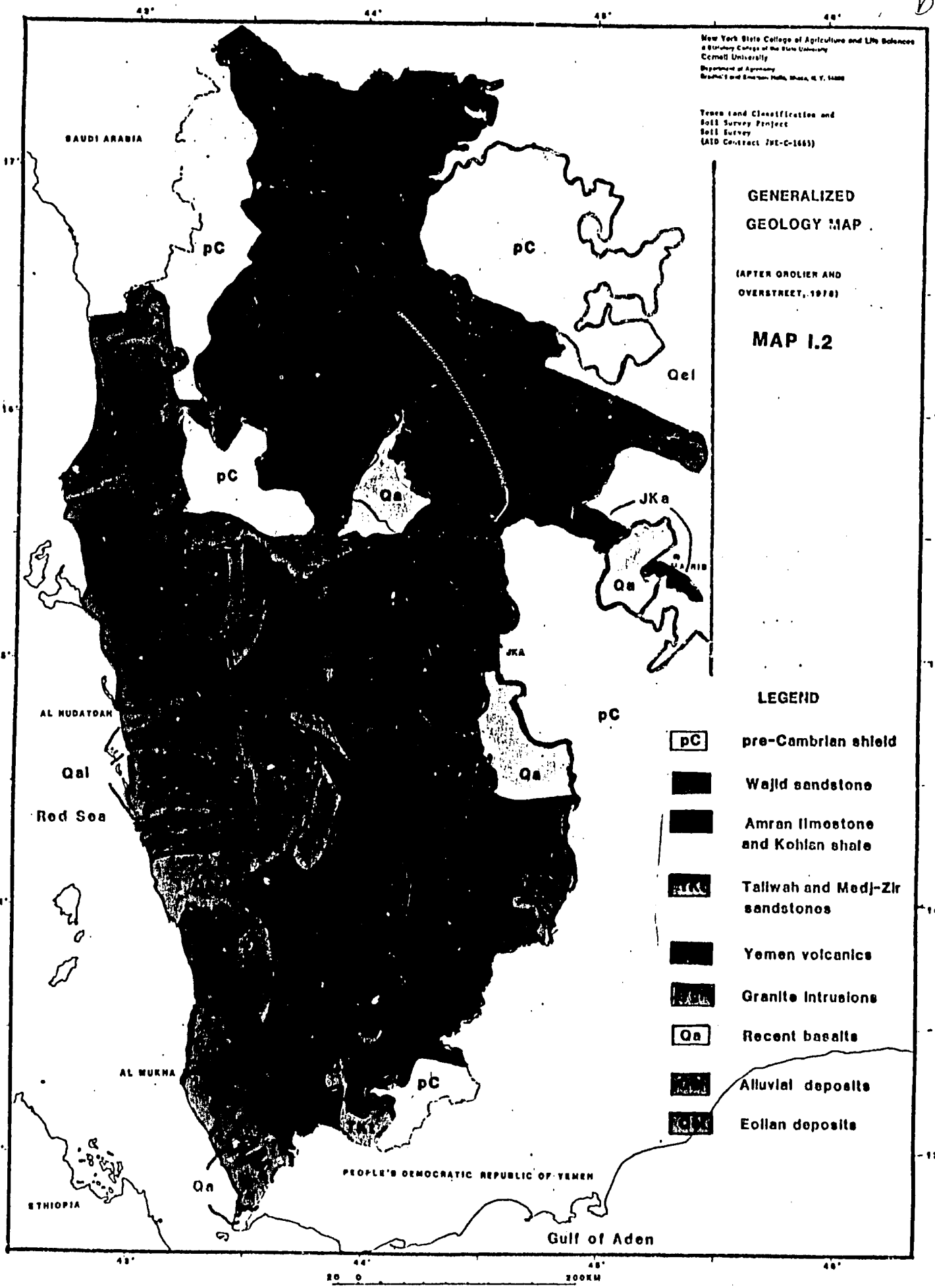
Pre-Cambrian Shield

The pre-Cambrian shield is the basement of the Arabian peninsula. It is composed of igneous and metamorphic rocks. The igneous rocks include pink orthoclase granites, diorite, gabbro, and mafic volcanics. Metamorphic rocks include mica, chlorite and garnet schists, gneiss, quartzite, marble, slate, and amphibolite. The structure of the shield is very complex, because the rocks have been folded and faulted several times.

YEMEN ARAB REPUBLIC



YEMEN ARAB REPUBLIC



Sedimentary Rocks

There are three sets of sedimentary rocks in Yemen, the Wajid sandstone, the Kohlan and Amran groups and the Taliwah and Medj-Zir groups, going from oldest to youngest.

All of the sedimentary rock groups are approximately horizontal. The Wajid sandstone is on top of the basement rocks. The Kohlan group is also in contact with basement rocks at its base. The Kohlan and Amran groups and the Taliwah and Medj-Zir groups are conformable. The Amran and Taliwah groups are unconformable. The Yemen Volcanics Trap Formation is the upper contact of the sedimentary rocks.

Wajid Sandstone : The Ordivician Wajid sandstone is a cross-bedded, coarse-grained, well-rounded, quartz sandstone. It includes frequent conglomeratic gravel lenses. The grain size decreases to the north. It contains no fossils.

Kohlan and Amran Groups : The Jurassic Kohlan group consists of green silty shale and arnaceous sandstone which includes conglomerate lenses. The sandstone is interbedded with and overlies the shale. The sandstone becomes purer in quartz to the north. The Kohlan Series is generally unfossiliferous.

The Kohlan group grades into the overlying Jurassic Amran group. The Amran group contains fossiliferous blue and light gray limestone, marl and calcareous shale and sandstone. The Amran group varies in lithology from place to place, depending on environmental conditions in each area at the time of deposition.

Tawilah and Medj-Zir Groups : The third group of sedimentary rocks includes the Cretaceous Tawilah and Tertiary Medj-Zir Groups. They are cross-bedded, coarse-grained quartz sandstones. They generally contain hematite nodules where they are in contact with volcanic materials. The lower Tawilah group includes conglomerate layers interbedded with red and green shale layers. The Medj-Zir group contains locally fossiliferous layers of calcerous shales.

Tertiary and Quarternary Volcanics

Yemen Volcanics : The Yemen volcanics includes Tertiary volcanic rocks (the Trap Series) and contemporaneous granite laccoliths. The Trap Series (Geukens, 1966) is made up of alternating lava flows, basalts, porphyries and various tuffs. The original volcanic craters are rare. The Trap Series includes sedimentary deposits, which were laid down during

volcanically quiet times. These deposits includes fossils.

The granite laccoliths are exposed both within and adjacent to the Trap Series, and also in the sedimentary rocks north of Sana. They are heavily dissected.

Quarternary Volcanics : Granites which are younger than the Trap Series, and volcanos whose cones are still intact are present throughout Yemen. These were emplaced in the Quarternary. The granites include tourmaline and amphibole crystals. The volcanoes are basaltic and are often enclosed in layers of tuff. The most recent volcanism is located in the Dhamar-Rada area.

Quarternary Alluvial Deposits

Quarternary alluvial deposits can be divided on the basis of their mode of transportation into wind-laid and water-laid material.

Wind Deposits

Loess: Loess deposits are found in areas where mountains are high enough to be a barrier to the wind, causing it to drop its load. The loess of Yemen probably originated in the desert to the northeast, the direction of the prevailing winds.

Dunes: In the survey area, sand dunes are found primarily on the Tihama, where the ground is level. Barcans and some longitudinal dunes are found, indicating that sand supply is the limiting factor of dune formation. The source of the sand is probably the wadi beds and alluvial fans, which receive sand from wadis coming out of the mountains. The great sand seas of the Rub Al Khali are outside of the survey area.

Fluvial Deposits

Alluvial fans and plains: Alluvial fans are deposited where a quick decrease in slope causes a wadi to slow down and drop its load. Plains are laid down in areas of little relief, where wadis spread out and lose more of their speed. Fans are found on the Tihama and along the Wadi Al Jawf, where mountains meet level areas. Alluvial plains are found in the same places, and also in mountainous areas, where inter-mountain basins act as traps of sediments carried by wadis. The fans and plains are made up of coarse-grained material, since the dryness and lack of vegetation allow the wind to carry away finer particles. The source of the sediments carried by the wadis is the weathering of the mountains, which are made up of the rocks described

above.

(c) Physiography

Landform Regions

A map of the landform regions of the Yemen Arab Republic is given in figure I.3. The legend of the map is given in Table I.1. It divides the country into areas in which similar soils occur as associations in a generally uniform pattern. The landform regions were recognized on the basis of topography, bedrock geology, and climate. The topographic relationships between the landform regions are shown in Figure I.1.

The sources used for the preparation of this map were the USGS 1:500,000 geologic and geographic maps (Grolier and Overstreet, 1978), which used Landsat imagery as their base. Selected areas were also examined with airphotos at 1:40,000 scale, obtained from the Resource Information Laboratory at Cornell University. Because of the scale (1:500,000) of the information used, only general landform regions were outlined. Possible soils expected to occur in each area were tentatively classified to the Soil Taxonomy subgroup level.

The country was divided into seven general areas, with as many subdivisions as possible. These are: pre-Cambrian shield areas, sedimentary rock areas, the Yemen volcanics area, recent basalt flows, loess deposits, the coastal area and inland alluvium.

Descriptions of Landform Regions

Basalt Flows (Ba) Recent basalt flows occur throughout the country and vary widely in the amount of area covered. Three major flows are distinguished. Smaller isolated flows and cones are grouped within one of the three major divisions.

The first flow observed (labelled Bal) is located about 100 km north of Sana in an area which receives about 300 mm of rainfall per year. It is relatively unweathered. It does not appear to support agriculture, although nearby alluvial areas receiving irrigation are heavily cultivated. Isolated basalt cones were grouped in the Bal category because their alluvium could support agriculture, given enough moisture. At present however, there are

generally no crops around these features, due to lack of rainfall and irrigation.

The second flow (Ba2) is located just west of Marib. It receives less than 200 mm of rain per year and is unweathered. Sparse irrigation agriculture exists in alluvial areas.

These two basalt regions are landscapes of basalt cones and flows surrounded by colluvium grading into alluvial fans. The Ba2 flow is much less weathered than Ba1.

The third basalt flow (Ba3) region occurs about 80 km east of Dhamar and receives more rainfall than the other two. Airphotos were unavailable for this area, but it appears on the satellite photos to be more weathered than the other two basalt areas. This area is a dissected basalt plateau. Again, areas of basalt alluvium are heavily cultivated.

