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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 the 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 1 000 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
0 100 200 300 400 Km
GULF OF ADEN
DJIBOUTI
SOMALIA
SUDAN
KENYA
SOMALIA
Abay
Wabi Shebele
Genale
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 Harerge. 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°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°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 autumn merging together.
D Rains in autumn, winter and spring merging together.
Small rains in summer.
E Small rains in spring, big rains in summer merging together.
F Big rains in spring, small rains in autumn
0 100 200 300 400Km.
RED SEA
GULF OF ADEN
DJIBOUTI
SUDAN
SOMALIA
SOMALIA
SOMALIA
UGANDA
KENYA
A
B
C
D
E
F
35°
37°
39°
41°
43°
45°
12°
10°
8°
6°
4°

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 spring or by a prolonged period of moderate rainfall
F	- Two short rainy seasons. Main rains in spring, small in autumn.

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

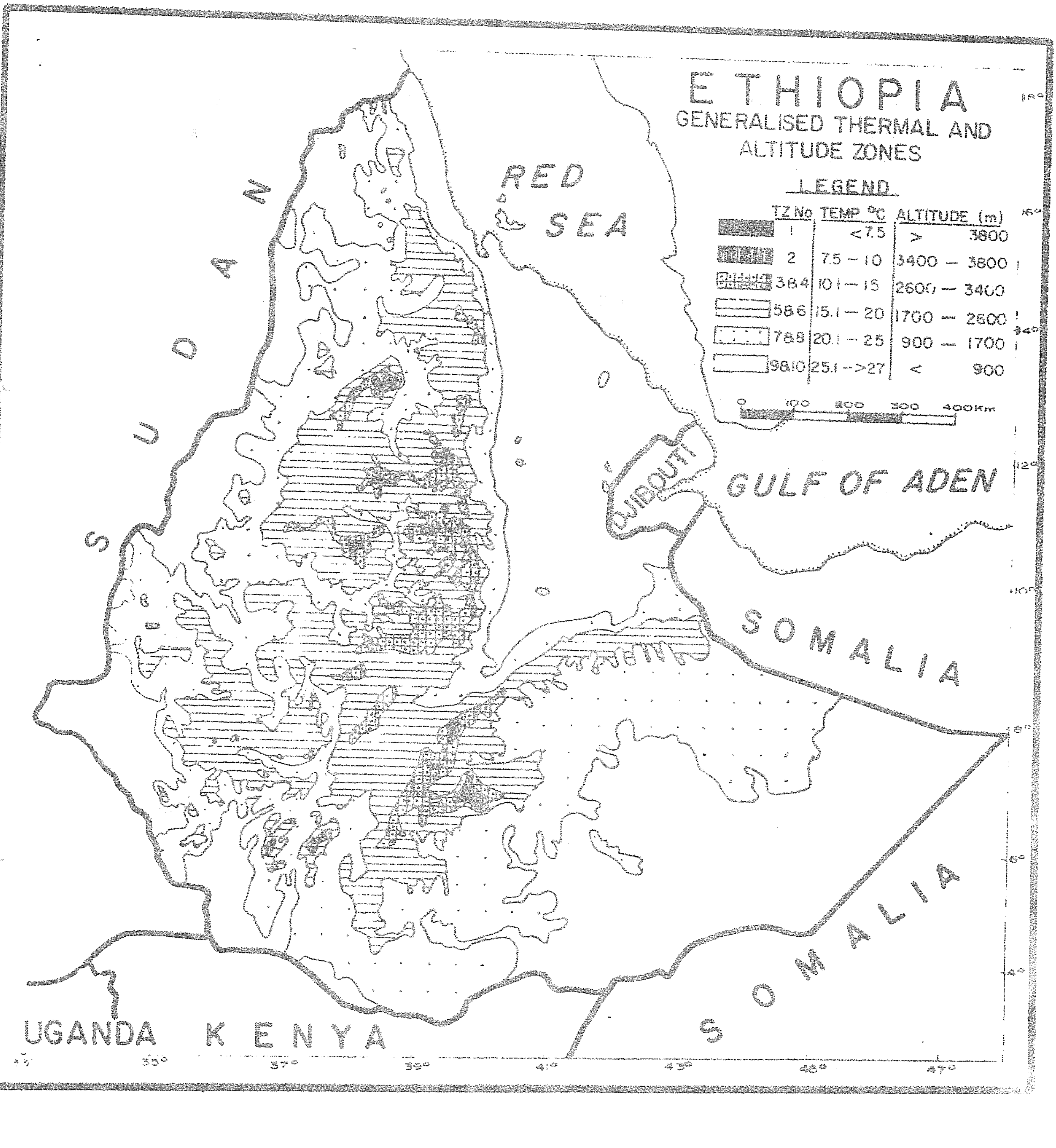

ETHIOPIA
GENERALISED THERMAL AND ALTITUDE ZONES
LEGEND
TZ No | TEMP °C | ALTITUDE (m)
1 | <7.5 | > 3800
2 | 7.5 – 10 | 3400 — 3800
3&4 | 10.1 – 15 | 2600 — 3400
5&6 | 15.1 – 20 | 1700 — 2600
7&8 | 20.1 – 25 | 900 — 1700
9&10 | 25.1 –>27 | < 900
0 100 200 300 400Km
RED SEA
GULF OF ADEN
DJIBOUTI
SUDAN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

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^{0}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.

