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Field Document 3

ASSISTANCE TO LAND-USE PLANNING

ETHIOPIA

GEOMORPHOLOGY AND SOILS

UNITED NATIONS DEVELOPMENT PROGRAMME

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME, 1984

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ASSISTANCE TO LAND USE PLANNING

ETHIOPIA

GEOMORPHOLOGY AND SOILS

Report prepared for
the Government of Ethiopia

by

the Food and Agriculture Organization of the United Nations
acting as executing agency for
the United Nations Development Programme

based on the work of
B.L. Henricksen, S. Ross, Sultan Tilimo
and H.Y. Wijntje-Bruggeman

UNITED NATIONS DEVELOPMENT PROGRAMME
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ADDIS ABABA, 1984

FAO. Assistance to Land Use Planning, Ethiopia. Geomorphology and Soils, Based on the work of B.L. Henricksen, S. Ross, Sultan Tilimo and H.Y. Wijntje Bruggeman. Addis Ababa, 1984. P 425, 11 Figure, 4 Tables supplement including 8 sheets and extended legend. AG:DP/ETH/78/003, Field Document 3.

ABSTRACT

This report describes the compilation of a 1:1 000 000 scale Geomorphology and Soils map of Ethiopia, used in the development of a master land use plan for the country.

A geomorphological interpretation of 71 frames of Landsat imagery was made, combined with field traverses and examination of existing data. Soils information is based on the interpretation of available surveys, field traverses, Landsat derived data and agroclimatic information. These data were combined, as landscape units, in a Geomorphology and Soils map at 1:1 000 000 scale with extended legend. The FAO system of classification is used in the description of soil types. Approximately 380 landscape units are described and mapped. For each landscape unit significant land facets (those covering over 10 percent of the area) are described, but are not mapped. This map effectively updates the FAO/Unesco Soil Map of the World for the section covering Ethiopia. A general description of the physical environment of Ethiopia, in relation to soil forming processes, is included. Cross-sections of landscape units and tables of related soil associations arranged by land facet are provided, together with annotated plates derived form landsat imagery of the image signatures of selected landscape units.

Previous soil related studies in Ethiopia are discussed and descriptions of all major soil types occuring in the country, including representative field profile descriptions and corresponding laboratory analysis, are given.

ACKNOWLEDGEMENTS

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In addition, particular acknowledgement is directed to tne staff of the Ethiopian Mapping Agency whose contributions in the preparation of the many maps and legends associated with this report have been invaluable.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

This document is one of a series produced during the course of the FAO/UNDP/ETH/78/003 project, Assistance to Land Use Planning, in the Land Use Planning and Regulatory Department (LUPRD) of the Ministry of Agriculture (MOA), Ethiopia. One of the main objectives of the project has been the development of a master land use plan (MLUP) for agriculture in the country, based on the FAO agroecological zones methodology for land suitability assessment (1978) developed for continental Africa.

A fundamental requirement of the planning exercise has been the compilation of a comprehensive land resources inventory of physical land resources of the country. Without this comprehensive land resources data base, land suitability evaluation and development strategies could not have been considered in terms of geographical realities. A location map of Ethiopia is shown in Figure 1 for reference.

1.2 METHODS AND RESULTS

The report summarizes the methods employed and the results obtained in generating a 1:1 000 000 scale Geomorphology and Soils map of Ethiopia primarily in support of the requirement for a land resources data base referred to above.

Geomorphology and Soils data included in the map and legend and in this report are derived from a geomorphic interpretation of 71 scenes of Landsat imagery, available surveys, field traverses, topographic maps, land use data and agroclimatic information. Landscape units approximating small groups of land systems (Christian and Stewart, 1953), and individual land systems in some cases, were identified in this way. Each landscape unit identified contains a unique soil association.

Figure 1 LOCATION MAP

The Geomorphology and Soils map compiled in the manner described is comprised of eight 1:1 000 000 scale map sheets and has an extended matrix legend. Since the map and legend were intended to stand as the most complete, independent data source on the geomorphology and soils of Ethiopia at the time of their completion, in addition to providing the neccessary thematic data on geomorphology and soils for the MLUP exercise, both are considerably detailed. In its present form the map represents an update, for the section covering Ethiopia, of the only other comprehensive soil map of country, the 1:5 000 000 scale FAO/UNESCO Soils Map of the World (1977).

To provide a comprehensive understanding of the nature and distribution of the various map units identified and the methods used to delineate them, the remainder of this report is structured in such a way as to give a progressively more detailed picture of the different components of each. Chapter 2 for example includes a general summary of physical environment of the country with background on climate, geology, geomorphology, land use and soils. Details of the methods used to compile the map and legend are contained in Chapter 3, with particular reference to the influence of remote sensing and image analysis in the derivation of the final map. Chapter 4 provides details characterization of the geomorphology of the various map units identified. Cross-sections of each of the geomorphic units identified and the 382 resultant landscape units, together with a summary of the soil associations which characterize the geomorphic delineations as particular landscape units, are included in this chapter. In addition, plates are provided in the second half of Chapter 4 to illustrate the nature of the image signatures of many of the geomorphic subdivisions used in the construction of the legend.

Chapter 5 makes up the bulk of the report with details of soils occuring in Ethiopia, supported by considerable field and laboratory data gleaned from numerous existing soils related reports and from field and laboratory investigations carried out by the Assistance to Land Use Planning Project.

2. PHYSICAL ENVIRONMENTS

A brief description of climate, geology, gemorphology, land use and soils follows.

The intent of including information on climate, geology and land use in this chapter is to provide a physical and geographic setting for the geomorphic and soil patterns that are briefly set out here in overview form. Thus the information on climate, land use and geology is in no sense complete, while the expositions on geomorphology and soils are very general but will be elaborated upon in subsequent chapters.

At the end of this chapter, a list of previous studies with a geomorphology and/or soils emphasis, or with geomorphology and/or soils as a significant component, is given.

2.1 CLIMATE

Ethiopia is distinctive in Africa with regard to climate for its large extent of high altitudes and cool tropics. However great variations in climate occur across Ethiopia, and are to a large extent responsible for the country's widely varying soils, and to a lesser extent, widely varying landforms. From the deserts of the Danakil to the mountains of southwestern Ethiopia where precipitation reaches over 2 500 mm annually, climate is quite faithfully reflected in gross patterns of soil development.

2.1.1 Circulation and Precipitation

The main influences on circulation in Ethiopia are the Inter-Tropical Convergence Zone (ITCZ), the Northeast Trade Winds and the Southwest Monsoon. Precipitation is in turn strongly influenced by the relative movement of these circulation systems over the Ethiopian land mass. In January for example, the southern position of the ITCZ brings most of the country under the influence of the Northeast Trade Winds, resulting in an extensive dry season (Hurni and Stähli, 1982).

Northward movement of the ITCZ over Ethiopia in the period March to June encourages the progressive movement from the southwest of moisture laden monsoonal air masses. By July, most of the country is under the influence of this Southwest Monsoon which brings about the onset of the main rainy season (krempt) over much of the Ethiopian land mass.

A small rainy season (belg) results from the movement of a high pressure system over the Arabian Pennisula and from the southwest winds over the Indian Ocean (Hurni and Stähli, 1982). The belg precedes the main rainy season in the south and southwestern highlands of Ethiopia.

Apart from the effects of major circulation systems, the physiographic abruptness with which the high altitude Ethiopian land mass stands above the surrounding lowlands is a major influence on precipitation throughout the country. Total amounts of rainfall are substantially higher for much of Ethiopia, therefore, than for bordering low lying countries.

Rainfall amounts vary widely throughout Ethiopia and are principally determined by i) the direction of moisture bearing seasonal air currents and ii) the elevation (Gamachu, 1977). A generalised map of mean annual rainfall is given in Figure 2.

The highest values of mean annual rainfall occur in the southwestern highlands of Ilubabor, near Gore. Here mean annual rainfall is 2 200 mm. In fact, all highland areas in the southwest of over 1 m elevation receive between 1 400 and 2 200 mm (Gamachu, 1977). For much of the remaining highland areas mean annual rainfall lies between 1 000 and 1 800 mm, higher elevations generally receiving more than lower elevations.


ETHIOPIA
MEAN ANNUAL RAINFALL (mm.)
RED SEA
GULF OF ADEN
DJIBOUTI
SUDAN
SOMALIA
SOMALIA
KENYA
0 100 200 300 400 Km
Abay
Wabi Shebele
35°
37°
39°
41°
43°
45°
47°

Figure 2

Rainfall decreases abruptly descending off the highlands down the escarpments of the Rift margins in eastern Welo and Tigray and in northern Hererge. Mean annual rainfall in the Danakil Depression and on the Red sea coast falls below 200 mm. The rainfall gradient is much more gentle to the south, southeast and west. Mean annual rainfall in the Ogaden only eventually decreases to less than 200 mm, and in the western lowlands of Ethiopia values generally remain above 1 000 mm.

Seasonal distribution of rainfall is an important feature in Ethiopia. Rainfall pattern regions are shown in Figure 3. Marked wet and dry seasons occur over most of the country, the exceptions being i) the extremely dry areas, as on the Red Sea coast, where even during the "wet" season there is very little precipitation and ii) the extremely wet areas, as in the southwestern highlands, where even during the "dry" season there is significant precipitation. The time of year of occurence of wet and dry seasons, as well as their relative length, vary widely.

2.1.2 Temperature

Temperature is greatly influenced by the rapidly changing altitudes in Ethiopia. Lateral variations of relatively few kilometers may result in vertical changes of 1 000 meters or more in some of the major canyons, on the slopes of high mountains, and along the Rift Valley escarpments.

The high correlation between altitude and mean daily temperature during the growing period (R=.79 for the southeastern lowlands and the Ogaden and R=.95 for the rest of Ethiopia) allows a definition of thermal zones based on contours. This is shown in Figure 4. Mean annual temperatures tend to be 2-4^{o}C lower than those temperatures indicated in the figure for each given zone, however the temperature pattern of Ethiopia is clearly indicated.

Extremes in temperature range from the mean annual temperature of 34.5^{o}C in the Danakil depression at 180 below Msl to mountain slopes over 4 000 m above Msl where minimum temperatures fall below

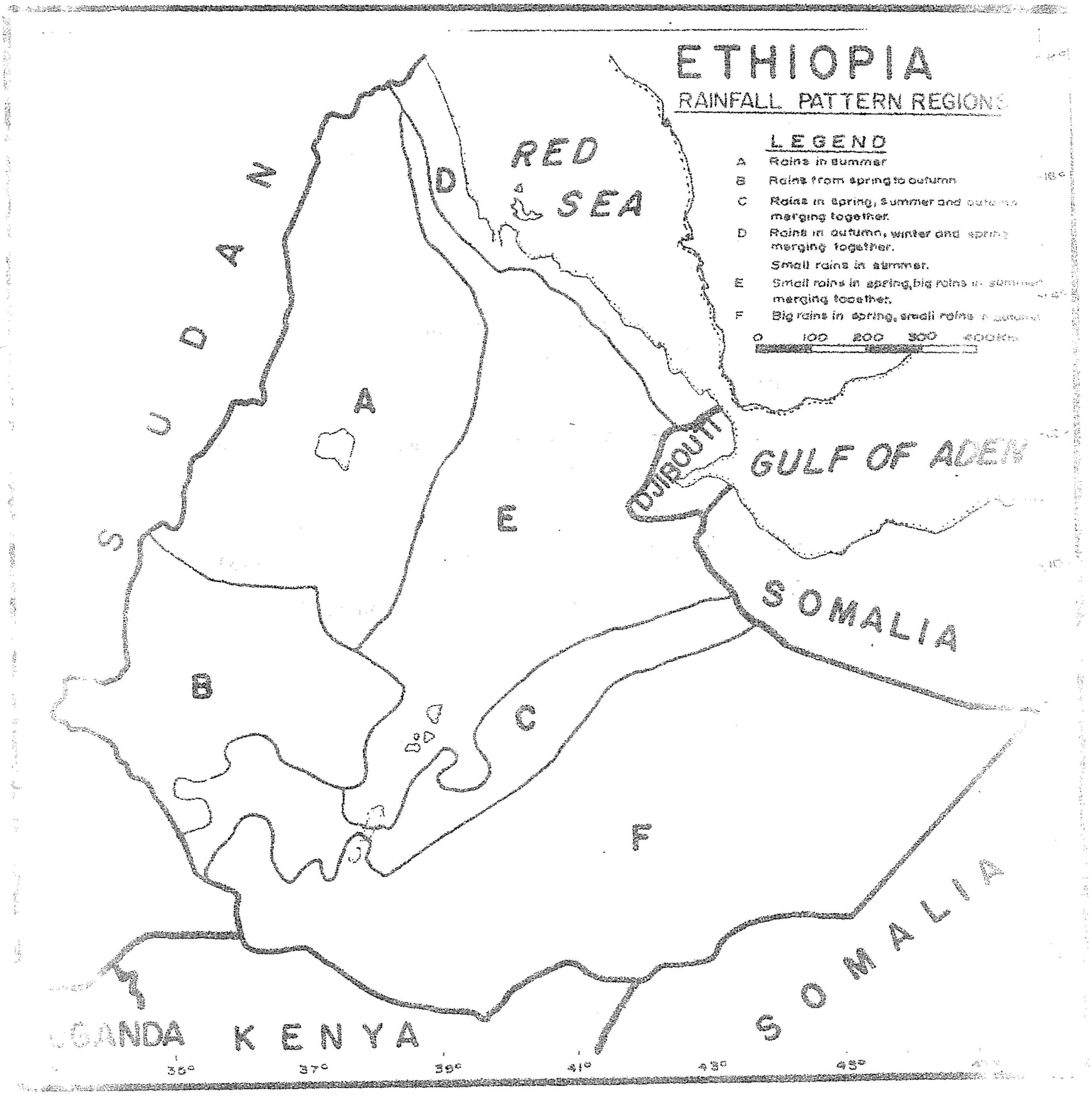

ETHIOPIA
RAINFALL PATTERN REGIONS
LEGEND
A Rains in summer
B Rains from spring to autumn
C Rains in spring, Summer and
merging together.
D Rains in autumn, winter and
merging together.
Small rains in summer.
E Small rains in spring, big rains
merging together.
F Big rains in spring, small rains
0 100 200 300
RED SEA
GULF OF ADEN
DJIBOUTI
SUDAN
SOMALIA
SOMALIA
KENYA
GANDA
A
B
C
D
E
F
35°
37°
39°
41°
43°
45°

Figure 3

TABLE 1 : RAINFALL PATTERN REGIONS OF ETHIOPIA
- LEGEND TO FIGURE 3

Code	Summary Description
A	- One comparatively short rainy season in summer
B	- One comparatively long rainy season; dry season in winter. Some stations with year round growing period
C	- One comparatively long rainy season with rainfall peaks in spring and autumn separated by a season with less but still considerable rainfall
D	- Long rainy season in winter and small rainfall peak in summer
E	- Main rains in summer preceded by a small rainfall peak in spring or by a prolonged period of moderate rainfall
F	- Two short rainy seasons. Main rains in spring, small rains in autumn.

NB: Spring, summer, autumn and winter refer to seasons of the year according to common usage in the temperate northern hemisphere

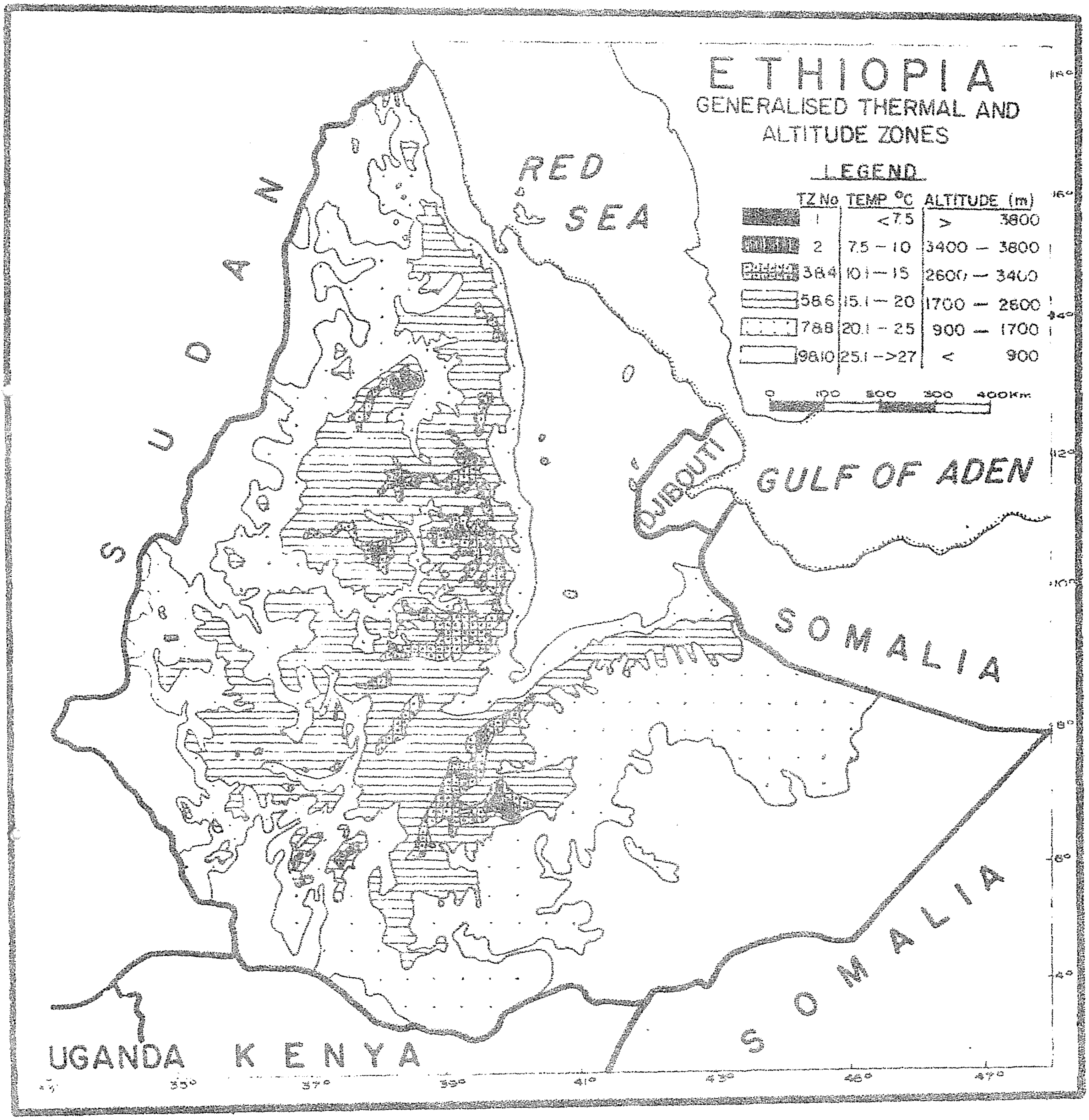

ETHIOPIA
GENERALISED THERMAL AND ALTITUDE ZONES
LEGEND
TZ No | TEMP °C | ALTITUDE (m)
1 | <7.5 | > 3800
2 | 7.5 – 10 | 3400 – 3800
3&4 | 10.1 – 15 | 2600 – 3400
5&6 | 15.1 – 20 | 1700 – 2600
7&8 | 20.1 – 25 | 900 – 1700
9&10 | 25.1 – >27 | < 900
0 100 200 300 400Km
RED SEA
GULF OF ADEN
DJIBOUTI
SUDAN
SOMALIA
SOMALIA
UGANDA
KENYA
35°
37°
39°
41°
43°
45°
47°
18°
16°
14°
12°
10°
8°
6°
4°

Figure 4

zero overnight. On the upper reaches of Mt. Ras Dejen, light snow falls are recorded in most years. Between these extremes are vast areas of highland plateaux and marginal slopes where mean annual temperatures are between 10 and 20°C.

2.1.3 Evaporation

The potential evapotranspiration (PET) varies widely over the country. The highest values are found in the lowlands (yearly PET for Gode, msl 320 m: 1886 mm), and the lowest values at altitudes (yearly PET for Goba, msl. 2700 m : 901 mm).

More important than the yearly values of PET's are the ratio's PET/P over the year (Fig.5). In the western highlands with their high precipitation (P), yearly PET does not exceed P and only during a short period in the year P is lower than PET. Also at high altitudes in areas with a rather prolonged rainy season PET exceeds P only during a short period in the dry season. The opposite is true for the dry areas in north, east and southeast Ethiopia. PET exceeds P during the year except during the very short rainy season. In the relatively dry Rift valley, in the northwestern lowlands and in the southern lowlands, yearly PET exceeds yearly P. During the rainy seasons however P is higher than PET. In the highlands yearly P and PET are about equal. During the dry period PET exceeds P, during the wet seasons P exceeds PET.

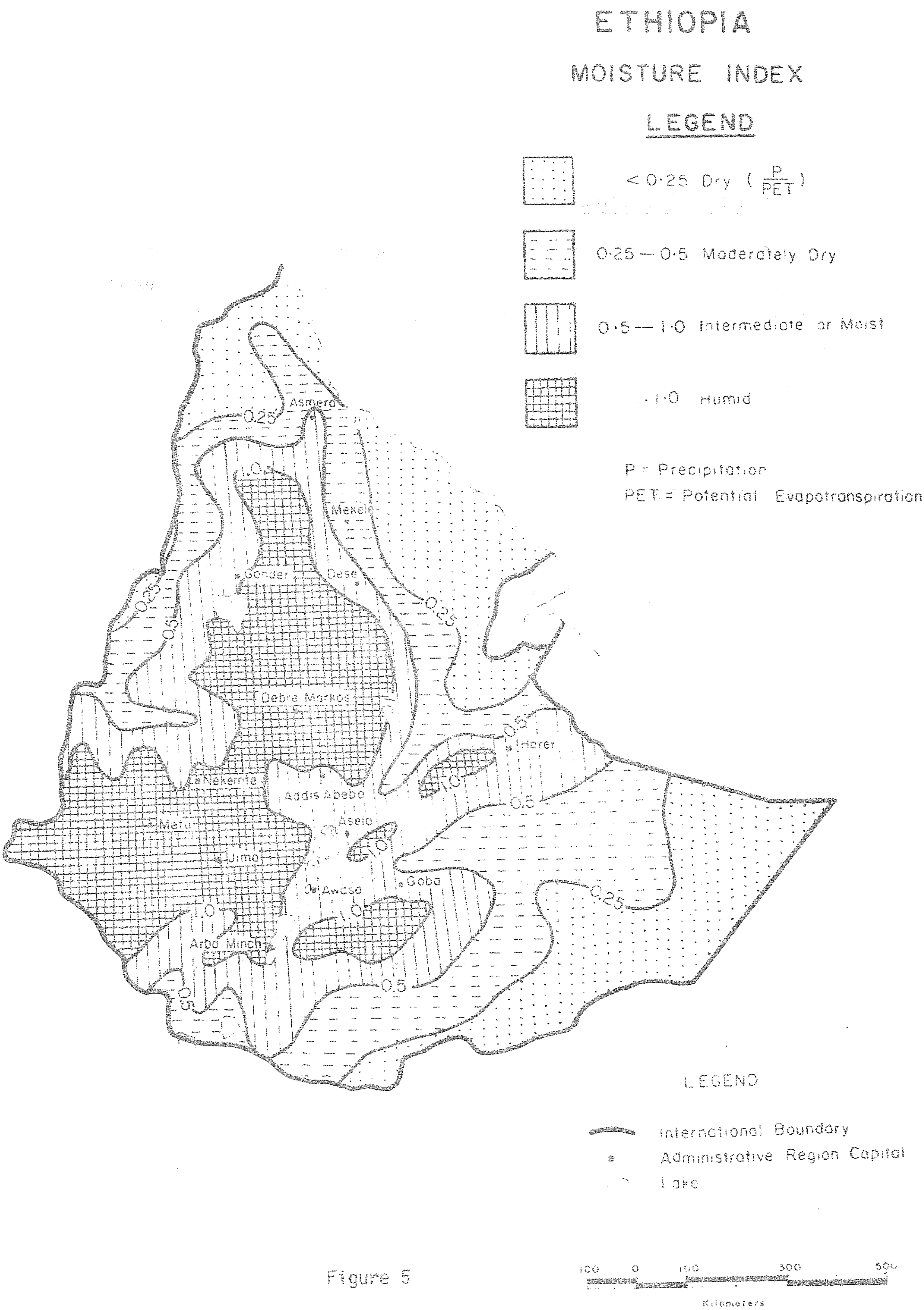

ETHIOPIA
MOISTURE INDEX
LEGEND
< 0·25 Dry (P / PET)
0·25 — 0·5 Moderately Dry
0·5 — 1·0 Intermediate or Moist
1·0 Humid
P = Precipitation
PET = Potential Evapotranspiration
Asmera
Mekele
Gonder
Dese
Debre Markos
Harer
Nekemte
Addis Abeba
Metu
Asela
Jima
Awasa
Goba
Arba Minch
0.25
0.5
1.0
LEGEND
International Boundary
Administrative Region Capital
Lake
100 0 100 300 500
Kilometers

Figure 5

2.2 GEOLOGY AND GEOMORPHOLOGY

2.2.1 Geological Setting

Ethiopia forms part of the major structural unit of the earth's crust referd to as the Horn of Africa. The unit comprises the Arabian penninsula, the Red Sea and the Gulf of Aden, Djibouti, Somalia and the northern part of Kenya. The geological history of the Horn of Africa is closely related to that of the rest of the continent but does differ significantly in some aspects.

The following is a summary of the succession of strata in the Horn of Africa, modified after Mohr (1971).

Quaternary: localized areas of aeolian and fluvial, and extensive lacustrine sediments, chiefly in the Rift System; glacial and glaciofluvial sediments on the highest peaks; reef limestones and marine terraces along the coasts.

earlier alkaline and silicic lavas and pyroclasts followed by recent basaltic fissure erutions.

Tertiary: thick flood basalts (trap series) in central Ethiopia, with intermediate and silicic lavas and pyroclastic sediments interstratified towards the top of the series.

contined deposition of limestone and gypsum in the eastern Horn.

Mesozoic: Jurassic-Cretaceous regressive sandstone facies deposited on gypsum-shale facies.

Jurassic-Cretaceous limestone, thinning to the west and finally wedged out between two sandstone horizons.
Triassic-Jurassic transgressive sandstone facies, followed by shale and then gypsum horizons.

Paleozoic: apart from some very minor and doubtful exceptions, not found (unconformity).

Precambrian: various grades and types of schist and gneiss, as well as almost unaltered sedimntary rocks and igneous intrusions; these rocks underlying the whole of Ethiopia and forming an intensely folded and foliated metamorphic basement; schistosity and axes of folding generally trending north-south or northeast-southwest, tentatively divided by an unconformity into an older more metamorphosed group and a younger weakly metamorphosed group; this complex is generally refered to in total as the Basement Complex.

Where Mesozoic sediments have been wedged out in western Ethiopia, Tertiary basalts directly overlie the Basement or alternatively, the crystalline Basement itself is exposed, except where overlain by alluvium.

Figure 6 is a generalized geological map of Ethiopia.

2.2.2 Geomorphology and Structure

The Horn of Africa has been strongly influenced by two major tectonic episodes in the earth's history; the Arabo-Ethiopia swell in the Eocene to early Oligocene, and the major rift faulting movements throughout the whole of the African Rift System from the Miocece to the Quaternary.

The northeast-southwest trending Great Rift System of Africa bifurcates in the Afar lowlands of Ethiopia with major escarpments trending north and east respectively after the point of separation. The original land mass resulting from the enormous, uplifted swell has thus been divided into two extensive plateau units by the Rift System - the Ethiopian Plateau to the west and the Somalian Plateau

Figure 6 GENERALIZED GEOLOGICAL MAP
(modified after Kazmin, 1972)

to the east.

Much of the Ethiopian plateau lies above 2 000 m altitude and comprises extensive areas of structurally horizontal table-land. This is an expression of the essentially flat lying nature of the peneplained Precambrian basement rocks underlying the Mesozoic marine sediments and the Tertiary flood basalts which followed the great swell (Mohr, 1971).

Despite the dominance of tectonics on the large scale physiography of Ethiopia, on a smaller scale denudational, depositional, and volcanic processes have been significant in shaping the surface of the country. Erosion for example has subdued the original stepped tectonic scarps along both the east and the west margins of the Ethiopian plateau, although the western escarpment facing the Rift still remains somewhat dramatic in relief, more so than the Sudan border scarps to the west. Since the great swell, enormous energy has been available to streams descending from the plateau to sea level over relatively short distances. Consequently, the plateau is deeply incised by huge canyons and gorges such as those of the Abay (Blue Nile) and Tekezi rivers. Descents from the plateau, to rivers below, of 1 000 m or more over relatively few kilometers horizontally are common in such situations.

In addition to these massive erosional scars, extensive Tertiary volcanic piles, including Mt. Ras Dejen (4 543 m) occur on the otherwise flat plateau.

According to Mohr (1971), "The Somalian Plateau lies to the southeast of the Rift System. This part of the original swell shows a much more appreciable tilt, towards the southeast, than does the Ethiopian Plateau, and the dip of the strata is closely reflected in the physiography of the Somalian Plateau... The plateau has no clearly defined margin to the southeast, but slopes gradually down in this direction through Somalia and beneath the Indian Ocean."

High summits occur along structurally controlled ridges of the eastern Rift horst and atop Tertiary volcanic piles such as Mt. Batu (4 307 m) in Bale.

The Rift Valley itself is an extensive graben, cluttered with evidence of recent volcanism in the north and bounded by impresive stepped horsts of the plateaux on the west and southeast margins. It widens significantly at the intersection of the East African Rift, the Red Sea and the Gulf of Aden tectonic alignments, beyond Awash in Shewa, into an area refered to as the Afar Triangle. The effects of extensive fault swarms are also visible throughout the Rift in the morphology of structural alignments. These lineations are mostly aligned in sympathy with one or more of the main tectonic zones mentioned above.

The southern and central portions of the Rift contain a number of lake basins characterized by their alkalinity. In this region the Rift floor reaches elevations as high as 1 800 m near Lake Ziway, but descends to below sea level in the Danakil Depression further north and to around 400 m at Lake Turkana in the south.

As a general rule, lithology is a very significant factor in the development of landforms in Ethiopia. Granitic intrusions into gneisses and schists of the Precambrian basement tend to be more resistant to erosion than the host rocks, standing out as inselbergs in the otherwise undulating to rolling landscapes of areas such as the Borana, Ilubabor and the Eritrean lowlands. Subhorizontal Mesozoic sediments, including limestones and sandstones, tend to form plateaux or plains in northern Ethiopia and the Ogaden region, and benches in major river gorges. Plateaux and benches terminate in steep, dissected escarpments where resistant strata have been broken down by the elements.

The essentially flat lying piles of Tertiary flood basalts have preserved the relatively flat underlying Mesozoic sediments. Volcanic cones and domes form high relief mountains in many areas of the country and represent the most distinctive example of the influence of parent material on landform genesis.

Fluvial and lacustrine deposits, particularly in the Rift Valley and in the southwestern lowlands, have produced vast plains with little or no relief. Examples of such depositional landforms include the lower Awash plain in the central Rift and the Gambela to Sudan border area in southest Ethiopia.