Soil subgroups suggested for all three areas include Ustochreptic Calciorthids, Natric Calciorthids, and Lithic Camborthids.

Coastal Area This area is usually referred to as the Tihama. Three types of landforms were distinguished: wadis, alluvial fans and coastal plain.

Alluvial fans (F): Alluvial fans are low, relatively flat masses of loose rock material, shaped like a segment of a cone and deposited by a wadi where it issues from a narrow mountain valley.

The coastal alluvial fans were grouped as F1. The material making up the fans comes from the highlands; the Yemen volcanics in the south and the pre-Cambrian shield in the north. They receive very little rainfall (200-300 mm/year), but are used for agriculture when wadi water is available. The most heavily cultivated areas are at the mouths of the wadis coming out of the mountains. Other areas were cultivated as possible, some using bund farming. Generally, the southern fans have more water available from wadis than northern fans, due to higher rainfall in the south.

Coastal wadis (W): Wadis are stream channels that are dry except during the rainy season. Wadis on the coastal plain generally receive water from the mountains to the east. There is little to no rainfall on the Tihama to supply wadis directly. Most wadis dry up before reaching the Red Sea. Wadi alluvium, which is brought from the mountains and adjacent fans, forms flat plains. It is cultivated, but not as extensively as the fans. In drier

8a

YEMEN ARAB REPUBLIC

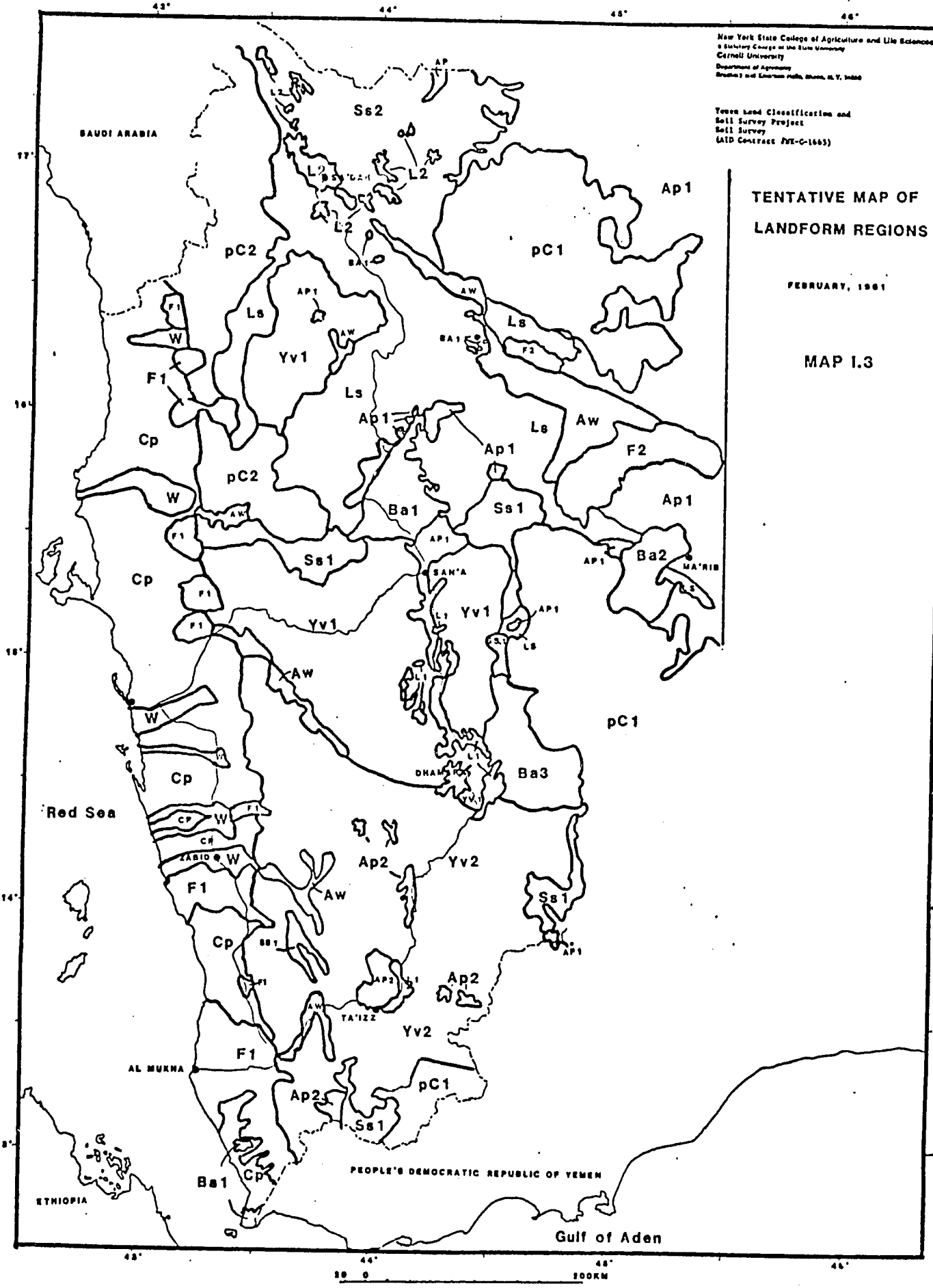


TABLE I.1 LANDFORM REGIONS OF YEMEN

MAP SYMBOL	LANDFORM REGION	DESCRIPTION	ELEVATION (M)	RAINFALL (MM)	AMOUNT OF AGRICULTURE	ACCESSIBILTY	POSSIBLE SOIL SUBGROUPS
Ap1	Alluvial plains	Broad plains with protruding volcanic cones	2500	300	Moderate	Good	Typic Torrifluvents Fluventic Camborthids Aridic Argiustolls
Ap2	Alluvial plains	same as above	1500	900	Extensive	Good	same as above
Aw	Wadi alluvium	Wadis between steep valley walls	Variable	Variable	In wadi flood plains	Variable	Typic Torrifluvents Fluventic Camborthids
Ba1	Basalt flows	Basalt cones and flows, colluvium grading into alluvial fans	2000-2200	300	Low	Good	Ustochreptic Calciorthids Natric Camborthids Lithic Camborthids
Ba2	Basalt flows	same as above	1200	200?	Low	Good	same as above
Ba3	Basalt flows	Dissected basalt plateau	2500	400	Moderately extensive	Fair	same as above
Cp	Coastal plain	Flat to gently rolling alluvial plain; Barcans and some longitudinal dunes	60	<200	None	Good	Fluventic Camborthids Typic Camborthids Fluventic Haplustolls Typic Torrifluvents Typic Calciorthids Typic Paleorthids Typic Salorthids
F1	Alluvial fans	Alluvial fans cut with wadis	0-300.	200-300	Extensive; bund farming in drier areas	Good	same as above
F2	Alluvial fans	same as above	1000	0-100	None	Poor	same as above
L1	Loess	Sharp pinnacles;dissected terraces	2000	400	Extensive, heavily terraced	Good	Aridic Natrustolls Aridic Calciustolls Aridic Argiustolls Natric Camborthids
L2	Loess	More dissected, less terrace area than above	2600	400	Low	Good	Lithic Calciorthids Lithic Camborthids Aridic Calciustolls Anthropic Camborthids Natric Camborthids

Ls	Limestone	Dissected and jointed limestone plateau	1800	200	Extensive; but no terracing on valley walls	Good	Ustochreptic Calciorthids Lithic Calciorthids
pC1	pre-Cambrian shield	Jagged mountainous terrain with braided stream channels	1800	200	None (some minor in valleys in north)	Poor	Typic Torrifluvents Complexes of rock outcrop
pC2	pre-Cambrian shield	same as above with terracing for agriculture	1000-2600	600	Important in valleys and heavily terraced	Fair	Typic Torrifluvents Ustochreptic Calciorthids Lithic Calciorthids Aridic Calciorthids Anthropic Camborthids Aridic Argiustolls
Ss1	Sandstone	Highly dissected sandstone plateau with entrenched streams	2000	600	None	Poor	Lithic Camborthids Fluventic Camborthids
Ss2	Sandstone	same as above	1500	100	Little	Poor	same as above
W	Coastal Wadis	Intermittent stream channels on coastal plain	<300	<200	Moderately extensive; threatened by blowing sand	Good	Fluventic Camborthids Typic Camborthids Fluventic Haplustolls Typic Torrifluvents Typic Calciorthids Typic Paleorthids Typic Salorthids
Yv1	Yemen Volcanics	Highly dissected volcanic plateau with alluvial plains between mountains	2400	<600	Little- in river valley few terraces	Good	Lithic Camborthids Fluventic Camborthids Typic Torrifluvents
Yv2	Yemen Volcanics	Moderately dissected volcanic plateau	2000	>600	Moderate; extensive terraces	Fair to Good	Aridic Natrustolls Natric Camborthids