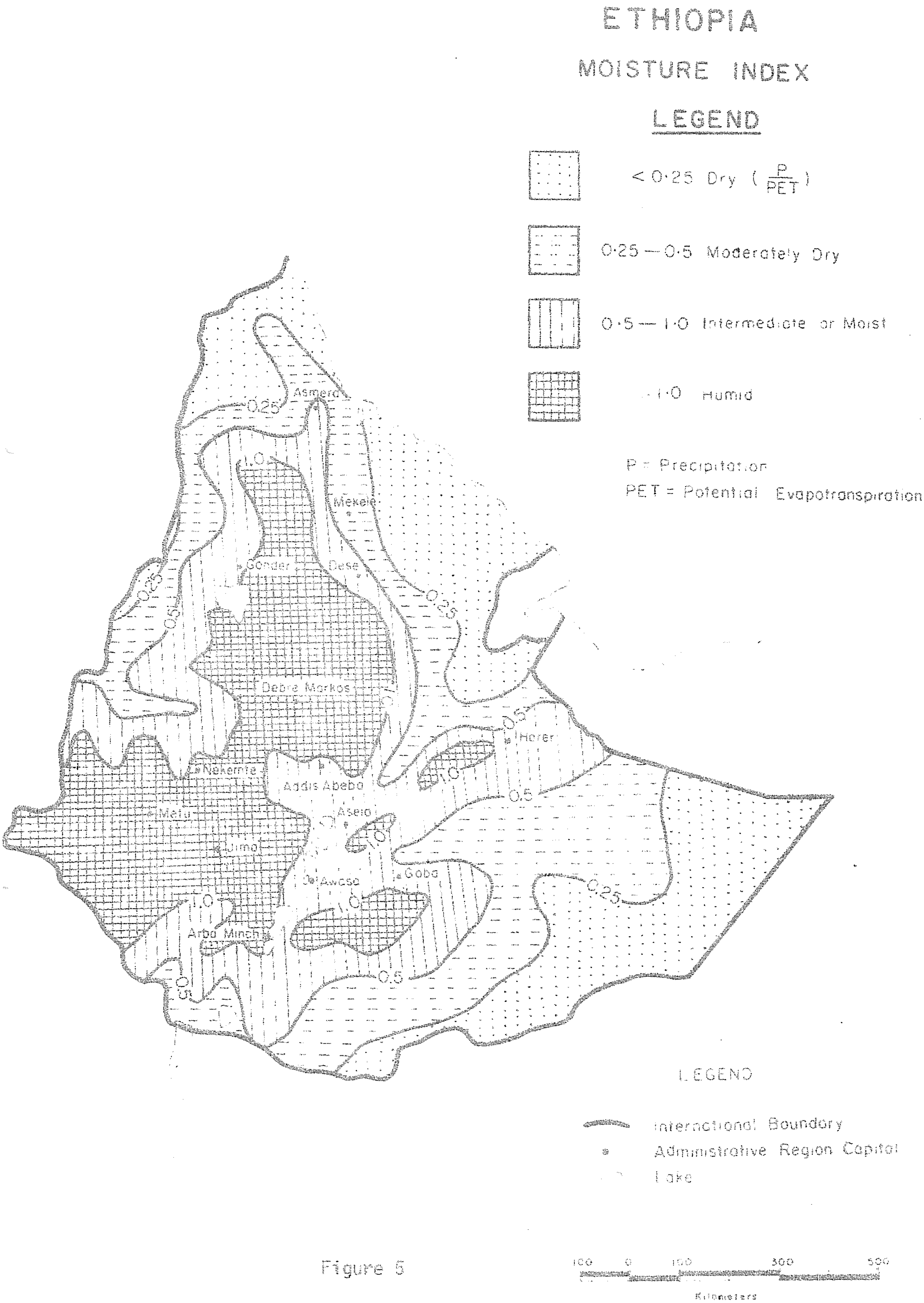

ETHIOPIA
MOISTURE INDEX
LEGEND
< 0·25 Dry (P / PET)
0·25 — 0·5 Moderately Dry
0·5 — 1·0 Intermediate or Moist
1·0 Humid
P = Precipitation
PET = Potential Evapotranspiration
Asmera
Mekele
Gonder
Dese
Debre Markos
Harer
Nekemte
Addis Abeba
Metu
Asela
Jima
Awasa
Goba
Arba Minch
0.25
0.5
1.0
LEGEND
International 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 Re' 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.

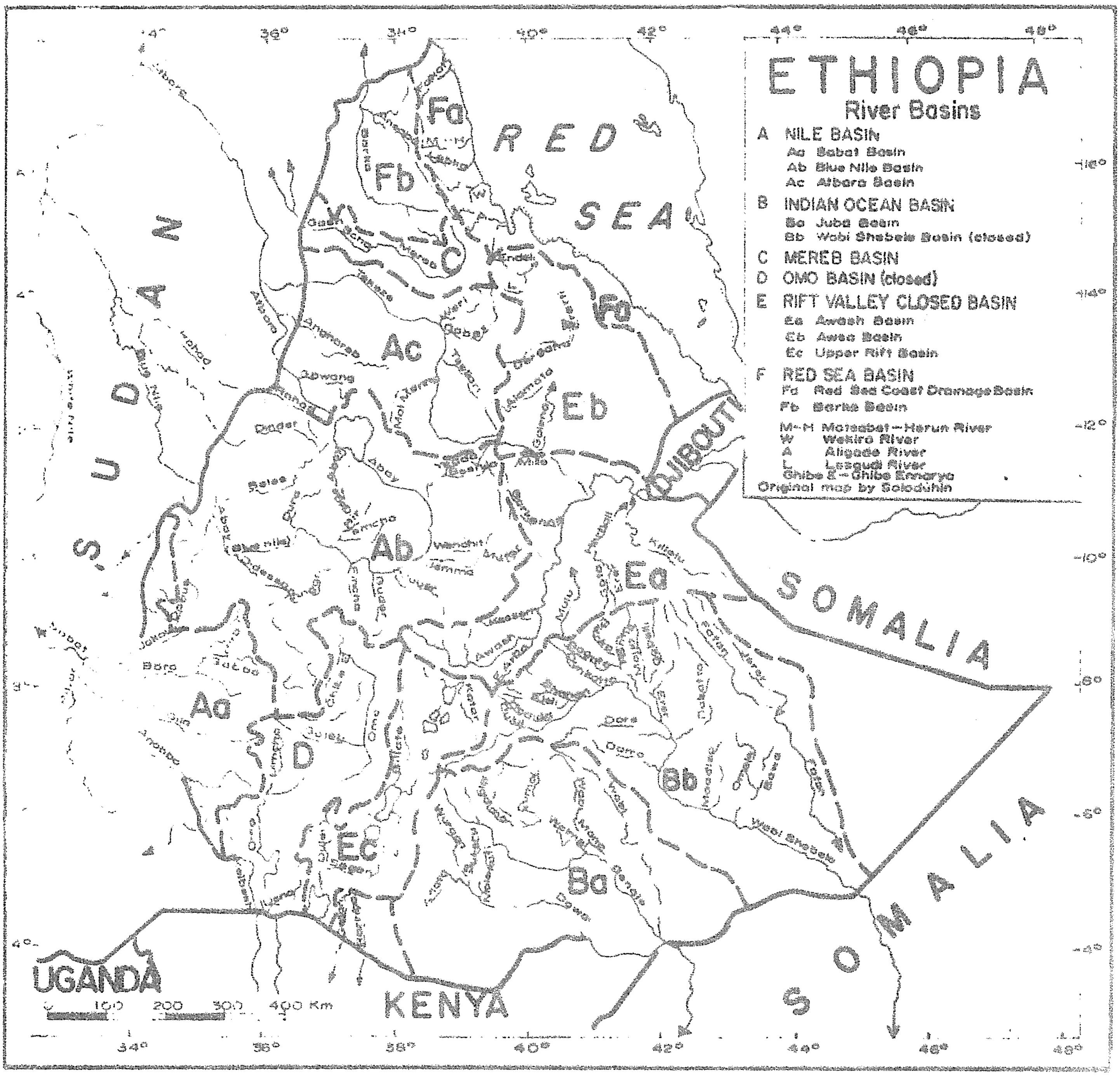


Figure 7 MAIN RIVER BASINS (modified after Gamachu, 1977)

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, southerm 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.