2.2.3. Drainage

The unique highland physiography of much of Ethiopia and its privileged exposure to favourable climatic influences, has led to the development of an extensive network of rivers and streams in the country. Many rivers rising in Ethiopia are also the source of major water resources in neighbouring countries. A generalized map of major river basins is shown in Figure 7.

The Ethiopian Plateaux refered to in the previous section is the source of the Abay (Blue Nile), Tekezi, Mereb, Baro, Akobo and Omo rivers. In general these flow in a westerly direction with the exception of the Omo, which flows southward into the closed Turkana basin. The most impressive basin of the Ethiopian Plateau, the Blue Nile, is an immense river system of historical note served by important tributaries which include the Muger, Jemma, Guder, Didessa, Dabus and Beles rivers. The Blue Nile rises in the northwestern region of the central highlands, near Lake Tana, and flows through hundreds of kilometers of intricately dissected canyons and gorges which it and its tributaries have excavated in the plateau, to finally meet the White Nile in the Sudan.

The Awash river, important for its irrigated agriculture, rises in part on the Ethiopian plateau west of Addis Abeba, but flows east from the plateau and then southeast through the northern half of the Rift Valley. It is also served by tributaries from both the western and eastern horst margins of the Rift. After meandering through a vast alluvial plain along the floor of the Rift, the Awash terminates in Lake Abbe, a closed salt lake basin on the Djibouti border. Other rivers of the central and southern Rift Valley flow from both west and east plateau margins into closed lake basins within the Rift.

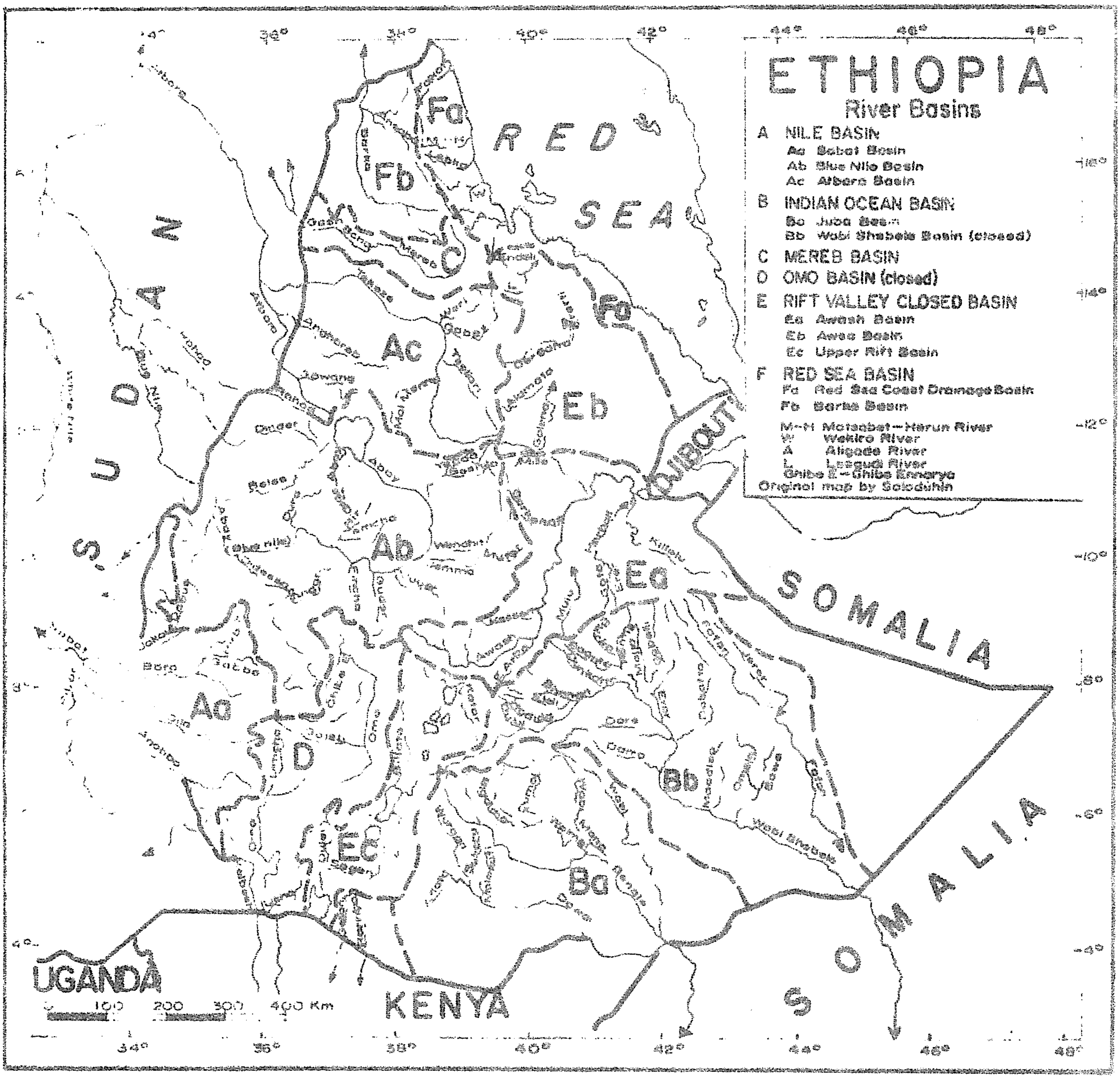


Figure 7 MAIN RIVER BASINS (modified after Gamachu, 1977)

River drainage on the Somalian Plateau is noticeably influenced by the southeasterly surface dip of the geological strata, with most rivers flowing in this direction. The upper reaches of the Wabi Shebele, the main river system on the Somalian Plateau, rises in the Chercher highlands on the east side of the eastern Rift horst and in the Chilalo mountains of Arsi. The Wabi Shebele has developed a distinctive gorge in its upper catchment but this diminishes markedly as the river flows out into the Ogaden plains. It also fails to reach the sea, terminating in a closed basin in Somalia. Other main rivers of the Somalian Plateau include the Fafen, Genale, and Dawa, all of which terminate in closed basins in or near Somalia.

An important additional control on the development of many rivers in Ethiopia is the underlying geological structure. The most apparent of those main rivers affected by fault control over long sections of their channels are the Omo, the Didessa and the Fafen.

2.3. LAND USE

Three main factors appear to have influenced both the use of the land and the natural vegetation cover type as they are presently expressed in Ethiopia.

The influence of climate is manifested by the response in land using activities to its rainfall and temperature parameters and their various implications. Rainfed crop cultivation is the principal activity in most of the area where adequate rainfall is available. In semi-arid to arid conditions, pastoral livestock raising becomes predominant. Response to the temperature factor is also manifested in several ways; predominance of sorghum and cotton, for example in warmer areas, and that of barley in cooler areas; or prevalence of horses as "beasts of burden" in the cooler areas and that of donkeys and camels in the warmer areas. The climate of Ethiopia ranges from the hot desert type in the Danakil to the cool temperate type in the highlands, affecting the concomitant variations in land using activities.

Slope and stoniness are the two parameters of the terrain to which land use activities show response. Precipitous slopes are generally still under natural vegetation cover, while the rolling plateaux and terraces are intensively used for cropping and/or grazing. Where population presssure (see below) has not overridden this parameter, rocky patches are used as unimproved pastures. Cultural practices are also influenced by slopes, as for example terracing and/or hand cultivation on steeply sloping land.

Population, in both its distribution and size, as well as in its cultural orientation and practices, has had a tremendous impact on the cover type of the country. Large areas in the north of the country with high population densities are completely devoid of vegetative cover outside of the cropping period. Some areas have no soil cover left due to previous agricultural mismanagement which resulted in total erosion of the soil cover and exposure of extensive areas of the bedrock. The southern, western and southwestern parts of the country have not experienced comparable population pressures and therefore have large areas of natural cover types intact.

Figure 8 is a generalized land use/land cover map of Ethiopia.

About 10% of Ethiopia is intensively cultivated land. Hardly any tree vegetation is visible, virtually all the land being opened up for cropping (largely grains, legumes and oil seeds) and/or grazing of livestock. Grazing land tends to be over-stocked and vegetative cover is rarely more than a few centimeters high even at the peak of the rainy season. Crop residues are also grazed. Thus there are extensive areas of bare soil by the end of the dry season at the onset of the following rains. Tremendous erosion ensues, more so of course when population pressure has forced this farming system up onto steeper slopes. Where the cycle has been practiced for hundreds of years - as in northern Shewa , Welo, Tigray and Gonder - land is severely degraded. Terracing is increasing in such areas, but much land may be beyound repair.

Moderately cultivated land makes up another 11% of Ethiopia. Although the farming systems are comparable, the presence of some natural vegetation and more extensive grazing lands somewhat reduces pressure on the land. Erosion, while less severe, is ongoing. With population pressure, these moderately cultivated lands which are generally distributed around the intensively cultivated lands, are becoming more intensively used.

Significant areas in northern Sidamo, southern Welega and Shewa Kefa, Gamo Gofa, Ilubabor and the Chercher highlands are under perennial crop cultivation with little land under annual crops. These areas are approximately 1.6% of the country. Occasionally however cropping of perennials is combined with extremely intensive associated land use, as for example in the areas of ensete cultivation where grazing lands are severely degraded due to very high livestock densities, or for example in the areas of chat and coffee cultivation in the Chercher highlands where sorghum is intensively cultivated on steep slopes.

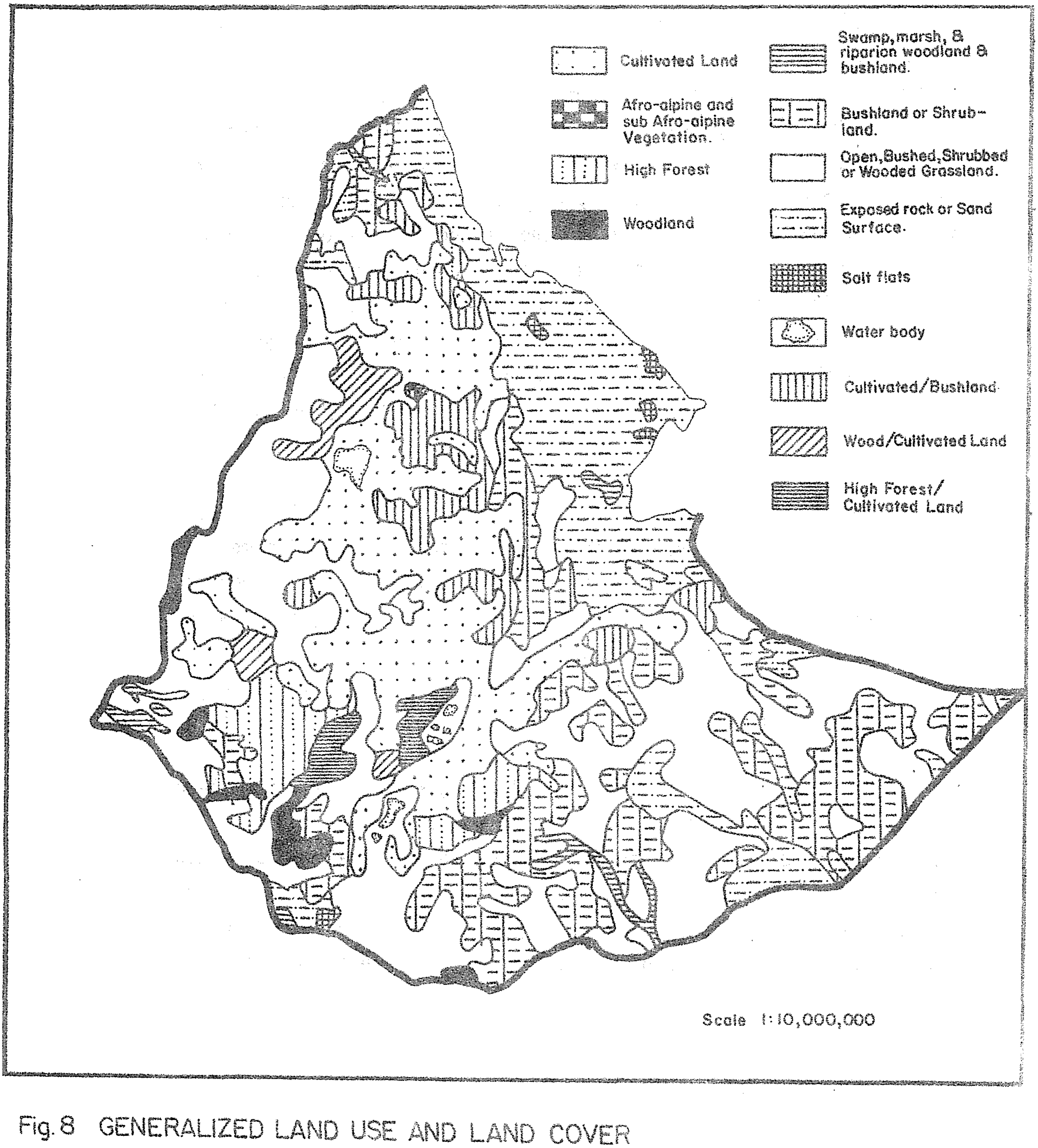


Fig. 8 GENERALIZED LAND USE AND LAND COVER

Approximately .2% of Ethiopia has been developed as state farms. Generally on the flattest land, erosion does not present much problem, however particularly along the Awash river irrigation has occasionally accenturated vertic characteristics and salinity and induced heavy silting of the soil surface.

Dense coniferous and dense mixed high forests have been removed over most of their extent in Ethiopia, and cover now only 2.3% of the country. A further 2% is under disturbed high forest, that is high forests that are currently being cleared for human settlement. Only remnants of coniferous forest are still found, of Podocarpus in the southwest and of Juniperus in central Sidamo and the Chercher highlands. Most of the mixed high forest is in the southwest, where rainfall is above 1 500 mm.

Woodland, bushland, shrubland and grassland, with varying densities of tree, bush, shrub and grass cover make up approximately 55% of Ethiopia. In the parts of the country with higher precipitation, such areas are generally given over to peasant livestock grazing with scattered crop cultivation. In drier parts of the country, pastoral livestock grazing predominates.

Approximately .8% of Ethiopia is perennial and seasonal swamp and marsh and 16% bare land. These lands are generally not economically productive, with the occasional exception of some nomadic or peasant livestock grazing, and such activities as for example, mining of salt flats in the Danakil.

2.4 SOILS

The very wide ranges of climate, topography, parent material and land use of Ethiopia have the result that soils are extremely variable and that, in different parts of the country, different soil forming factors take precedence.

2.4.1 Western Ethiopia

In northern Kefa and Gamo Gofa, Ilubabor, Welega and parts of Gojam and Gonder, soils are predominantly developed on Trap Series volcanics and felsic and metamorphic Precambrian basement materials. As this area of western Ethiopia includes the descent of the highland plateau to the lowlands of the Sudan, soils over large areas are also developed on the alluvial and colluvial materials mentioned previously.

The range of parent materials on the highland plateau is not, however, strongly reflected in soil development. High rainfall of up to greater than 2 200 mm annually has resulted in very similar soils irrespective of parent materials. The predominant soil association is one of Dystric Nitosols and Orthic Acrisols, with inclusions of Dystric Cambisols and Lithosols on the steepest slopes. Where fine textured alluvium and colluvium have concentrated, and where rainfall permits, Chromic and Pellic Vertisols occur, as on the extensive colluvial slopes at the base of the highland plateau.

In western Ilubabor, after descent from the highland plateau, the flood plain of the Baro river opens out to cover thousands of square kilometers. Soils are predominantly Chromic Vertisols, however Eutric Gleysols and Eutric Histosols also occur in those very large areas within the flood plain that experience extreme seasonal flooding. Eutric Fluvisols occur along the Baro and its many tributaries.

2.4.2 Central Ethiopia

The soils of Shewa, eastern Gojam and Gonder, Arsi, and northern Bale and Sidamo are predominantly developed on Trap Series volcanics, although large areas in southern Shewa are covered by more recent pyroclastic materials. Limestone, sandstone and basement materials all appear locally, most notably in the Blue Nile gorge. Rainfall ranges from 900 to 1 500 mm. Soil differences across the central highland plateau are largely a response to topography.

Eutric Nitosols and Chromic Luvisols, with inclusions of Chromic Cambisols and Lithosols, occur on the hills and mountains. Pellic and Chromic Vertisols occur on the flatter landforms, including a great number of both small and large basins with seasonal drainage deficiencies which are littered across the highland plateau. The soils of the gorges of the Blue Nile and its tributaries are variable, reflecting the range of parent materials present, however they have in common extreme stoniness and generally very shallow profiles as a result of the dramatic topography. In addition, localized occurences of Mollic Andosols exist, particularly around the Mt. Batu massif, and compacted ash layers are frequently found in the soils developed on those volcanic plateaux where the main parent materials are pyroclastic deposits.

2.4.3 The Northeastern Escarpment

Eastern Shewa and central Welo have soils developed almost exclusively on Trap Series volcanics. Much of the area forms the so called northeastern escarpment of Ethiopia, i.e. the northeastern extremity of the central plateau formed by the western horst arm of the Rift described in section 3.1.1, resulting in strong structural influence on landform and soil development. This influence is reflected primarily in the accelerated erosion and the extreme stoniness of the soils, and in the mountainous topography. In addition, the area has been intensively cultivated for hundreds of years which has added man made erosion to the geological erosion.

Soils on the flatter landforms, which include wide parallel valleys, sideslopes and volcanic plateaux, are generally stony phase Chromic and Pellic Vertisols or Vertic Cambisols. Where intensively cultivated, even on minimum slopes, these highly erodable soils can and have become quite shallow. On the steeper landforms, Eutric

Cambisols predominate, with lithic phases and Lithosols occuring on the steepest slopes. Large areas, not only on the steepest slopes, are eroded and extensive areas of rock outcrop occur. In many areas narrow terraces have been constructed, however even on these, soils are shallow, very stony and depleted.

2.4.4 The Chercher highlands

Parent materials include Trap Series volcanics toward the west, Mesozoic sandstones throughout, and felsic Precambrian basement materials limestones toward the east. The area is part of the eastern horst arm of the Rift. As such, parent materials are very mixed, particularly toward the east where felsic materials, sandstones alternate over very short distances. Strong structural influence and intensive cultivation have had effects similar to those on the north-eastern escarpemtn. Rainfall is fairly uniform throughout at between 900 and 1 200 mm, but drops off abruptly with altitude to the north, south and east.

Toward the west, where the Chercher highlands are wettest, where structural influence is less evident and where volcanics predominate, the soil association includes Chromic Vertisols, Eutric Nitosols, Chromic Luvisols and Chromic Cambisols as is typical of central Ethiopia. Where sandstones occur soils are similar, although of coarser texture, but Vertic Luvisols rather than Vertisols occur on the flatter landforms.

Toward the east, felsic materials, sandstones and limestones alternate but soil development very strongly reflects topography, land use and rainfall as well. Chromic Vertisols and Vertic Luvisols, depending on parent material, develop in the wide parallel valleys in the highest rainfall areas. These quickly give way to shallow stony Eutric Cambisols and Rendzinas on the steeper landforms where geological and man made erosion are often severe. As rainfall decreases with descent, stony lithic phase Eutric Cambisols and Lithosols become predominant.

2.4.5 The Northern Highlands

In western Tigray and northern Gonder and Welo, parent materials include Trap Series volcanics, felsic and metamorphic Precambrian basement materials, limestones, Mesozoic and Upper Paleozoic sandstones as well as glacial deposits and windblown pyroclastics. The area has been strongly affected by structural movements and topography is extremely rugged. Over a comparatively short distance, rainfall decreases from a high of over 2 200 mm to less than 700 mm. Land use is equally variable,much of the area has been intensively cultivated for hundreds of years while in other parts dense bush and shrub vegetation predominate.

Soils are thus extremely variable over very short distances. Nitosols, Acrisols, Luvisols, Vertisols, Andosols, Rendzinas, Phaeozems, Arenosols, Fluvisols, Cambisols and Lithosols all cover substantial areas, according to the particular conjunction of geology, climate, topography and land use at any given point. Generally, Nitosols and associated soils predominate north of Lake Tana, Vertisols predominate on the colluvial slopes of the area along the Sudan border, and Cambisols very often with lithic phases, occur over much of the rest of the area with its substantially drier climate. However this pattern is not consistent.

2.4.6 Southern Bale and Hararge (the Ogaden)

Soils here have developed on a range of parent materials. Limestone, sandstone and evaporites all occur. Colluvium of mixed origin covers large areas and alluvium of equally mixed origin is found on the flood plains of the Genale, the Wabi Shebele and the Fafen rivers. With rainfall rarely exceeding 400 mm, evapotranspiration rates uniformly high and topography comparatively flat, parent material has the dominant effect on soil differentiation across the region.

On the vast plains in the area, gypsic and calcic Xerosols and Yermosols occur. Petrogypsic and petrocalcic phases are common, according to the parent material, particularly on colluvial slopes. Saline phases and Orthic Solonchaks frequently occur on evaporite deposits. On the large sandstone plains of the eastern Ogaden Cambic Arenosols occur, although the area has so much windblown material that Eutric and Calcic Regosols probably predominate. On the infrequent occurences of steeper landforms, soils have not developed to any significant extent.

On the flood plains of the major rivers, saline phase Chromic Vertisols occur where fine textured alluvium has concentrated. Elsewhere saline phase Eutric and Calcaric Fluvisols occur, according to the origin of the alluvium.

2.4.7 Central Hareṙge and Bale

These areas are transitional between the Ogaden and the Chercher highlands. Limestone predominates as parent material, although sandstones occur along the Somalia border. Topography is generally flat, but directly south of the Cherċher highlands the gorges of the Wabi Shebele river dissect the limestone plains on a major scale. Rainfall decreases from 700 mm in the north of the area to below 400 mm in the south. It is this gentle rainfall gradient that is largely responsible for soil differences.

On the limestone plains to the north of the area, where rainfall approaches 700 mm, Chromic Vertisols, often with deep mollic A horizons, predominate. Towards the south and east, Vertisols grade to Calcic Cambisols, commonly with petrocalcic phases, as rainfall drops off, and then to the Xerosols and Yermosols of the Ogaden itself. Lithosols predominate in the gorges of the Wabi Shebele and its tributaries and on the infrequent steep landforms on the plains.

2.4.8 Southern Sidamo

Soils here are predominantly developed on deeply weathered rhyolites on the flatter landforms and on felsic Precambrian basement materials, most commonly gneisses and granites, on the steeper landforms, although minor limestone inclusions occur. Toward the north, in the area transitional to the highland plateau, the rhyolites disappear and Precambrian basement materials predominate. Rainfall across the area ranges from 400 mm in the south to 1 000 mm toward the north.

On the flatter landforms in the south, soils are Eutric Cambisols. They are very deep due to the nature of the parent materials. In addition, large areas of Vertisols are found in numerous basins with seasonal drainage deficiencies. As slopes exceed approximately 15% the rhyolites give way to gneisses and granites. Lithic phase Eutric Cambisols and Lithosols occur on these materials.

With the increase in rainfall toward the north, Cambisols grade to an association of Vertic Luvisols on the flatter landforms and Chromic Luvisols and Eutric Cambisols on the steeper landforms. Orthic Acrisols and Dystric Cambisols become more common as rainfall increases.

2.4.9 The Southern Rift Valley

This area includes the zone from Lake Chew Bahir on the Kenya border to Lake Koka south of Addis Abeba. Geology is complex. Parent materials include Tertiary pyroclastics and Quaternary basalts. Much of the area around the numerous Rift Valley lakes is covered by lacustrine deposits of various origins. Evaporites occur around Lake Chew Bahir. Finally, much volcanic and granitic colluvium covers extensive colluvial slopes and fans on the Rift margins, particularly in southern Sidamo and Gamo Gofa.

Vitric and Mollic Andosols occur throughout, although the largest areas are concentrated to the north of Lake Abaya. Andosols have developed on ash and pumice laid down both as aerial and as lacustrine deposits. Sodic phases are common throughout and saline phases and Orthic Solonchaks occur around Lake Shala. Where Quaternary basalts outcrop, Lithosols and extensive areas of rock outcrop occur.

The Rift Valley narrows at Lake Abaya and the very steep topographic gradient has resulted in extensive colluvial slopes and fans. Where colluvium has originated in the fine textured soils of the volcanics of the highland plateau, Chromic Vertisols occur, as they do on the fine textured fluvial and lacustrine deposits laid down on the margins of Lake Abaya. Where colluvium originates in the coarser textured granitic soils further south, Eutric Fluvisols predominate. South of Lake Abaya, particularly on the colluvial slopes and on the flood plains of rivers,saline phases begin to appear as rainfall decreases, culminating in the playas of Chew Bahir

With the exception of the southern extreme, the Rift margins are transitional to the highland plateau. Moving upward out of the Rift, Andosols grade to Eutric Cambisols and then to the association of Nitosols and Vertisols typical of the central highlands

2.4.10 Northern Harerge and eastern Shewa and Welo

These areas comprise largely semi-desert, with the exception of the Awash river valley. The Awash river flows permanently and many lakes and permanent and seasonal swamps-- often saline-- are found along its courses. Over most of the area of this northern part of the Rift Valley, parent materials are Tertiary and Quaternary volcanics, with alluvium and colluvium originating in the highland volcanics found along the Awash river and on the colluvial slopes and fans coming down from the northeastern escarpment and from the Chercher highlands. Structural features are common, and colluvium and evaporite deposits collect in numerous small graben basins. Rainfall is between 300 and 500 mm and evapotranspiration rates are very high.

The area is young enough geologically and is dry enough that soils have only developed significantly on the alluvial and colluvial materials. Eutric and Calcaric Fluvisols occupy the flood plain of the Awash river, and Eutric Histosols and Gleysols occur where flooding is extreme. Saline phases and occasionally sodic phases increase in frequency toward the Djibouti border. Orthic Solonchaks are most common on the colluvial slopes at the base of the northeastern escarpment and in the graben basins. At the base of the Chercher highlands, salinity is less a problem and Eutric Fluvisols predominate. Stony phases are very common on these colluvial slopes and fans.

Elsewhere, Lithosols, lithic phase Eutric Regosols and extensive areas of rock outcrop occur, the latter often as lava flows. There are occasional instances of Eutric Regosols on the flattest landforms and of Vitric Andosols where volcanic ash deposits are found.

2.4.11 Northeastern Welo, eastern Tigray, the Eritrean coast and Northwestern Eritrea

These areas are primarily desert. Parent materials include Tertiary and Quaternary volcanics, colluvium from the highland plateau, aeolian deposits, marine deposits along the Eritrean coast, felsic and metamorphic Precambrian basement materials in northwestern Eritrea and occasional inclusions of limestone. Rainfall is less than 200 mm. Soils are not developed, but unconsolidated deposits do occur as sand dunes, colluvial and alluvial fans and beach sands, all more often than not saline. Playas, extensive lava flows and occasional occurences of Eutric Regosols and Vitric Andosols are also found. Rock outcrop predominates on sloping landforms.

2.4.12 Areas of different soil types in Ethiopia

Table 2 indicates the areal extent in sq kms of the various soil types mapped on the Geomorphology and Soils map of Ethiopia. The percentage of the total area of the Country cavered by each is also indicated.

2.5 PREVIOUS STUDIES

There are a number of previous soil, land system and/or land classification studies of various parts of Ethiopia. The kind, amount and quality of the soil data vary quite widely. Few of these studies have had soil mapping as a goal, thus much additional information in any number of fields is included in the reports of the work.

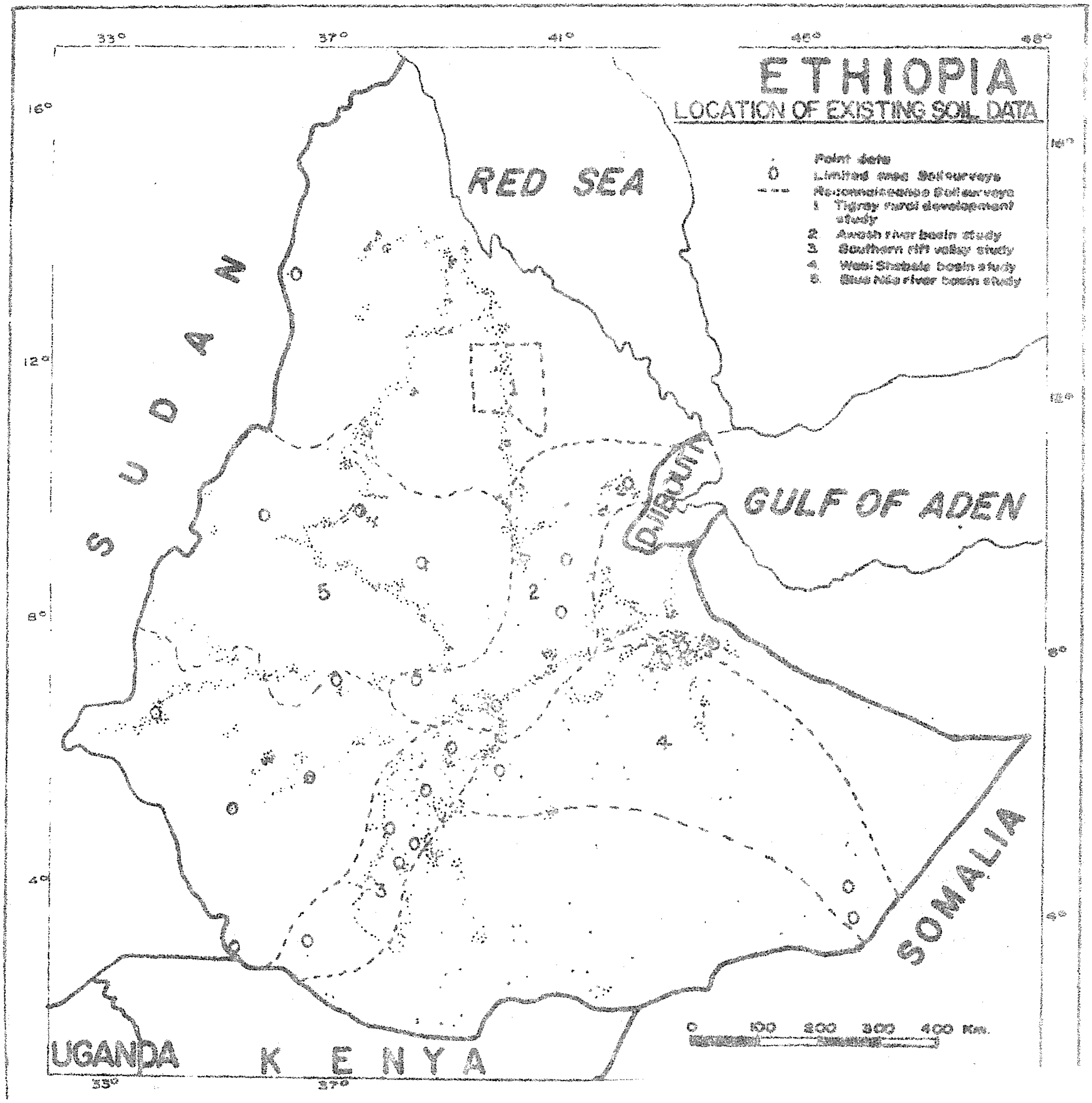
Locations of the main previous study areas and approximate density of soil point samples are shown in Figure.9.. The more useful and easily available studies are summarized below.