Topographic Cross-Section of Landform Regions

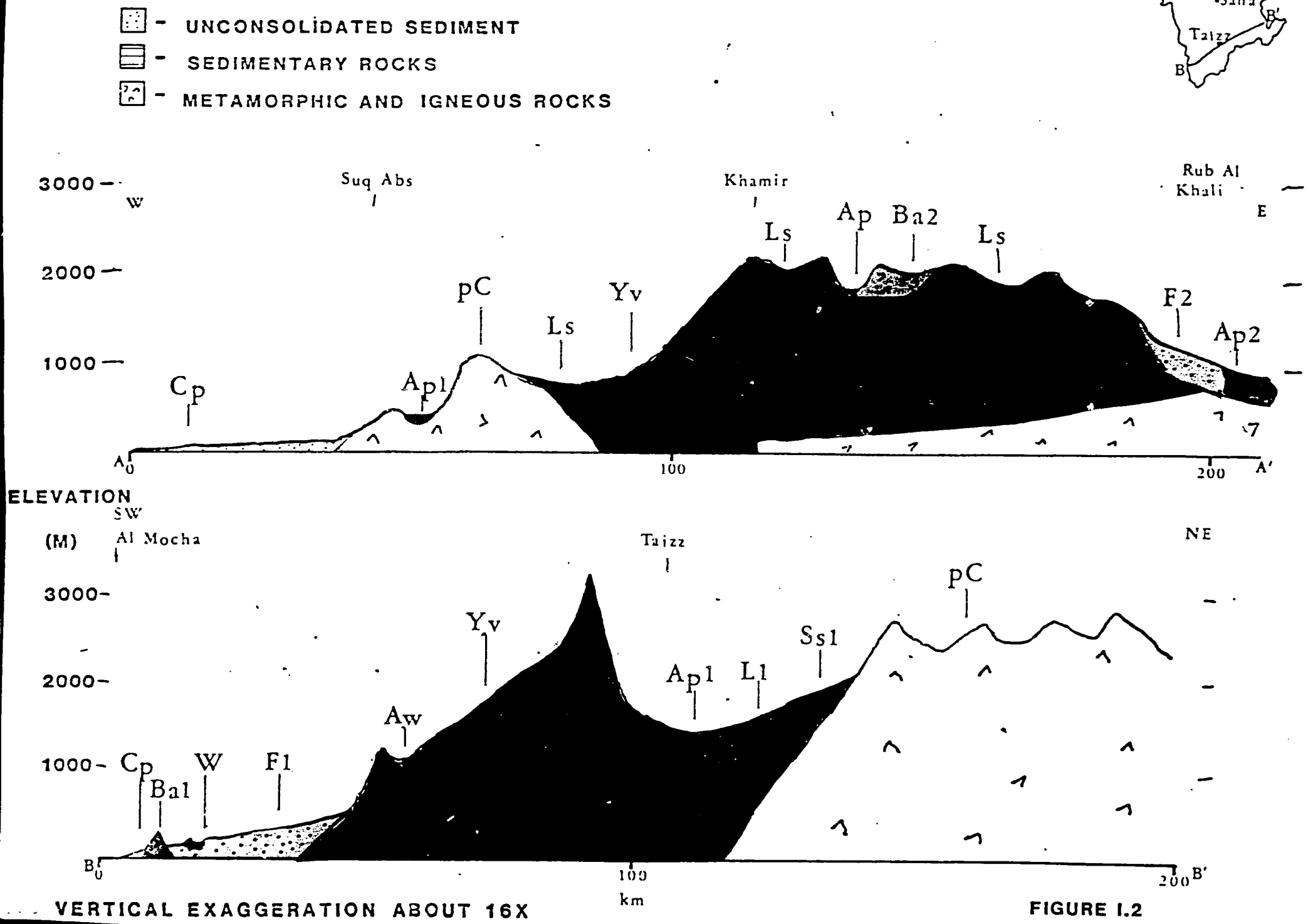


FIGURE I.2

areas, blowing sand often threatens cultivated fields. There is little relief associated with wadi beds.

Coastal plain (Cp): The coastal plain is the area on the Tihama outside the wadi and alluvial fan areas. It is extremely dry, and wind is the primary landform-shaping force. Longitudinal dunes and barcans are prevalent. There is little relief besides the dunes on the coastal plains and no agriculture.

Inland Alluvium The areas of inland alluvium were divided into three categories; alluvial plains, wadi alluvium and inland alluvial fans.

Alluvial plains (Ap): Alluvial plains are broad plains of alluvium covering bedrock between mountains. Some plains show protruding volcanic cones. The alluvium is a mixture of products of the weathering of the surrounding rock outcrops (volcanic and sandstone formations) and materials deposited by the wind. Two major classes of alluvial plains were separated on the basis of rainfall. Those with close to 1000 mm/year of rain supported extensive agriculture (Ap2). Those in drier areas (rainfall around 300 mm/year) supported less agriculture. The intensity of agriculture appears to be dependent on the parent material of the alluvium. Basalt alluvium is more cultivated than Yemen volcanic or sandstone alluvium.

Wadi alluvium (Aw): In the mountains, wadis are entrenched in steep valleys between mountain ridges. The areas along the major wadis in the mountains generally have a reliable supply of water and can support agriculture in the flood-plain. The moisture conditions of any individual wadi vary depending on the amount of rainfall and the type of alluvial material deposited.

Inland alluvial fans (F2): This unit includes two fans along the Wadi Al Jawf. These inland alluvial fans receive almost no rainfall (0-100 mm/year) and cannot support agriculture. There is almost no weathering of the alluvial material and thus no soil formation.

In general, soils expected for inland alluvium areas include Typic Torrifluvents, Fluventic Camborthids and Aridic Argiustolls.

Loess (L) : Areas of loess deposits were divided into two groups, based on the amount of rainfall. Loess deposits are generally heavily eroded, especially on steep hillsides. The loess in the wetter areas (L1) generally is more dissected than that in the drier areas of the north, and is used more extensively for agriculture. Both loess areas are intensively terraced for agricultural purposes. Soils expected in the moister areas are Aridic

Natrustolls, Aridic Calciustolls, Aridic Argiustolls and Natric Camborthids. In the dry L2 areas, Lithic Camborthids, Lithic Calciorthids, Aridic Calciustolls, Anthropic Camborthids and Natric Camborthids are possible.

Pre-Cambrian Shield Areas (pC) : The pre-Cambrian shield is made up of erosion-resistant igneous and metamorphic bedrock. Consequently, the terrain is very jagged and mountainous. Mountain ridges are separated by wadis or linear areas of alluvium. There appears to be little deposition of alluvial material in wadi beds, which are braided stream channels.

The pre-Cambrian shield areas are divided on the basis of rainfall. The pC1 unit is located in very dry areas (rainfall <100 mm/year), and is unable to support agriculture, except in isolated areas along major wadis. The wetter areas (rainfall of 600 mm/year) make up the pC2 area. Agriculture is found both in the stream flood plains and on terraces up the sides of the ridges in these areas.

Soils in the pC areas probably include Typic Torrifluvents in the dry pC1 areas and Typic Torrifluvents, Ustochreptic Calciorthids, Aridic Calciorthids, Aridic Calciustolls, Anthropic Camborthids and Aridic Argiustolls in the moist areas.

Sedimentary Rock Areas Limestone and sandstone are the two major kinds of sedimentary rocks deposited in Yemen. There are several different formations of each kind, but they appear to form similar landscapes.

Limestone areas (Ls): These are found in the drier areas of Yemen and are consequently very resistant to erosion. The area is dissected, generally along structural features, particularly joints. Agriculture is extensive where the water supply permits, but where rainfall is limited, little or no agriculture takes place. In the drier areas, these is little soil formation, due to lack of weathering of the rocks. Soil subgroups expected in limestone areas include Lithic Calciorthids and Ustochreptic Calciorthids.

Sandstone areas (Ss): There are two major sandstone formations: the Taliwah group (Ss1) and the Wajid sandstone (Ss2). The Taliwah group is located in areas of relatively high rainfall and is highly dissected, with entrenched wadis between high mountain ridges. There appears to be little soil formation on the mountain sides or in the stream channels. There is little agriculture in these areas.

The Wajid sandstone outcrops in the dry northern area. They are less rugged than the Taliwah areas, with broader

plains between mountains. Some agriculture is found on these plains, where rainfall or groundwater supplies permit.

Soils expected in the sandstone areas include Lithic Camborthids and Fluventic Camborthids.

Yemen Volcanics (Yv) The Yemen Volcanics formation occurs extensively over southwestern Yemen. The area is generally a rugged igneous plateau, which has been strongly dissected. Mountainsides are rocky, with some soil formation in protected areas. Agriculture is concentrated in valley bottoms, with some terracing on less steep slopes.

The Yemen Volcanics area was divided into two areas on the basis of rainfall. The area with less than 600 mm of rain per year (Yv1) is more dissected and rugged. Farming in these areas is limited to wadi valleys, with a few terraces. The area receiving more than 600 mm/year is designated Yv2. In these areas, agriculture is more extensive, with a large amount of terracing.

Soils expected in the drier areas include Lithic Camborthids, Fluventic Camborthids and Typic Torrifluvents. In the wetter Yv2 areas, Aridic Natrustolls and Natric Camborthids are possible.

CHAPTER 2: SURVEY METHODS

The soil survey methods will be adapted to the 1:500,000 scale of the final map. This scale only permits the delineation of associations of different kinds of soils which occur in a certain pattern in the landscape. The map units will be recognized on the basis of climate, geology, relief and vegetation and by analyzing imagery obtained by satellite and aerial photography.

The survey work will consist in delineating the major soil associations on 1:250,000 scale topographic maps and in identifying the soils which form the associations. The field maps will be reduced to the final scale of 1:500,000.

Progress will be made by individual sheets, the locations of which are shown in map II.1, starting from the south and going to the north. All field operations should be completed within

18 months.

(a) Office methods

Landform regions or landscape units will be delineated, using satellite imagery and air-photos and pilot areas will be selected in representative locations. Detailed soil surveys will be carried out in these areas, taking as much advantage as possible of existing information. The currently available soils and agricultural information is indexed in map II.1. The soils observed in the field will be described, sampled and analyzed in order to classify them according to Soil Taxonomy at the level of the subgroup.

Two sets of satellite imagery are being used. The first was processed using optical methods and the second set was computer processed (see below). Both methods combine three Landsat bands in order to make spatial differences most visible. The optically produced imagery used is a color infrared composite, which combines bands 4, 5 and 7 of Landsat data. The composite was enlarged to scales of 1:250,000 and 1:100,000. The computer processed images include a color infra-red image, using 4, 5 and 7 bands and an eigen transformation of the 4, 5 and 7 bands. The eigen transformation accents subtle differences in the reflectance data. The computer images were also produced at scales of 1:100,000 and 1:250,000.

(b) Field methods

The purpose of mapping the major components of the soil associations at large scales (about 1:25,000) in the pilot areas is to estimate the percentage each individual soil occupies in the association. The methodology will follow the guidelines of the USDA Soil Survey Manual. During these field observations, an effort will be made to study the correlation between field characteristics and airphotos and satellite imagery, in order to elaborate an identification key for the interpolation and extrapolation of soils data to inaccessible areas. Another objective of the field studies is to relate crop production and potential with soil and land characteristics,

and to make interpretations for land-use.

(c) Laboratory methods

The analyses of the samples collected during the soil survey will be carried out at the Ausseifere Agricultural Experiment Station. The analyses will help define the soil characteristics which are needed for identification in the classification system. Specialized analysis will be conducted as needed at Cornell University.

The soil analyses are only a supplement to the field observations, to confirm and verify the accuracy of the classification and mapping. The level of detail will probably not be adequate for purposes beyond tne objectives of the general survey, such as for feasibilty studies of irrigation or other development projects. The map and report will, however, indicate what kind of detailed survey and analysis will be needed, if irrigation, drainage or reclamation activities are to be carried out.

REPORTS INDEXED IN MAP II.1

1) Agrar- und Hydrotehnik GmbH. 1980. Development of Wadi Jawf and its Tributaries, Technical Report: Soils. Yemen Arab Republic, Ministry of Agriculture.