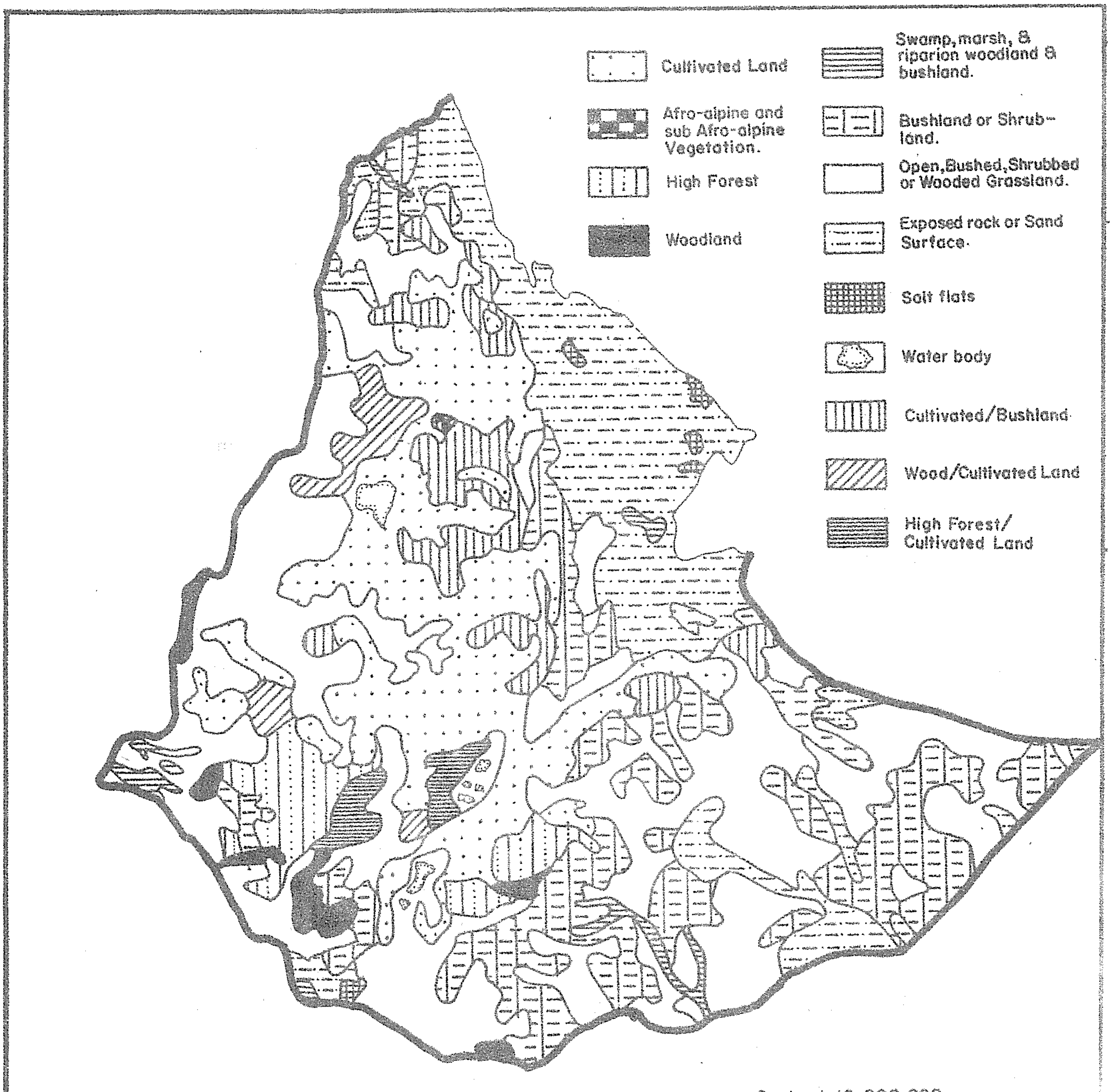


Fig. 8 GENERALIZED LAND USE AND LAND COVER

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 msterials 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 Harerge (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 Harerge 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 Chercher 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.

TABLE 2 AREA PERCENT OF DIFFERENT SOIL TYPES IN ETHIOPIA

FAO Classification	Area %
Acrisols	3
Andosols	1
Arensols	0.5
Cambisols	11.5
Chernozems	< 0.1
Fluvisols	6
Gleysols	0.5
Histosols	< 0.3
Lithosols	16
Luvisols	6
Nitosols	12
Phaeozems	2
Regosols	4
Rendzinas	2
Solonchaks	7
Vertisols	10
Xerosols	8.5
Yermosols	3
Swamp and marsh	0.5
Rock and stone	4.5
Sand	< 0.2

NB. Areas are rounded to nearest 0.5 where possible

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 mapped at 1:100 000. Soil profile descriptions and laboratory data

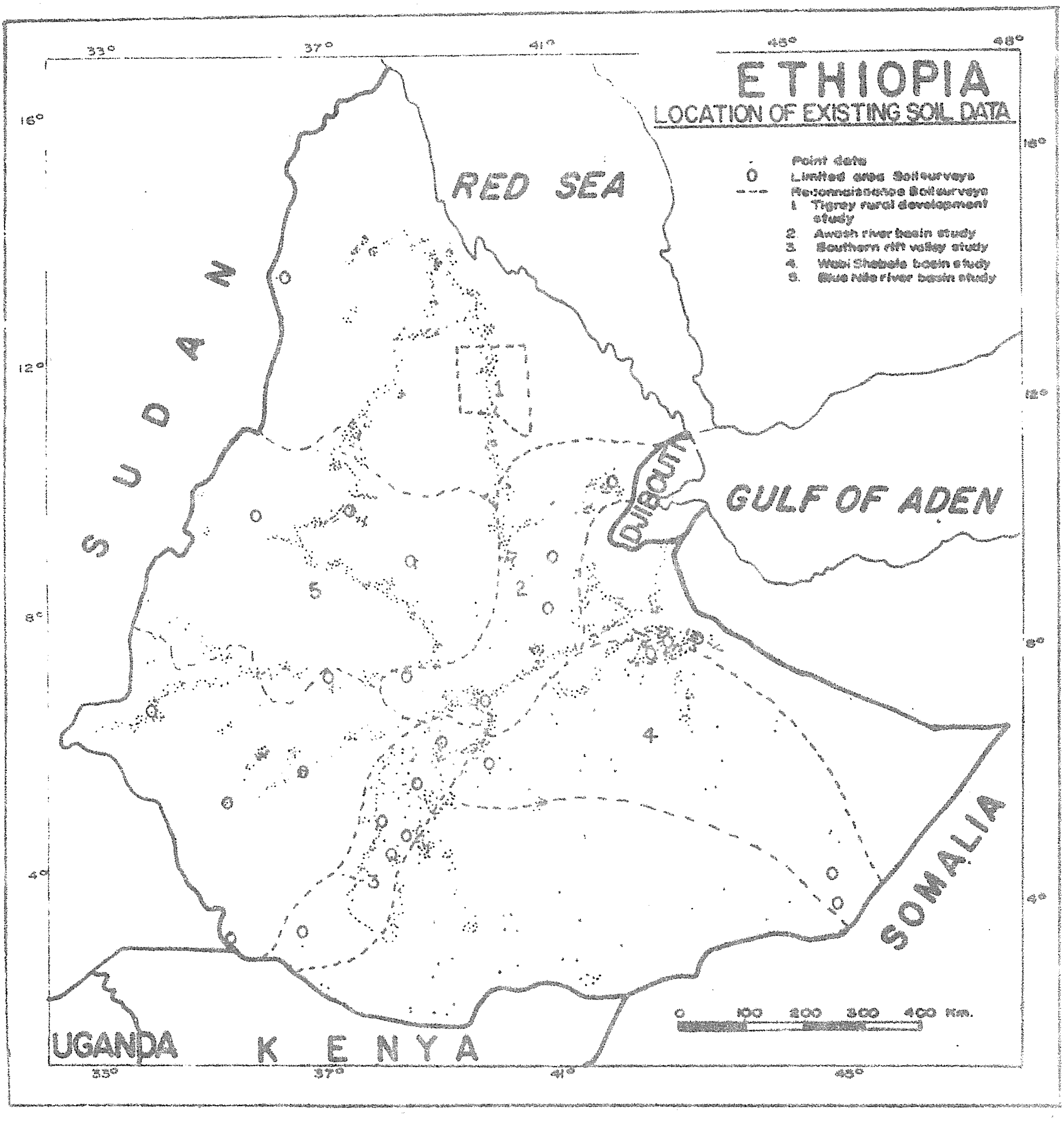

ETHIOPIA
LOCATION OF EXISTING SOIL DATA
Point data
Limited area Soilsurveys
Reconnaissance Soilsurveys
1 Tigrey rural development study
2. Awash river basin study
3. Southern rift valley study
4. Wabi Shebele basin study
5. Blue Nile river basin study
RED SEA
SUDAN
GULF OF ADEN
DJIBOUTI
SOMALIA
UGANDA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