1. FAO/Unesco Soil Map of the World, Vol. I Legend and Vol. II Africa, Unesco, Paris, 1977. The soils of Ethiopia are mapped, as part of a much larger project, at 1:5 000 000 using the FAO/Unesco legend. The map units are associations of soil units divided into texture and slope classes. No soil data for Ethiopia are included in the accompanying report.

2. Blue Nile River Basin Study, Bureau of Reclamation, U.S. Department of the Interior, 1963. 17 potentially irrigable areas of approximately 11 070 km^2 within the 204 000 km^2 of the basin are mapped as to the land capability classes of the Bureau of Reclamation, at a scale of 1:100 000. Limited soil data are included in the report.

3. Wabi Shebelle Survey, ORSTROM, Paris, 1973. The 180 000 km^2 of the Wabe Shebele are mapped according to the French soil classification at 1:1 000 000. Profile descriptions and laboratory data are included in the report. The lower Wabe Shebele and Fafen rivers are mapped at 1:50 000 and 1:60 000 respectively. These soil maps cover 382 km^2. The reports include profile descriptions and laboratory data.

4. Survey of the Awash River Basin, FAO, Rome, 1975. The 70 000 km^2 of the Awash basin are mapped according to the French soil classification system at 1:1 000 000. 19 570 km^2 in the middle and lower Awash are mapped at 1: 250 000 and 5 020 km^2 in the same areas


ETHIOPIA
LOCATION OF EXISTING SOIL DATA
Point data
Limited area Soilsurveys
Reconnaissance Soilsurveys
1 Tigray rural development study
2. Awash river basin study
3. Southern rift valley study
4. Wabi Shabale basin study
5. Blue Nile river basin study
RED SEA
GULF OF ADEN
SUDAN
SOMALIA
DJIBOUTI
UGANDA
KENYA
0 100 200 300 400 Km.

for soils of the middle and lower Awash are included in the report. (There are in addition a large number of detailed studies done by various agencies for small potential irrigation sites along the Awash river, too numerous to list.)

5. Development Prospects in the Southern Rift Valley, Ethiopia, Land Resource Study 21, Ministry of Overseas Development, Surrey, England, 1975. 55 000 km^2 of the southern rift valley are mapped according to land systems at 1:250 000. Land systems have been generalized, and soil associations assigned to the resultant units to produce a 1:1 000 000 soil map using the FAO/Unesco legend. Some soil laboratory data is included in a supplementary report (King and Birchall, 1975).

6. Tigrai Rural Development Study, Hunting Technical Services Ltd., England, 1976. 20 000 km^2 of central Tigray are mapped at 1 250 000 for landform and for land suitability. 3 400 km^2 around and to the north of Mekele are mapped at 1:50 000 for landforms and soils. The FAO/Unesco legend is used for soil mapping. Profile descriptions and laboratory data are included in the report.

7. The Humera Report, TAMS Agricultural Development Group, New York, 1973. 10 000 km^2 in northwestern Ethiopia are soil mapped at 1:1 000 000 on the basis of textural differentiation. The USDA 7th Approximation soil classification is given. Profile descriptions and laboratory data are included in the report.

8. Le Milieu Naturel du Bassin des Lacs Abaya et Chamo, M. Raunet, IRAT, Paris, 1978 and Le Milieu Naturel du Bassin du Gidabo, M. Raunet, IRAT, Paris, 1977. 5 000 km^2 on the western shores and 3 800 km^2 on the eastern shores respectively of Lakes Abaya and Chamo have been mapped at 1:100 000 according to morpho-pedologic units. (These units are analogous to land systems.) Soils associations are assigned to mapping units, using the FAO/Unesco legend. The report includes generalized descriptions of soils but no profile descriptions or laboratory data.

9. Kobo-Alamata Agricultural Development Programme, German Consult, Essen, 1976. Approximately 800 km^2 in northern Welo are mapped on the basis of textural differentiation. The USDA 7th Approximation soil classification is given. Profile descriptions and laboratory data are included in the report.

10. Gambella Project Feasibility Report, TAMS Agricultural Development Group, New York, 1973. 665 km^2 on the southern bank of the Baro river are mapped for soils at 1:60 000 using the USDA 7th Approximation. Limited soil data is included in the report.

11. Southern Gamu-Gofa Project, Sogreah, Grenoble, France, 1979. 230 km^2 on the Weito river and 200 km^2 on the lower Omo river are soil mapped at 1:60 000 using the FAO/Unesco legend and adding a third level of differentiation. Profile descriptions and laboratory data are included in the report.

12. Weito Irrigation Project Feasibility Study, Halcrow-ULG Ltd., Wiltshire, England, 1982. 60 km^2 of the area covered under item 11 above are soil mapped at 1:50 000. Mapping is based on textural differentiation and the FAO/Unesco and USDA 7th Approximation classifications are given. Profile descriptions and laboratory data are included in the report.

13. Dabus Irrigation Project Feasibility Study, Halcrow-ULG Ltd., Wiltshire, England, 1982. 239 km^2 on the Dabus river are soil mapped at 1:50 000. Mapping is based on soil associations and FAO/Unesco and USDA 7th Approximation classifications are given. Profile descriptions and laboratory data are included in the report.

14. Meki and Galana Areas Land Evaluation Survey, Sogreah, Grenoble, France, 1982. 220 km^2 west of Lake Ziway and 109 km^2 east of Lake Abaya are soil mapped at 1:50 000 using the FAO/Unesco legend with additional subdivisions based on irrigation suitability. Profile descriptions and laboratory data are included in the report.

15. Prospects for Irrigation Development around Lake Zwai, Ethiopia, Land Resources Study 26, Ministry of Overseas Development, Surrey, England, 1976. 190 km^2 of the shoreline of Lake Ziway are soil mapped at 1:50 000 largely on the basis of textural differentiation. The FAO/Unesco legend designations are given. Profile descriptions and laboratory data are included in the report.

A Report on Some Soils of Ethiopia, H.F. Murphy, Experiment Station Bulletin No. 44, USAID, 1968. This report includes some 3 500 sample points of inexact location and site description. Most of the points are located along the roads. Basic textural and chemical data are given for most of the points.

In addition to these, a number of sources of data exist within various institutions in Ethiopia although these are rarely in published form. Kind, amount and quality of data vary widely.

The Institute for Agricultural Research (IAR) has carried out soil surveys at some of their research stations and has point soil data for many others. The Soils Laboratory of the Ministry of Agriculture has for some years been analysing samples for many organizations and has the resulting data on file. The Ministry of Agriculture has undertaken a number of special project soil surveys at detailed scale. Student and faculty projects at Alemaya Agricultural College and at Addis Abeba University have produced soil maps and laboratory data for a number of locations. All these data, sometimes difficult to find and interpret, are available to anyone interested.

CHAPTER 3

DEVELOPMENT OF THE GEOMORPHOLOGY AND SOILS MAP

3.1 GENERAL

A1:1 000 000 scale Geomorphology and Soils map, in eight sheets and with extended legend, has been compiled for the whole of Ethiopia. This activity was in support of a master land use planning exercise carried out for the country by the FAO/UNDP/ETH/78/003 project and forms an integral component in the inventory of Ethiopia's land resources, essential to the success of the land evaluation methods applied in this assessment. The landscape units defined on the map can be located on the ground, at least as precisely as the scale limits allow, and so offered the opportunity to develop site-specific land evaluation when combined with appropriate agroclimatic information.

The Geomorphology and Soils map also represents an update of the relevant section of the FAO/UNESCO Soils Map of the World.

3.2 METHODS

3.2.1 Background

Mapping was achieved through the use of Landsat satellite imagery interpretation, available surveys, field traverses and agroclimatic data. The relationship between the various inputs and activities involved in the production of the Geomorphology & Soils map is shown schematically in the flow chart in Fig.10

Considerable emphasis was placed on remote sensing techniques to accomplish the geomorphology and soils mapping because of number of interactive factors which, although not individually peculiar to Ethiopia, when taken together would have inevitably limited the intended output unless extensive use of remote sensing techniques had not been made.

MAIN INPUTS AND ACTIVITIES INVOLVED IN THE DEVELOPMENT OF THE GEOMORPHOLOGY AND SOILS MAP

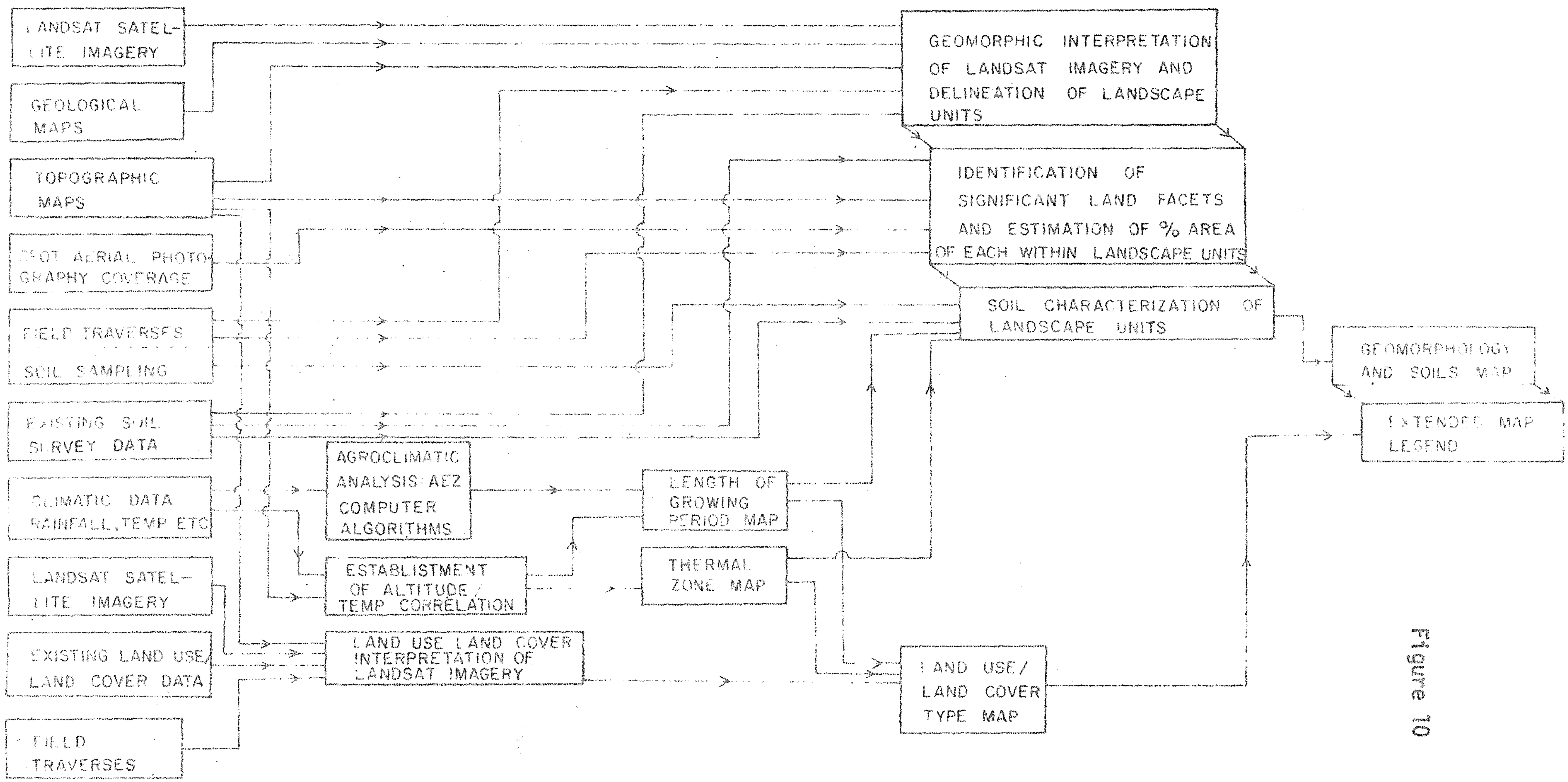


Figure 10

The limiting factors include the following:-

- extensive area of the country (1.22 million sq kms)
- limited accessibility
- lack of a comprehensive and suitably detailed nationwide data base on land resources
- limited availability of equipment and trained manpower to conduct integrated surveys
- lack of a suitable 1:1 000 000 scale base map at the start of project activities
- total time available for project output (3½ years)

At an early stage in planning overall project activities and strategies, Landsat was recognized as a desirable data base for the manual generation and compilation of the Geomorphology and Soils map of Ethiopia. The reasons for this are directly related to the requirements of the envisaged master land use plan and the limitations mentioned above. The scale of presentation of the map components of the master plan are 1:1 000 000 and time for project output limited. Therefore, the synoptic nature of the 71 Landsat scenes covering Ethiopia (see Figure) and their inherent level of generalization, with respect to geomorphic detail for example, are ideally suited to the mapping requirements.

In contrast, the number of stereoscopic pairs of conventional aerial photographs required to cover the whole of Ethiopia at 1:50 000 scale (the scale generally available for the country) is about 30 000. Although an increased level of landform detail may have been delineated on aerial photographs of this scale compared to Landsat, the required level of generalized landform detail, existing limitations, the vastly greater time for conventional photointerpretation, respective dates of coverage (important for land cover assessment), and the high cost of purchasing nation-wide coverage of aerial photographs compared to Landsat imagery coverage, are all factors which weighed heavily in favour of using Landsat.

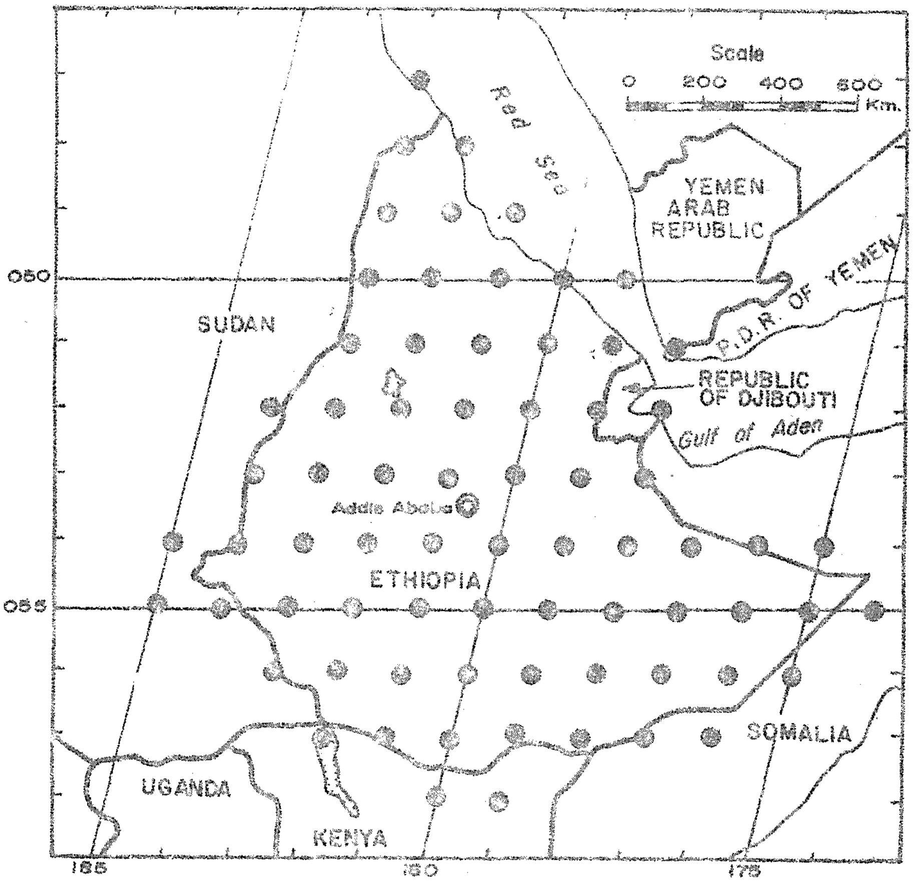


Figure 10

Landsat index map of Ethiopia. Dots indicate image centres. Marginal numbers are path/row identifiers.

Prior to commencement of geomorphology and soils mapping, it was apparent that 1:1 000 000 scale base maps of Ethiopia available at that time were unsatisfactory for the project requirements, because of the limited topographic detail shown. At 1:1 000 000 scale the 71 Landsat scenes covering Ethiopia introduced the possibility of compiling a convenient wall-size mosaic ideally suited to presentation of the level of geomorphology and soils data generated. Such a mosaic was constructed in cooperation with the Ethiopian Mapping Agency (EMA) and all geomorphology and soils data were initially compiled on this base. This was later transferred to a topographic base when it became available.

3.2.2 Development of geomorphic units

A basic assumption in the preparation of the Geomorphology and Soils map is that geomorphic units delineated by manual interpretation of Landsat contain recurrent patterns of landforms, soils and vegetation, much as described by Christian and Stewart (1953) for their land systems. Land systems have been shown to provide a meaningful base for reconnaissance level resources mapping, at a scale between 1:250 000 and 1:1 000 000. At such scales the genetically linked subdivisions, or land facets, responsible for the recurrent patterns of a land system and their correspondingly unique image signatures, cannot usually be separated. A land facet may be defined as an ecosystem within which any sample site would yield data in respect of slope, soil, vegetation, parent material and other factors which would not differ significantly from the data related to those factors recorded at another site in the same facet. As facets represent important units at the agricultural management level, an attempt was made at all times during map compilation to identify and characterize significant land facets within mapping units through the use of existing data, field traverses, and aerial photographs.

Because of the small scale and the correspondingly reduced level of visible detail, groups of land systems rather than individual land systems are more often apparent on Landsat (Mitchell and Howard, 1978). Both individual land systems, where these were mappable, and groups of land systems, form the basic units for geomorphology and soils mapping described here. Groups of land systems and individual land systems are collectively referred to on the Geomorphology and Soils map as landscape units.

3.2.3 Imagery interpretation methods

Having first established the landscape unit as the basic mapping unit, morphologic criteria were developed for separating landscape units on the imagery. These criteria include degree of dissection, drainage pattern and density, relief, land cover and, more particularly, evidence of landform genesis (such as patterns indicating volcanic, structural or alluvial origin).

With these criteria, mapping of landscape units proceeded through the manual interpretation of Eros Data Center standard photographic imagery products of 1:1 000 000 and 1:250 000 scales. False colour composite and black and white (bands 5 and 7) images of each scene were available at both scales. Delineations were made on clear acetate overlays attached to the 1:1 000 000 scale false colour composites. The small amount of stereoscopic side-lap between images from adjacent orbit paths was used to full advantage to separate landscape units. Transparent, 1:250 000 scale topographic map overlays provided by the EMA were placed on false colour composites of the same scale to further assist interpretation in areas where difficulties arose. These transparent maps overlayed on Landsat images were also indispensable for precise location and orientation during field traverses. After initial identification of landscape units, details were transferred to the 1:1 000 000 scale black and white satellite imagery mosaic sheets. This data was subsequently transferred to a topographic base map of the same scale at a later date during the project.

Although Landsat provided the backbone for data generation, it is important to emphasize that examination of all relevant existing data, such as geological and topographic maps, as well as extensive field surveys, were necessary in the development of the Geomorphology and Soils map and legend of Ethiopia. Field traverses in particular were important in testing the validity of Landsat generated geomorphic boundaries. An iterative process of feeding back field derived information on geomorphic units served to continually upgrade the reliability of boundary delineations and legend development.

3.2.4 Landscape units

An heirarchial classification system is used for landscape units shown on the Geomorphology and Soils map of Ethiopia. At the breadest level 12 subdivisions exist, which are related to the general physiographic character of the landforms. These are as follows:

1. Wetland
2. Seasonal wetland and seasonally waterlogged land
3. Plains and undulating sideslopes
4. Plains and low plateaux with hills, moderately dissecte sideslopes and plateaux
5. Hills with plains
6. Low to moderate relief hills
7. Moderate to high relief hills, severely dissected sideslopes and plateaux
8. High to mountainous relief hills
9. High plateaux
10. Moderately dissected plateaux, plateaux with hills and rolling to hilly plateaux
11. Rubble land and rock outcrop
12. Sand and salt deposits

These 12 subdivisions are important in relation to the ordering of the different map units in the legend, but do not influence the actual map codes. Many of the terms used have a general connotation of significance, but are further defined below in relation to the manner in which they have been used on the map, because of the inevitable ambiguity in the use of such otherwise general terms.

The use of such terms in the context of the Geomorphology and Soils map legend is therefore explained as follows:

- plains; gently sloping or flat land which occur predominantly below 1 200 m elevation amsl.
- low plateaux; gently sloping or flat land standing clearly above surrounding lower landforms, often as mesa-like forms in isolation, with elevations generally between 1 200 and 1 700 m amsl.

- high plateaux; greatly elevated, gently sloping or flat land comprising much of the highland massive of Ethiopia, often dissected by deeply entrenched rivers such as the Blue Nile and generally standing at elevations above 2 000 m amsl, but occuring in the range 1 700-4 000 m amsl.
- low to moderate relief hills; hills with a mean relief difference between the crests of the hills and the bottoms of intervening valleys of less than 300 m
- moderate to high relief hills; hills with a mean relief difference between the crests of the hills and the bottoms of intervening valleys of between 300 and 700 m
- high to mountainous relief hills; hills and mountains with a mean relief difference between the crests of the hills and major intermontane valleys of generally greater than 700 m

Terms such as rolling and hilly follow the values given in the FAO publication Guidelines for Soil Profile Description (1977), and refer to the predominant slope and land form characteristics of the landscape unit described.

3.2.4.1 Landform genesis

Within each of the 12 broad classes of landforms six further subdivisions are possible, although all do not always occur in each of the preceding major classes. These six subdivisions reflect the genesis of the landforms and include the following classes:

Landform genesis	Code
Alluvial	A
Aeolian	D
Evaporite	E
Volcanic	V
Structural	S
Residual	R

These are the codes indicated on the Geomorphology and Soils map of Ethiopia for the various map units.

Using the two levels of classification discussed, 70 geomorphic types were identified for the country. Each of the Alluvial, Aeolian, Evaporite and Volcanic subclasses of the geomorphic types is identified on the map by two symbols. Examples include Ac (colluvial slopes), Da (sand dunes and salt encrusted sand deposits), Ep (playas and salinas), and Vn (moderately dissected volcanic plateaux).

Symbols used to denote structural and residual landforms however, require a total of three characters. For example, Rg_v, Rg_g, Sh_c, etc. The suffixes used to identify the main parent material origin of the landforms are as follows:

Parent material	Code
Volcanic (basalts,tuffs, etc)	v
Felsic Precambrian basement (including gneisses,granites, etc)	g
Metamorphic Precambrian basement (slates,schists,phyllites, etc)	m
Evaporite (predominantly gypsum)	e
Sandstone	s
Calcareous (predominantly limestone)	c

Such symbols are normally used alone but may be used together, for example $Sh_{c/g}$, where parent materials are mixed and not easily separated at this scale of mapping.

Geomorphic units are further subdivided on the basis of soil associations which occur within them, into final landscape units of the type described previously. The final subdivision is represented by superscript numbers, for example, Rm_g^2, Sh_v^3, Ab^1. Approximately 380 landscape units have been identified for Ethiopia and are shown on the Geomorphology and Soils map.

3.2.4.2 Characterization of landscape units by soil association

Once the landscape unit boundaries had been delineated, existing and newly generated soil data were used to characterize each unit.

The choice of soil parameters used in this characterization was determined by land evaluation requirements and by data availability. These parameters are discussed further in the next section.

In the case of Ethiopia, there is a considerable amount of existing soil data (see chapter 2) although much is of uneven quality or of inexactly described location, or both. Data for over 3 500 point samples exist, approximately 30% of the country has been surveyed and mapped at a reconnaissance level and a number of detailed and semi-detailed studies of very limited area have been completed. This work has been done by various government and international agencies, consulting firms and individuals. In addition, a 1:5 000 000 soil map exists, as part of the FAO/UNESCO Soil Map of the World (1977).

The processing of these data was complicated by a number of factors. Both point data, and to a lesser extent the survey data, are fragmentary. Rarely are the analytic results, or the site descriptions were they exist, comprehensive enough to provide the requisite information. Thus, difficulties arose both in soil classification (for mapping) and in the quantification of land characteristics and qualities (for the land suitability evaluation leading to the MLUP). Most of the point data, for example, are for surface soils and provide only colour, texture, pH, organic matter and total nitrogen percentages, and qualitative estimates of exchangeable cations. Analytic methods are not standardized and frequently are not described. Where soils have been classified, various classification systems have been used.

Before data were assigned to individual landscape units, existing sample sites had to be located on the 1:1 000 000 base maps. The locations are generally given in only very broad terms, for example, as "38 kms west of Ambo". Once located, the point data were overlaid on the geomorphic delineations generated from Landsat. Points falling within each landscape unit were used to characterize, by dominant soil, each major facet within each unit.

Existing reconnaissance soil maps were also overlaid. The Landsat generated boundaries and those on these maps generally approximate each other, being similarly derived from geomorphic interpretation of images at various scales. The Landsat generated boundaries were retained countrywide in order to standardize the mapping. In addition, the Landsat generated geomorphic units provided more information than the reconnaissance maps because of the breakdown of these units into their constituent facets.

The characterization of landscape units by soil association required, in a sense, some working backward. The working scale was small, the point data locations are poor and the reconnaissance data are often more generalized than required. Thus, although it was possible to approximate the geographic location of sample points and reconnaissance map data, it was not always possible to locate all this information in relation to individual facets within geomorphic units. Facet location for data was therefore often deduced from the data itself. This was supplemented by comparison with data of known facet locations, by field observation and sampling, and by some extrapolation.

Large areas of Ethiopia are not covered by either adequate density of point data or reconnaissance surveys, nor was it possible to conduct field studies in some of these areas. At this point extrapolation began. using total annual rainfall and growing period maps, geological and geomorphic information obtained from Landsat imagery and existing maps, land use/land cover maps and soil information available for similar environments in other locations.

3.2.5 The map legend

A comprehensive legend detailing the geomorphic and soil characteristics of each landscape unit and its constituent land facets was compiled to accompany the Geomorphology and Soils map. An example of the extended legend is given in Table

The main aim, as indicated previously, in producing the Geomorphology and Soils map and extended legend was to provide soil and landform data for the intended land suitability evaluation. The extended legend however, contains considerable data in excess of the final requirements of the land evaluation. This comes about because the data requirements of the land evaluation evolved throughout the course of the project and simplified somewhat. Since the map is also intended to stand as an independent data source, it was decided to maintain the original level of detail. This was further reinforced by the possibility of establishing a computerized data base in the future for soils and land resources.

3.2.5.1 Significant land facets

The specific features upon which the detailed descriptions of landscape units are based in the legend of the map are land facets. These are defined in section 3.2.2. To be classed as a significant land facet however, the described feature must occupy a minimum of 10% or more by area of the landscape unit of which it forms part. Only significant land facets are included for description in the map legend.

Two important features must be emphasized at this point:

- the same unit made up of the same facets can occur in widely separated parts of the country.
- the same facets but combined in different proportions can form two entirely different landscape units.

The homogenity of the facet and its constant proportion in relation to other facets in a landscape unit ensures the uniqueness of description which is essential to effective land evaluation work.

The various characteristics used to describe each significant land facet are to be found at the top of the extended Geomorphology and Soils map legend. They include:

Landscape unit No.	Soils
Geomorphology	FAO classification
Total area (km^2)	Colour (moist)
Significant land facet	Texture
Area (%)	Drainage class
Geology	Rock outcrop
Slope range	Surface stones
Dominant vegetation	Erodability classification
and/or land use	Effective depth
Remarks	pH
(by land facet)	OM (organic matter) (%)
(by landscape unit)	CEC (Cation exchange capacity)
	Available P
	SMU (Soil management unit) No

A number of these parameters are self explanatory but, in order to characterize landscape units fully, classes had to be established for some of the variables listed. The classes used for the relevant parameters are given in Table and reflect the soil and landform requirements anticipated as necessary for the land evaluation at the outset of the project.

3.2.5.2 Soil management units (SMU's)

The soil management number shown in the Geomorphology and Soils map legend represents a unique but somewhat generalized combination of the following components of significant land facets:

- slope
- soil

    texture
    drainage
    stoniness
    effective depth
    pH

The various combinations of these factors repeat themselves across significant land facets of different landscape units. This fact, coupled with the need to simplify land evaluation inputs on landform and soils to make the task of manual suitability matching more manageable, led to the identification of SMU's.

Table 4 CLASSES OF CHARACTERISTICS USED TO DESCRIBE LANDSCAPE UNITS IN THE GEOMORPHOLOGY AND SOILS MAP LEGEND

Slope (%)

0 - 2
2 - 8
8 - 16
16 - 30
30 - 50
50+

Soil drainage

Drainage classes follow FAO Guidelines for Soil Profile Description, but for this exception: For lands subject to seasonal flooding two classes are given, one for the period during the rainy season and one for the rest of the year. This was done to accommodate requirements of the land evaluation.

Rock outcrop

Follows FAO Guidelines, as above

Effective soil depth (cm)

≤25
25 - 50
50 - 100
100 - 150
≥150

Soil texture

Follows USDA texture classes

Soil classification
Follows FAO, Soil Map of the World

Soil colour
Follows, Munsell Soil Colour Chart

Soil erodability class

This consists of the numbers. The first represents erodability as a function only of soil classification, texture and phase. The second incorporates the slope factor. Calculation was done according to the methodology set out in FAO, A Provisional Methodology for Soil Degradation Assessment (1979).

Stoniness (% of Area)

None	≤1
fairly stony	1 - 3
stony	3 - 10
Very stony	10 - 50
exceedingly stony	50 - 90
rubble land	≥90

Soil pH

5.5
5.5 - 6.7
6.7 - 7.3
7.3 - 8.0
8.0

Organic Matter (%)

≤1
1 - 3
3 - 10
≥10

Cation exchange Capacity (m. e./100g)

≤16
16 - 35
35 - 70
≥70

Available phosphorous (P) - Olsen (ppm)

≤5
5 - 10
10 - 15
15 - 25
≥25

CHAPTER 4

DETAILED GEOMORPHOLOGY AND ASSOCIATED SOILS OF LANDSCAPE UNITS

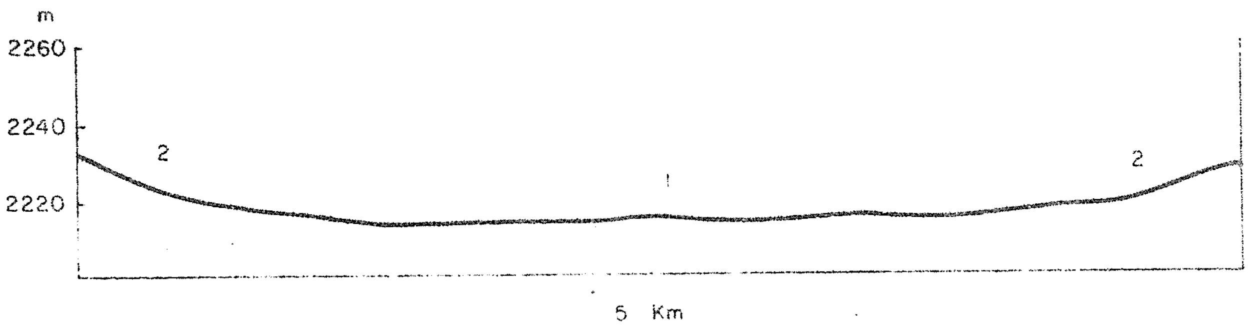
4.1 INTRODUCTION

The following chapter illustrates the detailed nature of the various geomorphic subdivisions included in the legend of the Geomorphology and Soils map of Ethiopia, together with a summary of soil associatations which characterize them as particular landscape units.