2) Boros, I.J., Szabolos, I. and Varallyay, G. 1970. Soil survey in the Tihama lowland (Yemen Arab Republic) I. Factors of Soil Formation ; II. Soils and land capability classes . Agrokemia es Talajtan 19:405-464.

2) Boros, I.J., and Lesztak, J. 1971. Soil survey in the Tihama lowland (Yemen Arab Republic) III. Water management properties of soils. Agrokemia es Talajtan 20:217-230.

3) Egli, E. 1978. "Landnutzung und Landnutzungsveraenderung in der region Wadi Mawr Arabische Republik Jemen." Geographischen Institut der Universtat Zurich.

4) Electrowatt Engineering Services, Ltd. 1978. Marib Dam and Irrigation Project, Yemen Arab Republic: Annexes I. Soil and Land Classification; III. Agriculture; V. Geology and Geotechniques; VII. Hydrology. Government of Abu Dhabi, Presidential Court.

5) Halcrow, W. and Partners. 1978. Wadi Surdad: Development on the Tihama. Volume 4-Soils and Land Capability Annex C Yemen Arab Republic, Ministry of Agriculture.

6) Pacheco, R.A. 1978. "The Application of Landsat Imagery to Soil and Land-use Mapping in the Central Region of the Yemen Arab Republic." FAO Seris AGLT, FAO, Rome.

7) Western, S. 1972. The classification of arid zone soils. II. The classification of sedasols in Saudi Arabia. Journal of Soil Science 23:279-297.

REPORTS ON YEMEN IN GENERAL

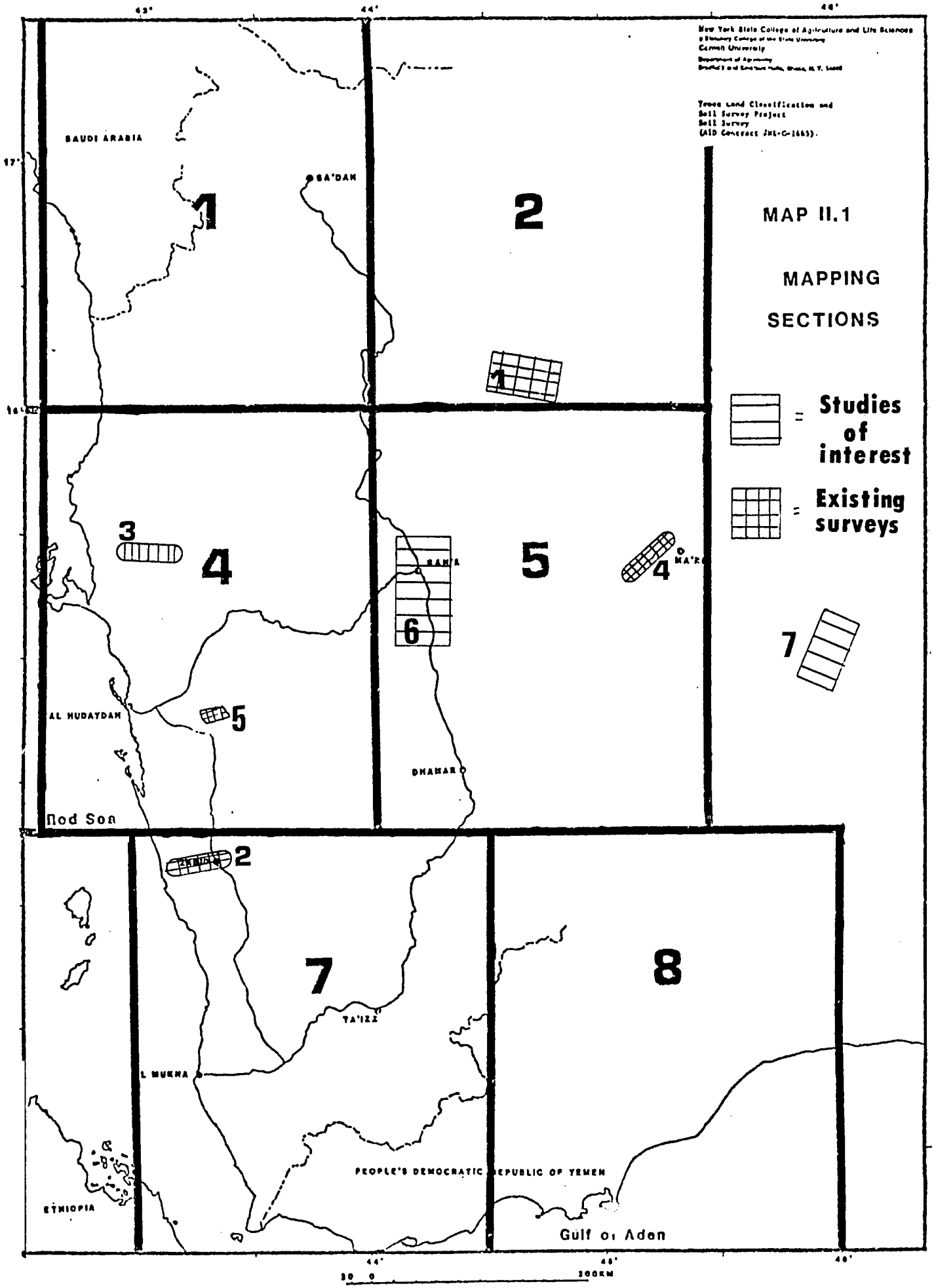
Asmaev, L.R. 1969. Data on soils of the southwestern part of the Arabian penisula. in Kovda, V.A. and Labova, E.V. (ed.) Geography and Classification of Soils of Asia. Israel Program for Scientific Translations, p.249-257.

Kopp, H. 1975. Die Raumliche Differenzierung der Agrarlandschaft in der Arabischen Republik Jemen (Nordjemen). Erdkunde 29:59-68.

Schoch, R. 1977. Regionale Gliederung der Jemenitischen Arabischen Republik mit Hilfe von Landsat-Satellitenbildern. Thesis, Geographischen Institut der Universitat Zurich.

14a

YEMEN ARAB REPUBLIC



PART II: OPERATIONS

SUMMARY OF PROGRESS

OUTLINE OF STAFFING AND ADMINISTRATION

Contract AID/NE-C-1665 was signed March 12, 1980 for a Land Classification and Soil Survey of the Yemen Arab Republic for a total estimated contract cost of $637,031.

A search plan for the Senior Research Associate position to be located in Yemen was implemented, with the intent of having a field soil survey officer in Yemen as soon as possible. A total of 16 candidates applied for this position. Most of them were third country nationals. A candidate was selected and clearance requested through the contract office. In October, notification was received that the candidate could not be approved. A second candidate, a U.S. citizen, was selected and clearance procedures requested. The position was offered to Dr. Jack King, contingent upon USAID clearance and approval.

In August, a second Research Associate position was classified and was posted along with a technican position, and applications of qualified candidates were solicited.

In November, Dr. Terry Forbes was temporarily appointed to the second Research Associate position. Ralph Stuart was hired for the technician position.

Jeff Lee, desk officer for Yemen in AID Near East Bureau, visited the Cornell Campus in December, and discussed the project workplan and logistic support required in Yemen to carry out the soil survey.

At the end of December, clearance was obtained from AID Yemen Mission for Dr. King, and plans were begun for him to travel to Yemen for a short term visit to review facilities for soil analysis, and meet with Yemen government and USAID personnel regarding field operations for the project. Stopovers in Zurich and London were made to obtain any mapping information available for the soil survey project.

Dr. King went to Yemen on January 8, 1981 (see below). An operational bank account was to be opened for the project in a

bank in Taizz or Sana, but was delayed due to currency exchange problems. Dr. King returned to Cornell University February 6, 1981, and equipment for field work in Yemen was ordered and assembled for shipment in March.

Final arrangements for Dr. King's departure for Sana were completed. He left to start the 18 month field operations in Yemen on March 9. Dr. Forbes joined him to assist in soil survey procedures.

An outline was prepared for the preparation of the final project publication and report for the soil survey, using computer storage and editing facilities.

TRIPS TO YEMEN

1) Dr. A. Van Wambeke

Dr. Van Wambeke traveled to Yemen May 3-7, 1980 to be informed on the status of the logisitic support to be provided by the Yemen government and the USAID mission in Sana. He met with C. Bell, acting USAID Mission Director, Harry Johnson, USAID program officer, Campbell S. McCluskey and Arthur Britton, USAID project officers, Mohammed Sharaf Addin, Acting Director, Ministry of Agriculture and Yaya Sharga, Sana Provincal Agricultural Officer.

According to Mr. Johnson vehicles for the survey would be provided by USAID rather than the Yemen government. One vehicle was available for field work from the inception of the contract and another was on loan to another project.

The Mission Director and the project officers insisted that Cornell have a man on the scene as soon as possible in order to contribute to the US effort for Yemen's development. The Mission Director also indicated that the Yemen government felt that too many short term (TDY) visits were taking place and too few Yemen based activities were being executed and brought to completion.

Dr. Van Wambeke visited the Soils Laboratory at Ausseifere (Taizz) and met with Dr. Salah Elgawhary, Director of the FAO project. He examined the soils laboratory with R.K. Sharma (U.N. volunteer) and A.R.S. Qassim. All equipment is in place for routine soil analyses, including texture, pH, cation exchange capacity, organic carbon, nitrogen, electrical conductivity, exchanageable bases and soluble salts. A problem may be obtaining priority for the Cornell soil samples. There will be a maximum of 1500 to be analyzed as soon as possible after arrival at the laboratory. According to Mr. Sharma there

should be no problem.

It was decided that because most agricultural research in Yemen is carried out in Taizz, the resident soil surveyor is to be stationed at Taizz to allow better interaction with local soil scientists and increase cooperation between FAO, UN, Yemen and the project.

2) Dr. J. King

Dr. King visited Yemen in January, 1981 to investigate the preparations required for the soil survey. His trip included visits to Sana, Taizz, and Hodeida.

Taizz: In Taizz, Dr. King visited the Soils Laboratory of the Agricultural Research Service at Ausseifere. A brief but useful conversation on the relationship between the Cornell soil survey and the research station was held with Dr. Faud, director of the station, as well as with other members of the station staff. Dr. King met with Dr. Salah Elgawhary, Dr. Ismail Gewaifel, R.K. Sharma and Dhruba Shrestha. The soil tests performed are those reported by Dr. Van Wambeke. The methods used are those described in FAO Soils Bulletin 10: Physical and Chemical Methods of Soil and Water Analysis and Methods of Soil Analysis by the American Society of Agronomy. The laboratory equipment available includes an atomic absorption spectrometer, a flame photometer, a colorimeter and pH and conductivity meters.