Figure 9

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

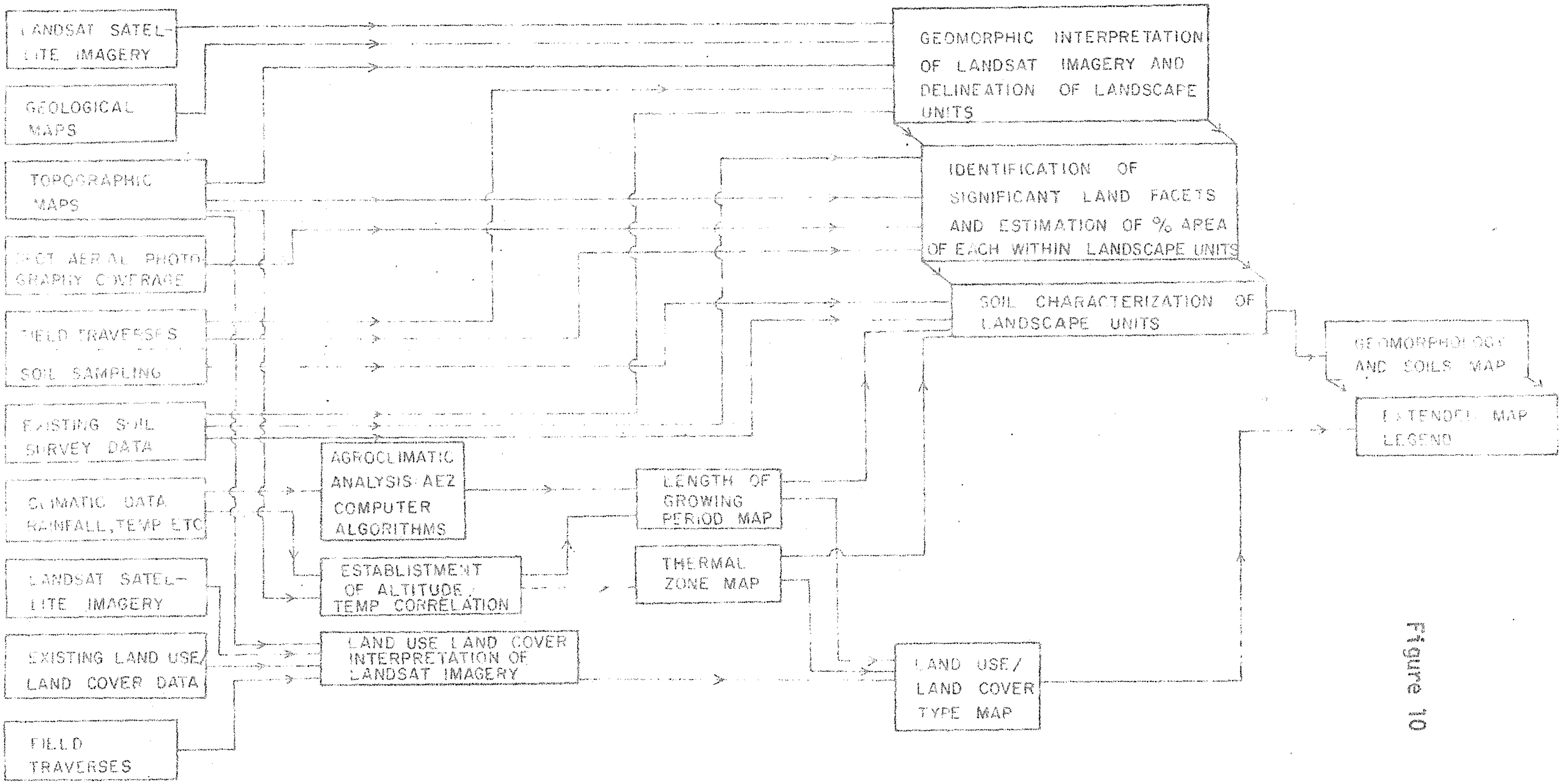


Figure 10

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.

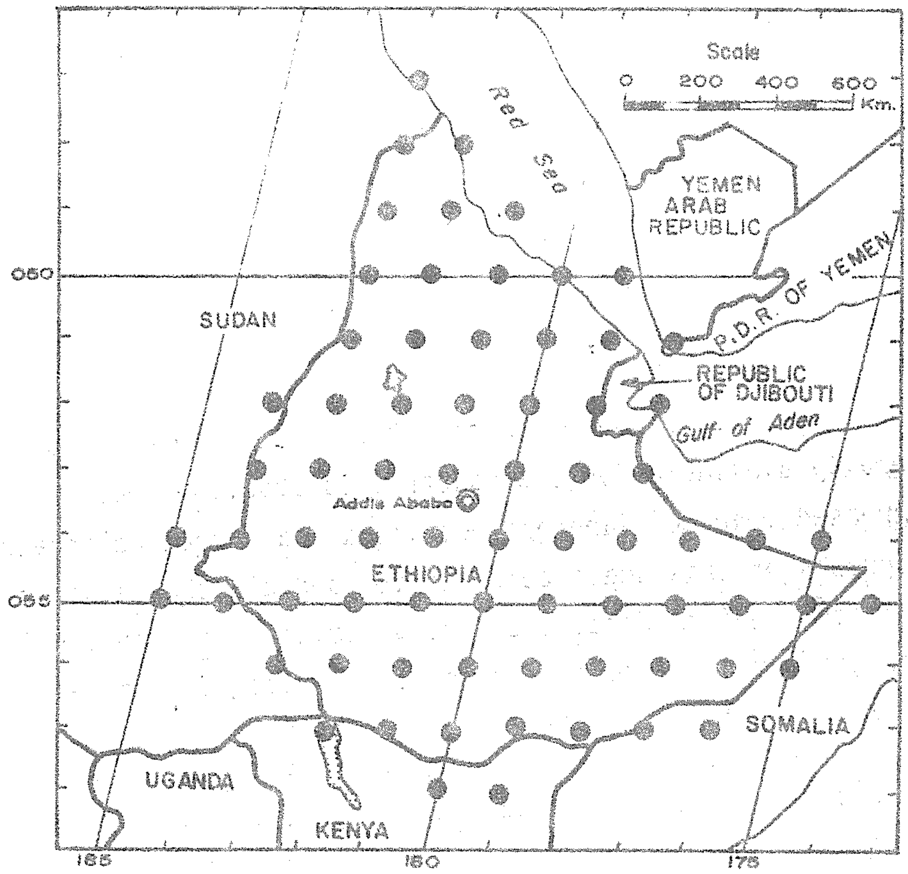


Figure 10

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 dissected 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.

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 parametere 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 pH

5.5
5.5 - 6.7
6.7 - 7.3
7.3 - 8.0
8.0

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

≤16
16 - 35
35 - 70
>70

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

Organic Matter (%)

≤1
1 - 3
3 - 10
>10

Available phosphorous (P) - Olsen (ppm)

≤5
5 - 10
10 - 15
15 - 25
>25

CHAPTER 4

DETAILED GEOMORPHOLOGY AND ASSOCIATED SOILS OF LANDSCAPE UNITS

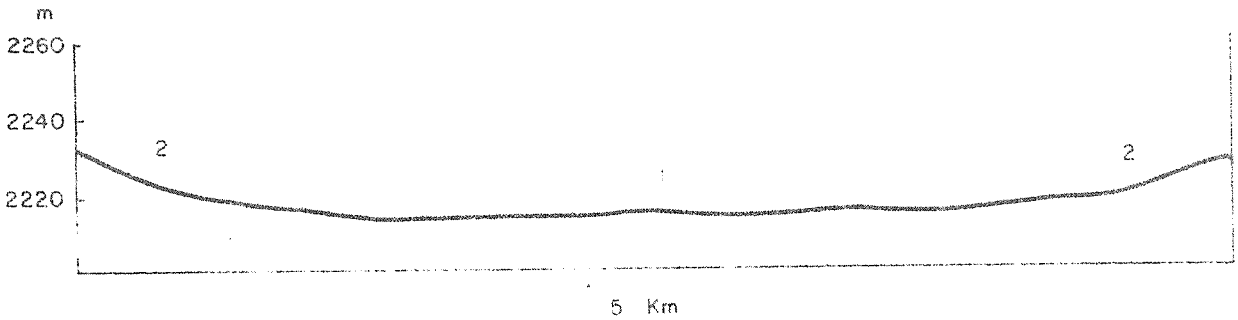
4.1 INTRODUCTION

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.

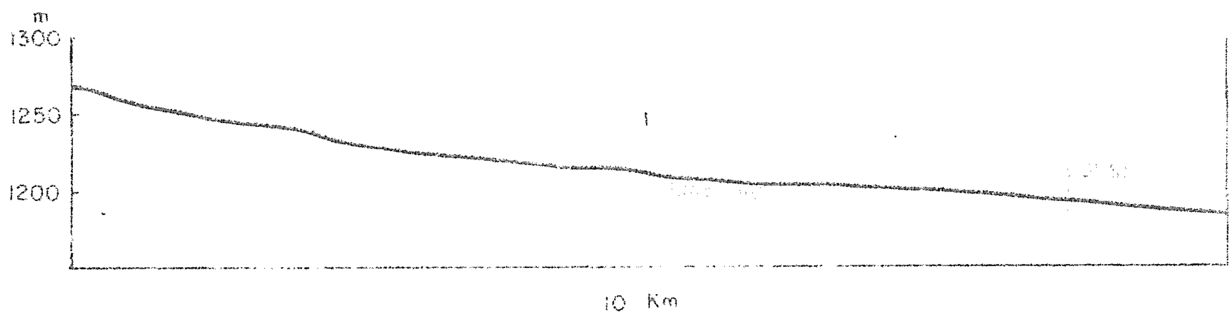
Ab - Basins and depressions with seasonal drainage deficiencies