The chapter is divided into two main parts. In the first section cross-sections of the various geomorphic units are given, followed by landform and soil summaries by significant land facet. The cross-sections are arranged in alphabetical order for easy reference, for each of the main landform genesis types which include alluvial, residual, structural and volcanic landform types. Cross-sections are only intended to indicate the general form of the landscape units and are not drawn to either a strict vertical or horizontal scale, but to approximate secles.

Plates used to illustrate the image signatures of geomorphic types on Landsat provide details of a selection of landscape units for comparison, and are included to provide a more complete understanding of the characteristics used to separate the various geomorphic types during the image analysis stage and in the construction of the Geomorphology and Soils map legend.

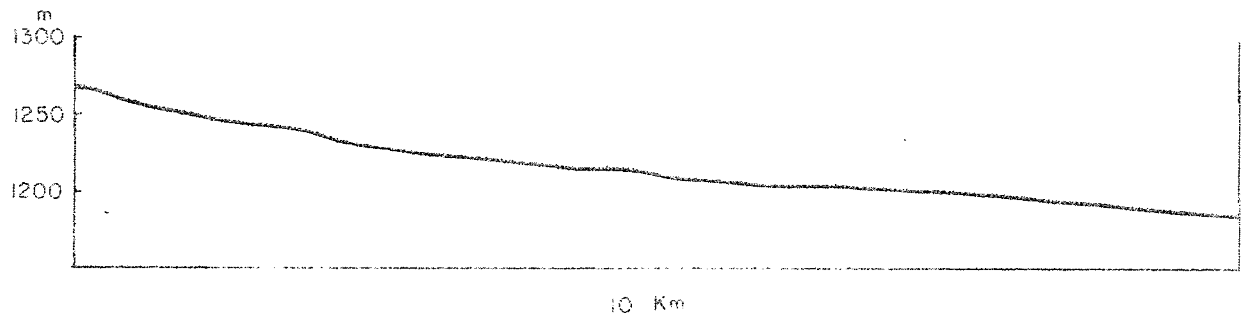
Ab - Basins and depressions with seasonal drainage deficiencies



NUMBER	1	2
FACET	basin plains	colluvial margins
AREA (%)	90	10
SLOPE (%)	0-2	2-8
SOIL		
Ab^1	Pellic Vertisols	Eutric Nitosols
Ab^2	Pellic Vertisols	Dystric Nitosols
Ab^3	Haplic Phaeozems	Vertic Cambisols*

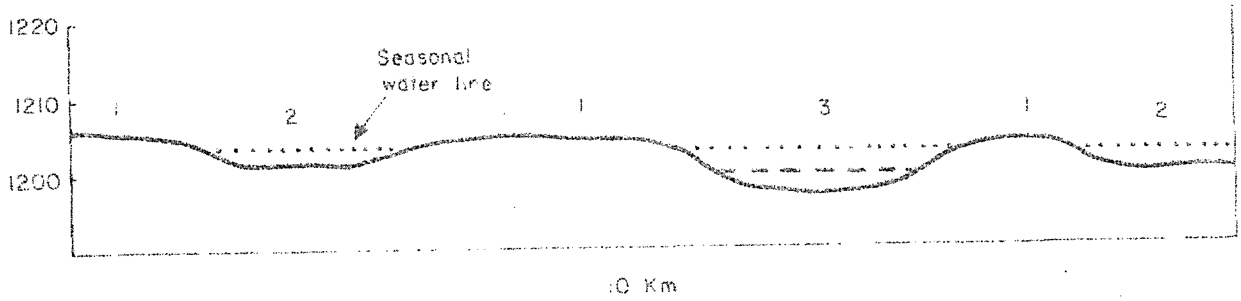
* Slopes of colluvial margins in Ab^3 are 0-2%

Ac - Alluvial/colluvial slopes and outwash fans



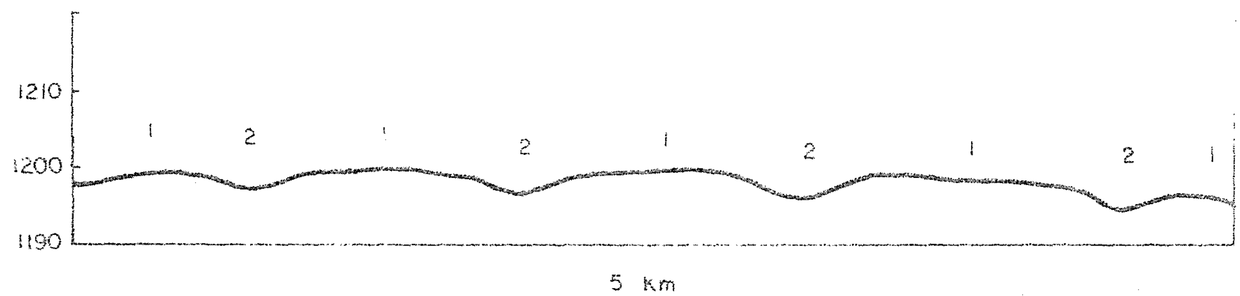
NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	0-8
SOIL	
Ac^1	Chromic Vertisols
Ac^2	Eutric Fluvisols
Ac^3	Eutric Fluvisols
Ac^4	Calcic Xerosols (saline phase)
Ac^5	Orthic Solonchaks (petrogypsic phase)
Ac^6	Orthic Solonchaks
Ac^7	Chromic Vertisols
Ac^8	Eutric Fluvisols (stony phase)
Ac^9	Vertic Cambisols

Ad - Deltas



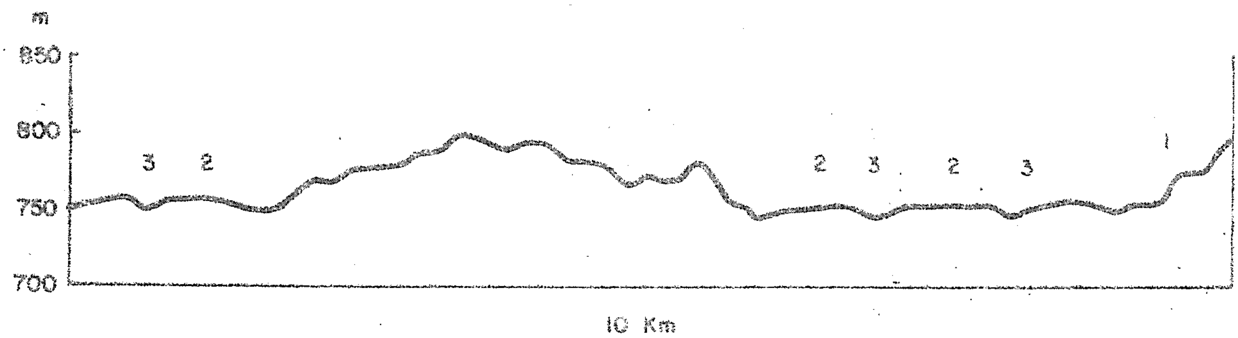
NUMBER	1	2	3
FACET	alluvial plains	seasonal swamps	permanent swamp
AREA (%)	40	40	20
SLOPE (%)	0.2	0.2	0.2
SOIL			
Ad[1]	Chromic Vertisols	Eutric Fluvisols	n.a.
Ad[2]	Eutric Fluvisol (saline phase)	Eutric Fluvisols (saline phase)	n.a. n.a.

Af - Alluvial fans and bajadas



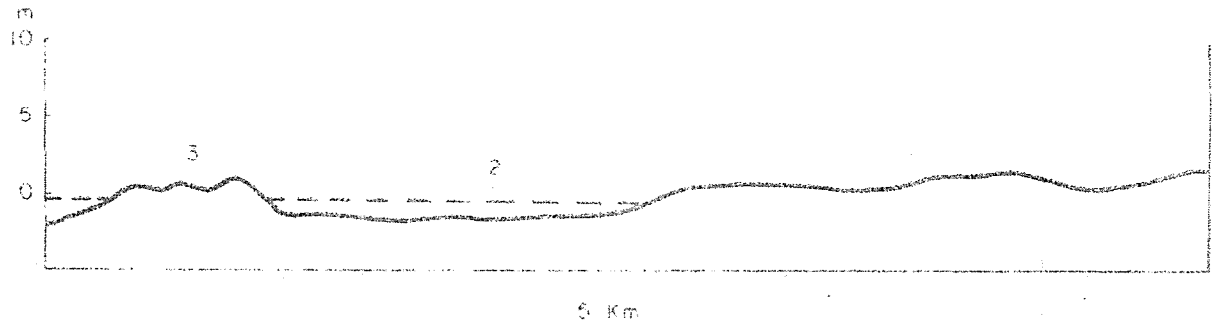
NUMBER	1	2
FACET	convex fan slopes	braided channels
AREA (%)	80	20
SLOPE (%)	2-8	2-6
SOIL		
Af^1	Eutric Fluvisols	rubble land
Af^2	Eutric Fluvisols	rubble land
Af^3	Eutric Fluvisols (saline phase)	rubble land

Af^4 - Complexes of eroded residual land forms of low to moderate relief and interspersed fan deposits.



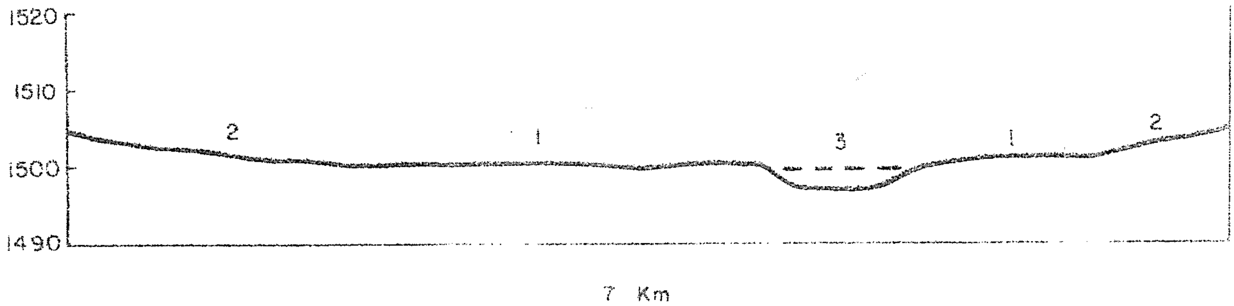
NUMBER	1	2	3
FACET	low relief hills	convex fan slopes	braided channels
AREA (%)	50	40	10
SLOPE (%)	8-16	2-8	2-16
SOIL			
Af^4_v	Lithosols	Eutric Fluvisols	rubble land
$Af^4_{c/v}$	Lithosols	Eutric Fluvisols	rubble land
Af^4_s	Lithosols	Calcaric Fluvisols (saline phase)	rubble land

Ak - Coastal margin plains



NUMBER	1	2	3
FACET	undulating coastal plains	coastal marshes	beaches
AREA (%)	50	30	20
SLOPE (%)	0-8	0-2	0-2
SOIL	Orthic Solonchaks	n.a.	sand

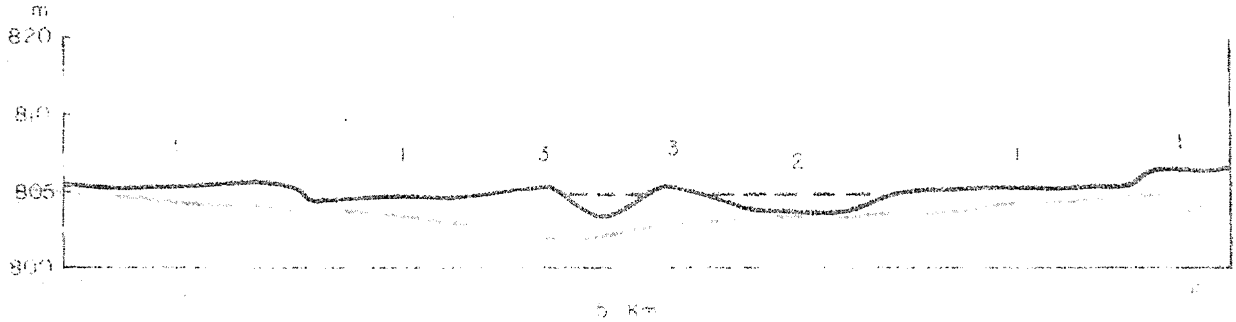
A1 - Lacustrine and fluvio - lacustrine plains



NUMBER	1	2	3
FACET	fluvio-lacustrine plains	colluvial margins	marshy depressions
AREA (%)	60	30	10
SLOPE (%)	0-2	2-8	0-2
SOIL			
$A1^1$	Chromic Vertisols*	Chromic Vertisols	Eutric Fluvisols
$A1^2$	Chromic Vertisols	Chromic Vertisols	Chromic Vertisols
$A1^3$	Eutric Fluvisols (sodic phase)	Mollic Andosols (sodic phase)	Eutric Fluvisols (sodic phase)

* Fluvio-lacustrine plains are seasonally flooded in $A1^1$

Am - Meander belts of major rivers

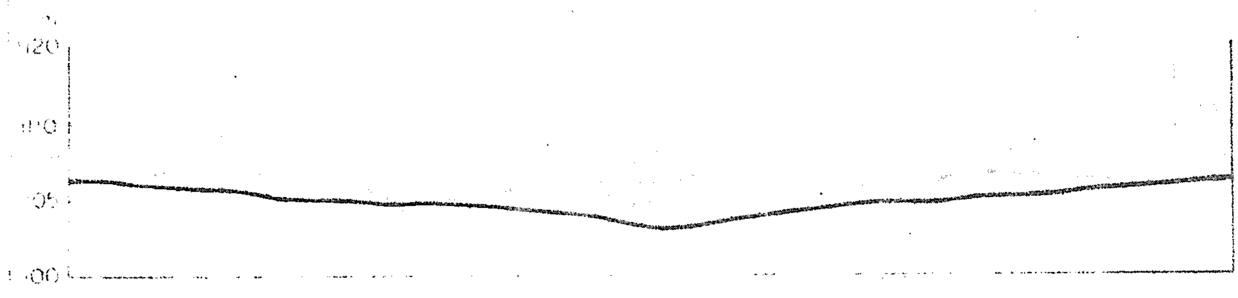


NUMBER	1	2	3
FACET	flood plains and low terraces	marshy depressions	levees
AREA (%)	60	20	20
SLOPE (%)	0-2	0-2	0-2
SOIL			
Am^1	Eutric Fluvisols	n.a.*	Eutric Fluvisols
Am^2	Eutric Fluvisols	Eutric Fluvisols	Eutric Fluvisols
Am^3	Calcaric Fluvisols+ (saline phase)	Calcaric Fluvisols (saline phase)	Calcaric Fluvisols (saline phase)
Am^4	Eutric Fluvisols	Eutric Fluvisols	Eutric Fluvisols
Am^5	Calcaric Fluvisols (saline phase)	Calcaric Fluvisols (saline phase)	Calcaric Fluvisols (saline phase)
Am^6	Eutric Fluvisols	Eutric Fluvisols	Eutric Fluvisols

* Marshy depressions are permanently wet in Am^1

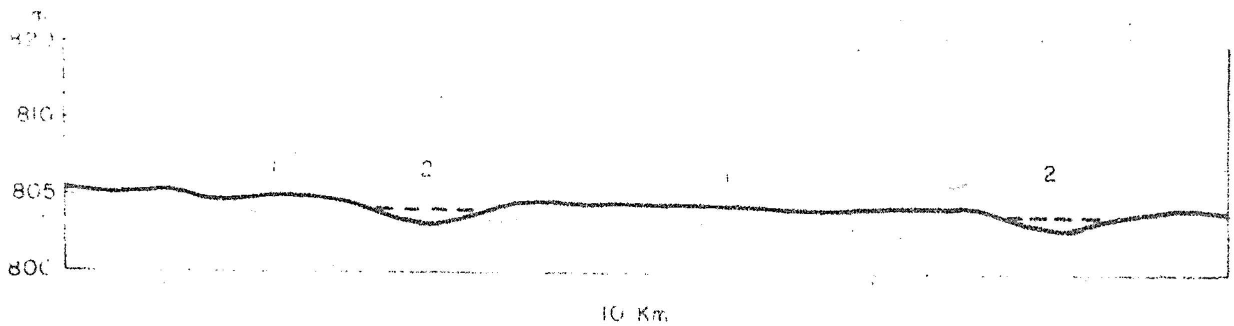
+ Chromic Vertisols (saline phase) occur on low terraces in Am^3

An - Dry river channels of gentle slope with seasonal flow in most years



NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	0-2
SOIL	
An[1]	Chromic Vertisols (saline phase)
An[2]	Eutric Fluvisols (saline phase)

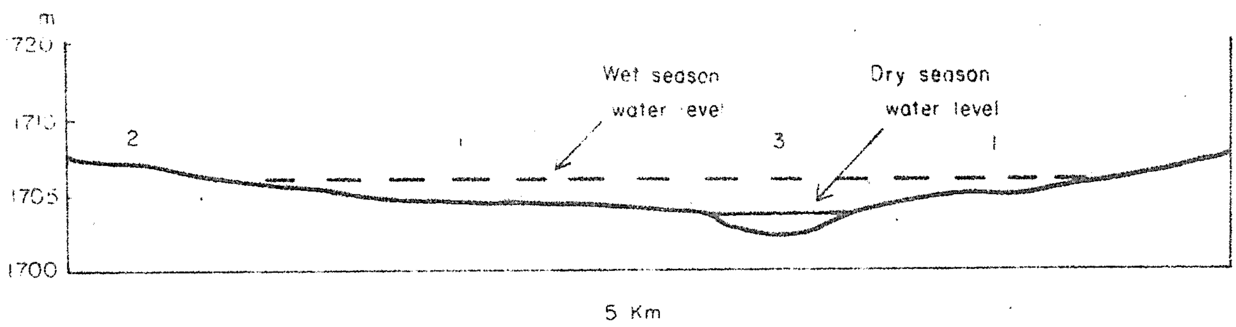
Ap - Alluvial plains



NUMBER	1	2
FACET	plains and low terraces	seasonal marshes
AREA (%)	80	20
SLOPE (%)	0-2	0-2
SOIL		
Ap^1	Chromic Vertisols*	Chromic Vertisols
Ap^2	Eutric Fluvisols	Eutric Fluvisols
Ap^3	Orthic Solonchaks (sodic phase)	Gleyic Solonchaks (sodic phase)
Ap^4	Vitric Andosols (sodic phase)	Eutric Gleysols (sodic phase)
Ap^5	Eutric Cambisols	Eutric Fluvisols
Ap^6	Eutric Fluvisols	Eutric Fluvisols
Ap^7	Haplic Xerosols	Eutric Gleysols

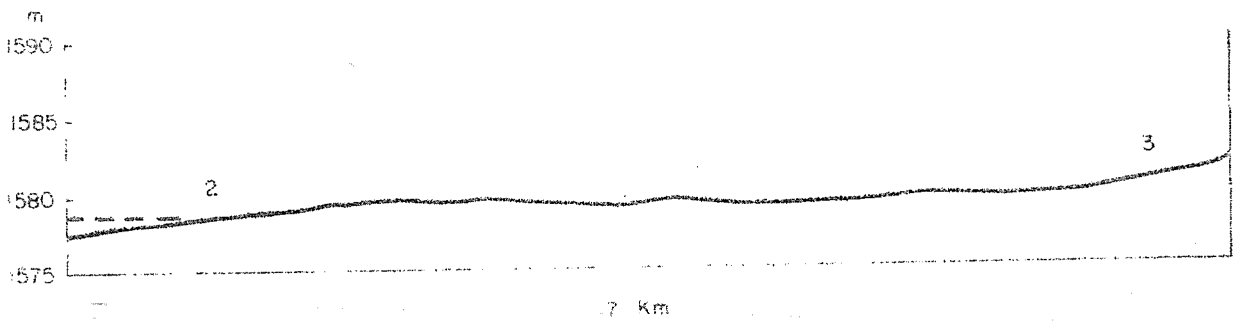
* Plains and low terraces are seasonally flooded in Ap^1

As - Seasonal swamps and marshes



NUMBER	1	2	3
FACET	seasonally inundated depressions	gently sloping margins	permanent marsh
AREA (%)	70	20	10
SLOPE (%)	0-2	0-2	0-2
SOIL			
As^1	Eutric Fluvisols	Eutric Fluvisols	n.a.
As^2	Calcaric Fluvisols	Calcaric Fluvisols	n.a.
As^3	Chromic Vertisols	Chromic Vertisols	n.a.
As^4	Gleyic Solonchaks	Orthic Solonchaks	n.a.

Av - Volcano-lacustrine plains

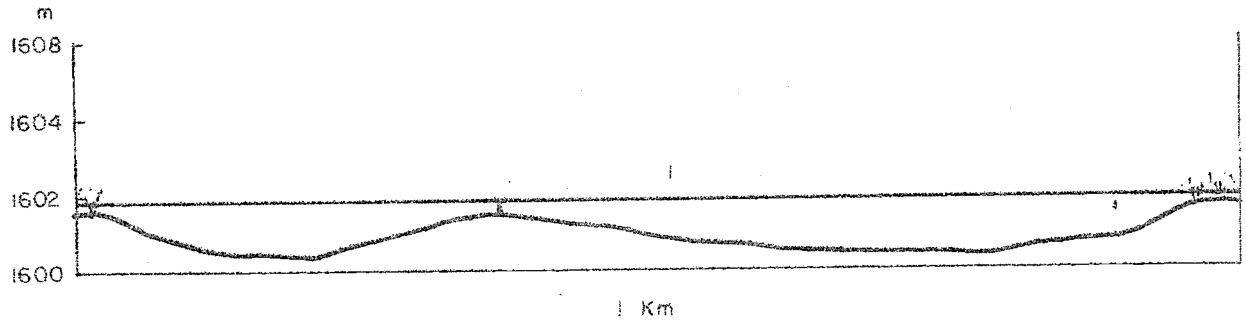


NUMBER	1	2	3
FACET	lacustrine plains	lake margins	colluvial margins
AREA (%)	80	10	10
SLOPE (%)			
SOIL			
Av^1	Vitric Andosols (sodic phase)	Eutric Fluvisols	Eutric Cambisols
Av^2	Orthic Solonchaks*	Eutric Fluvisols (saline phase)	Eutric Cambisols*
Av^3	Luvic Phaeozems (sodic phase)	-	-

* Lacustrine plains make up 70% and colluvial margins 20% of Av^2

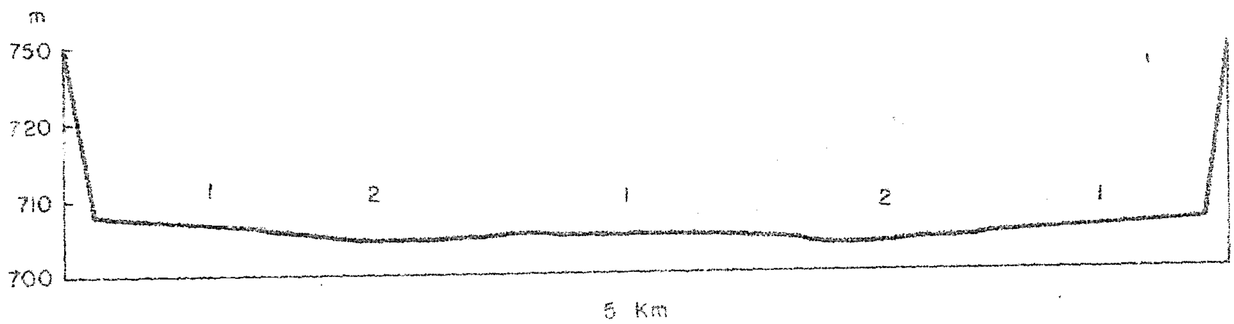
\+ Lacustrine plains make up 100% of Av^3

Aw - Permanent fresh water swamps and marshes



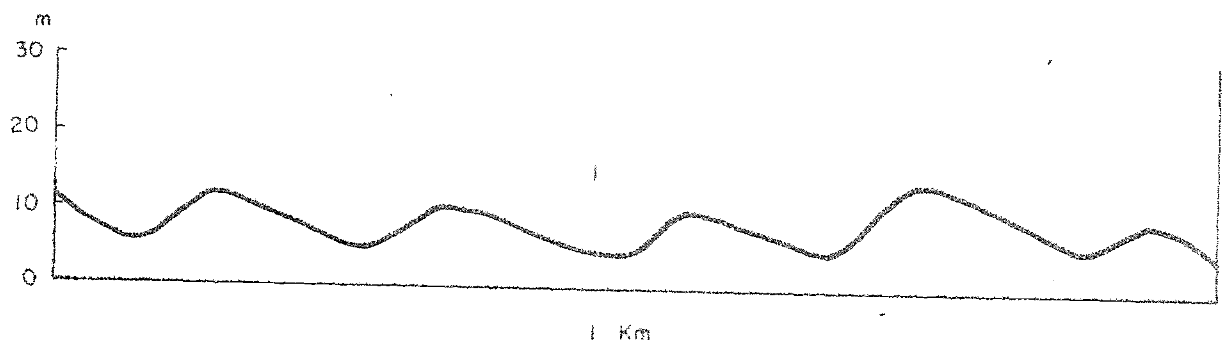
NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	0-2
SOIL	n.a.

Ay - Small closed basins and depressions of the Afar triangle filled with alluvium, colluvium and evaporite deposits



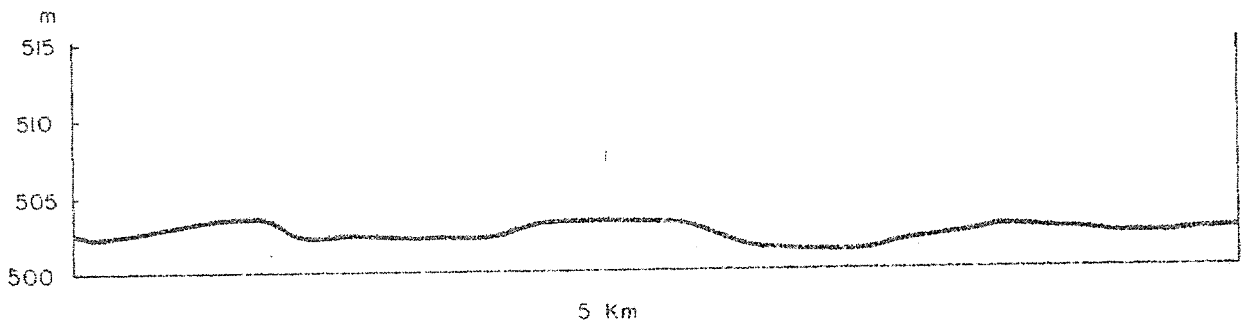
NUMBER	1	2
FACET	graben valleys	playas
AREA (%)	80	20
SLOPE (%)	0-2	0-2
SOIL	Orthic Solonchaks (petrogypsic phase)	Orthic Solonchaks (petrogypsic phase)

Da - Sand dunes and salt encrusted sand deposits



NUMBER 1
FACET n.a.
AREA (%) 100
SLOPE (%) 2-30
SOIL Sand surface

Ec - Evaporite pediments with associated alluvium



NUMBER 1

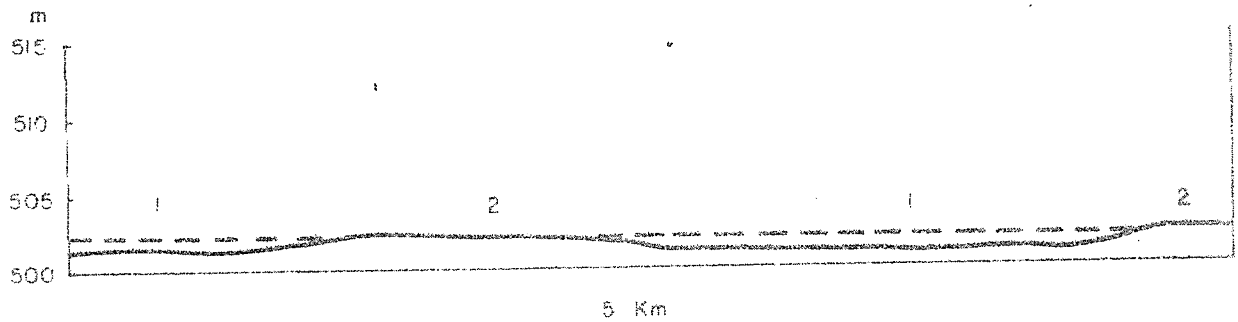
FACET n.a.