In Sana, Dr. King met with USAID officers, primarily C. McCluskey and T. Bertotti, representatives of the Consortium for International Development and the Yemen Ministry of Agriculture.

In Hodeidah, Dr. King visited Mr. Tewari and Mr. Bamatraf and visited the Surdad farm project.

SEARCH FOR EXISTING INFORMATION

Off-Campus Search

Dr. Terry Forbes visited the U.S. Geological Survey and the Soil Conservation Service, U.S. Department of Agriculture in Washington, D.C. January 21-23, 1981 in order to gather unpublished or otherwise inaccessible geological, hydrological, meteorological and soils information on the Yemen Arab Republic. He met with Dr. David Davidson, Mr. Lopez, and Mr. J. Morgan (USGS) and Drs. R. Arnold, R. Gilbert, Mr. L. Miller and Mr. W. Reybold (SCS).

An hydrological study is being compiled by the Geological Survey in final report form. A draft copy and overlay map (1:500,000) of "A Qualitative Appraisal of the Yemen Arab Republic from Landsat Images- Open-File Report 80-(565)" is to be sent to Cornell.

Dr. R. Gilbert (SCS) provided a copy of The Physical, Chemical and Mineralogical Properties of Certain Soil Areas in the Kingdom of Saudi Arabia, August 15, 1980. The possible application of future results of the Agristar project was also discussed. Application of Agristar techniques is not presently feasible.

Mr. Reybold and Miller provided a copy of the SCS draft Soil Map of the World covering Yemen. Dr. F. Newhall's research records were examined for possible climatic data on Yemen. None were found.

On his return trip from Yemen in January, Dr. King visited several places in Europe to acquire information useful for the survey.

Rome, Italy: He visited Dr. Pacheco and Dr. Pecrot of FAO. Dr. Pecrot gave him access to the FAO library and maps. There was no new information found. Dr. Pacheco provided a copy of his reconnaissance soil study of North Yemen and two other related studies.

Tubingen, Germany: Dr. King met with Professor Kopp, who is working on a 1:500,000 land use map of North Yemen, which will be published in April in German and September in Arabic and English. It defines regions of land use and should prove useful for survey work.

Zurich, Switzerland: Dr. King met with Dr. Ing. Reimer Bohave and Mr. Miroslav Trinacity of Electrowatt Engineering Services, Ltd. and Rudolph Schoch, University of Zurich. Dr. Bohave and Mr. Trinacity provided information on the soils, geology, agriculture and hydrology of the Marib area, including a 1:50,000 scale soil map covering 5000 hectacres. Rudolph Schoch provided a copy of Erwin Egli's thesis on land use at Wadi Mawr.

England: Dr. King visited two engineering firms, Sir Alexander Gibb and Partners and Sir Willian Halcrow and Partners, and the Directorate of Overseas Surveys. The engineering firms were unable to provide copies of their reports immediately. The Directorate of Overseas Surveys provided information about the availabilty of maps and air photos required for the survey work. A study of the soils of

the Montane Plains would be available in April from them.

Cornell Campus Literature Search

The Cornell library was used to provide as much background information as possible on Yemen, with particular emphasis on the types of soils expected in arid tropical regions. Over two hundred articles were copied for use in Yemen. Most of these are given in the bibliography at the end of this report.

TESTING OF LABORATORY METHODS

The staff has been testing the Differential Thermal Analyzer located in Bradfield Hall in order to have it available for mineralogical analysis of clay samples sent back from Yemen.

Techniques of particle size analysis, separation and mounting of sand particles for microscopic examination, and clay separation have been established for soil samples to be sent to Cornell from Yemen.

Computer programs for the analysis of climatic data have been developed and tested. A system has been established for entering and maintaining a running copy of laboratory data for the final report in the computer.

PREPARATION OF TENTATIVE MAPS

Tentative maps of landform regions and generalized geology of Yemen have been produced by the staff (above). Probable modal rainfall maps have been reproduced from other publications. Maps of the index sheets and pilot areas for southern Yemen have been drawn.

PURCHASE OF SATELLITE IMAGERY

Optically processed imagery from remote sensing data was obtained from the Resource Information Laboratory at the College of Agriculture at Cornell (Dr. E. Hardy and R. Senykoff). This imagery is being tested in the field.

The soil survey staff also contacted the Cornell Center for Remote Sensing about the possibilty of using computer-processed Landsat data for making the soil survey. Cornell does not presently have the hardware necessary to produce the imagery for survey use. Dr. Warren Phillipson referred the staff to Dr. Gary Petersen of Penn State University.

Dr. Jack King, Dr. Terry Forbes and Ralph Stuart visited Pennsylvania State University in order to discuss the feasibility of using Landsat digital imagery to draw more precise delineations for a 1:500,000 soils map of Yemen. They met with Dr. Gary Petersen, Dr. George McMurtry, Dr. Brian Turner, Dr. Gold, Mr. Dean Mimms and Mr. Rich Day (all of the Office of Remote Sensing of Earth Resources (ORSER)).

The results of ORSER's research on specific applications in semi-arid Utah were discussed. A copy of M. L. Imhoff's thesis on The Role of Landsat Data Products in Soil Surveys and documentation on ORSER's computer software were received. ORSER suggested that enhanced imagery transformed by principal components would be a significant contribution to survey remote sensing in Yemen. This imagery was produced by Earth Satellite Corporation (Washington, D.C.). False color imagery to be used in the field is now available for testing in the same areas as the optically processed images.

PART III: FINANCIAL REPORT
SOIL SURVEY OF THE YEMEN ARAB REPUBLIC
March 12, 1980- March 12, 1981
AID/NE-C-1665

BUDGET CATEGORY	USAID BUDGET	EXPENSES THROUGH 3/31/81	EXPENSES BEING PROCESSED	BALANCE
A. Salaries and Wages	$114,625	$23,514.01		$91,110.99
B. Fringe Benefits	28,083	5760.93		22,322.07
C. Indirect Costs	62,184	17,329.83		44,854.17
D. Differential/ Allowances	17,615	753.94	783.20	16,077.86
E. Travel & Transport	36,543	7995.94	4062.22	24,484.84
F. Equipment & Materials	4,500	4987.90		-487.90
G. Communications, Postage, Xerox, Office Supplies	5,500	2472.09	60.08	2967.83
H. Yemen Costs	111,000	20.00	1012.50	
			1515.28	108,452.22
I. Defense Insurance	5400			5400
J. Miscellaneous Expenses:				
a.) Services:		344.03	44.25	
b.) Employment Expenses:		869.65		
c.) Computer:		793.31		-2051.24
Totals:	$385,450	$64,841.63	$7,477.53	$313,130.84

GLOSSARY OF TERMS

Barcan: A moving, isolated, crescent-shaped sand dune which forms where sand supply is limited and wind is constant and moderate in speed.

Laccolith: A lens-shaped concordant igneous intrusion, less than 8 kilometers in diameter.

Loess: Widespread, unconsolidated, commonly nonstratified deposit of fine-grained, highly calcerous material. Loess is generally beleived to be wind blown dust of Pleistocene age.

Marl: Unconsolidated deposits of a mixture of clay and calcium carbonate, formed under marine, or especially freshwater conditions.

Sabkhah: Coastal and inland salt flats or playas, built up by deposition of silt clay and muddy sand in shallow, sometimes extensive, depressions. The deposits are completely saturated with brine and are often salt encrusted.

Wadi: A stream bed or channel, or a steep-sided and bouldery ravine, that is usually dry, except during the rainy season. Wadis often form oases. Also, the stream that runs in the bed.

REFERENCES

Aandahl, A.R. 1958. Soil survey interpretation- theory and purpose. Soil Science Society of America Proceedings 22:152-154.

Acres, B.D. 1980. Soils and land suitability of the Montane Plains in Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resources survey. Land Resources Development Center. Surbiton, Surrey, England.

Agrar- und Hydrotehnik GmbH. 1980. Development of Wadi Jawf and its Tributaries, Technical Report: Soils. Yemen Arab Republic, Ministry of Agriculture.

Anderson, I.P., 1979. Soil Survey and Irrigation Suitability Classification of Wadi Rima in Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resources survey. Land Resources Development Center, Surbiton, Surrey, England.

Arkley, R.J. 1963. Calculation of carbonate and water movement in soil from climatic data. Soil Science 96:239-248.

Arkley, R.J. 1967. Climates of some great soil groups of the western United States. Soil Science 103:389-400.

Asmaev, L.R. 1969. Data on soils of the southwestern part of the Arabian penisula. In Kovda, V.A. and Labova, E.V. (ed.) Geography and Classification of Soils of Asia. Israel Program for Scientific Translations, p.249-257.

Aubert, G. 1965. Classification des sols. Cahiers ORSTOM Serie Pedioligie 3:269-288.

Aubert, G. 1968. Classification des sols utilisee par les pedologues francais. pp.78-94. In Approaches to Soil Classification, FAO/UNESCO World Soil Resources Report 32, FAO, Rome.

Avery, B.W. 1968. General soil classification: Hierarchical and co-ordinate systems. Ninth International Congress of Soil Science Transactions 4:169-175.

Avery, B.W. 1973. Soil classification in the soil survey of England and Wales. Journal of Soil Science 24:324-338.

Avery, T.E. 1977. Intrpretation of Aerial Photographs. Burgess Publishing Company, Minneapolis, Minnesota.

Bagnold, R.A. 1951. Sand formations in south Arabia. Geographical Journal 117:78-86

Barshad, I. 1946. A pedologic study of California prairie soils. Soil Science 61:423-442.

Barshad, I. 1964. Chemistry of soil development, pp.1-70. In Bear, F.E. (ed.) Chemistry of the Soil. Reinhold, New York, New York.

Baxter, F.P. and Hole, F.D. 1967. Ant (Formica cinera) pedoturbation in a prairie soil. Soil Science Society of America Proceedings 31:425-428.

Beckett, P.H.T. and Webster, R. 1971. Soil variabilty:A review. Soils and Fertilizers 34:1-16.

Beckingham, C.F. and Serjent, R.B. 1944. A journey by two Jesuits from Dhufar to Sana in 1590. Geographical Journal 93:194-207.

Bennema, J., Boulaine, J., Dudal, R., Gerasimov, I.P., Mockenhausen, E. and Simonson, R.W. 1968. Soil horizon decription and definitions. Soil Science Society of America Proceedings 32:153-154.

Beyth, M. 1973. Correlation of Paleozoic-Mesozoic sediments in northern Yemen and Tigre, northern Ethiopia. American Association of Petroleum Geologists Bulletin 57:2440-2443.