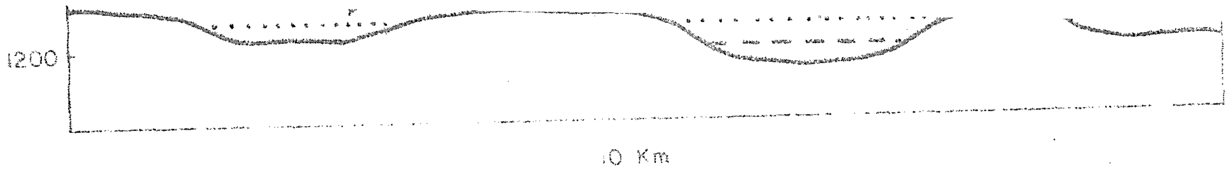
NUMBER	1	2
FACET	basin plains	colluvial margins
AREA (%)	90	10
SLOPE (%)	0-2	2-8
SOIL		
Ab^1	Pellic Vertisols	Eutric Nitosols
Ab^2	Pellic Vertisols	Dystric Nitosols
Ab^3	Haplic Phaeozems	Vertic Cambisols*

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

Ac - Alluvial/colluvial slopes and outwash fans

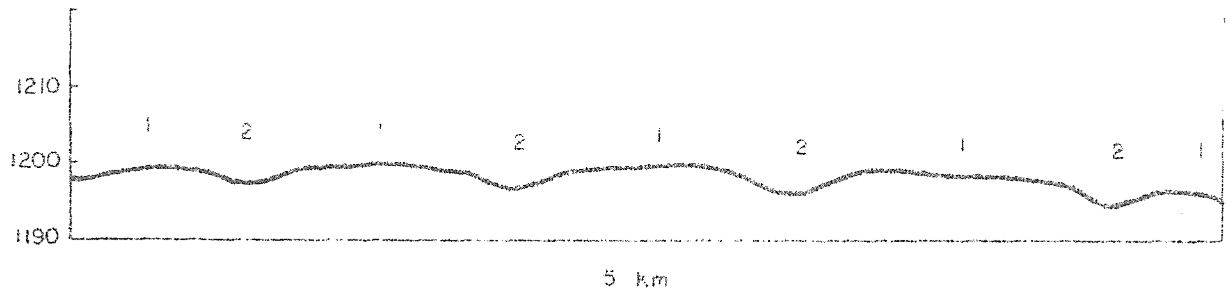


NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	0-8
SOIL	
Ac^1	Chromic Vertisols
Ac^2	Eutric Fluvisols
Ac^3	Eutric Fluvisols
Ac^4	Calcic Xerosols (saline phase)
Ac^5	Orthic Solonchaks (petrogypsic phase)
Ac^6	Orthic Solonchaks
Ac^7	Chromic Vertisols
Ac^8	Eutric Fluvisols (stony phase)
Ac^9	Vertic Cambisols



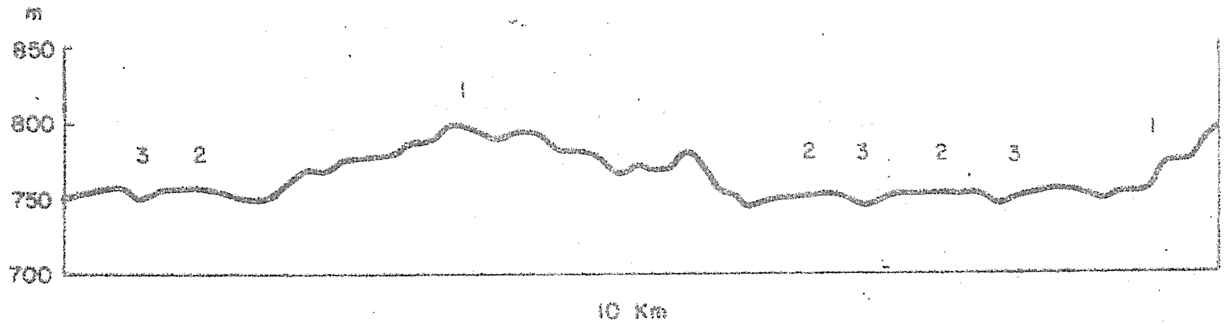
NUMBER	1	2	3
FACET	alluvial plains	seasonal swamps	permanent swamp
AREA (%)	40	40	20
SLOPE (%)	0.2	0.2	0.2
SOIL			
Ad[1]	Chromic Vertisols	Eutric Fluvisols	n.a.
Ad[2]	Eutric Fluvisols (saline phase)	Eutric Fluvisols (saline phase)	n.a. n.a.

Af - Alluvial fans and bajadas



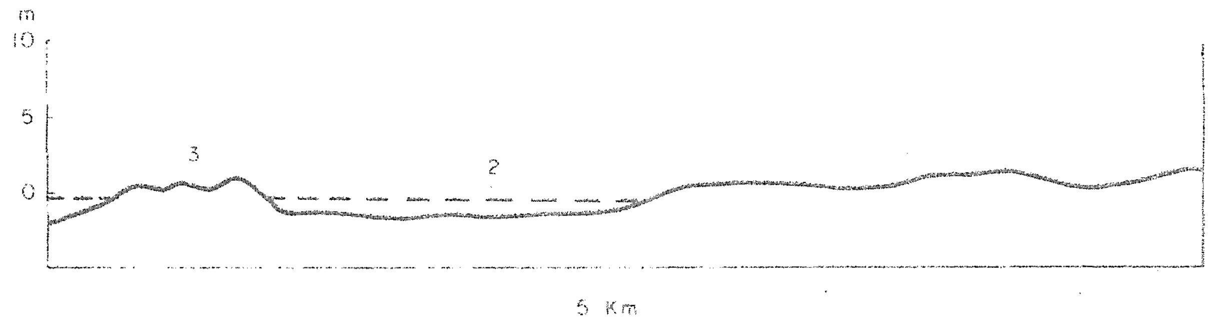
NUMBER	1	2
FACET	convex fan slopes	braided channels
AREA (%)	80	20
SLOPE (%)	2-8	2-6
SOIL		
Af^1	Eutric Fluvisols	rubble land
Af^2	Eutric Fluvisols	rubble land
Af^3	Eutric Fluvisols (saline phase)	rubble land

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



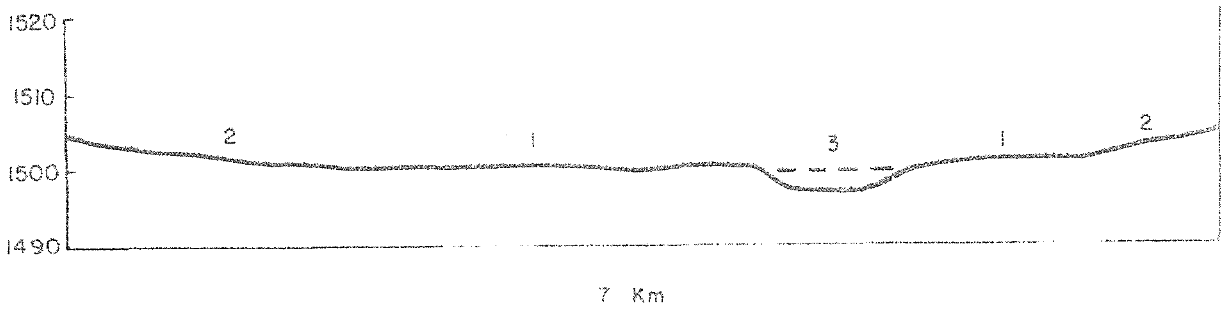
NUMBER	1	2	3
FACET	low relief hills	convex fan slopes	braided channels
AREA (%)	50	40	10
SLOPE (%)	8-16	2-8	2-16
SOIL			
Af^4_v	Lithosols	Eutric Fluvisols	rubble land
$Af^4_{c/v}$	Lithosols	Eutric Fluvisols	rubble land
Af^4_s	Lithosols	Calcaric Fluvisols (saline phase)	rubble land