AREA (%) 100

SLOPE (%) 0-8

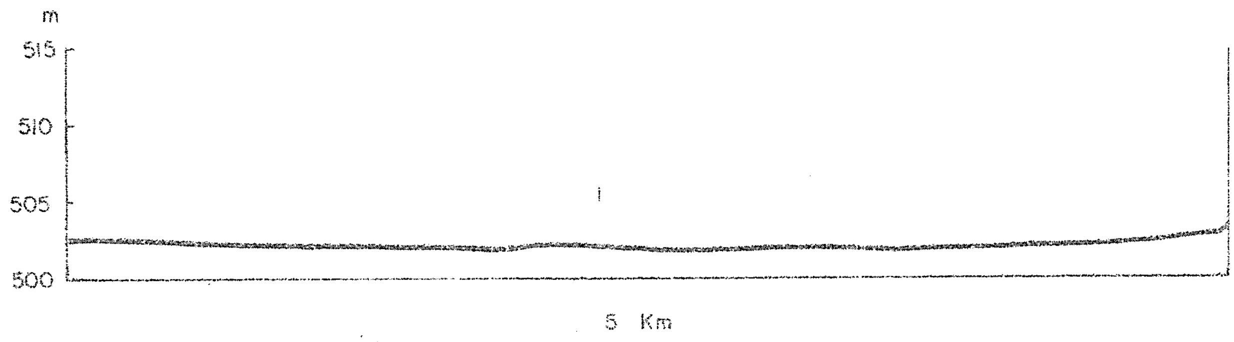
SOIL Orthic Solonchaks (petrogypsic phase)

E1 - Brackish playa lakes and marshes situated in enclosed basins or at the inland termination of blind streams



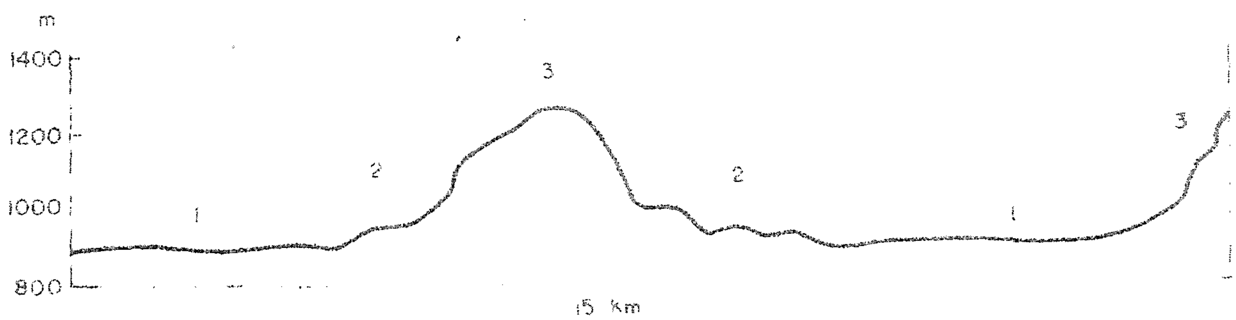
NUMBER	1	2
FACET	playa lakes and marshes	playas
AREA (%)	80	20
SLOPE (%)	0-2	0-2
SOIL	n.a	Gleyic Solonchaks (petrogypsic phase)

Ep - Playas and salinas



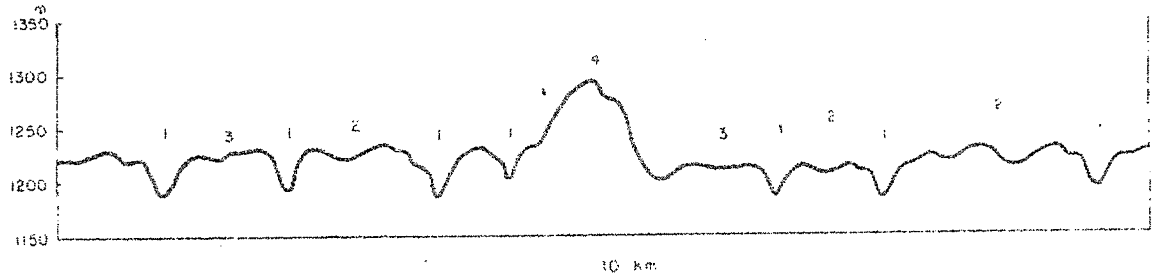
NUMBER 1
FACET n.a.
AREA (%) 100
SLOPE (%) 0-2
SOIL Orthic Solonchaks
(Petrogypsic phase)

Ra - Hilly plains comprised of undulating plains and low plateaux with a substantial proportion of moderate to high relief hills



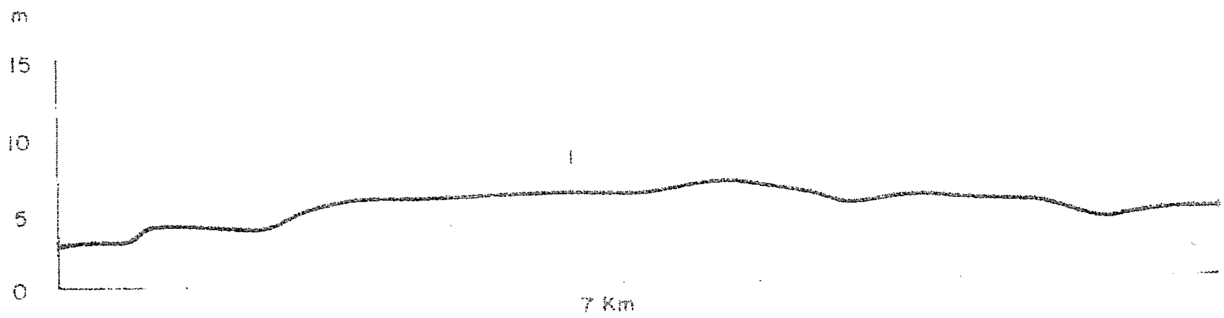
NUMBER	1	2	3
FACET	undulating plains and low plateaux	rolling plains and low plateaux	moderate to high relief hills
AREA (%)	60	20	20
SLOPE (%)	2-8	8-16	16-30
SOIL			
Ra_g^1	Haplic Xerosols (stony phase)	Haplic Xerosols (lithic plase)	Lithosols
Ra_g^2	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols

Rb - Dissected lowland plains and low plateaux



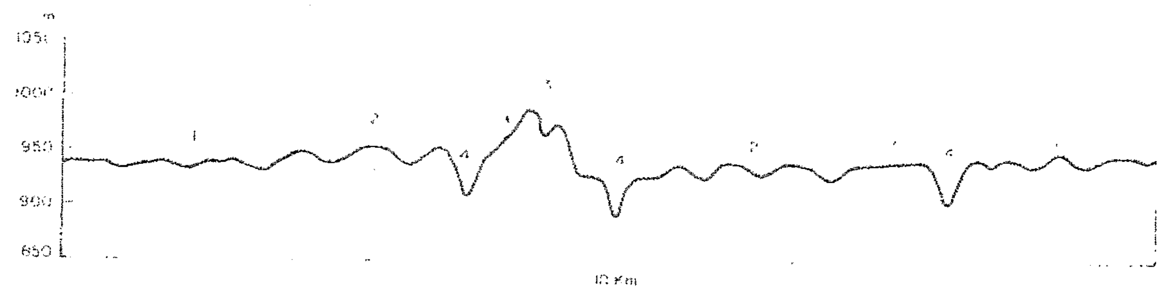
NUMBER	1	2	3	4
FACET	incised valleys	rolling plains and low plateaux	undulating plains and low plateaux	hills
AREA (%)	40	40	10	10
SLOPE(%)	30-50+	8-16	2-8	16-30
SOIL				
Rb_g^1	Lithosols	Chromic Luvisols	Eutric Nitosols	Chromic Luvisols
Rb_g^2	Lithosols	Chromic Cambisols	Chromic Cambisols	Lithosols
Rb_c^1	Lithosols (lithic phase)	Calcic Xerosols	Orthic Solonchaks	Lithosols
Rb_c^2	Lithosols (lithic phase)	Rendzinas	Haplic Phaeozems	Rendzinas (lithic phase)
Rb_m	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Lithosols

Rc - Uplifted reefs



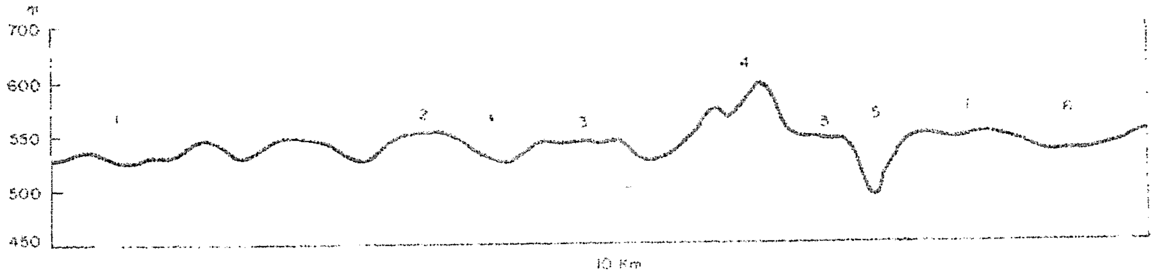
NUMBER	1
FACET	n.a
AREA (%)	100
SLOPE (%)	0-8
SOIL	Calcaric Regosols (lithic phase)

Rd - Undulating to rolling lowland plains and low plateaux



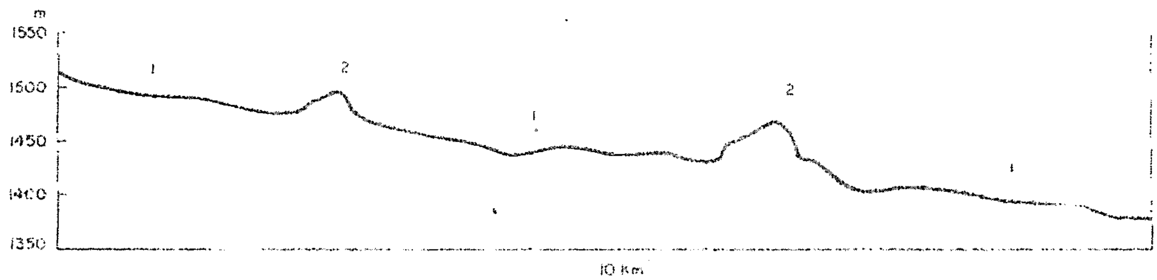
Number	1	2	3	4
FACET	undulating plains and low plateaux	rolling plains and low plateaux	hills	incised valleys
AREA (%)	40	40	10	10
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Rd_v	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols	Lithosols
Rd_g^1	Chromic Luvisols	Chromic Luvisols	Chromic Luvisols (stony phase)	Lithosols
Rd_g^2	Dystric Nitosols	Dystric Nitosols	Orthic Acricsols	Lithosols
Rd_g^3	Eutric Nitosols	Chromic Luvisols	Chromic Luvisols	Lithosols
Rd_g^4	Haplic Xerosols	Haplic Xerosols	Lithosols	Lithosols
Rd_g^5	Chromic Cambisols	Chromic Cambisols	Lithosols	Lithosols
Rd_c^1	Calcic Xerosols	Calcic Xerosols (lithic phase)	Lithosols	Lithosols
Rd_c^2	Eutric Cambisols	Calcic Cambisols (lithic phase)	Lithosols	Lithosols
Rd_c^3	Orthic Solonchaks	Calcic Xerosols	Lithosols	Lithosols
Rd_c^4	Chromic Cambisols	Chromic Cambisols	Eutric Cambisols (lithic phase)	Lithosols
Rd_s^1	Cambic Arenosols	Cambic Arenosols	Lithosols	Lithosols
Rd_s^2	Chromic Cambisols	Chromic Cambisols	Lithosols	Lithosols
Rd_s^3	Chromic Luvisols	Chromic Luvisols	Chromic Cambisols	Lithosols
Rd_e	Gypsic Yermosols (saline phase)	Gypsic Yermosols (saline phase)	Lithosols	Lithosols
Rd_m^1	Chromic Luvisols	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Lithosols
Rd_m^2	Eutric Cambisols	Eutric Regosols (lithic phase)	Lithosols	Lithosols
$Rd_{m/g}$	Chromic Luvisols	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Lithosols

Rd_s/V_r - Undulating to rolling lowland plains and low plateaux/dissected lavas and extensive rock outcrop



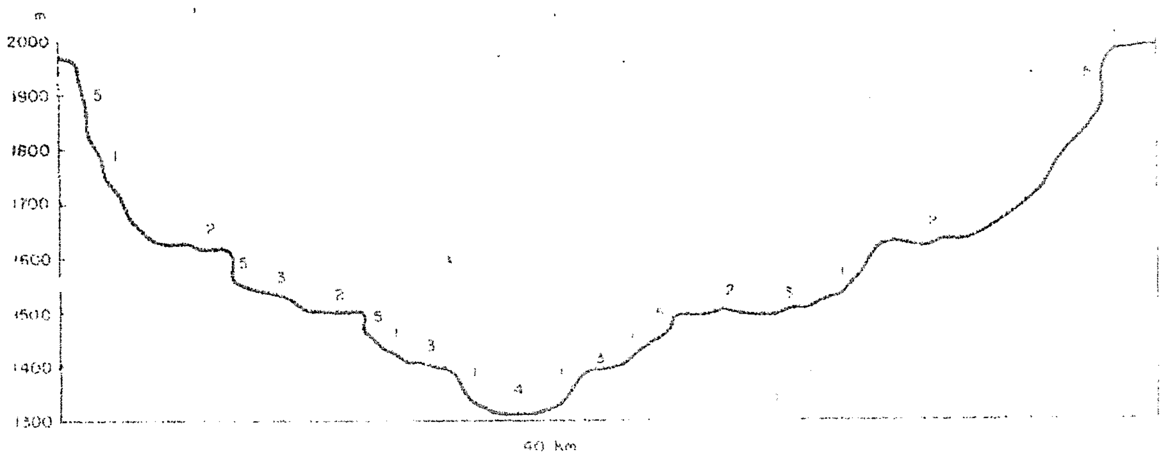
NUMBER	1	2	3	4	5	6
FACET	undulating plains	rolling plains	stony terraces	hills	dissected valleys	undulating basins
AREA (%)	30	30	10	10	10	10
SLOPE (%)	2-8	8-16	2-8	16-30	30-50+	2-8
SOIL	Calcic Xerosols (petrocalcic phase)	Calcic Xerosols (lithic phase)	Rubble land	Lithosols	Lithosols	Calcic Xerosols

Rf - Undulating sideslopes and piedmont zones strongly influenced by colluvial processes but retaining distinct residual characteristics



NUMBER	1	2
FACET	undulating sideslopes	low hills
AREA (%)	90	10
SLOPE (%)	2-8	8-16
SOIL		
Rf_v^1	Chromic Vertisols	Eutric Nitosols
Rf_v^2	Chromic Vertisols (stony phase)	Eutric Regosols (lithic phase)
Rf_v^3	Chromic Vertisols	Orthic Luvisols (stony phase)
Rf_v^4	Mollic Andosols	Eutric Cambisols
Rf_v^5	Eutric Regosols (lithic phase)	Lithosols
Rf_v^6	Dystric Nitosols	Dystric Nitosols
Rf_g^1	Haplic Xerosols (stony phase)	Lithosols
Rf_g^2	Dystric Nitosols	Dystric Nitosols
Rf_g^3	Eutric Cambisols	Eutric Cambisols
Rf_g^4	Eutric Nitosols	Chromic Luvisols
Rf_c^1	Vertic Cambisols	Calcic Cambisols (lithic phase)
Rf_c^2	Chromic Vertisols	Calcic Cambisols (petrocalcic phase)
Rf_c^3	Orthic Solonchaks	Lithosols
Rf_c^4	Eutric Regosols	Calcic Xerosols
$Rf_{c/e}$	Orthic Solonchaks (petrogypsic phase)	Lithosols
Rf_s^1	Eutric Regosols	Eutric Regosols (lithic phase)
Rf_s^2	Chromic Cambisols	Cambic Arenosols (lithic phase)
Rf_e	Orthic Solonchaks (petrogypsic phase)	Lithosols
Rf_m^1	Chromic Vertisols	Eutric Nitosols
Rf_m^2	Vertic Cambisols	Eutric Cambisols (lithic phase)
Rf_m^3	Haplic Xerosols (stony phase)	Lithosols
$Rf_{m/g}$	Vertic Cambisols	Eutric Cambisols (lithic phase)

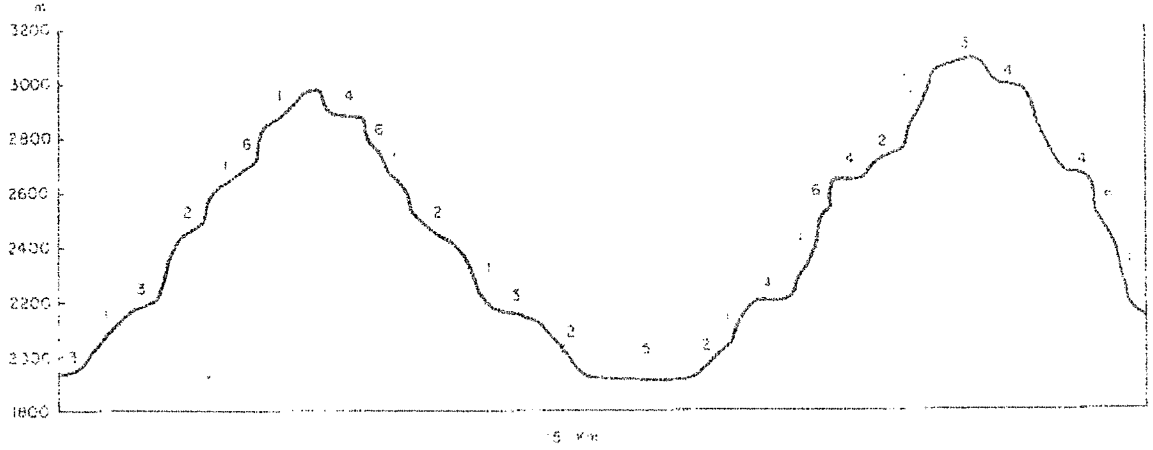
R_g - Major river gorges, canyons and escarpments
(may include Rm, Rh etc.)



NUMBER	1	2	3	4	5
FACET	very steep sideslopes	plateau terraces	steep sideslopes	gorge's bottom	escarpments
AREA (%)	30	30	20	10	10
SLOPES (%)	30-50+	8-16	16-30	2-8	50+
SOIL					
Rg_v	Lithosols	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Rock surface
Rg_g	Lithosols	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Rock surface
Rg_c	Lithosols	Rendzinas (lithic phase)	Rendzinas (lithic phase)	Eutric Cambisols (stony phase)	
Rg_s	Lithosols	Cambic Arenosols (stony phase)	Cambic Arenosols (lithic phase)	Cambic Arenosols (stony phase)	Rock surface
Rg_m	Lithosols	Eutric Cambisols (sony phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Rock surface

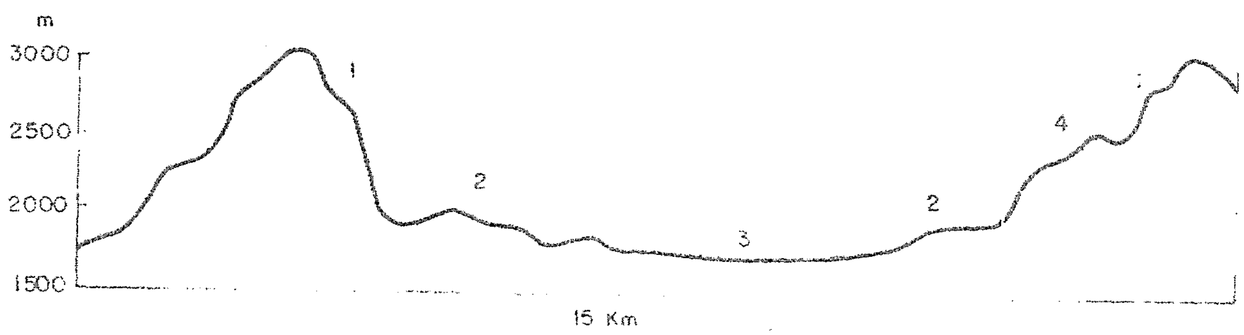
+ In Rg_v very steep sideslopes make up 40 percent and plateau terraces occupy 20 percent of the unit

Rh - High to mountainous relief hills



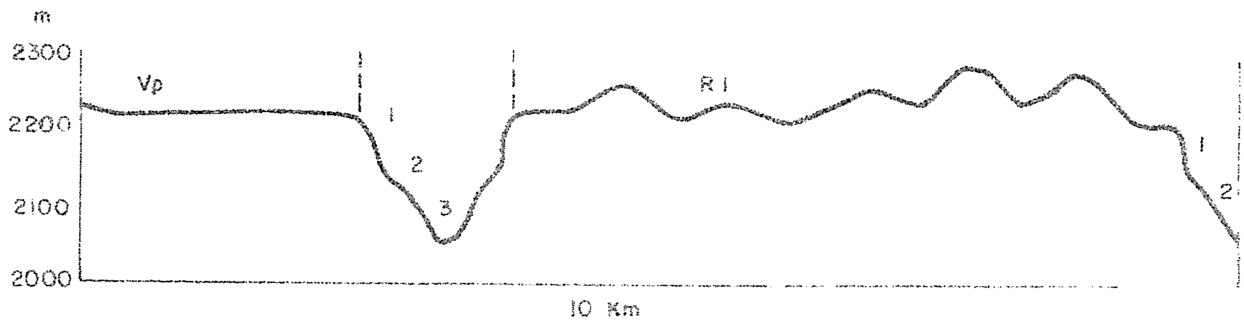
NUMBER	1	2	3	4	5	6
FACET	very steep sideslopes	steep sideslopes	moderate sideslopes	plateau terraces and gentle sideslopes	intermontane valleys	escarpments
AREA (%)	50	10	10	10	10	10
SLOPE (%)	30-50+	16-30	8-16	2-8	0-8	50+
SOIL						
Rh_v^1	Chromic Luvisols (stony phase)	Chromic Luvisols	Eutric Nitosols	Eutric Nitosols	Eutric Fluvisols	Rock surface
Rh_v^2	Orthic Acrisols (stony phase)	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols	Dystric Fluvisols	Rock surface
Rh_v^3	Lithosols	Eutric Regosols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Rock surface
Rh_v^4	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Orthic Luvisols (stony phase)	Eutric Nitosols (stony phase)	Eutric Fluvisols (stony phase)	Rock surface
Rh_v^5	Lithosols	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols stony phase)	Eutric Cambisols (stony phase)	Rock surface
$Rh_{v/s}$	Eutric Cambisols (lithic phase)	Chromic Luvisols (stony phase)	Chromic Luvisols	Chromic Luvisols	Eutric Fluvisols	Rock surface
Rh_g^1	Dystric Cambisols (lithic phase)	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols	Dystric Fluvisols	Rock surface
Rh_g^2	Chromic Cambisols (lithic phase)	Chromic Luvisols	Chromic Luvisols	Eutric Nitosols	Eutric Fluvisols	Rock surface
Rh_g^3	Rock surface	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Eutric Fluvisols	Rock surface
Rh_g^4	Lithosols	Lithosols	Chromic Cambisols (lithic phase)	Chromic Cambisols	Eutric Fluvisols	Rock surface
Rh_m	Lithosols	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols	Eutric Fluvisols	Rock surface

Ri - High relief hills and mountains with a substantial proportion of moderately sloping valleys interspersed throughout



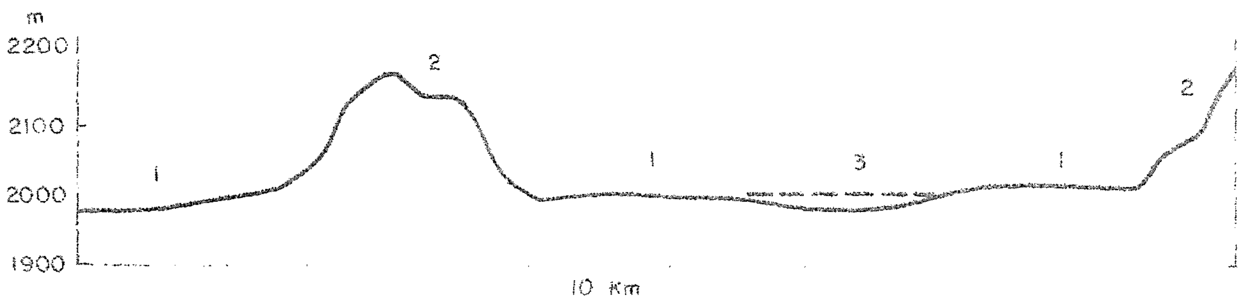
NUMBER	1	2	3	4
FACET	high relief hills and mountains	footslopes	valleys	high relief hills and mountains
AREA (%)	50	20	20	10
SLOPE (%)	30-50+	8-16	0-8	16-30
SOIL				
Ri_v	Lithosols	Eutric Regosols (lithic phase)	Vertic Cambisols (lithic phase)	Eutric Regosols (lithic phase)

Rj - Minor river gorges and ravines



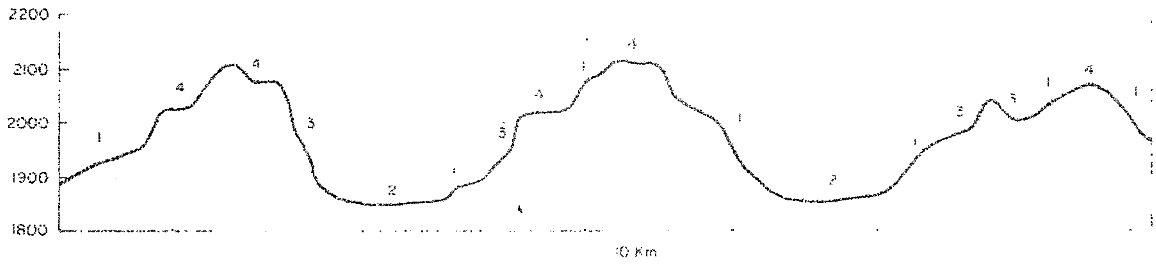
NUMBER			
FACET	very steep side slopes	escarpments	gorge's bottom
AREA (%)	50	40	10
SLOPE (%)	30-50	50+	2-8
SOIL			
Rj_v	Lithosols	Rock surface	Eutric Fluvisols
Rj_g	Lithosols	Rock surface	Eutric Fluvisols (stony phase)
Rj_c	Lithosols	Rock surface	Calcaric Fluvisols (stony phase)

Rk - High plateaux with scattered moderate relief hills and substantial areas of seasonal marshland interspersed throughout

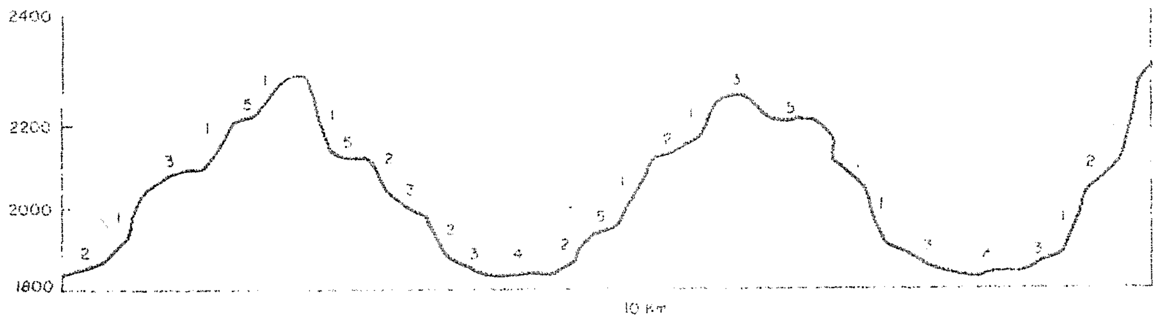


NUMBER	1	2	3
FACET	undulating plateaux	moderate relief hills	seasonal marshes
AREA (%)	50	30	20
SLOPE (%)	2-8	16-30	0-2
SOIL			
Rk_v^1	Dystric Nitosols	Dystric Nitosols	Dystric Gleysols
Rk_v^2	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)	Chromic Vertisols

Rl - Low to moderate relief hills

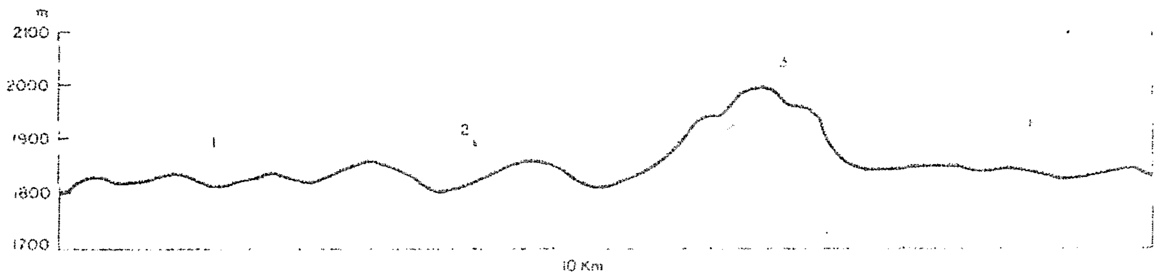


NUMBER	1	2	3	4
FACET	sideslopes	small valleys	steep sideslopes	plateau terraces and gentle sideslopes
AREA (%)	60	20	10	10
SLOPE (%)	8-16	0-8	16-30	2-8
SOIL				
Rl^{1}_{v}	Eutric Nitosols	Chromic Vertisols	Eutric Nitosols	Chromic Vertisols
Rl^{2}_{v}	Eutric Cambisols (stony phase)	Eutric Cambisols	Lithosols	Eutric Cambisols
Rl^{3}_{v}	Orthic Luvisols (stony phase)	Chromic Vertisols	Orthic Luvisols (stony phase)	Orthic Luvisols (stony phase)
Rl^{4}_{v}	Eutric Cambisols (lithic phase)	Vertic Cambisols (stony phase)	Eutric Regosols (lithic phase)	Eutric Cambisols (stony phase)
Rl^{5}_{v}	Lithosols	Eutric Regosols (saline phase)	Lithosols	Eutric Regososl (litnic phase)
$Rl_{v/e}$	Lithosols	Orthic Solonchaks (stony phase)	Lithosols	Eutric Regosols (lithic phase)
Rl^{1}_{g}	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols	Dystric Nitosols
Rl^{2}_{g}	Chromic Luvisols	Vertic Luvisols	Chromic Luvisols	Eutric Nitosols
Rl^{3}_{g}	Haplic Xerosols (lithic phase)	Haplic Xerosols	Lithosols	Haplic Xerosols (stony phase)
Rl^{4}_{g}	Eutric Cambisols (lithic phase)	Eutric Cambisols	Lithosols	Eutric Cambisols
Rl^{1}_{c}	Calcic Xerosols (lithic phase)	Orthic Solonchaks	Lithosols	Calcic Xerosols
Rl^{2}_{c}	Calcic Cambisols (lithic phase)	Chromic Vertisols	Lithosols	Calcic Cambisols
Rl^{3}_{c}	Calcic Xerosols (lithic phase)	Eutric Regosols	Lithosols	Calcic Xerosols
Rl^{4}_{c}	Haplic Phaeozems	Chromic Vertisols	Eutric Cambisols (lithic phase)	Haplic Phaeozems
Rl^{1}_{s}	Lithosols	Eutric Regosols (stony phase)	Lithosols	Eutric Regosols (stony phase)
Rl^{2}_{s}	Cambic Arenosols (lithic phase)	Chromic Cambisols	Cambic Arenosols (lithic phase)	Chromic Cambisols
Rl^{3}_{s}	Cambic Arenosols (lithic phase)	Chromic Cambisols	Lithosols	Cambic Luvisols (lithic phase)
Rl^{4}_{s}	Chromic Luvisols	Vertic Luvisols	Chromic Cambisols	Chromic Luvisols
Rl_{e}	Gypsic Yermosols (saline phase)	Orthic Solonchaks (petrogypsic phase)	Lithosols	Gypsic Yermosols (saline phase)
Rl^{1}_{m}	Eutric Nitosols	Chromic Vertisols	Chromic Luvisols	Eutric Nitosols
Rl^{2}_{m}	Eutric Cambisols (stony phase)	Eutric Cambisols	Eutric Cambisols (lithic phase)	Chromic Luvisols
Rl^{3}_{m}	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Lithosols	Haplic Xerosols (stony phase)
$Rl_{m/g}$	Eutric Nitosols	Chromic Vertisols	Chromic Luvisols	Eutric Nitosols