Bidwell, O.W. and Hole, F.D. 1965. Man as a factor of soil formation. Soil Science 99:65-72.

Birot, P. 1968. The Cycle of Erosion in Different Climates. Chapters 1-3 and 6-7. University of California Press.

Blake, W.P. 1901. The caliche of southern Arizona: An example of deposition by the vadose circulation. American Institute of Mining Engineers Transactions 31:220-226.

Boersma, L., Simmon, G.H. and Watts, D.G. 1972. Soil morphology and water table relationships. Soil Science Society of America Proceedings 36:644-653.

Boros, I.J., and Lesztak, J. 1971. Soil survey in the Tihama lowland (Yemen Arab Republic) III. Water management properties of soils. Agrokemia es Talajtan 20:217-230.

Boros, I.J., Szabolos, I. and Varallyay, G. 1970. Soil survey in the Tihama lowland (Yemen Arab Republic) I. Factors of Soil Formation ; II. Soils and land capability classes Agrokemia es Talajtan 19:405-464.

Bretz, J.H. and Horberg, L. 1950. Caliche in southeastern New

Mexico. Journal of Geology 57:491-511.

Brogan, J.C., Lemos, P., and Carlyle, R.E. 1965. A Survey of Soils Laboratories in Sixty-Four FAO Member Countries, FAO Soils Bulletin No. 2, FAO, Rome.

Brown, G.F. 1970. Eastern margin of the Red Sea and the coastal structures in Saudi Arabia. Philosophical Transactions of the Royal Society, London, Series A 267:75-87.

Brown, I.C. and Drosdoff, M. 1940. Chemical and physical properties of soil and their colloids from granitic materials in the Mojave Desert. Journal of Agricultural Research 61:335-352.

Brown, J.H., and Davidson, D.W. 1977. Competition between seed-eating rodents and ants in desert ecosystems. Science 196:880-882.

Bryan, K. 1925. Date of channel trenching (arroyo cutting) in the arid southwest. Science 62:338-344.

Buffington, L.C. and Herbel, C.H. 1965. Vegetational changes on a semidesert grassland from 1858 to 1963. Ecological Monographs 35:139-164.

Buol, S.W. 1965. Present soil-forming factors and processes in arid and semi-arid regions. Soil Science 99:45-49.

Buol, S.W. and Yesilsoy, M.S. 1964. A genesis of a Mohave sandy loam profile. Soil Science Society of America Proceedings 28:254-256.

Bushnell, T.M. 1942. Some aspects of the soil catena concept. Soil Science Society of America Proceedings 7:466-476.

Campbell, J.B. 1977. Variation of selected properties across a soil boundry. Soil Science Society of America Journal 41:578-582.

Carey, J.W. and Evans, D.D. (ed.). 1974. Soil Crusts. Arizona Experimental Station Technical Bulletin no. 214.

Cline, M.G. 1944. Principles of soil sampling. Soil Science 58:275-288.

Cline, M.G. 1945. Methods of collecting and preparing soil samples. Soil Science 59:3-5.

Cline, M.G. 1949. Basic principles of soil classification. Soil Science 67:81-91.

Cline, M.G. 1961. The changing model of soil. Soil Science Society of America Proceedings 27:432-438.

Cline, M.G. 1963. Logic of the new system of classification. Soil Science 96:17-22.

Coen, G. 1973. Soil survey and interpretation procedures in mountainous Waterton Lakes National Park, Canada. Geoderma 10:75-86.

Colwell, J.D. 1968. Assessments of factors limiting the significance of soil tests for fertilizer requirements. Ninth International Congress of Soil Science Transactions 4:709-717.

Cornell Department of Agronomy. 1977. Soil Resource Inventories Agronomy Mimeo No. 77-23, New York State College of Agriculture and Life Sciences, Cornell University, Ithaca, New York.

Cortes, A. and Franzmeier, D.P. 1972. Climosequence of ash-derived soils in the central cordillera of Columbia. Soil Science Society of America Proceedings 36:653-659.

Crocker, R.L. 1952. Soil genesis and the pedogenic factors. Quarterly Review of Biology 27:139-168.

Crowther, E.M. 1953. The sceptical soil chemist. Journal of Soil Science 4:107-122.

DeMent, J.A. and Bartelli, L.J. 1969. The role of vertic subgroups in the comprehensive soil classification system. Soil Science Society of America Proceedings 33:129-131.

Dewis, J. and Freitas, F. 1970. Physical and Chemical Methods of Soil and Water Analysis, FAO Soils Bulletin No. 10, FAO, Rome.

Dower, M.M. and Olsen, K.R. 1980. Revised pipet method of particle size analysis. Cornell Agronomy Mimeo 80-17.

Duchaufour, P. 1963. Soil classification: A comparision of the American and French systems. Journal of Soil Science 14:149-155.

Dudal, R. 1963. Dark clay soils of tropical and subtropical regions. Soil Science 95:264-270.

Dudal, R. 1965. Dark clay soil of tropical and subtropical regions. FAO Agricultural Development Paper 83.

Dudal, R. 1968. Problems of international soil correlation, pp.137-143. In Approaches to Soil Classification, FAO/UNESCO World Soil Resources Report 32, Rome.

Egli, E. 1978. Landnutzung und Landnutzungsveraenderung in der

region Wadi Mawr Arabische Republik Jemen. Geographischen Institut der Universtat Zurich.

Electrowatt Engineering Services, Ltd. 1978. Marib Dam and Irrigation Project, Yemen Arab Republic: Annexes I. Soil and Land Classification; III. Agriculture; V. Geology and Geotechniques; VII. Hydrology. Government of Abu Dhabi, Presidential Court.

Engel, C.G. and Sharp, R.P. 1958. Chemical data on desert varnish. Geological Society of America Bulletin 69:487-519.

Fieldes, M. 1968. Constitutional classification of soils. Ninth International Congress of Soil Science Transactions 4:177-185.

Flach, K.W., Nettleton, W.D., Gile, L.H. and Cady, J.G. 1969. Pedocementation: Induration by silica, carbonates, and sesquioxides in the Quarternary. Soil Science 107:442-453.

Flach, K.W. and Smith, G.D. 1969. The new system of soil classification as applied to arid-land soils In McGinnies, W.G. and Goldman, B.J. (ed.) Arid Lands in Perspective. American Association for the Advancement of Science and University of Arizona Press. p. 61-73.

Folster, H., Kalk, E. and Moshreti, N. 1971. Complex pedogenesis of ferralitic savanna soils in south Sudan. Geoderma 15:305-312.

Fridland, V.M. 1976. The soil-cover pattern: Problems and methods of investigation, pp.3-31. In Fridland, V.M. (ed.) Soil Combinations and their genesis.;Amerind Publishing Company, New Delhi, India.

Fuller, W.H., Cameron, R.E. and Raica, N. 1960. Fixation of nitrogen in desert soils by algae. Transactions of the Seventh International Congress of Soil Science, Madison, Wisconsin, U.S.A. 2:617-624.

Gardner, J.L. 1951. Vegetation of the creosotebush area of the Rio Grande Valley in New Mexico. Ecological Monographs 21:379-403.

Gardner, L.R. 1972. Origin of the Morman Mesa caliche, Clark County, Nevada. Geological Society of America Bulletin 83:143-156.

Gerasimov, I.P. 1968. Development of the concepts of weathering and soil formation in Soviet soil science, geography and geology. Ninth International Congress of Soil Science Transactions 4:377-379.

Geukens, F. 1966. Geology of the Arabian Penisula: Yemen. United States Geological Survey Professional Paper 560-B.

Gile, L.H. 1961. A classification of ca horizons in soils of a desert region, Dona Ana County, New Mexico. Soil Science Society of America Proceedings 25:52-61.

Gile, L.H. 1966a. Coppice dunes and the rotura soil. Soil Science Society of America Proceedings 30:657-660.

Gile, L.H. 1966b. Cambric and certain noncambric horizons in desert soils of southern New Mexico. Soil Science Society of America Proceedings 30:773-781.

Gile, L.H. 1967. Soils of an ancient basin floor near Las Cruces, New Mexico. Soil Science 103:265-276.

Gile, L.H. 1970. Soils of the Rio Grande Valley border in southern New Mexico. Soil Science Society of America Proceedings 34:465-472.

Gile, L.H. 1975a. Causes of soil boundries in an arid region: I. Age and parent materials. II. Dissection, moisture and faunal activity. Soil Science Society of America Proceedings 39:316-330.

Gile, L.H. 1975b. Holocene soils and soil-geomorphic relations in an arid region of southern New Mexico. Quarternary Research 5:321-360.

Gile, L.H. and Grossman, R.B. 1968. Morphology of the argillic horizon in desert soils of southern New Mexico. Soil Science 106:6-15.

Gile, L.H., Grossman, R.B. and Hawley, J.W. 1969. Effects of landscape dissection on soils near University Park, New Mexico. Soil Science 108:273-282.

Gile, L.H. and Hawley, J.W. 1966. Periodic sedimentation and soil formation on an alluvial fan piedmont in southern New Mexico. Soil Science Society of America Proceedings 30:261-268.

Gile, L.H. and Hawley, J.M. 1968. Age and comparitive development of desert soils at the Gardner Spring radiocarbon site, New Mexico. Soil Science Society of America Proceedings 32:709-716.

Gile, L.H. and Hawley, J.M.. 1972. The prediction of soil occurance in certain desert regions of the southwestern United States. Soil Science Society of America Proceedings 36:119-124.

Gile, L.H. , Peterson, F.F. and Grossman, R.B. 1965. The K

horizon: A master soil horizon of carbonate accumulation. Soil Science 99: 74-82.

Gile, L.H., Peterson, F.F. and Grossman, R.B. 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Science 101: 347-360.,

Gillette, D. and Goodwin, P.A. 1974. Microscale transport of sand-sized soil aggregates eroded by wind. Journal of Geophysical Research 79:4080-4084.

Glazovskaya, M.A. 1968. Geochemical landscapes and types of geochemical soil sequences. Ninth International Congress of Soil ScienceTransactions 4:303-311.

Gibbons, F.R. 1968. Limitations to the usefulness of soil classification. Ninth International Congress of Soil Science Transactions 4:159-167.

Goetz, A.F.H., and Rowan, L.C. 1981. Geologic remote sensing. Science 211:781-791.

Golden, J.P., Lemos, P., Carlyle, R.E. and Freitas, F.C.R. 1966. Guide on General and Specialized Equipment for Soils Laboratories, FAO Soils Bulletin No.3, FAO, Rome.