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

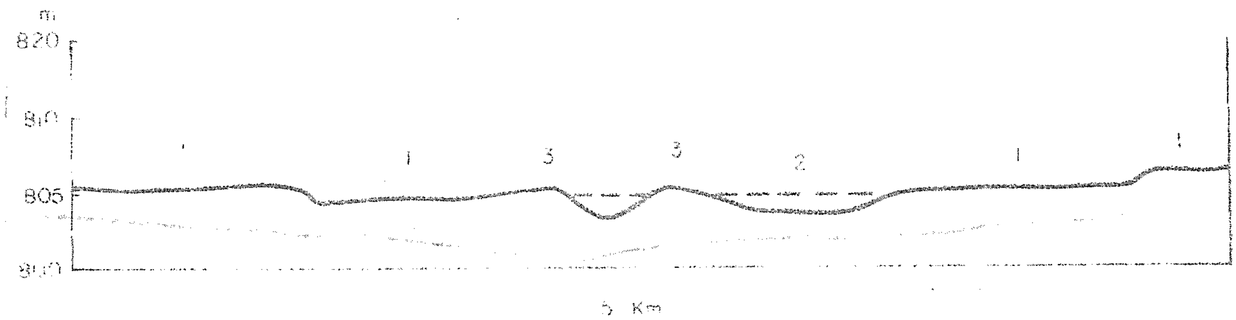
A1 - Lacustrine and fluvio - lacustrine plains



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

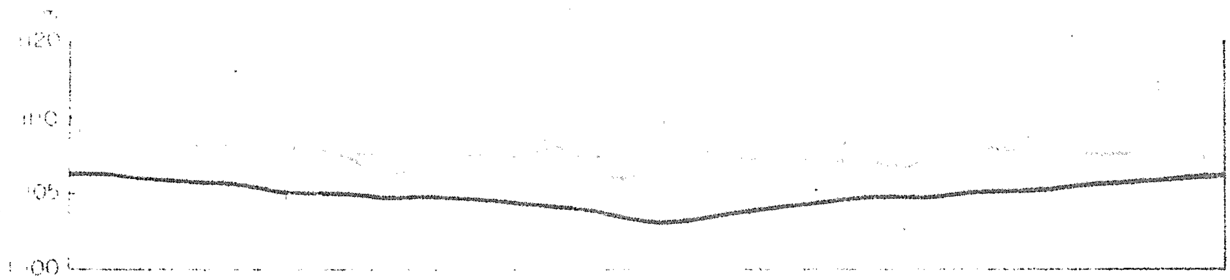


NUMBER	1	2	3
FACET	flood plains and low terraces	marshy depressions	levees
AREA (%)	60	20	20
SLOPE (%)	0-2	0-2	0-2
SOIL			
Am^1	Eutric Fluvisols	n.a.*	Eutric Fluvisols
Am^2	Eutric Fluvisols	Eutric Fluvisols	Eutric Fluvisols
Am^3	Calcaric Fluvisols+ (saline phase)	Calcaric Fluvisols (saline phase)	Calcaric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

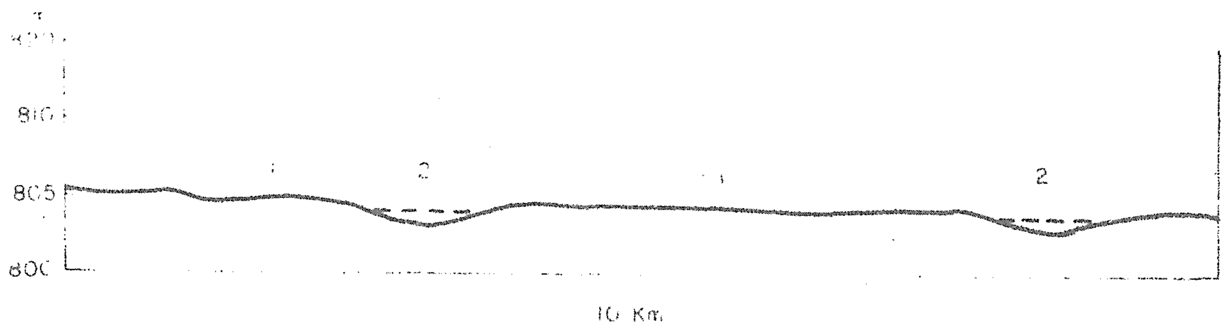
+ Chromic Vertisols (saline phase) occur on low terraces in Am^3

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)

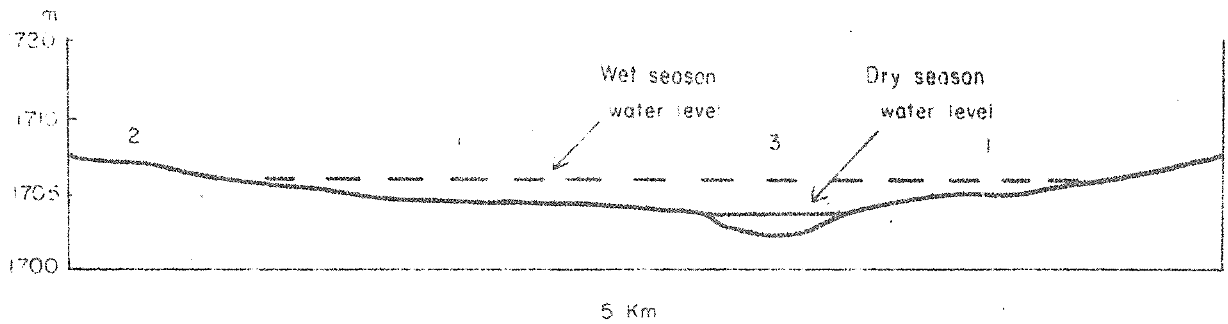
Ap - Alluvial plains



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

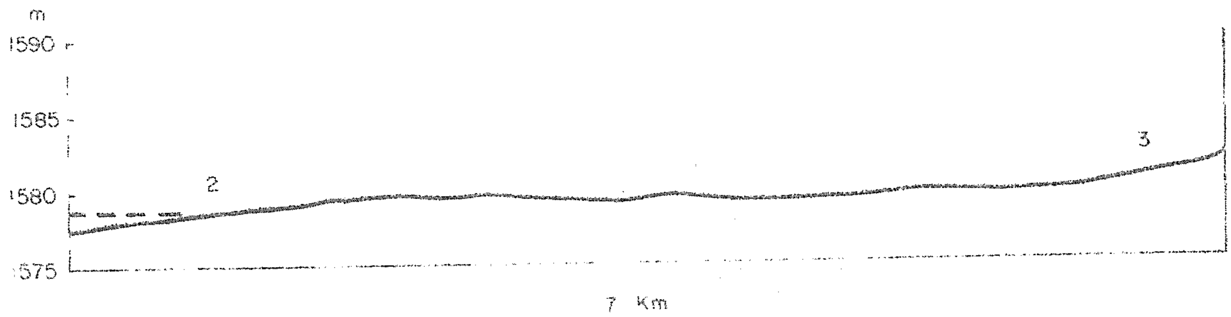
* Plains and low terraces are seasonally flooded in Ap[1]

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

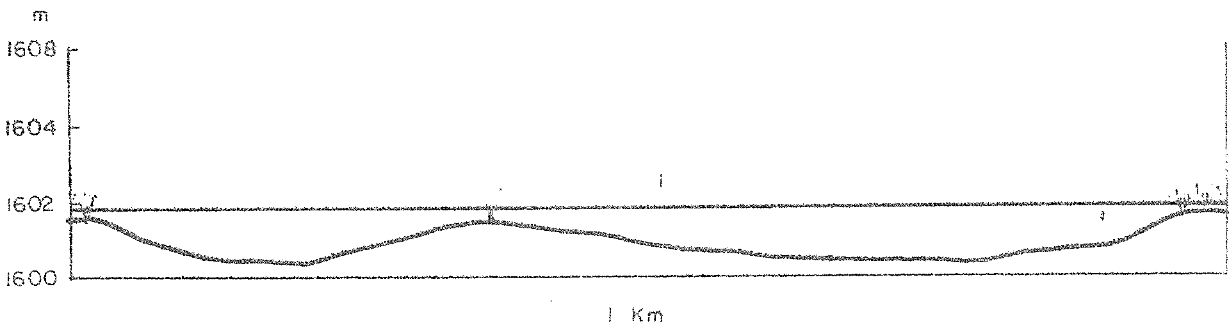


NUMBER	1	2	3
FACET	lacustrine plains	lake margins	colluvial margins
AREA (%)	80	10	10
SLOPE (%)			
SOIL			
Av[1]	Vitric Andosols (sodic phase)	Eutric Fluvisols	Eutric Cambisols
Av[2]	Orthic Solonchaks*	Eutric Fluvisols (saline phase)	Eutric Cambisols+
Av[3]	Luvic Phaeozems (sodic phase)	-	-