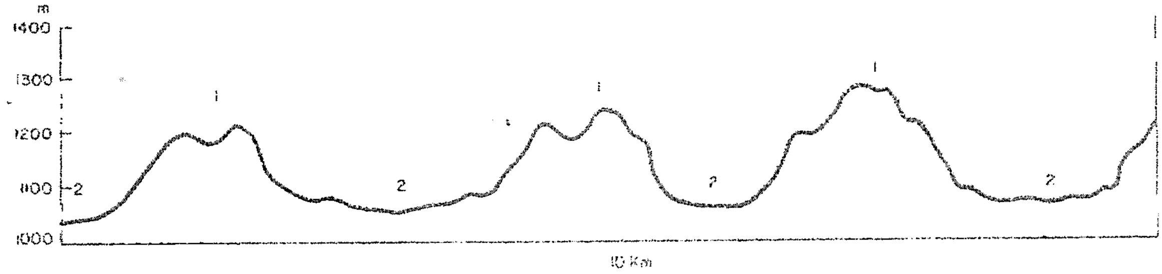
NUMBER	1	2	3	4	5
FACET	very steep sideslopes	steep sideslopes	moderate sideslopes	small valleys	plateau terraces and gentle sideslopes
AREA (%)	30	20	20	20	10
SLOPE (%)	30-50	16-30	8-16	0-8	2-8
SOIL					
Rm$_v^1$	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)	Chromic Luvisols	Chromic Vertisols	Eutric Nitosols
Rm$_v^2$	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Rm$_v^3$	Orthic Luvisols (stony phase)	Orthic Luvisols (stony phase)	Orthic Luvisols (stony phase)	Eutric Nitosols (stony phase)	Eutric Nitosols (stony phase)
Rm$_v^4$	Lithosols	Lithosols	Lithosols	Eutric Regosols (stony phase)	Eutric Regosols (lithic phase)
Rm$_v^5$	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols	Vertic Cambisols	Eutric Cambisols
Rm$_v^6$	Lithosols	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols	Eutric Cambisols (stony phase)
Rm$_v^7$	Lithosols	Eutric Regosols (lithic phase)	Eutric Cambisols (lithic phase	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)
Rm$_{v/g}$	Orthic Acrisols	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Rm$_{v/s}$	Eutric Cambisols (lithic phase)	Chromic Luvisols (stony phase)	Chromic Luvisols	Vertic Luvisols	Chromic Luvisols
Rm$_g^1$	Orthic Acrisols	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Rm$_g^2$	Chromic Cambisols (lithic phase)	Chromic Luvisols (stony phase)	Chromic Luvisols	Vertic Luvisols	Chromic Luvisols
Rm$_g^3$	Chromic Cambisols (lithic phase)	Chromic Luvisols (stony phase)	Chromic Luvisols	Vertic Luvisols	Eutric Nitosols
Rm$_g^4$	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Orthic Solonchaks	Eutric Regosols (saline phase)
Rm$_g^5$	Lithosols	Lithosols	Chromic Cambisols (lithic phase)	Chromic Cambisols	Chromic Cambisols
Rm$_c^1$	Lithosols	Lithosols	Calcic Xerosols (lithic phase)	Orthic Solonchaks	Calcic Xerosols
Rm$_c^2$	Lithosols	Lithsols	Calcic Cambisols (lithic phase)	Chromic Vertisols	Eutric Cambisols (stony phase)
Rm$_c^3$	Lithosols	Lithosols	Calcic Cambisols (lithic phase)	Calcaric Fluvisols	Chromic Cambisols
Rm$_c^4$	Lithosols	Eutric Cambisols (lithic phase)	Haplic Phaeozems (stony phase)	Chromic Vertisols	Haplic Phaeozems
Rm$_{c/g}$	Lithosols	Eutric Cambisols (lithic phase)	Haplic Phaeozems (stony phase)	Chromic Vertisols	Haplic Phaeozems
Rm$_s^1$	Lithosols	Cambic Arenosols (lithic phase)	Cambic Arenosols (lithic phase)	Chromic Cambisols	Chromic Cambisols
Rm$_s^2$	Lithosols	Lithosols	Cambic Arenosols (lithic phase)	Chromic Cambisols	Cambic Arenosols
Rm$_s$	Lithosols	Lithosols	Gypsic Yermosols (saline phase)	Orthic Solonchaks (petrogypsic phase)	Gypsic Yermosols (saline phase)
Rm$_m^1$	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Eutric Cambisols	Chromic Luvisols
Rm$_m^2$	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Haplic Xerosols (lithic phase)
Rm$_{m/g}^1$	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Eutric Cambisols	Chromic Luvisols
Rm$_{m/g}^2$	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Haplic Xerosols (lithic phase)

Rn - Hilly plains comprised of undulating plains and low plateaux with a substantial proportion of low to moderate relief hills



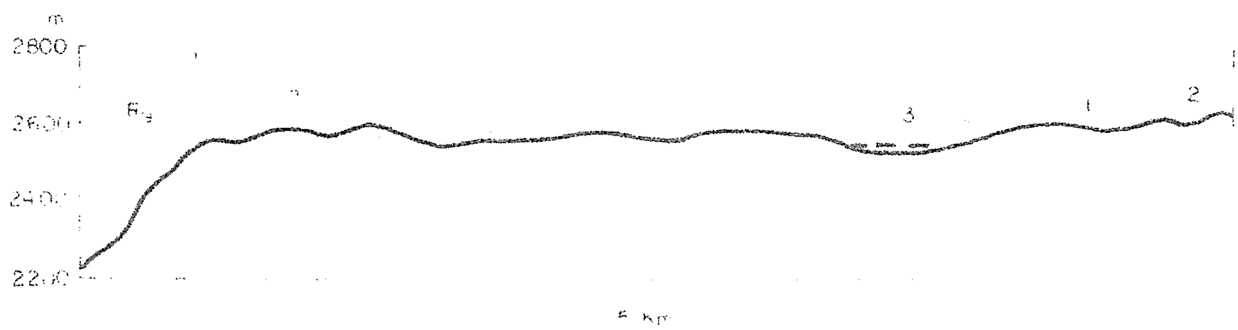
NUMBER	1	2	3
FACET	undulating plains and low plateaux	rolling plains and low plateaux	low to moderate relief hills
AREA (%)	60	20	20
SLOPE (%)	2-8	8-16	16-30
SOIL			
Rn_v^1	Eutric Nitosols	Eutric Nitosols	Chromic Luvisols
Rn_v^2	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Rn_v^3	Eutric Nitosols	Orthic Luvisols (stony phase)	Orthic Luvisols (stony phase)
Rn_v^4	Eutric Cambisols (stony phase)	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)
Rn_v^5	Eutric Regosols (lithic phase)	Lithosols	Lithosols
Rn_g^1	Haplic Xerosols	Haplic Xerosols (lithic phase)	Lithosols
Rn_g^2	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols
Rn_g^3	Chromic Cambisols	Chromic Cambisols	Lithosols
Rn_g^4	Eutric Nitosols	Chromic Luvisols	Chromic Luvisols
Rn_c^1	Calcic Xerosols	Calcic Xerosols (lithic phase)	Lithosols
Rn_c^2	Eutric Cambisols	Calcic Cambisols (lithic phase)	Lithosols
Rn_c^3	Haplic Phaeozems	Haplic Phaeozems	Eutric Cambisols (lithic phase)
Rn_s	Cambic Arenosols	Cambic Arenosols (lithic phase)	Lithosols
Rn_m^1	Eutric Nitosols	Eutric Nitosols	Chromic Luvisols
Rn_m^2	Chromic Luvisols	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)
Rn_m^3	Haplic Xerosols	Haplic Xerosols (lithic phase)	Lithosols

Ro - Hilly terrain of low to moderate relief with a substantial proportion of moderately sloping valleys interspersed throughout.



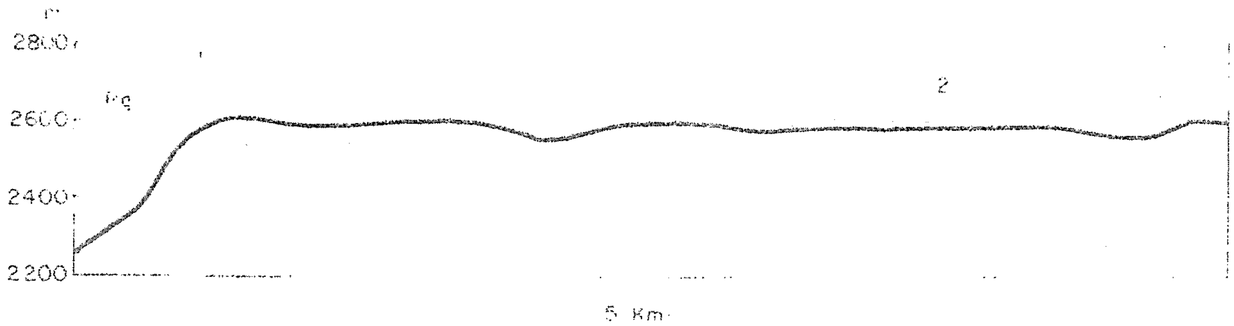
NUMBER	1	2
FACET	low to moderate relief hills	valleys
AREA (%)	60	40
SLOPE (%)	16-30	0-8
SOIL		
Ro_v^1	Nithosols	Eutric Regosols (stony phase)
Ro_v^2	Dystric Nitosols	Dystric Nitosols
Ro_v^3	Chromic Luvisols (stony phase)	Chromic Vertisols
Ro_v^4	Eutric Cambisols (stony phase)	Vertic Cambisols (stony phase)
Ro_v^5	Chromic Luvisols	Chromic Vertisols
Ro_g^1	Orthic Acrisols	Dystric Nitosols
Ro_g^2	Chromic Luvisols	Vertic Luvisols
Ro_g^3	Lithosols	Haplic Xerosols
Ro_g^4	Lithosols	Chromic Cambisols
Ro_c^1	Lithosols	Orthic Solonchaks
Ro_c^2	Calcic Cambisols (petrocalcic phase)	Vertic Cambisols
Ro_c^3	Eutric Cambisols (lithic phase)	Chromic Vertisols
Ro_s	Lithosols	Eutric Regosols (saline phase)
Ro_e	Lithosols	Orthic Solonchaks (petrogypsic phase)
Ro_m^1	Chromic Luvisols	Chromic Vertisols
Ro_m^2	Eutric Cambisols (lithic phase)	Eutric Cambisols
Ro_m^3	Lithosols	Haplic Xerosols

Rp - Undulating to rolling high plateaux



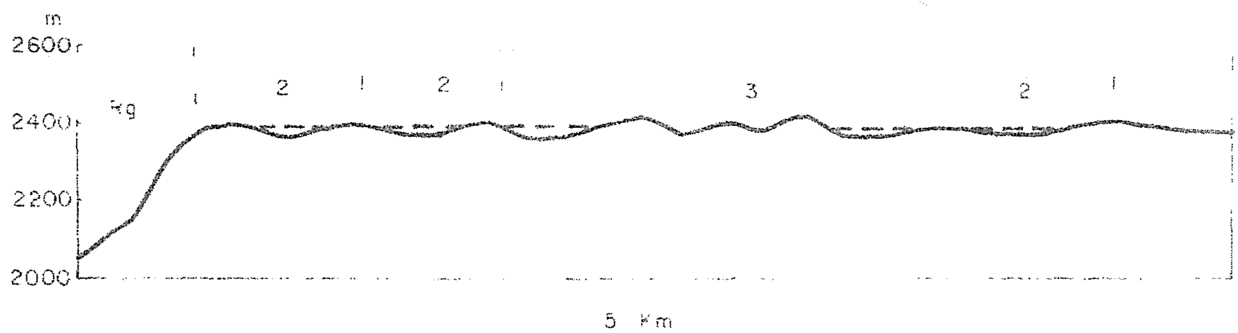
NUMBER	1	2	3
FACET	undulating plateaux	rolling plateaux	depressions with seasonal drainage deficiencies
AREA (%)	60	30	10
SLOPE (%)	2-8	8-16	0-2
SOIL			
Rp_v^1	Eutric Nitosols	Eutric Nitosols	Chromic Vertisols
Rp_v^2	Dystric Nitosols	Dystric Nitosols	Dystric Gleysols
Rp_g	Eutric Nitosols	Chromic Luvisols	Vertic Luvisols
Rp_c	Vertic Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Chromic Vertisols
Rp_m	Chromic Cambisols	Eutric Cambisols (lithic phase)	Chromic Vertisols

Rp_V^3 - Undulating plateaux



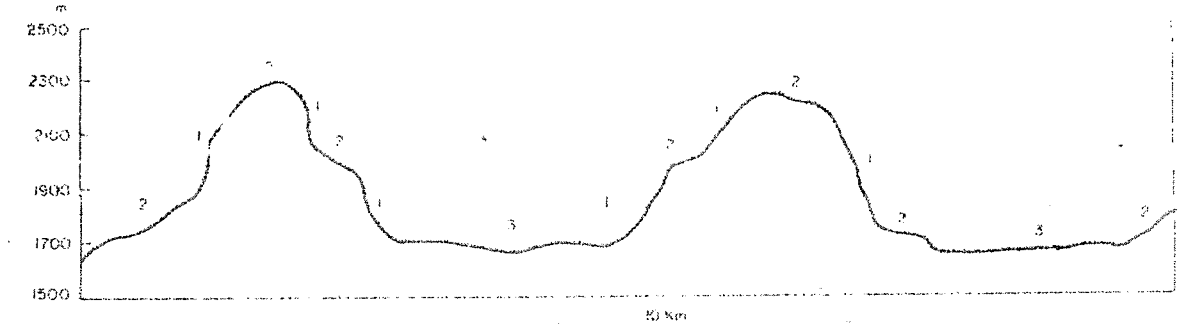
NUMBER	1	2
FACET	undulating plateaux	flat plateaux
AREA (%)	70	30
SLOPE (%)	2-8	0-2
SOIL		
Rp_V^3	Chromic Luvisols (stony phase)	Chromic Vertisols

Rp_v^4



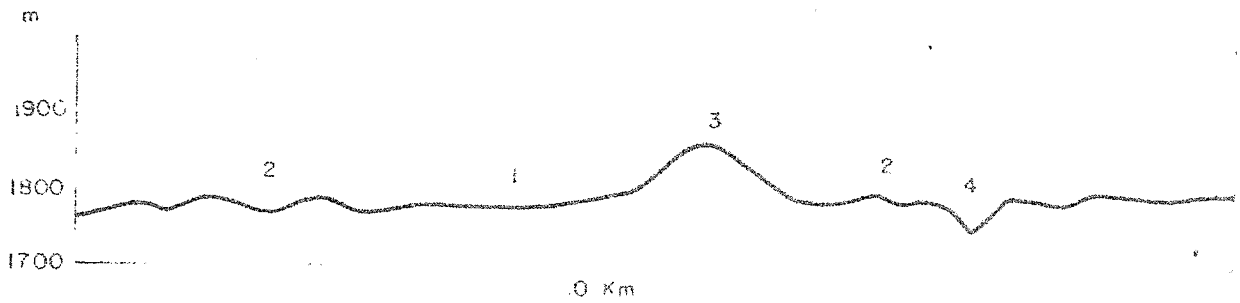
NUMBER	1	2	3
FACET	undulating plateaux	depressions with seasonal drainage deficiencies	rolling plateaux
AREA (%)	40	40	20
SLOPE (%)	2-8	0-2	8-16
SOIL			
Rp_v^4	Chromic Vertisols	Eutric Fluvisols	Dystric Nitosols

Rq - Hilly terrain of moderate to high relief with a substantial proportion of moderately sloping valleys interspersed throughout



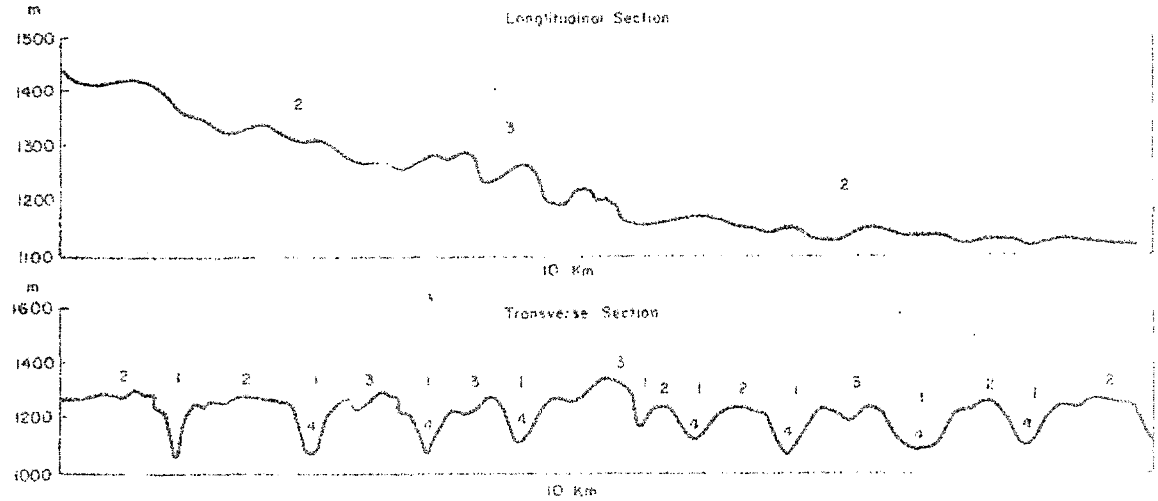
NUMBER	1	2	3
FACET	moderate to high relief hills	moderate to high relief hills	valleys
AREA (%)	40	30	30
SLOPE (%)	30-50	16-30	0-8
SOIL			
Rq_v^1	Lithosols	Eutric Regosols (lithic phase)	Vertic Cambisols (stony phase)
Rq_v^2	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols
Rq_v^3	Lithosols	Lithosols	Eutric Regosols (saline phase)
Rq_g^1	Orthic Acrisols	Orthic Acrisols	Dystric Nitosols
Rq_g^2	Lithosols	Lithosols	Haplic Xerosols
Rq_c	Lithosols	Lithosols	Chromic Vertisols
Rq_s^1	Lithosols	Cambic Arenosols (lithic phase)	Chromic Cambisols
Rq_s^2	Lithosols	Lithosols	Chromic Cambisols
Rq_m^1	Lithosols	Lithosols	Eutric Fluvisols
Rq_m^2	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols

Rr - Gently sloping rises and low plateaux



NUMBER	1	2	3	4
FACET	undulating plains	rolling plains	hills	incised valleys
AREA (%)	40	40	10	10
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Rr_v^1	Luvic Phaeozems (sodic phase)	Luvic Phaeozems (sodic phase)	Eutric Cambisols	Lithosols
Rr_v^2	Chromic Vertisols	Chromic Luvisols	Chromic Luvisols (stony phase)	Lithosols

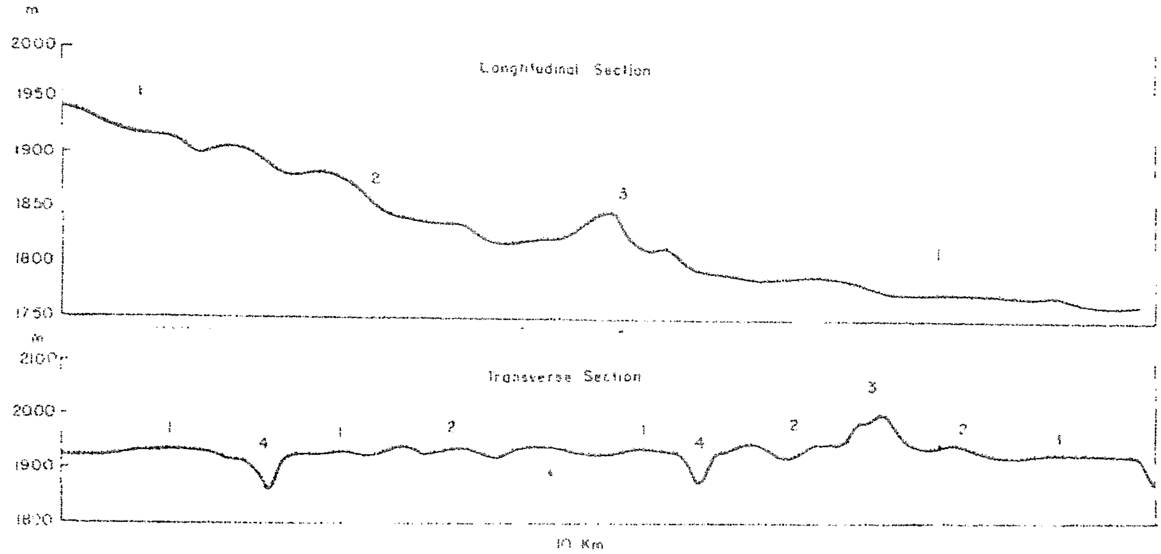
Rs - Severely dissected sideslopes and piedmont zones



NUMBER	1	2	3	4
FACET	deeply incised valleys*	rolling sideslopes	hilly sideslopes	valley bottoms*
AREA (%)	40	30	20	10
SLOPE (%)	30-50+	8-16	16-30	0-2
SOIL				
Rs_v^1	Lithosols	Eutric Nitosols	Chromic Luvisols (stony phase)	Chromic Vertisols
Rs_v^2	Lithosols	Dystric Nitosols (lithic phase)	Dystric Nitosols (lithic phase)	Dystric Nitosols (stony phase)
Rs_v^3	Lithosols	Eutric Regosols (lithic phase)	Eutric Regosols (lithic phase)	Vertic Cambisols (stony phase)
$Rs_{v/s}$	Lithosols	Eutric Nitosols	Chromic Luvisols (stony phase)	Eutric Nitosols
Rs_g	Lithosols	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Rs_c^1	Lithosols	Calcic Xerosols (lithic phase)	Lithosols	Calcaric Fluvisols
Rs_c^2	Lithosols	Calcic Cambisols (lithic phase)	Calcic Cambisols (lithic phase)	Calcaric Fluvisols
Rs_c^3	Lithosols	Calcic Cambisols (petrocalcic phase)	Calcic Cambisols (lithic phase)	Orthic Solonchaks
Rs_c^4	Lithosols	Chromic Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Eutric Fluvisols
Rs_e	Lithosols	Gypsic Yermosols (saline phase)	Lithosols	Orthic Solonchaks (petrogypsic phase)
Rs_m^1	Lithosols	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Gleyic Cambisols
Rs_m^2	Lithosols	Eutric Cambisols (stony phase)	Lithosls	Gleyic Cambisols

* Deeply incised valleys and valley bottoms are generally parallel to slope, thus do not show up on cross-section 1.

Rt - Moderately dissected sideslopes and piedmont zones

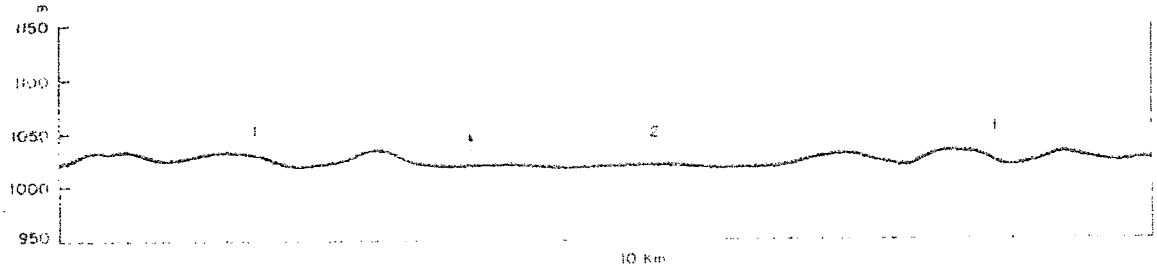


NUMBER	1	2	3	4
FACET	undulating sideslopes	rolling sideslopes	hills	incised valleys*
AREA (%)	40	40	10	10
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Rt_v^1	Chromic Vertisols	Eutric Nitosols	Chromic Luvisols	Lithosols
Rt_v^2	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols	Lithosols
Rt_v^3	Chromic Vertisols	Eutric Nitosols	Orthic Luvisols (stony phase)	Lithosols
Rt_v^4	Eutric Cambisols (stony phase)	Eutric Regosols (lithic phase)	Eutric Regosols (lithic phase)	Lithosols
Rt_v^5	Eutric Regosols (lithic phase)	Eutric Regosols (lithic phase)	Lithosols	Lithosols
Rt_g^1	Eutric Nitosols	Chromic Luvisols	Chromic Luvisols (stony phase)	Lithosols
Rt_g^2	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols	Lithosols
Rt_g^3	Eutric Nitosols	Chromic Luvisols	Chromic Luvisols	Lithosols
Rt_g^4	Chromic Cambisols	Chromic Cambisols (stony phase)	Lithosols	Lithosols
Rt_c^1	Calcic Xerosols	Cacic Xerosols (lithic phase)	Lithosols	Lithosols
Rt_c^2	Eutric Cambisols	Calcic Cambisols (lithic phase)	Calcic Cambisols (lithic phase)	Lithosols
Rt_c^{3*}	Eutric Regosols	Calcic Cambisols (lithic phase)	Lithosols	-
Rt_c^4	Haplic Phaeozems	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Lithosols
$Rt_{c/g}$	Haplic Phaeozems	Haplic Phaeozems (stony phase)	Eutric Cambisols (lithic phase)	Lithosols
Rt_s^1	Eutric Regosols	Calcic Xerosols (lithic phase)	Lithosols	Lithosols
Rt_s^2	Chromic Cambisols	Chromic Cambisols (lithic phase)	Cambic Arenosols (lithic phase)	Lithosols
Rt_s^3	Cambic Arenosols	Cambic Arenosols (lithic phase)	Lithosols	Lithosols
$Rt_{s/g}$	Chromic Cambisols	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Lithosols
Rt_e	Orthic Solonchaks (pertogypsic phase)	Gypsic Yermosols (saline phase)	Lithosols	Lithosols

* Incised valleys are generally parallel to slope, thus do not show up on the longitudinal cross-section

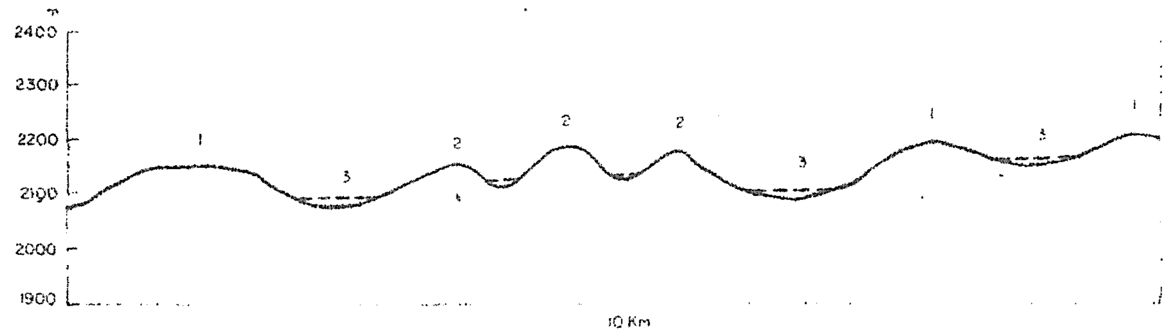
+ Incised valleys do not occur in unit Rt_c^3 and hills make up 20% of the unit

Ru - Flat to undulating lowland plains and low plateau



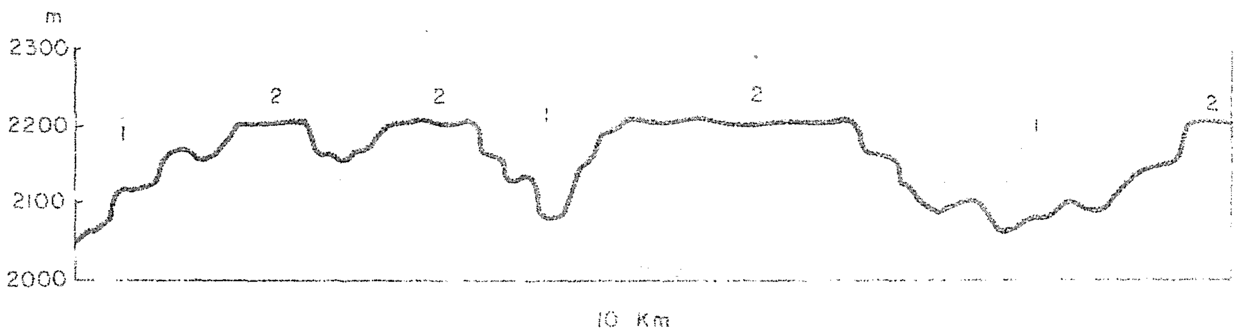
NUMBER	1	2
FACET	undulating plains	flat plains
AREA (%)	70	30
SLOPE (%)	2-8	0-2
SOIL		
Ru_v	Dystric Nitosols	Chromic Vertisols
$Ru_{v/g}$	Chromic Cambisols	Chromic Cambisols
Ru_g^1	Haplic Xerosols	Haplic Xerosols
Ru_g^2	Dystric Nitosols	Dystric Nitosols
Ru_g^3	Eutric Nitosols	Eutric Nitosols
Ru_g^4	Chromic Cambisols	Chromic Cambisols
Ru_c^1	Calcic Xerosols	Calcic Xerosols
Ru_c^2	Chromic Vertisols	Chromic Vertisols
Ru_c^3	Eutric Cambisols	Chromic Vertisols
Ru_c^4	Chromic Cambisols	Chromic Cambisols
Ru_s^1	Calcic Xerosols (petrocalcic phase)	Calcic Xerosols (petrocalcic phase)
Ru_s^2	Calcic Cambisols (petrocalcic phase)	Vertic Cambisols (petrocalcic phase)
Ru_s^3	Cambic Arenosols	Vertic Cambisols
Ru_s^4	Chromic Vertisols	Chromic Vertisols
Ru_e	Gypsic Yermosols (saline phase)	Orthic Solonchak (petrogypsic phase)
Ru_m^1	Eutric Nitosols	Chromic Vertisols
Ru_m^2	Chromic Luvisols	Chromic Vertisols
$Ru_{m/g}^1$	Eutric Nitosols	Chromic Vertisols
$Ru_{m/g}^2$	Chromic Luvisols	Chromic Vertisols

Rw - Rolling to hilly plateaux



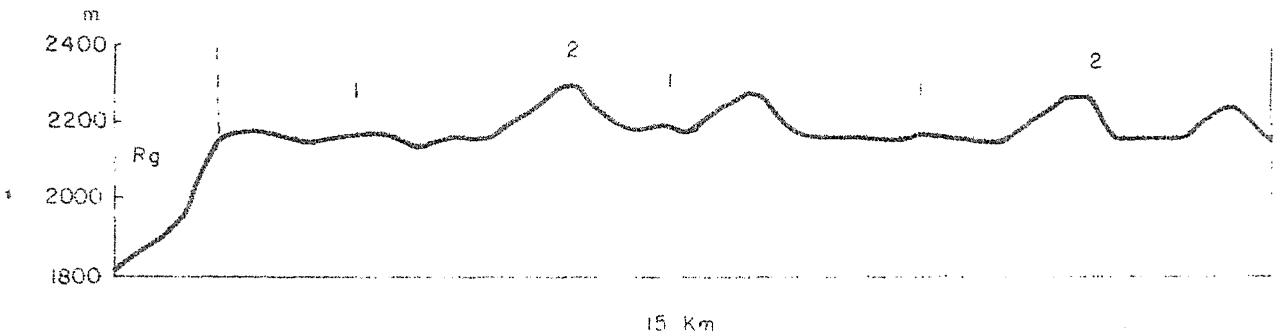
NUMBER	1	2	3
FACET	rolling plateaux	hilly plateaux	depressions with seasonal drainage deficiencies
AREA (%)	70	20	10
SLOPE (%)	8-16	16-30	0-2
SOIL			
Rw_v^1	Dystric Nitosols	Dystric Nitosols	Dystric Gleysols
Rw_v^2	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)	Chromic Vertisols
Rw_v^3	Eutric Nitosols	Eutric Nitosols	Chromic Vertisols
Rw_v^4	Eutric Cambisols (stony phase)	Eutric Regosols (lithic phase)	Chromic Vertisols
Rw_g^1	Chromic Luvisols	Chromic Luvisols	Vertic Luvisols
Rw_g^2	Dystric Nitosols	Orthic Acrisols	Dystric Gleysols
Rw_g^3	Chromic Luvisols.	Chromic Luvisols	Vertic Luvisols
Rw_g^4	Eutric Cambisols (lithic phase)	Lithosols	Gleyic Cambisols
Rw_c^1	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Chromic Vertisols
Rw_c^2	Haplic Phaeozems	Haplic Phaeozems (lithic phase)	Chromic Vertisols
Rw_s	Eutric Cambisols (lithic phase)	Cambic Arenosols (lithic phase)	Gleyc Cambisols
Rw_m	Chromic Luvisols	Lithosols	Eutric Gleysols