Goosen, Doeko. 1967. Aerial Photo Interpetation in Soil Survey, FAO Soils Bulletin No. 6, FAO, Rome.

Graham, E.R. 1950. The plagioclase feldspars as an index to soil weathering. Soil Science Society of America Proceedings 23:152-156.

Graustein, W.C., Cormack, K. and Sollins, P. 1977. Calcium oxalate: Occurance in soils and effect on nutrient and geochemical cycles. Science 198:1252-1254.

Gray, M.G., McAfee, R. and Wolf, C.L. (ed.). (1972). Glossary of Geology American Geological Institute, Washington,D.c.

Grolier, M.J. and Overstreet, W.C. 1978. Geologic map of the Yemn Arab Republic (Sana). United States Geological Survey Miscellaneous Investigations Series Map I-1143-b.

Hagenzieker, F. 1963. Contribution to the agropedological knowledge of the Tropical Black Earths of southern Ghana. Netherlands Journal of Agricultural Science 11:54-65.

Hagenzieker, F. 1964. The Tropical Grey and Black Earths of the Accra Plains, Ghana; their environment, characteristics and air-photograph mapping. Netherlands Journal of Science 12:123-131.

Hain, W. 1969. Intial agricultural development of the Yemeni Tihama. Beitrage zur Tropischen und Subtropischen Landwirtschaft und Tropenveterinarmedizin 7:241-251.

Hallsworth, E.G. and Beckmann, G.G. 1969. Gilgai in the Quarternary. Soil Science 107:409-420.

Haseman, J.F. and Marshall, C.E. 1945. The use of heavy minerals in the studies of the origin and development of soils. Missouri Agricultural Experiment Station Research Bulletin 387.

Hawley, J.W. 1965. Geomorphic surfaces along the Rio Grande Valley from El Paso to Caballo, New Mexico. New Mexico Geological Society Guidebook of southwestern New Mexico, II:188-198.

Hawley, J.W. 1972. Geologic-geomorphic mapping to serve soil resource development. Soil Conservation Society of America Annual Meeting Proceedings p.24-30.

Heller, J.L. 1963. The nomenclature of soils, or what's in a name? Soil Science Society of America Proceedings 27:216-220.

Herbel, C.H. and Gile, L.H. 1973. Field moisture regimes and morphology of some arid-land soils in New Mexico, in Bruce, R.R. et al (ed.) Field Soil Water Regimes. Special Publication no. 5, Soil Science Society of America. p.119-152.

Hole, F.D. 1953. Suggested terminology for describing soils as three-dimensional bodies. Soil Science Society of America Proceedings 17:131-135.

Hole, F.D. 1978. An approach to landscape analysis with emphasis on soils. Geoderma 21:1-23.

Holm, D.A. 1960. Desert geomorphology in the Arabian penisula. Science 132:1369-1379.

Hooke, R.L., Yang, H. and Weiblen, P.W. 1969. Desert varnish: An electron probe study. Journal of Geology 77:275-288.

Hugie, V.K. and Passey, H.B. 1963. Cicadas and their effect upon soil genesis in certain soils in southern Idaho, northern Utah and northern Nevada. Soil Science Society of America Proceedings 27:78-82.

Jackson, M.L. 1965. Clay transformations in soil genesis during the Quarternary. Soil Science 99:15-22.

Jackson, M.L. 1968. Weathering of primary and secondary minerals in soils. Ninth International Congress of Soil

Science Transactions 4:281-291.

Jenny, H. 1958. Role of the plant factor in the pedogenic function. Ecology 39:5-16.

Jenny, H. 1968. The image of soil in landscape art, old and new, in Study Week on Organic Matter and Soil Fertility. Pontificiae Acvademiae Scientarius Scripta Varia, no. 32, John Wiley and Sons, New York, New York. pp. 947-962.

Jenny, H., Salem, A.E. and Wallis, J.R. 1968. Intraplay of soil organic matter and soil fertility with state factors and soil properties, in Study Week on Organic Matter and Soil Fertility. Pontificiae Academiae Scientarius Scripta Varia, John Wiley and Sons, New York, New York. pp.5-37.

Johnson, W.M., Cady, J.G. and James, M.S. 1962. Characteristics of some brown grumusols of Arizona. Soil Science Society of America Proceedings 26:389-393.

Kellogg, C.E. 1963. Why a new system of soil classification? Soil Science 96:1-5.

Kellogg, C.E. and Orvedal, A.C. 1969. Potentially arable soils of the world and critical measures for their use. Advances in Agronomy 21:109-170.

Klemmedson, J.O. 1964. Topofunction of soils and vegetation in a range landscape. American Society of Agronomy Special Publication 5, Madison, Wisconsin, pp.176-189.

Kopp, H. 1975. Die Raumliche Differenzierung der Agrarlandschaft in der Arabischen Republik Jemen (Nordjemen). Erdkunde 29:59-68.

Kottlowski, F.E. 1958. Lake Otero- Second phase in formation of New Mexico's gypsum dunes. (abstract) Geological Society of America Bulletin 69: 1733-1734.

Langohr, R., Scoppa, C.O. and Van Wambeke, A. 1976. The use of a composite particle size distribution index for numerical classification of soil parent materials: application to Mollisols of the Argentian pampas. Geoderma 15:305-312.

Laprade, K.E. 1957. Dust-storm sediments of the Lubbock area, Texas. American Association of Petroleum Geologists Bulletin. 41:709-726.

Lawton, K. 1955. Chemical composition of soils, in Bear, F.E. (ed.) Chemistry of the Soil. Reinhold Publishing Co. New York, New York. pp.53-84.

Lepsch, I.F., Buol, S.W. and Daniels, R.B. 1977. Soils-landscape relationships in the Occidential Plateau of Sao

Paulo State, Brazil: I. Geomorphic surfaces and soil mapping units, II. Soil morphology, genesis and classification. Soil Science Society of America Journal 41:104-115.

McCormack, D.E. 1971. Use of soil surveys in the identification of floodplains. Ohio Journal of Science 71:370-375.

McNeal, B.L. 1968. Prediction of the effect of mixed-salt solutions on soil hydraulic conductivity. Soil Science Society of America Proceedings 32:190-193.

McNeal, B.L. and Coleman, N.T. 1966. Effect of solution composition on soil hydraulic conductivity. Soil Science Society of America Proceedings 30:308-312.

McNeal, B.L., Coleman, N.T. and Norvell, W.A. 1966. Effect of solution composition on the swelling of extracted soil clays. Soil Science Society of America Proceedings 30:313-317.

Makatari, A.M.A. 1971. Water rights and irrigation practices in Lahj: A study of the applications of customary and Saharian law in southwest Arabia. pp.3-45.

Martin, W.P. and Fletcher, J.E. 1943. Vertical zonation of great soil groups on Mt. Graham, Arizona as correlated with climate, vegetation and profile charateristics. Arizona Experimental Station Technical Bulletin 99.

Mayland, H.F., McIntosh, T.H. and Fuller, W.H. 1966. Fixation of isotopic nitrogen on a semiarid soil by algal crust organisms. Soil Science Society of America Proceedings 30:56-60.

Mellanby, K. 1960. The biological importance of the invertebrate soil fauna. Soils and Fertilizers 23:8-9.

Melton, F.A. 1940. A tentative classification of sand dunes-its application to dune history in the southern high plains. Journal of Geology 48:113-145.

Miller, D.E. 1971. Formation of vesicular structure in soil. Soil Science Society of America Proceedings 35:635-637.

Muckenhirn, R.J., Whiteside, E.P., Templin, E.H., Chandler, R.F. and Alexander, L.T. 1949. Soil classification and the genetic factors of soil formation. Soil Science 67:93-105.

Nettleton, W.D., Flach, K.W. and Borst, G. 1968. A toposequence of soils in Tonalite Grus in the southern California Penisular Range. Soil Survey Investigations Report no. 21.

Nettleton, W.D., Nelson, R.E., and Flach, K.W. 1973. Formation

of mica in surface horizons of dryland soils. Soil Science Society of America Proceedings 37:473-478.

Nettleton, W.D., Nelson, R.E., Witty, J.E. and Hawley, J.W. 1975. Genesis of argillic horizons in soils of desert areas of the southwestern United States. Soil Science Society of America Proceedings 39:919-926.

Nikiforoff, C.C. 1937. General trends of the desert type of soil formation. Soil Science 43:105-131.

Nikiforoff, C.C. 1942. Fundamental formula of soil formation. American Journal of Science 240:847-866.

Nikiforoff, C.C. 1949. Weathering and soil formation. Soil Science 67:219-230.

Nikiforoff, C.C. 1953. Pedogenic criteria of climatic changes, in Shapley, H. (ed.), Climatic Change: Evidence, Causes and Effects. Harvard University Press, Cambridge, Massachusetts. pp. 189-200.

Norton, E.A. and Smith, R.S. 1930. The influence of topography on soil profile character. Journal of the American Society of Agronomy 22:258-262.

Oakes, H. and Thorp, J. 1950. Dark-clay soils of warm regions variously called Rendzina, Black Cotton Soils, Regur and Tirs. Soil Science Society of America Proceedings 14:347-354.

Oertel, A.C. 1968. Some observations incompatible with clay illuviation. Ninth International Congress of Soil Science Transactions 4:481-487.

Olson, K.R.and Donaldson, K. 1981. How to prepare soil monoliths for educational displays. Cornell Agronomy Mimeo 81-8.

Orchard, E.R., Van Der Eyck, J.J., Macvicar, C.H. and De Villiers, J.M. 1969. Soils of the Tugela Basin. Town and Regional Planning Commission, Natal.

Oschwald, W.R. 1966. Quantitative aspects of soil survey interpretation in appraisal of soil productivity, in Bartelli, L.J., Kingbiel, A.A., Baird, J.V. and Heddleson, M.R. (eds.) Soil Surveys and Land-use Planning. Soil Science Society of America and American Society of Agronomy, Madison, Wisconsion. pp.152-169.

Pacheco, R.A. 1977. Land inventory Karnali-Mahakali Watershed: A Basic Inventory for General Assessment of Land Degradation. FAO, Rome.

Pacheco, R.A. 1978. The Application of Landsat Imagery to Soil and Land-use Mapping in the Central Region of the Yemen Arab Republic. FAO Seris AGLT, FAO, Rome.

Pacheco, R.A. and Howard, J.A. Application of satellite remote sensing to landscapes and soils. p.I59-I72.

Parsons, R.B., Scholter, W.H. and Riecken, F.F. 1962. Soils of Indian mounds in northeastern Iowa as benchmarks for studies of soil genesis. Soil Science Society of America Proceedings 26:491-496.