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

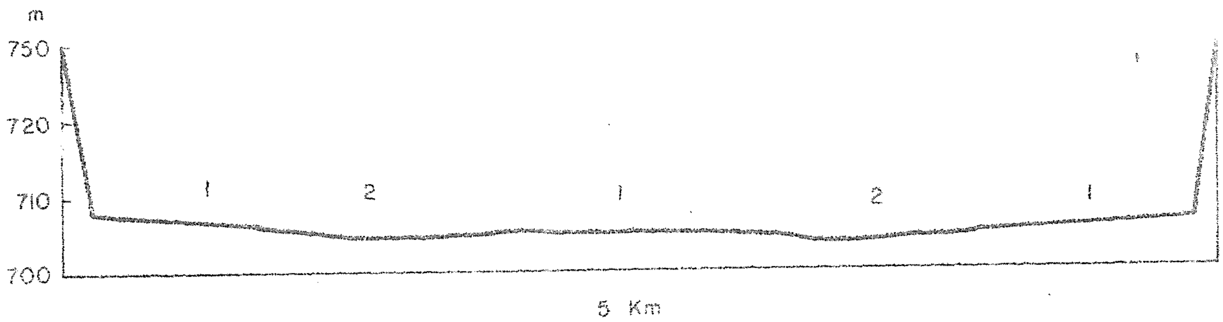
\+ Lacustrine plains make up 100% of Av[3]

Aw - Permanent fresh water swamps and marshes



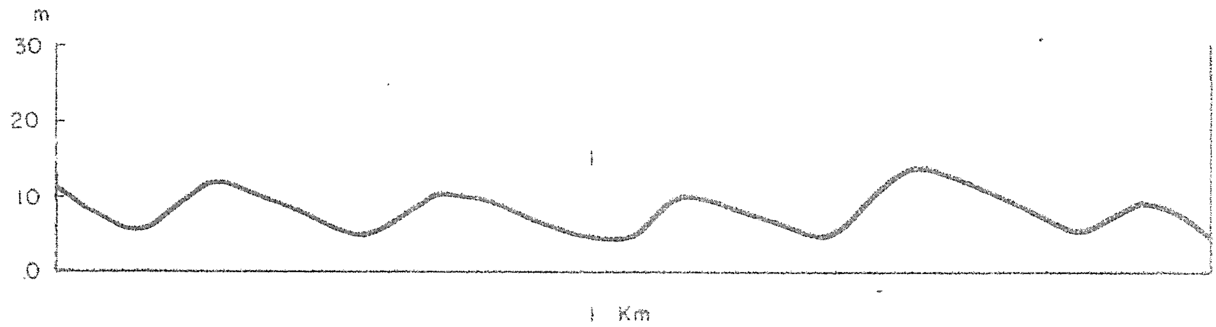
NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	0-2
SOIL	n.a.

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



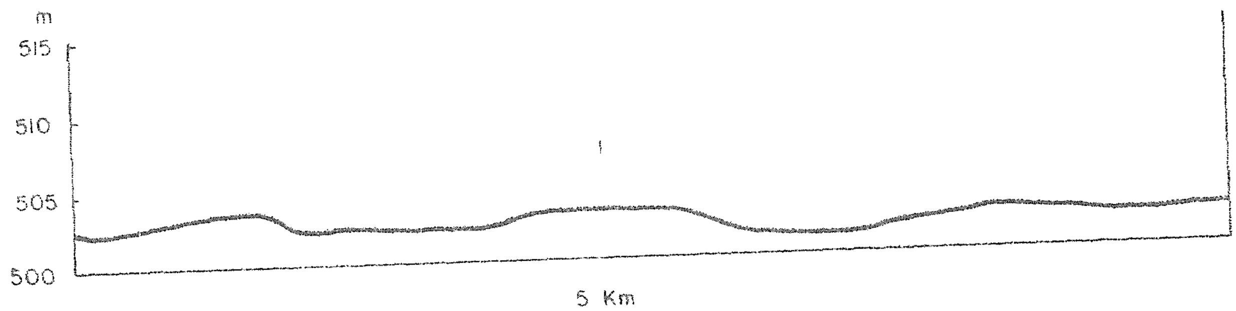
NUMBER	1	2
FACET	graben valleys	playas
AREA (%)	80	20
SLOPE (%)	0-2	0-2
SOIL	Orthic Solonchaks (petrogypsic phase)	Orthic Solonchaks (petrogypsic phase)

Da - Sand dunes and salt encrusted sand deposits



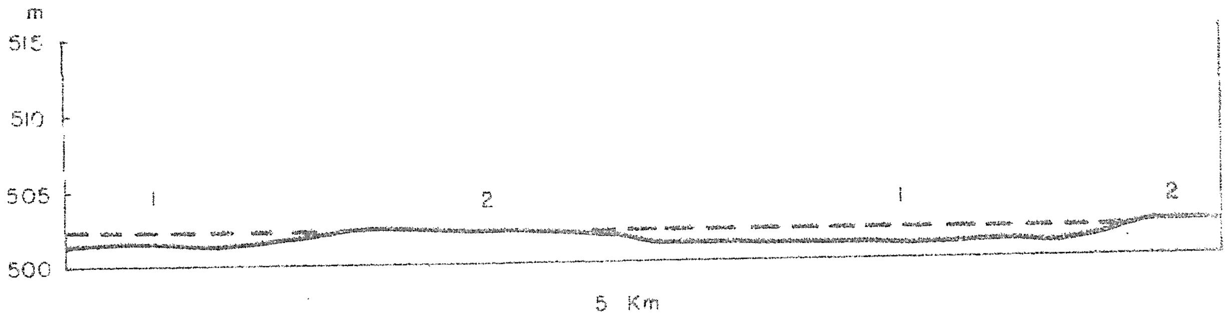
NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	2-30
SOIL	Sand surface

Ec - Evaporite pediments with associated alluvium



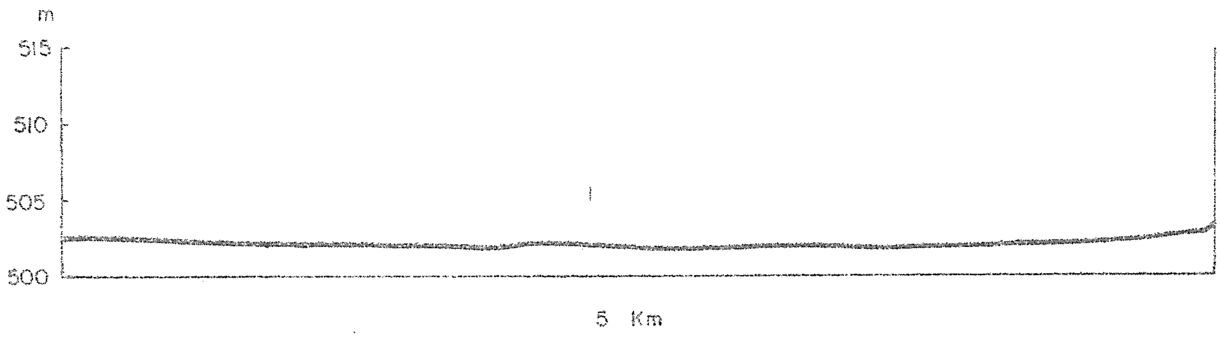
NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	0-8
SOIL	Orthic Solonchaks (petrogypsic phase)

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

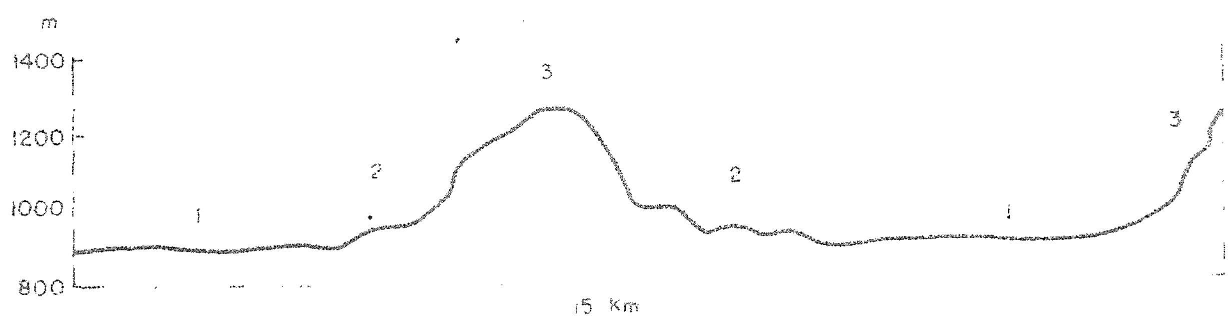
FACET n.a.