Rx - Severely dissected plateaux with moderate relief hills



NUMBER	1	2
FACET	steep sideslopes	plateau remnants
AREA (%)	60	40
SLOPE (%)	30-50	2-8
SOIL		
Rx_V	Chromic Cambisols (lithic phase)	Chromic Luvisols (stony phase)
Rx_C	Lithosols	Rendzinas (lithic phase)

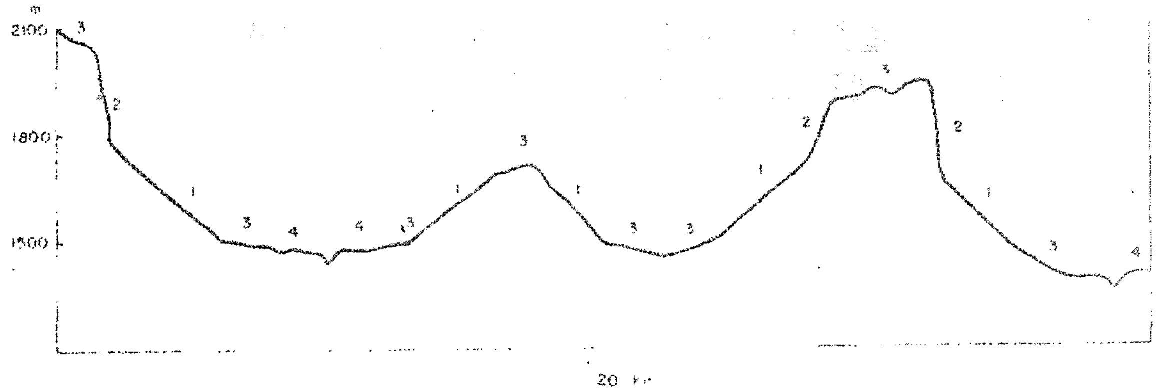
Ry - Undulating high plateaux with a substantial proportion of hills interspersed throughout



NUMBER	1	2
FACET	undulating	moderate relief hills
AREA (%)	60	40
SLOPE (%)	2-8	16-30
SOIL		
Ry_v^1	Dystric Nitosols	Dystric Nitosols
Ry_v^2	Eutric Cambisols (stony phase)	Eutric Regosols (lithic phase)
Ry_v^3	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)
Ry_v^{4+}	Eutric Cambisols (stony phase)	Lithosols
Ry_v^5	Eutric Nitosols	Chromic Luvisols
$Ry_{v/s}$	Vertic Luvisols	Chromic Luvisols
Ry_g	Eutric Cambisols (stony phase)	Lithosols
Ry_m	Chromic Luvisols	Eutric Cambisols (lithic phase)

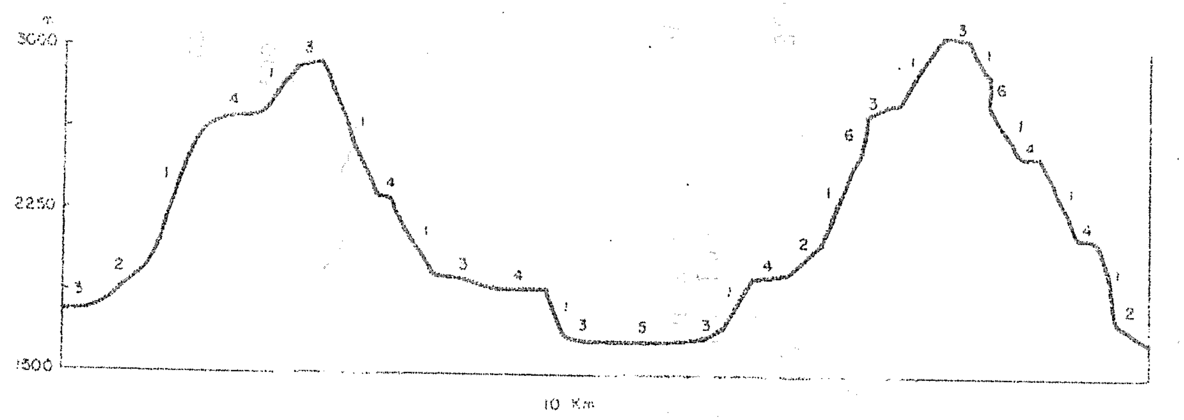
+ In Ry_v^4 volcanic plugs instead of moderate relief hills

S_g - Structural river gorges



NUMBER	1	2	3	4
FACET	steep sideslopes	very steep sideslopes and fault scarps	moderate sideslopes	gorge's bottom
AREA (%)	50	20	20	10
SLOPE (%)	16-30	30-50+	8-16	2-8
SOIL				
Sg_c	Lithosols	Lithosols	Eutric Cambisols (lithic phase)	Eutric Fluvisols
Sg_m	Eutric Cambisols (lithic phase)	Lithosols	Eutric Cambisols (lithic phase)	Eutric Fluvisols

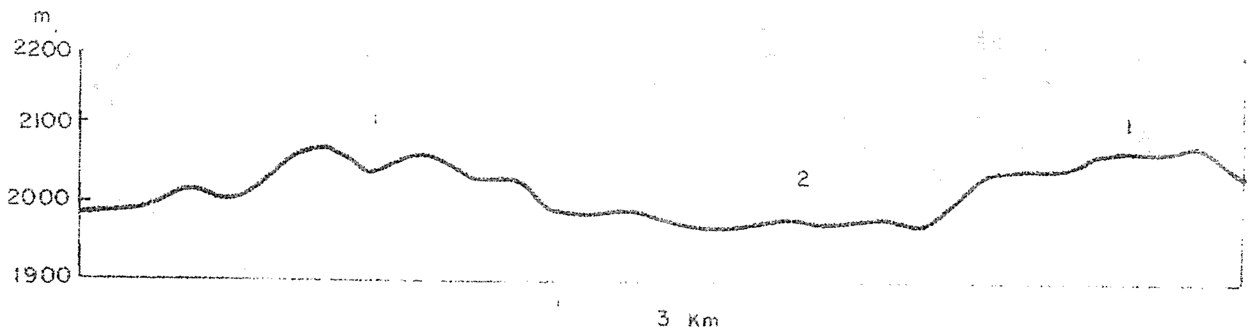
Sh - High to mountainous relief parallel ridge and valley topography associated with extensive fault sets



NUMBER	1	2	3	4	5	6
FACET	very steep sideslopes of parallel ridges	steep sideslopes	moderate sideslopes	plateau terraces and gentle sideslopes	intermontane valleys	escarpments
AREA (%)	50	10	10	10	10	10
SLOPE (%)	30-50+	16-30	8-16	2-8	0-8	50+
SOIL						
Sh_v^1	Chromic Cambisols (lithic phase)	Chromic Luvisols	Chromic Luvisols	Eutric Nitosols	Chromic Vertisols	Rock surface
Sh_v^{2+}	Lithosols	Lithosols	Eutric Cambisols	-	-	Rock surface
Sh_v^3	Dystric Cambisols (lithic phase)	Dystric Cambisols (lithic phase)	Orthic Acrisols (stony phase)	Dystric Nitosols (stony phase)	Dystric Nitosols	Rock surface
Sh_v^4	Lithosols	Eutric Regosols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Rock surface
Sh_g^1	Dystric Cambisols (lithic phase)	Orthic Acrisols (stony phase)	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols	Rock surface
Sh_g^2	Chromic Cambisols (lithic phase)	Chromic Luvisols (stony phase)	Chromic Luvisols	Eutric Nitosols	Vertic Luvisols	Rock surface
Sh_g^3	Rock surface	Lithosols	Lithosols	Eutric Regosols (lithic phase)	Haplic Xerosols (stony phase)	Rock surface
$Sh_{c/g}$	Lithosols	Eutric Cambisols (lithic phase)	Haplic Phaeozems (stony phase)	Haplic Phaeozems	Chromic Vertisols	Rock surface
Sh_m	Lithosols	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Eutric Fluvisols	Rock surface
$Sh_{m/g}$	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Haplic Xerosols (stony phase)	Rock surface

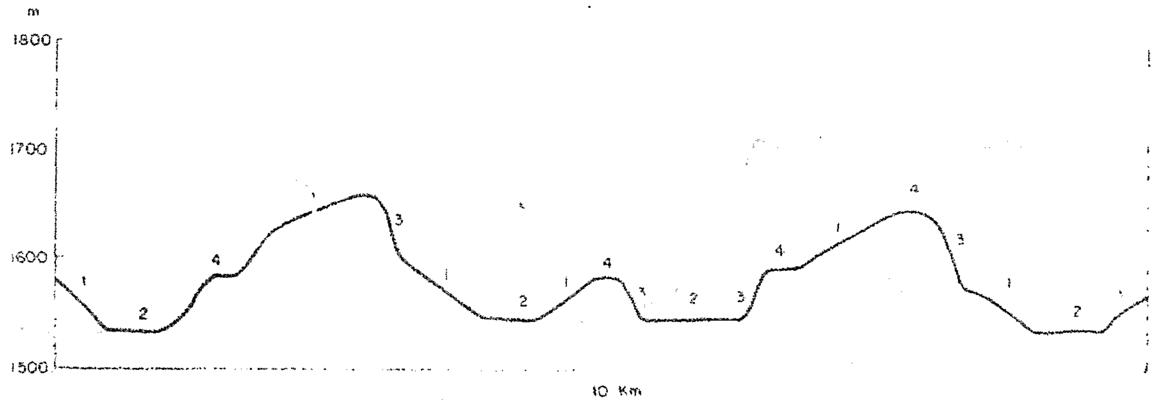
+ Steep sideslopes and moderate sideslopes make up each 20 percent in Sh_v^2; plateau terraces and gentle sideslopes and intermontane valleys are absent

Sk - Hill and valley landforms of low to moderate relief resulting from fold structures



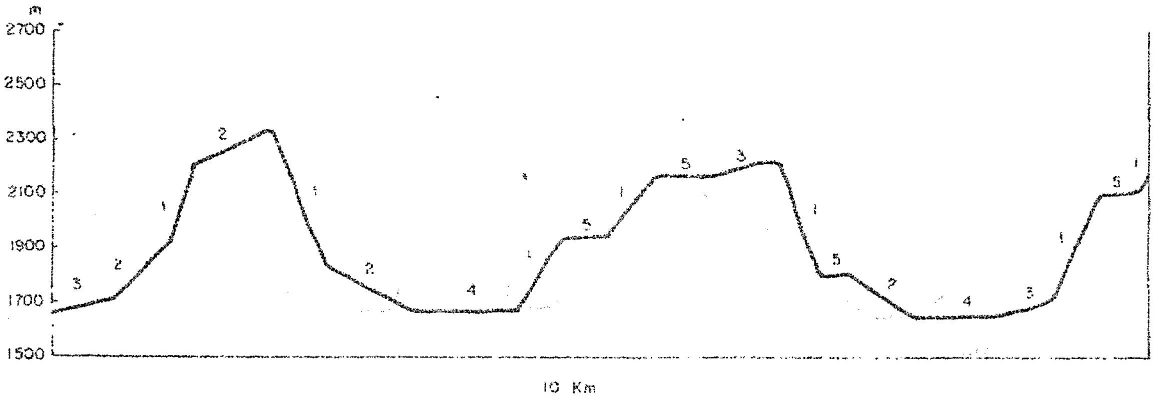
NUMBER	1	2
FACET	low parallel rolling hills	broad undulating valleys
AREA (%)	60	40
SLOPE (%)	8-16	0-8
SOIL		
Sk_c	Eutric Cambisols	Vertic Cambisols

Sl - Low to moderate relief parallel ridge and valley topography associated with extensive fault sets.



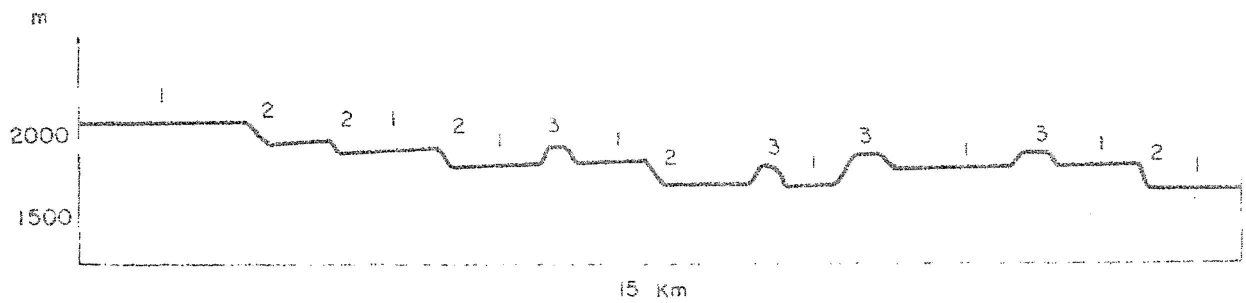
NUMBER	1	2	3	4
FACET	sideslopes	small parallel valleys	steep sideslopes	plateau terraces and gentle sideslopes
AREA (%)	60	20	10	10
SLOPE (%)	8-16	0-8	16-30	2-8
SOIL				
Sl_v	Eutric Regosols (lithic phase)	Eutric Cambisols (stony phase)	Lithosols	Eutric Cambisols (stony phase)
Sl_g^1	Dystric Nitosols	Dysteic Nitosols	Orthic Acrisols	Dystric Nitosols
Sl_g^2	Lithosols	Orthic Solonchaks	Lithosols	Orthic Solonchaks
Sl_g^3	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Lithosols	Eutric Cambisols (stony phase)
Sl_c	Rendzinas (lithic phase)	Eutric Cambisols (stony phase)	Rendzinas (lithic phase)	Eutric Cambisols
Sl_m^1	Eutric Nitosols	Chromic Vertisols	Chromic Luvisols	Eutric Nitosols
Sl_m^2	Eutric Cambisols (lithic phase)	Eutric Cambisols	Eutric Cambisols (lithic phase)	Orthic Luvisols

Sm - Moderate to high relief parallel ridge and valley topography associated with extensive fault sets



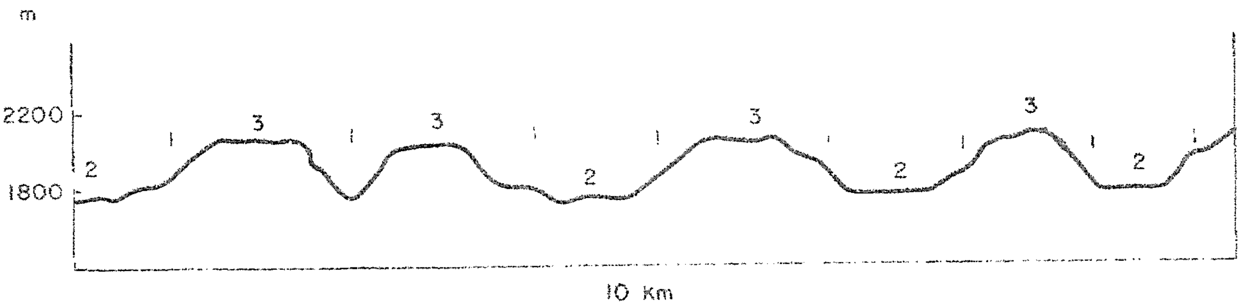
NUMBER	1	2	3	4	5
FACET	very steep sideslopes	steep sideslopes	moderate sideslopes	small parallel valleys	plateau terraces & gentle sideslopes
AREA (%)	30	20	20	20	10
SLOPE (%)	30-50	16-30	8-16	0-8	2-8
SOIL					
Sm_v^1	Eutric Cambisols (lithic phase)	Orthic Luvisols (stony phase)	Orthic Luvisols (stony phase)	Eutric Nitosols (stony phase)	Eutric Nitosols (stony phase)
Sm_v^2	Lithosols	Eutric Regosols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)
Sm_v^3	Lithosols	Lithosols	Lithosols	Orthic Sonlonchaks (stony phase)	Eutric Regosols (lithic phase)
Sm_g^1	Orthic Acrisols (stony phase)	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Sm_g^2	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols	Vertic Cambisols	Eutric Cambisols
Sm_g^3	Lithosols	Lithosols	Eutric Cambisols (lithic phase)	Eutric Fluvisols (stony phase)	Eutric Cambisols (lithic phase)
Sm_c	Lithosols	Lithosols	Lithosols	Calcaric Fluvisols (stony phase)	Calcic Xerosols (lithic phase)
Sm_m^1	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Gambisols	Orthic Luvisols
Sm_m^2	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Haplic Xerosols (stony phase)
$Sm_{v/g}^1$	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols	Orthic Luvisols
$Sm_{v/g}^2$	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Haplic Xerosols (stony phase)

Sp - Step faulted plateaux of the Ethiopian rift margin



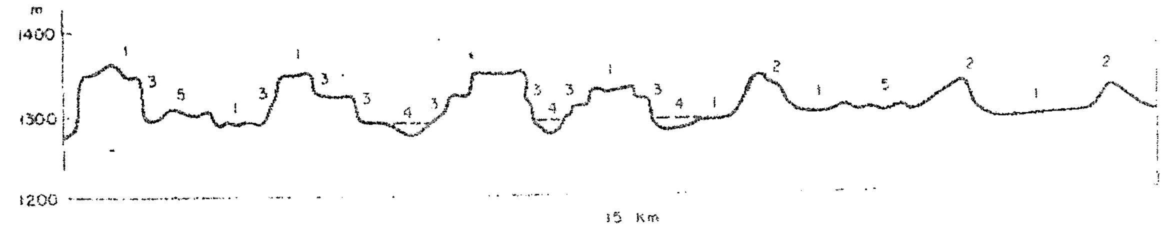
NUMBER	1	2	3
FACET	plateaux	fault scarps	horst crests
AREA (%)	70/50	20/30	10/20
SLOPE (%)	2-8	50+	2-8
SOIL			
Sp_v^1	Vertic Cambisols	Rock surface	Eutric Cambisols (stony phase)
Sp_v^2	Vertic Cambisols (stony phase)	Rock Surface	Eutric Cambisols (stony phase)

Sq - Linear ridges with wide intervening parallel valleys



NUMBER	1	2	3
FACET	ridge sideslopes	broad parallel valleys	crests
AREA (%)	50	30	20
SLOPE (%)	16-30	0-8	8-16
SOIL			
Sq_v	Chromic Luvisols	Pellic Vertisols	Eutric Nitosols

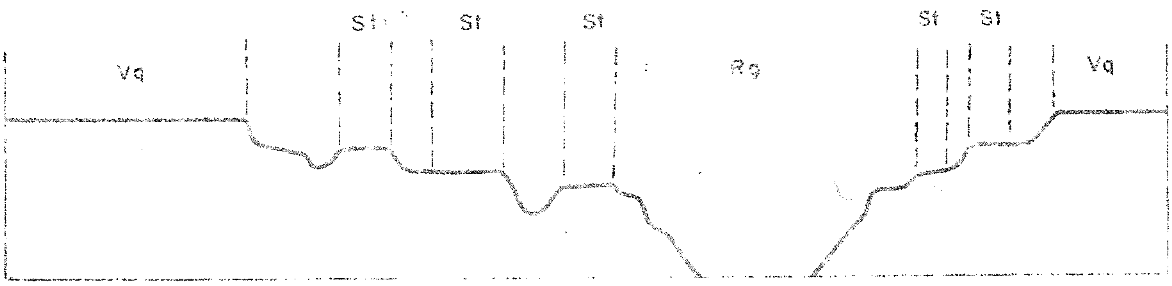
Ss - Step faulted plain and low plateau complexes of the Ethiopian rift with numberous fault scarps, sags and associated vents, craters and other volcanic remnants

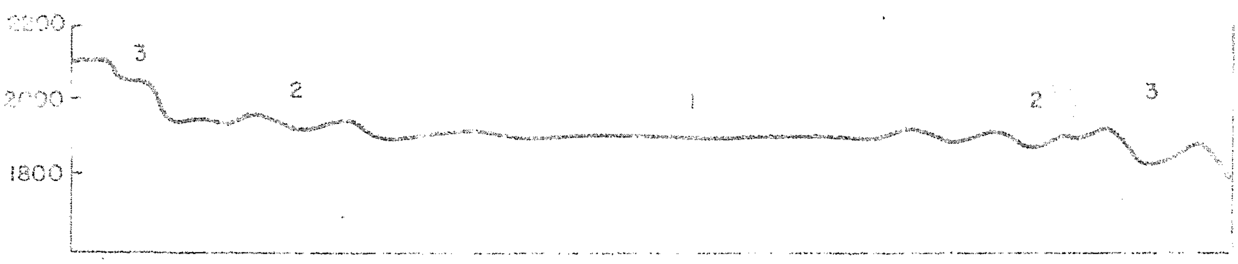


NUMBER	1	2	3	4	5
FACET	undulating plains and caldera floors	caldera rims and volcanic cones and plugs	fault scarps and very steep sideslopes	permanent marsh	rolling plain
AREA(%)	30	30	20	10	10
SLOPE (%)	2-8	16-30	30-50+	0-2	8-16
SOIL					
Ss_V	Mollic Andosols	Eturic Cambisols (lithic phase)	Lithosols	n.a	Mollic Andosols

St - High structural benches, terraces and plateaux within major river gorges

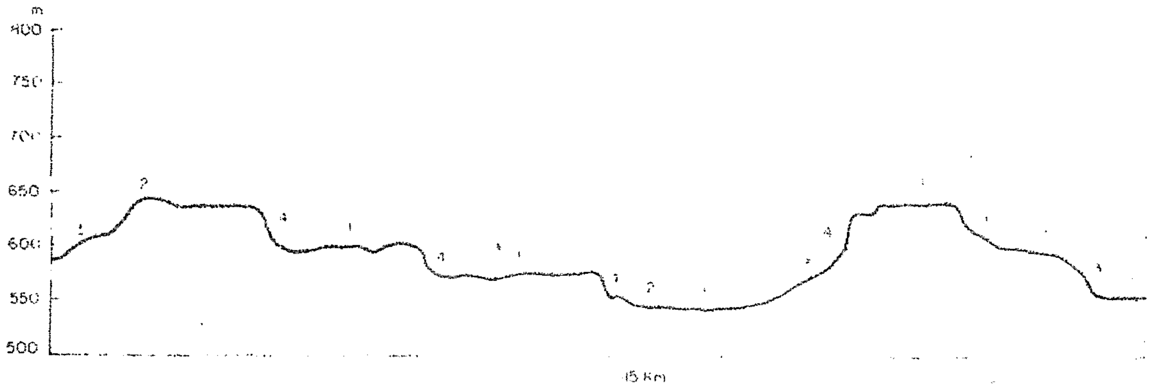
General Section





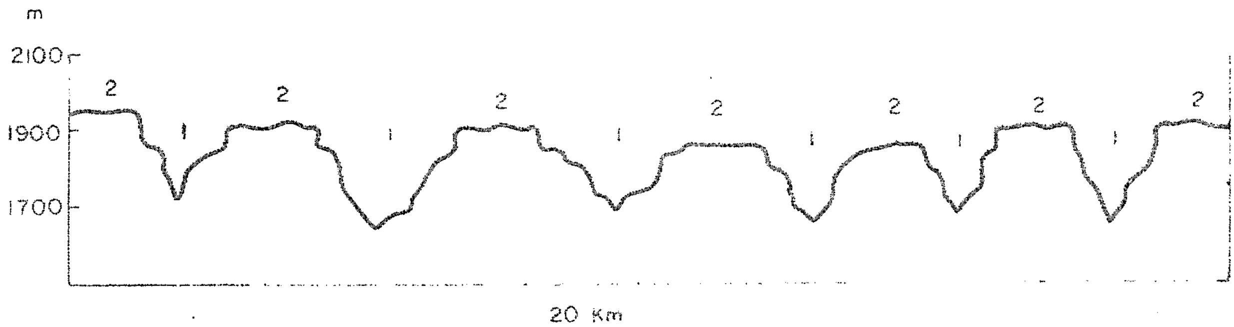
NUMBER	1	2	3
FACET	undulating plateaux	rolling plateaux	hills and steep sideslopes
AREA (%)	50	40	10
SLOPE (%)	2-8	8-16	16-30
SOIL			
St_v	Eutric Nitosols	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)
St_c	Haplic Phaeozems	Haplic Phaeozems (stony phase)	Eutric Cambisols (lithic phase)
St_s	Chromic Luvisols	Chromic Luvisols	Chromic Cambisols (stony phase)

Su - Intensively faulted lava platforms of the Afar lowlands



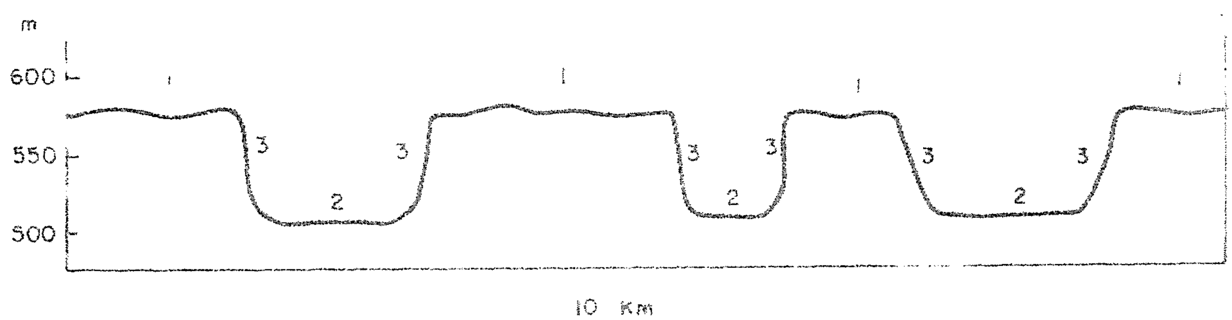
NUMBER	1	2	3	4
FACET	benches and valley bottoms	moderate slopes	steep slopes	very steep slopes and fault scarps
AREA (%)	40	20	20	20
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Su_v^1	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Lithosols Lithosols	Rock outcrop Rock outcrop
Su_v^2	Orthic Solonchaks	Lithosols		

Sx - Severely dissected rift margins and fault



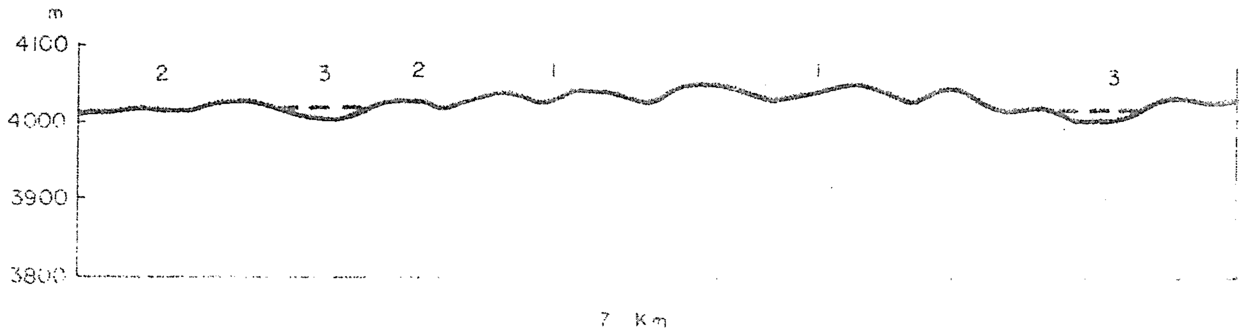
NUMBER	1	2
FACET	steep cut stream channels and escarpments	plateau remnants
AREA (%)	60	40
SLOPE(%)	50+	8-16
SOIL		
Sx_V	Lithosols	Eutric Cambisols

Sy - Intensively faulted lava fields and platforms of the Afar lowlands characterized by long linear fault scarps numberous plateaux horsts and associated grabens filled with alluvium.colluvium and evaporite deposits.



NUMBER	1	2	3
FACET	lava platforms and horst crests	grabens	fault scarps
AREA (%)	60	30	10
SLOPE (%)	2-8	2-8	50+
SOIL			
Sy_v	Lithosols	Orthic Solonchaks (petrogypsic phase)	Rock outcrop

Va[1] - Afro-alpine plateau summits associated with extinct central volcanoes of dramatic mountainous relief



NUMBER	1	2	3
FACET	rolling slopes	undulating slopes	alpine bogs
AREA (%)	50	40	10
SLOPE (%)	8-16	2-8	0-2
SOIL			
Va[1]	Eutric Cambisols	Eutric Cambisols	Dystric Histosols

5.16 YERMOSOLS

5.16.1 FAO classification

Yermosols are soils occuring under an aridic moisture regime; having a very weak ochric A horizon and one or more of the following; a cambic B horizon, an argillic B horizon, a gypsic horizon; lacking other diagnostic characteristics which are diagnostic for Vertisols, lacking high salinity; lacking permafrost within 200 cm of the surface.

Haplic Yermosols are Yermosols having no diagnostic horizons other than a very weak A horizon and a cambic B horizon; lacking takyric features.

Calcic Yermosols are Yermosols having a calcic horizon within 125 cm of the surface (the depth requirement varies with the weighted average of the textural class); lacking an argillic B horizon overlying the calcic horizon; lacking takyric features.

Gypsic Yermosols are Yermosols having a gypsic horizon within 125 cm of the surface (the depth requirement varies with the weighted average of the textural class); lacking an argillic B horizon overlying the gypsic horizon; lacking takyric features.

Luvic Yermosols are Yermosols having an argillic B horizon; a calcic or a gypsic horizon may be present if underlying the B horizon, lacking takyric features.

Takyric Yermosols are Yermosols showing takyric features.

5.16.2 General environment

Yermosols cover approximately 3% of Ethiopia, and are thought to occur almost exclusively on the evaporite landforms of southern Harerge and southern Bale. They occur on the flatter land, giving way to Lithosols as slope angles increase.

Yermosols are essentially a more extreme version of Xerosols and should occur in desert, as opposed to arid and semi-arid environments. The distinction is made between the very weak ochric A horizon of the former and the weak ochric A horizon of the latter, as follows;

A very weak ochric A horizon has a very low content of organic matter with a weighted average percentage of less than 1 percent in the surface 40 cm if the weighted average sand/clay ratio for this depth is 1 or less; or less than 0.5 percent organic matter if the weighted sand/clay ratio is 13 or more; for intermediate sand/clay ratio is 13 or more; for intermediate sand/clay ratios the organic matter content is intermediate. When hard rock, a petrocalcic horizon, a petrogypsic horizon or a duripan occur between 18 and 40 cm, the contents of organic matter mentioned above are respectively less than 1.2 and 0.6 percent in the surface 18 cm of the soil.

A weak ochric A horizon has a content of organic matter which is intermediate between that of the very weak ochric A horizon and that required for the mollic A horizon.

Because accurate laboratory data is required to make this distinction and because such is not available for the arid areas of Ethiopia, the separation between Yermosols and Xerosols on the Geomorphology and Soils Map of Ethiopia is rather arbitrary. With evidence that on the flatter landforms in rainfall regimes of under 200 mm annually organic matter contents of the A horizon can reach 1.5% (see section 5.15.2) Yermosols were assigned to those landforms and geological environments within very low rainfall regimes where vegetation is particularly sparse, this largely due to salinity.