Philby, H.StJ.B. 1938. The land of Sheba. Geographical Journal 92:1-21.

Price, W.A. 1925. Caliche and pseudo-anticlines. American Association of Petroleum Geologists Bulletin 9:1009-1017.

Pias, J. 1968. Paleosols de la cuvette Tchadienne. Ninth International Congress of Soil Science Transactions 4:139-149.

Powers, R.W., Ramirez, L.F., Redmond, C.D. and Elberg, E.L. 1966. Geology of the Arabian Penisula: Sedimentary Geology of Saudi Arabia. United States Geological Survey Professional Paper 560-D.

Quirk, J.P. and Schofield, R.K. 1955. The effect of electrolyte concentration on soil permeability. Journal of Soil Science 6:163-178.

Richards, L.A., editor. 1954. Saline and Alkali Soils. USDA Agriculture Handbook no. 60. US Government Printing Office, Washington, D.C.

Riecken, F.F. 1963. Some aspects of soil classification in farming. Soil Science 96:49-60.

Riecken, F.F. 1965. Present soil forming factors and processes in temperate regions. Soil Science 99:58-64.

Riecken, F.F. and Smith, G.D. 1949. Lower catagories of soil classification: Family, series, type, and phase. Soil Science 67:107-115.

Ruellan, A. 1968. Les horizons d'individualisation et d'accumulation du calcaire dans les sols du Maroc. Ninth International Congress of Soil Science Transactions 4:501-509.

Ruhe, R.V. 1956. Geomorphic surfaces and the nature of soils. Soil Science 82:441-455.

Ruhe, R.V. 1959. Stone lines in soils. Soil Science 87:223-231.

Ruhe, R.V. 1960. Elements of the soil landscape. Transactions of the Seventh International Congress of Soil Science (Madison, Wisconsin) v.4:165-169.

Ruhe, R.V. 1964. Landscape morphology and alluvial plain deposits in southern New Mexico. Annals American Association of Geographers 54:147-159.

Ruhe, R.V. 1969. Principles for dating pedogenic events in the Quarternary. Soil Science 107:398-402.

Ruhe, R.V. and Daniels, R.B. 1958. Soils, paleosols and soil horizon nomenclature. Soil Science Society of America Proceedings 22:66-69.

Ruhe, R.V. and Daniels, R.B.. 1965. Landscape erosion-geologic and historic. Journal of Water and Soil Conservation. 20:52-57.

Ruhe, R.V. and Walker, P.H. 1968. Hillslope models and soil formation. I. Open systems, II. Closed systems. Ninth International Congress of Soil Science Transactions 4:551-567.

Russel, J.S. and Rhoades, H.F. 1956. Water table as a factor in soil formation. Soil Science 82:319-328.

Ruxton, B.P. 1968. Rates of weathering of Quarternary volcanic ash in north-east Papua. Ninth International Congress of ASoil Science Transactions 4:367-375.

St. Arnaud, R.J. and Herbillon, A.J. 1973. Occurrence and genesis of secondary magnesium-bearing calcites in soils. Geoderma 9:279-298.

Salisbury, E.J. 1925. Note on the edaphic succession in some dune soils, with special reference to the time factor. Journal of Ecology 13:322-328.

Schoch, R. 1977. Regionale Gliederung der Jemenitischen Arabischen Republik mit Hilfe von Landsat-Satellitenbildern Thesis, Geographischen Institut der Universitat Zurich.

Shantz, H.L. 1956. History and problems of arid lands development, in White, G.F. (ed.) The Future of Arid Lands. American Association for the Advancement of Science 43. pp. 3-25.

Sherman, G.D. and Ikawa, H. 1958. Calcerous concretions and sheets in soil near South Point, Hawaii. Pacific Science 12:255-257.

Shukri, N.M. and Basta, E.Z. 1955. A classification of the

pyroclastic rocks of Yemen. Bulletin de l'Institute d'Egypte 36:129-164.

Shokri, N.M. 1955. Petrography of the alkaline volcanic rocks of Yemen. Bulletin de l'Institut d'Egypte 36:165-175.

Simonson, R.W. 1951. Description of mottling in soils. Soil Science 71:182-192.

Simonson, R.W. 1952. Lessons from the first half-century of soil survey. I. Classification of soils. Soil Science 74:249-257.

Simonson, R.W. 1952. Lessons from the first half-century of soil survey. II. Mapping of soils. Soil Science 74:323-330.

Simonson, R.W. 1959. Outline of a generalized theory of soil genesis. Soil Science Society of America Proceedings 23:152-156.

Sir William Halcrow and Partners. 1978. Soils and Land Capability. Volume 4 annex C in Wadi Surdad Development on the Tihama.

Smith, B.R. and Buol, S.W. 1968. Genesis and relative weathering intensity studies in three semiarid soils. Soil Science Society of America Proceedings 32:261-265.

Smith, G.D. 1963. Objectives and basic assumptions of the new soil classification system. Soil Science 96:6-16.

Smith, G.D. 1968. Soil classification in the United States, in Approaches to Soil Classification, FAO/UNESCO World Soil Resources Report 32. FAO, Rome, pp. 6-24.

Smith, G.D. 1973. Soil moisture regimes and their use in soil taxonomies, in Field Soil Water Regimes, Soil Science Society of America Special Publication Seris, no. 5.

Smith, G.D., Newhall, F., Robinson, L.H. and Swanson, D. 1964. Soil temperature regimes: Their characteristics and predictabilty. SCS-TP-144. Soil Conservation Service.

Smith, R.M., Twiss, P.C., Krauss, R.K. and Brown, M.J. 1970. Dust deposition in relation to site, season and climatic variables. Soil Science Society of America Proceedings 34:112-117.

Smyth, A.J. 1970. The Preparation of Soil Survey Reports. FAO Soil Bulletin no. 9, Food and Agriculture Organization, Rome.

Springer, M.E. 1958. Desert pavement and vesicular layer of some soils of the desert of the Lahontan Basin, Nevada.

Soil Science Society of America Proceedings 22:63-66.

Steele, J. Gordon. 1967. Soil Survey Interpetation and its Use. FAO Soils Bulletin no. 8. Food And Agriculture Organization, Rome.

Stobbe, P.C. and Wright, J.R. 1959. Modern concepts of the genesis of Podzols. Soil Science Society of America Proceedings 23:161-164.

Syers, J.K., Jackson, M.L., Beiheiser, V.E., Clayton, R.N. and Rex, R.W. 1969. Eolian sediment influences on pedogenesis in the Quarternary. Soil Science 107:421-427.

Tan, K. 1970. Agricultural problems in south Arabia. World Crops 22:397-400.

Tavernier, R. and Marechal, R. 1962. Soil survey and soil classification in Belgium. International Soil Conference, New Zealand. pp. 298-307.

Telfair, D., Garner, M.R. and Miars, D. 1957. The restoration of a structurally degenerated soil. Soil Science Society of America Proceedings 21:131-134.

Tesco-viziterv-vituki. 1971. Survey of the Agricultural Potential of the Wadi Zabid, Yemen Arab Republic, Soils and Land Capability. Budapest, Hungary.

Thesiger, W. 1946. A new journey in southern Arabia. Geographical Journal 108:129-145.

Thesiger, W. 1948. Across the empty quarter. Geographical Journal 111:1-21.

Thornwaite, C.W. 1948. An approach toward a rational classification of climate. Geographical Review 38:55-94.

Thorp, J. 1965. The nature of the pedological record in the Quarternary. Soil Science 99:1-8.

Thorp, J. and Smith, G.D. 1949. Higher categories of soil classification: Order, suborder, and great soil groups. Soil Science 74:323-330.

Thorp, J., Strong, L.E. and Gamble, E. 1957. Experiments in soil genesis- the role of leaching. Soil Science Society of America Proceedings 21:99-102.

Travis, R.B. 1955. Classification of rocks. Colorado School of Mines Quarterly 50, no. 1.

Troeh, F.R. 1975. Measuring soil creep. Soil Science Society of America Proceedings 39:707-709.

United States Geological Survey. Geographic Map of Yemen Arab Republic (Sana). USGS Miscellaneous Investigations Series Map I-1143-A.

United States Soil Conservation Service. 1972. Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples. USDA Soil Survey Investigation Report No. 1. U.S. Government Printing Office, Washington, D.C.

Vanden Heuvel, R.C. 1972. The occurence of sepiolite and attapulgite in the calcareous zone of a soil near Las Cruces, New Mexico. Proceedings of the Thirteenth National Conference on Clays and Clay Minerals. pp.193-207.

Walker, P.H., Hall, G.F. and Protz, R. 1968a. Soil trends and variabilty across selected landscapes in Iowa. Soil Science Society of America Proceedings 32:97-100.

Walker, P.H., Hall, G.F. and Protz, R.. 1968b. Relation between landform parameters and soil properties. Soil Science Society of America Proceedings 32:101-104.

Walker, T.R. 1967. Formation of red beds in modern and ancient deserts. Geological Society of America Bulletin 78:353-368.

Watson, J.P. 1962. The soil below a termite mound. Journal of Soil Science 13:46-51.

Wegener, G. 1957. The water supply in Yemen. Wasserwirtschaft und Wassertechnik 7:241-242.

Western, S. 1972. The classification of arid zone soils. II. The classification of sedasols in Saudi Arabia. Journal of Soil Science 23:279-297.

Whittaker, R.H., Buol, S.W., Nicring, W.A., and Haveur, Y.H. 1968. A soil and vegetation pattern in the Santa Catalina Mountains, Arizona. Soil Science 105:440-450.

Wilde, S.A. 1954. Reaction of soils: Facts and fallacies. Ecology 35:89-92.

Wilding, L.P., Odell, R.T., Fehrenbacher, J.B. and Beavers, A.H. 1963. Source and distribution of sodium in solonetzic soils in Illinois. Soil Science Society of America Proceedings 27:432-438.

Wright, A.C.S. 1964. The "Andosols" or "Humic Allophane" soils of South America; Report on the meeting on the Classification and Correlation of soils from Volcanic Ash, Tokyo, Japan. World Soil Resources Report 14, FAO, Rome, Italy 1965 pp.9-22.

Yaalon, D.H. and Ganor, E. 1973.. The influence of dust on soils during the Quarternary. Soil Science 116:146-155.

Yaalon, B. and Yaron, B. 1966. Framework for man-made soil changes- an outline of metapedogenesis. Soil Science 102:272-277.

Zinke, P.J. and Crocker, R.L. 1962. The influence of giant sequoia on soil properties. Forest Science 8:2-11.