5.16.3 Characteristics

Similar to Xerosols, Yermosols have medium to coarse texture, weak structure, high pH, low organic matter and accumulations of $CaCO_3$ and $CaSO_4$. As Yermosols occur largely on evaporites, they are less chemically variable than the Xerosols of Ethiopia, and are very frequently saline.

5.16.4 Land use and natural vegetation

Yermosols in Ethiopia are almost exclusively under scattered natural vegetation and used for nomadic livestock grazing.

5.16.5 Management

Yermosols suffer the potential limits to agriculture of Xerosols, however these limits tend to occur more frequently and the more extreme. Petrogypsic horizons, shallow depths, salinity, coarse textures and/or very low organic matter contents are almost universal in Yermosols in Ethiopia.

5.16.6 Occurence

Of the five types of Yermosols defined above, it is not impossible that all occur in Ethiopia. However, Gypsic Yermosols, very frequently with saline, lithic and petrogypsic phases, are the most common.

5.16.7 Profile descriptions

5.16.7.1 Gypsic Yermosol (saline phase), lower Wabi Shebele

This soil occurs in association with the Lithosol described in section 5.3 . 5.1 and in association with the Solonchaks of the alluvial and colluvial slopes and of the undulating land on largely evaporite deposits in the southern Ogaden.

This soil is intermediate between the two, neither as shallow as the Lithosols of the steeper slopes nor as saline as the Solonchaks of the flattest land.

Not only low rainfall, but also surface salinity which reduces vegetative cover to a minimum is responsible for the very weak ochric A horizon.

Source: WABI SHEBELE

Lithic Soils with diffuse calcium sulphate on shallow slab derived from the main gypsum formation.

A) General

See section 5.3 . 5.1

B) Profile description

0-20 cm	A1	Yellowish white (5 Y 8/3); loam; single grained structure; very powdery and friable; some rootlets; short and uniform transition to:
20-50 cm	A1R	Yellowish white (5 Y 8/3); loam coating gypsum elements; not very hard, tending to powdery; very few rootlets; sudden transition to:
50+ cm	R	Gypsum slab in situ.

The upper horizon therefore consists of a regular gypsum powder resting on the gypsum slab. Disaggregation and exfoliation in situ of the gypsum slab may be observed and this is manifest in horizon A1R in the profile described. Part of this gypsum is solubilized by rain water and accumulated in water spreading zones on colluvial or alluvial deposits located in a lower position and it provides soils with crusts, but on the hills, there is no neocrystalization of gypsum. These soils are classed among soils with powdery lime since they contain from 10 to 20 percent carbonate.

C) Physical and chemical characteristics

See section 5.3.5.1

D) Cultural and pastoral fitness

See section 5.3.5.1

5.17 NITOSOLS

5.17.1 FAO classification

Nitosols are soils having an argillic B horizon with a clay distribution where the percentage of clay does not decrease from its maximum amount by as much as 20 percent within 150 cm of the surface; lacking a mollic A horizon; lacking an albic E horizon; lacking the tonguing which is diagnostic for the Podzoluvisols; lacking ferric and vertic properties; lacking plinthite within 125 cm of the surface; lacking an aridic moisture regime.

Eutric Nitosols are Nitosols having a base saturation of 50 percent or more (by NH_4OAc) throughout the argillic B horizon within 125 cm of the surface.

Dystric Nitosols are Nitosols having a base saturation of less than 50 percent (by NH_4OAc) in at least a part of the argillic B horizon within 125 cm of the surface; lacking a high organic matter content in the B horizon and lacking an umbric A horizon.

Humic Nitosols are Nitosols having a base saturation of less than 50 percent (by NH_4OAc) in at least a part of the argillic B horizon within 125 cm of the surface; having an umbric A horizon or a high organic matter content in the B horizon, or both.

5.17.2 General environment

Nitosols are found in Ethiopia in the highlands and in the western lowlands. They develop on a wide range of parent materials: volcanics, metamorphics, granites and felsic materials, sandstones and limestones.

Nitosols occur on the gently sloping to steep land, the flat land being mostly with Vertisols or Gleysols, the steeper slopes having more shallow soils - Acrisols/Luvisols and Cambisols. Nitosols make up 12 percent of the soils of Ethiopia.

5.17.3 Characteristics

Nitosols are clayey, reddish brown to red soils with an argillic B horizon, without abrupt textural changes. The soils are deep, have a stable angular to subangular blocky structure, shiny ped surfaces and are very porous. They have a high moisture storage capacity and a deep rooting volume. The clay is mainly kaolinitic, but there are still some weatherable minerals in the soil.

Dystric and Humic Nitosols have a low base saturation, the latter having a high organic matter content in the A and/or B horizon. Eutric Nitosols have a high base saturation.

5.17.4 Land use and natural vegetation

In areas with a moderate to high population density, Nitosols are intensely cultivated for annual as well as for perennial crops. Around Jima and in the Chercher highlands these soils are used for coffee growing.

In the west of Ethiopia, with a low population density, these soils are mainly under natural vegetation. This can be forest, tree savanna or open savanna, depending on the amount of precipitation and human influence.

5.17.5 Management

Nitosols have very good potential for agriculture. Physically they are porous, well drained, have a stable structure and a high water storage capacity. Workability does not create problems: even shortly after precipitation or in the dry season land can be prepared without great difficulty.

Chemically these soils have a rather low CEC for their clay content and available phosphorus are very low.

Dystric and Humic Nitosols are excellent coffee growing soils, although fertilizers have to be applied.

5.17.6 Occurence

All the above mentioned Nitosols occur in Ethiopia. Eutric Nitosols mainly occur in the central and eastern highlands; Dystric and Humic Nitosols occur in areas with high precipitation, the latter mainly under natural vegetation in the lowlands and in the highlands.

5.17.7 Profile descriptions

5.17.7.1 Humic Nitosol, Bako

These soils having a relatively light textured topsoil almost classify as Humic Acrisols. Due to this rather light texture, these soils are very erodable; also land preparation can cause compaction of the topsoil.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no:	PI, Bako
Classification:	Humic Nitosol
Authors:	Mesele, Shawel
Location:	3 km NW of Anno
Elevation:	1880 m
Physiographic position:	Plateau

110-190 cm Reddish brown (2.5 YR 4/5 moist); clay; weak medium sub-angular blocky; friable moist, non-plastic, non-sticky wet; many micro, many very fine, common fine pores; few fine grass roots.

B) Laboratory data

	Depth (cm)			
	0-20	20-40	40-110	110-150
Texture (%, mm)				
2-0.2	35	4	4	1
0.2-0.05	11	5	10	1
0.0.5-0.002	15	30	15	11
0.002	39	60	71	87
pH H_2O	4.6	4.6	4.3	4.8
KCl	4.0	3.9	4.1	4.2
$CaCO_3$ (%)				
Exchangeable cations (meg/100g)				
Na	1.7	2.6	0.9	1.7
K	0.5	0.5	0.5	0.5
Mg	11	8	6	6
Ca	2	2	4	1
Al+H	21.5	22.8	21.1	14.8
Mn	0.03	0.03	0.19	0.14
Sum	15.2	13.1	11.4	9.2
CEC (me/100 g)	52.4	51.0	36.2	47.0
Base saturation (%)	29	26	30	20
Organic C (%)	1.7	1.9	1.2	0.9
Total N (%)	0.15	0.18	0.15	0.08
C/N	8	10	8	11
Available P_2O_5 (ppm)	10	4	4	2
Available K (ppm)	1000	1000	1000	1500

5.17.7.2 Eutric Nitosol, Harar

These soils are developed on the slopes and colluvial slopes of the hilly landscape around Harer. The convex valleys are mostly in Vertic Luvisols (5.19.7.3) and the steep slopes in Chromic Luvisols (5.19.7.4)

Surrounding country:	dissected plateau
Microtopography:	gullies
Slope:	7%, convex, NE exposure
Vegetation:	Acacia; Croton Macrostachys; Erythrina Abyssinica; Ficus
Land use:	intensive cultivation
Climate:	humid temperate

- Information on the soil:

Parent material:	basalt
Run off:	medium
Permeability:	moderate
Internal drainage:	medium
Depth of ground water:	not encountered
Moisture condition:	moist throughout
Stoniness and rock-outcrop:	none

- Profile description:

Deep brown to red soil at the upper horizon and reddish brown at the lower horizons; abundant medium sized roots in the upper horizons.

0-20 cm	Dark reddish brown (5 YR 3/3 moist); clay; weak fine sub-angular blocky; friable moist, slightly sticky, non-plastic wet; many micro, many very fine, few medium pores; many medium sized grass roots; gradual, smooth boundary.
20-40 cm	Dusky red (2.5 YR 3/2 moist); clay; weak medium sub-angular blocky; friable moist, non-plastic, non-sticky wet; many micro, many very fine, few medium pores; many fine and very fine grass roots; clear wavy boundary.
40-110 cm	Dark red (2.5 YR 3/6 moist); clay; weak medium prismatic structure; friable moist, slightly sticky, non-plastic wet; many micro, many very fine, few fine pores; common fine grass roots; clear, wavy boundary.

Surrounding country:	dissected plateau
Microtopography:	gullies
Slope:	7%, convex, NE exposure
Vegetation:	<u>Acacia</u>; <u>Croton Macrostachys</u>; <u>Erythrina Abyssinica</u>; <u>Ficus</u>
Land use:	intensive cultivation
Climate:	humid temperate

- Information on the soil:

Parent material:	basalt
Run off:	medium
Permeability:	moderate
Internal drainage:	medium
Depth of ground water:	not encountered
Moisture condition:	moist throughout
Stoniness and rock-outcrop:	none

- Profile description:

Deep brown to red soil at the upper horizon and reddish brown at the lower horizons; abundant medium sized roots in the upper horizons.

0-20 cm	Dark reddish brown (5 YR 3/3 moist); clay; weak fine sub-angular blocky; friable moist, slightly sticky, non-plastic wet; many micro, many very fine, few medium pores; many medium sized grass roots; gradual, smooth boundary.
20-40 cm	Dusky red (2.5 YR 3/2 moist); clay; weak medium sub-angular blocky; friable moist, non-plastic, non-sticky wet; many micro, many very fine, few medium pores; many fine and very fine grass roots; clear wavy boundary.
40-110 cm	Dark red (2.5 YR 3/6 moist); clay; weak medium prismatic structure; friable moist, slightly sticky, non-plastic wet; many micro, many very fine, few fine pores; common fine grass roots; clear, wavy boundary.

The colluvial deposits are complex and include weathering material derived from limestone hills, some sandstone and granite.

Source: WABI SHEBELE

A) Profile description

Leaving Harar to the North, on a natural section due to weathering the following profile may be observed under a graminea cover:

0-50 cm	Dark reddish-brown (2.5 YR 3/4); clay; very well-developed crumb to granular structure;
50-470 cm	Dark red (10 YR 3/3); clay; small horizontal and vertical cracks delimiting shining prisms; the latter are very friable and provide material with a very well-developed medium angular blocky structure including shining aggregates; friable.
470-800 cm	Reddish-brown weathered sandstone.

This soil is dark reddish brown at the surface and dark red at depth and has a clayey texture. It is very thick with a granular structure in the topsoil turning into a very well-developed medium angular blocky structure at depth. The whole profile is very friable.

In the Alemaya and Adele regions, the upper horizon is brown to dark brown. This is not due to a greater content of organic matter, but to the presence, higher up, of limestone remnants providing brown weathered material overlaying the slopes in the form of colluvial deposits. In the upper part of the hills the weathering of limestone produces Calcaric Phaeozems (5.14.7.4) and Rendzinas (5.13.6.1).

B) Laboratory data

	Depth (cm)		
	0-50	50-470	470+
Texture	C	C	C
$CaCO_3$	0	0	0
Organic matter (%)	2.7	0.3	m
Total N (%)	0.12	m	m
C/N	12	m	m
pH	7.2	6.7	6.5
Exchangeable cations (me/100g)			
Ca	16.6	10.0	m
Mg	9.3	7.6	m
K	0.3	0.2	m
Na	0.1	0.1	m
Sum	26.3	17.9	m
CEC (me/100g)	26.3	17.9	m
Base saturation (%)	100	100	m
Total P_2O_5 (ppm)	500	400	400

The soil is not calcareous. The organic matter content is medium down to 50 cm depth. C/N is low and characterises a soon mineralized humus. The total N/Total P_2O_5 ratio is approximately 2 and reveals a nutrional unbalance detrimental to nitrogen.

C) Cultural fitness

These soils are largely cropped mainly to maize, sorghum and chatt (Catha edulis)which is a "cash-crop". Beans, sweet potatoes and various other vegetables (potatoes, onions, tomatoes) are also produced in large quantities.

The fertility level of these soils is medium as regards phosphorus and potash but is very poor as regards nitrogen.

Consequently, it is necessary to add nitrogen carriers in order to increase in a considerable proportion the yield of chatt plantations and of annual crops.

Besides, since the contents of phosphorus and potash are medium, adding phosphate and potassium carriers seems advisable if the economic conditions of cultivation make it possible.

The most urgent measure to be taken is erosion control. All the Harar region is affected by a very serious headwater erosion resulting in the formation of very deeply eroded gullies, and very often of "lavakas" 3 to 5 m deep quickly going up the hillslopes.

5.18 ACRISOLS

5.18.1 FAO classification

Acrisols are soils having an argillic B horizon with a base saturation of less than 50 percent (by NH_4OAc) at least in the lower part of the B horizon within 125 cm of the surface; lacking a mollic A horizon; lacking an albic E horizon overlying a slowly permeable horizon, the distribution pattern of the clay and the tonguing which are diagnostic for Planosols, Nitosols and Podzoluvisols respectively; lacking an aridic moisture regime.

Orthic Acrisols are Acrisols having an ochric A horizon; lacking ferric properties; lacking a high organic matter content in the B horizon; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Ferric Acrisols are Acrisols having a ochric A horizon; showing ferric properties; lacking a high organic matter content in the B horizon; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Humic Acrisols are Acrisols having an umbric A horizon or a high organic matter content in the B horizon, or both; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Plinthic Acrisols are Acrisols having plinthite within 125 cm of the surface.

Gleyic Acrisols are Acrisols showing hydromorphic properties within 50 cm of the surface; lacking plinthite within 125 cm of the surface.

5.18.2 General environment

Acrisols mainly occur in the high rainfall areas, associated with Dystric Nitosols and Dystric Cambisols. They are found on moderate to steep slopes.

5.18.3 Characteristics

Acrisols have a distinct argillic B horizon and a base saturation of less than 50 percent. They have a reddish brown to red colour and a well developed structure. pH is low. Acrisols are very porous.

5.18.4 Land use and natural vegetation

Acrisols are moderately suited for agriculture. Partly they are cultivated, partly they are left under natural vegetation for grazing purposes.

5.18.5 Management

Acrisols have good physical characteristics. They have a well developed structure and are porous. When they have a light textured topsoil, problems due to cultivation may arise as compaction and erosion increase under intensive use.

Chemically Acrisols are poor soils. CEC is low, base saturation is low, pH is low and available phosphorus contents are very low. Humic Acrisols, mainly occuring in the highlands, have a somewhat better chemical behaviour.

5.18.6 Occurence

Humic Acrisols are dominantly found in the highlands, Orthic Acrisols occur elsewhere. Ferric, Plinthic and Gleyic Acrisols are not reported to occur in Ethiopia.

5.18.7 Profile description

5.18.7.1 Humic Acrisol, Anno

This profile is taken from the western highlands. Although the topsoil is not very light in texture and the area not very sloping, gullies are developing.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.:	P_4
Authors:	Derting and Fikru
Date:	20/5/81
Classification FAO:	Humic Acrisol
USDA:	Udic Rhodustalf
Location:	6 km N of Anno town
Elevation:	1 850 m
Physiographic position:	lower quarter of slope
Land form:	dissected plateau
Microtopography:	summit area of the ridge, strong gully development
Slope:	7-10%, convex, S exposure
Land use:	50-60% cultivated, 40-50% left for grazing under trees
Climate:	humid temperate

- Information on the soil:

Parent material:	basalt
Drainage:	well drained
Depth of groundwater:	not encountered
Moisture condition:	the upper 0-45 cm is moist, 45-105 cm is dry, slightly moist below
Stoniness:	none to slightly stony
Rockiness:	none
Erosion:	slight sheet wash on slope, moderate gully on ridge top

- Profile description:

Uniformly dark reddish brown to dusky red clay profile with well developed fine structures and porous.

0-15 cm	Dusk red (2.5 YR 3/2 moist); clay; strongly developed, very fine, granular aggregates; slightly hard dry, friable moist, sticky non-plastic wet; many micro, many very fine, many fine, common medium pores; clear, smooth boundary.

15-45 cm	Dark reddish brown (2.5 YR 3/4 moist); clay; strongly developed, very fine, angular blocky aggregates; slightly hard dry, friable moist, sticky non-plastic wet; continous, thin ferriargillans; many very fine, many fine, common medium pores; clear, smooth boundary.
45-105 cm	Dark red (2.5 YR 3/6 moist) and dark reddish brown (2.5 YR 3/4 dry); clay; weakly developed, coarse, prismatic primary structures breaking into strongly developed; very fine, angular blocky aggregates; slightly hard dry, friable moist, sticky non-plastic wet; continuous thin, ferriargillans; many micro, many very fine, many fine, common medium pores; gradual smooth boundary;
105-195 cm	Dark reddish brown (2.5 YR 3/4 moist); clay; weakly developed, coarse, prismatic primary structures breaking into strongly developed, fine, angular blocky aggregates; very hard dry; friable moist, sticky non-plastic wet continous, thick ferriargillans; many micro, many very fine, many fine, coarse medium pores;

B) Laboratory data

	Depth (cm)			
	0-15	15-45	45-105	105-195
Texture (%, mm)				
2-0.2	11	4	2	10
0.2-0.05	6	4	1	3
0.05-0.002	15	7	4	13
0.002	67	84	92	73

	Depth (cm)			
	0-15	15-45	45-105	105-195
pH H_2O	4.7	4.5	4.9	4.9
KCl	4.5	4.0	4.3	4.6
Exchangeable cations (me/100g)				
Na	0.9	0.9	0.9	0.9
K	3.6	1.0	0.5	0.3
Ca	16	7	10	8
Mg	14	6	5	6
Sum	34.5	14.9	16.4	15.1
Al + H	19.2	16.0	15.0	15.5
Mn	0.03	0.03	0.03	0.03
CEC (me/100g)	51	45	39	33
Base saturation (%)	68	33	42	45
Organic C (%)	4.0	1.0	1.0	0.6
Total N (%)	0.21	0.11	0.84	0.07
C/N	19	9	12	8
Available P_2O_5 (ppm)	2	m	m	6
Available K (ppm)	1250	1000	100	1250

5.19 LUVISOLS

5.19.1 FAO classification

Luvisols are soils having an argillic horizon which has a base saturation of 50 percent or more (by NH_4OAc) at least in the lower part of the B horizon within 125 cm of the surface; lacking a mollic A horizon; lacking the albic E horizon overlying a slowly permeable horizon, the distribution pattern of the clay and the tonguing which are characteristic for Planosols, Nitosols and Podzoluvisols respectively; lacking an aridic moisture regime.

Orthic Luvisols are Luvisols having an argillic B horizon which is not strong brown to red; lacking an albic E horizon; lacking a calcic horizon, a gypsic horizon and concentrations of soft powdery lime within 125 cm of the surface; lacking ferric and vertic properties; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Chromic Luvisols are Luvisols having a strong brown to red argillic B horizon; lacking vertic and ferric properties; lacking an albic E horizon; lacking a calcic horizon and concentrations of soft powdery lime within 125 cm of the surface; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Calcic Cambisols are Luvisols having a calcic horizon or concentrations of soft powdery lime, or both, within 125 cm of the surface; lacking vertic properties; lacking an albic E horizon; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Vertic Luvisols are Luvisols showing vertic properties; lacking an allic E horizon; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Ferric Luvisols are Luvisols showing ferric properties; lacking vertic properties; lacking an albic E horizon; lacking a calcic horizon and concentrations of soft powdery lime within 125 cm of the surface; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Albic Luvisols are Luvisols having an albic E horizon; lacking plinthite within 125 cm of the surface; lacking hydromorphic properties within 50 cm of the surface.

Plinthic Luvisols are Luvisols having plinthite within 125 cm of the surface.

Gleyic Luvisols are Luvisols having hydromorphic properties within 50 cm of the surface; lacking plinthite within 125 cm of the surface.

5.19.2 General environment

Luvisols occur throughout the country where climatic conditions are favourable for clay movement, without having strong leaching characteristics. These conditions are met in areas with a pronounced wet and a pronounced dry season.

Luvisols do not occur in the arid and desert areas of northern Eritrea, the Afar Triangle and the Ogaden. Nor do they occur in the wet areas of the west and in the areas with higher rainfall in Gonder and Sidamo.

In the central and eastern highlands Luvisols are associated with Eutric Nitosols; the latter occuring on the relatively flat areas, the Luvisols on the steeper slopes. In the drier areas, especially the northern highlands and in the southern lowlands, Luvisols are associated with Cambisols; the Luvisols occuring on the flatter land.

5.19.3 Characteristics

Luvisols are soils having a distinct argillic B horizon and a base saturation of 50 percent or more. Generally these soils have good chemical conditions: base saturation is high and they have weatherable minerals. Physically, these soils vary widely. In soils with a heavy textured B horizon, permeability may be restricted and root development impeded. Vertic Luvisols tend to behave like Vertisols.

In the central and eastern highlands, Luvisols occur on steep slopes and are often stony.

5.19.4 Land use and natural vegetation

Luvisols are almost exclusively intensively cultivated. Only on the very steep slopes in areas with a moderate population, the stony Luvisols are used for peasant livestock grazing, while the flatter land is being cultivated. Also the flat areas, often in depressions, with water logging conditions during the rainy season, are dominantly used for grazing.

5.19.5 Management

Luvisols are among the best agricultural land in the tropics. Limiting factors for agriculture can be stoniness and steep slopes. In the latter case, these soils need terracing to prevent severe erosion. Permeability, drainage and workability can be a problem in the heavy textured Luvisols.

5.19.6 Occurence

Plinthic, Albic and Ferric Luvisols are not reported in Ethiopia. Calcic Luvisols can occur in the semi-arid regions. Orthic Luvisols mostly occur around Lake Tana, they have stony phases. Chromic, Vertic and Gleyic Luvisols occur in the northern-, central - and eastern highlands and in the soutern lowlands, the Vertic and especially the Gleyic Luvisols mainly occuring an flat land.

5.19.7 Profile descriptions

5.19.7.1 Chromic Luvisol, Humera

This profile was taken several kilometers east-northeast of Adabai. It is typical for the somewhat high, isolated convex areas in the Vertisol plain. The soils are developed in granite material.

The annual rainfall ranges from 570 ot 650 mm which nearly all falls from May through September.

Source: HUMERA

Tabeldi series - Deep, dark reddish brown soils with an argillic B horizon.

A) General

Tabeldi soils occur on level to somewhat convex positions (pediments) in residual deposits. They are deep and have a dark reddish brown color. Their B horizon is characterized by clay accumulation. Soils are neutral to slightly acid and non-calcareous. The surface horizon is hard and massive when dry.

B) Profile description

Profile no:	BC4
Soil name:	Tabeldi Series
Classification:	Chromic Luvisol
Location:	8 km. ENE of Adabai, 14° 12'N and 36° 48'E
Elevation:	approximately 600 m

Physiographic position:	level, somewhat convex pediment
Surrounding landform:	plain
Slope:	0-2 percent
Vegetation	tree vegetation: Dalbergia melanoxylon, Sclerocarya birroa and Adansonia digitata
Rainfall:	about 600 mm
Parent material:	granite

Profile description:

0-18 cm A1	Dark red (2.5 YR 3/5) moist and dark reddish brown (2.5 YR 3/4) dry, sandy loam with very few small subrounded granite gravel; massive structure; non-sticky and non-plastic, friable, hard when dry; non-calcareous; few very fine roots, occasional medium roots; clear smooth boundary; pH 7.0.
18-30 cm. A3	Dark red (2.5 YR 3/5) moist and dry, sandy clay loam with very few small granite gravel; massive structure; slightly sticky and non-plastic, friable, very hard; non-calcareous; few very fine roots, occasional medium roots; clear smooth boundary, pH 6.4.
30-45 cm. B2t	Dark reddish brown (2.5 YR 3/4) both moist and dry, sandy clay loam with very few small granite gravel; weak moderate subangular blocky structure with patchy thin clay films mostly on ped faces; slightly sticky and plastic, firm, very hard; non-calcareous; very few fine roots; few termite burrows; gradual smooth boundary; pH 7.3.
45-94 cm. B3	Dark reddish brown (5 YR 3/4) moist and reddish brown (5 YR 4/4) dry, sandy clay loam with frequent small and large granite gravel; massive structure; slightly sticky and plastic, firm, very hard; non-calcareous; occasional fine roots; few termite burrows; clear wavy boundary; pH 7.3.

94-130 cm. C	Somewhat cemented horizon of small and large angular granite gravel, partly weathered.
130-200 cm. R	Strongly weathered granite bedrock.

Moist colors of the A horizon may range from dark reddish brown to dark red. Organic matter content values of the A horizon are below 0.5 percent. Dominant textures of the A horizon are sandy loam and sandy clay loam. Structure is typically massive and hard or very hard when dry.

Characteristic B2 colors are dark reddish brown, the texture may range from sandy clay to sandy clay loam. The C horizon is quite variable both in composition and depth. Soil reaction may range from neutral to slightly acid.

C) Laboratory data

	Depth (cm)			
	0-18	18-30	30-45	45-94
Texture (%, mm)				
2-0.2	14	24	49	13
0.2-0.5	20	21	45	19
0.5-0.02	25	22	42	12
0.02-0.002	28	25	34	13
pH (H_2O,1:5)	7.4	7.4	7.1	7.5
$CaCO_3$	0.02	tr	0.01	0.04
EC (mmhos/cm,sat.ex)	0.1	0.1	0.1	0.3
Exchangeable cations (me/100g)				
Ca	8.2	10.3	12.4	17.2
Mg	3.7	5.1	5.4	7.5
K	0.3	0.1	0.2	0.2
Na	0.1	0.1	0.1	0.1
sum	12.3	15.5	18.1	24.9
CEC (me/100 g)	15.1	17.4	20.7	26.3
Base saturation (%)	81	89	87	95
Soluble cations (me/100 g, 1:5)				
Ca	0.3	0.1	0.2	0.2
Mg	0.2	0.1	0.1	0.1
K	0.0	tr	tr	tr
Na	0.2	0.1	0.2	0.1
sum	0.7	0.2	0.5	0.5

	Depth (cm)			
	0-18	18-30	30-45	45-94
Soluble anions (me/100 g, 1:5)				
CO_3	m	m	m	m
HCO_3	0.4	0.2	0.1	0.2
Cl	0.3	tr	0.3	0.3
SO_4	tr	tr	tr	tr
NO_3	tr	tr	tr	0.1
Org.C (%)	0.4	0.2	0.2	0.1
Total N (%)	0.05	0.03	0.04	0.04
C/N	7	8	5	3
P_2O_5 (ppm)	7	m	m	m
K_2O (ppm)	39	m	m	m

5.19.7.2 Chromic Luvisol (Stony phase), Mekele

This soil is taken from a dolerite intrusion on the Mekele Plateau. The parent material is medium to fine textured, non-calca eous and very low in quart .

Source: TIGRAI

Romanat series - Moderately deep reddish brown sandy clay loam well drained profiles.

A) General

- Environmental Characteristics: The series occurs extensively on the undulating plateau areas formed on dolerite sills as well as on the more level and less eroded-sites on the Adigrat Ridges. The land slope is usually in the range 2 to 7 percent. The present landuse is either cereal cultivation or livestock browsing, depending largely upon the degree of surface stoniness.

- Profile Characteristics: The soil is overlaid by a varied quantity of stones and boulders of dolerite, and limestone in some places. The upper horizon is reddish brown with sandy loam to loamy sand texture and weak angular blocky structure. Below 10 to 15 cm the texture is finer, usually sandy clay loam to clay loam, and colours are dark reddish brown to reddish brown (5 YR 3/3-4/4); rarely the textures are sandy loam. The structure in this horizon is strong medium angular blocky to weakly prismatic. Below 75 cm the profile grades into soft weathered dolerite rock which has a gritty loamy sand to sandy loam texture. Resistant cores of dolerite or basalt are common. Solid rock occurs at below 100 cm. The soils are non-calcareous, and porous, especially in the surface, where the roots are concentrated. Some roots penetrate the weathered subsoil.

- Analytical Characteristics: The soils are slightly acid to slightly alkaline, with very high base saturation. Exchangeable calcium is high to very high, and magnesium medium to very high. Sodium is sometimes medium in the topsoil. Soluble copper and zinc are very low.

- Land Capability Characteristics: Romanat soils usually occur on sites which are topographically suited to cultivation with moderate conservation measures but some sites are too steep for cultivation and should be retained under protective vegetation. The soils are generally moderately deep and the fine textured lower horizon should provide a reasonable rooting medium. The soil surface tends to seal rapidly, probably due to relatively high silt contents, and therefore special cultivation practices will be required to ensure that maximum rainfall enters the profile. In general the soils are suited to dryland arable cultivation (Classes II or III).

- Associated Soils: The Romanat soils occur on the upper plateaux in dolerite areas and also locally on the lower pediment in association soils, which lack the fine textured B horizon and probably represent a truncated version of Romanat Series. On adjacent steep slopes are soils which are very shallow Lithosols over solid dolerites.

B) Profile description

- Information on the site:

Profile no.:	MS/14
Soil name:	Romanat series
Classification:	Chromic Luvisol
Date:	27 March 1975
Author:	K.J. Virgo
Location:	15 km NW Mekele, Tigray Tselwa, Mekele-Hagere Selam Old Road

Elevation:	1900 m
Physiographic position:	dolerite plateau, edge of west facing escarpment
Surrounding landform:	undulating convex plateau
Microtopography:	resistant dolerite corestones (to 2m diameter) on surface; cultivation terrace to 50 cm high
Slope:	2 percent
Landuse:	arable
Vegetation:	cereals, few weeks
Rainfall	650 mm

- Information on the soil:

Parent material:	in situ weathered dolerite
Drainage-profile:	well drained
Drainage-site:	receiving site
Moisture condition:	dry throughout
Flood hazard:	none
Depth of groundwater:	not encountered
Surface condition:	dolerite boulders
Evidence of erosion:	cultivation terraces up to 50 cm high

- Profile description

Well defined reddish brown sandy loam plough layer, moderate subangular blocky structure overlying compact dark reddish brown clay loam subsoil with strong angular block structure and many burrows of subsoil fauna. This overlies gritty sandy clay loam of weathered dolerite and inclusions of dark subsoil down cracks. Below 130 cm is hard in situ weathered dolerite with fresh corestones.

0-15 cm	Reddish brown (5 YR 4/4) heavy sandy loam; moderate medium subangular blocky; dry and slightly hard; many medium and fine tubular pores; many fine roots; abrupt smooth boundary.
15-75 cm	Dark reddish brown (5 YR 3/2) clay loam to clay; strong medium angular blocky; dry hard; few tubular fine pores; few fine roots; traces of faunal burrows (1 cm); clear smooth boundary.