AREA (%) 100

SLOPE (%) 0-2

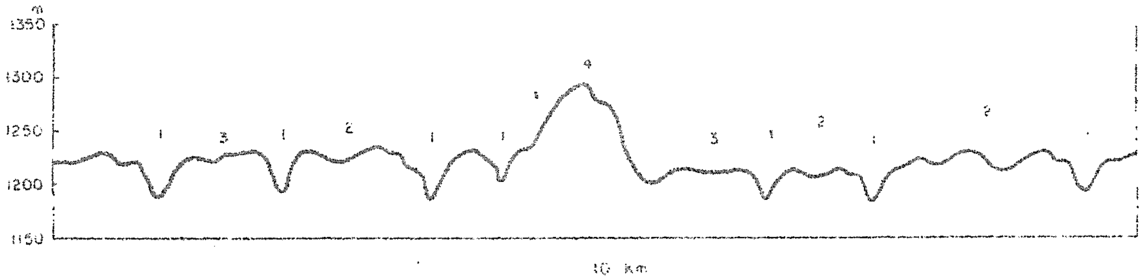
SOIL Orthic Solonchaks
(Petrogypsic phase)

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



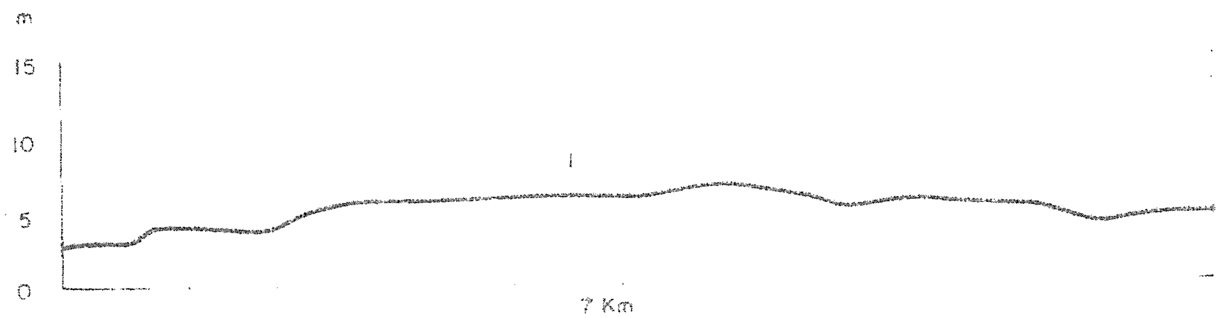
NUMBER	1	2	3
FACET	undulating plains and low plateaux	rolling plains and low plateaux	moderate to high relief hills
AREA (%)	60	20	20
SLOPE (%)	2-8	8-16	16-30
SOIL			
Ra_g^1	Haplic Xerosols (stony phase)	Haplic Xerosols (lithic plase)	Lithosols
Ra_g^2	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols

Rb - Dissected lowland plains and low plateaux



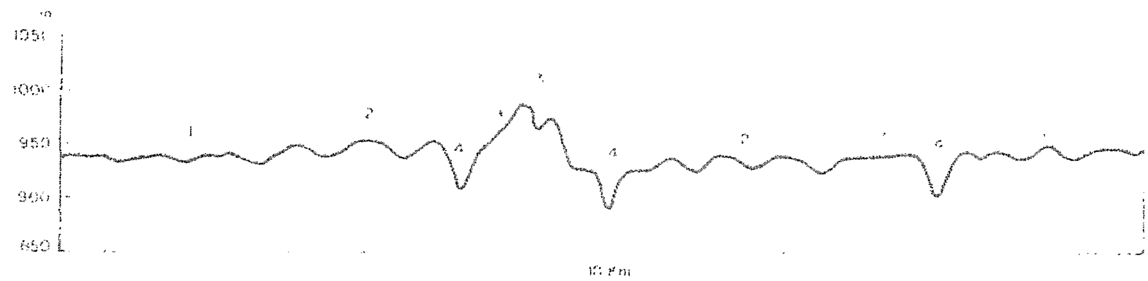
NUMBER	1	2	3	4
FACET	incised valleys	rolling plains and low plateaux	undulating plains and low plateaux	hills
AREA (%)	40	40	10	10
SLOPE(%)	30-50+	8-16	2-8	16-30
SOIL				
Rb^1_g	Lithosols	Chromic Luvisols	Eutric Nitosols	Chromic Luvisols
Rb^2_g	Lithosols	Chromic Cambisols	Chromic Cambisols	Lithosols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

Rc - Uplifted reefs



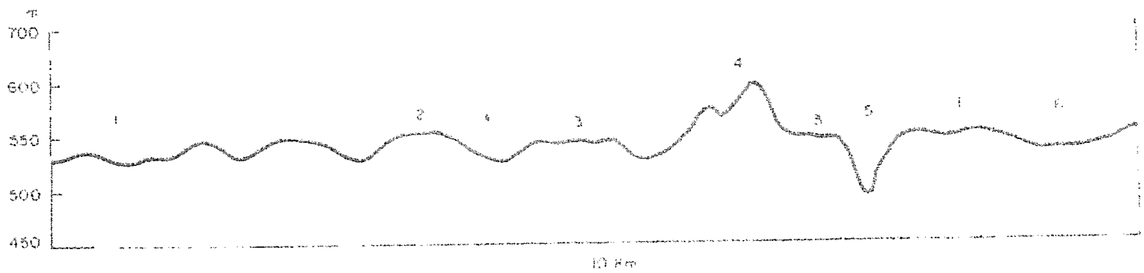
NUMBER	1
FACET	n.a
AREA (%)	100
SLOPE (%)	0-8
SOIL	Calcaric Regosols (lithic phase)

Rd - Undulating to rolling lowland plains and low plateaux



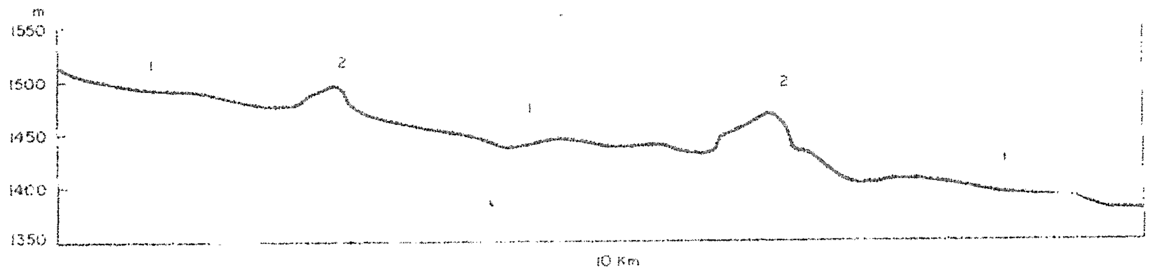
Number	1	2	3	4
FACET	undulating plains and low plateaux	rolling plains and low plateaux	hills	incised valleys
AREA (%)	40	40	10	10
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Rd_v	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols	Lithosols
Rd_g^1	Chromic Luvisols	Chromic Luvisols	Chromic Luvisols (stony 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_5/V_r - Undulating to rolling lowland plains and low plateaux/dissected lavas and extensive rock outcrop



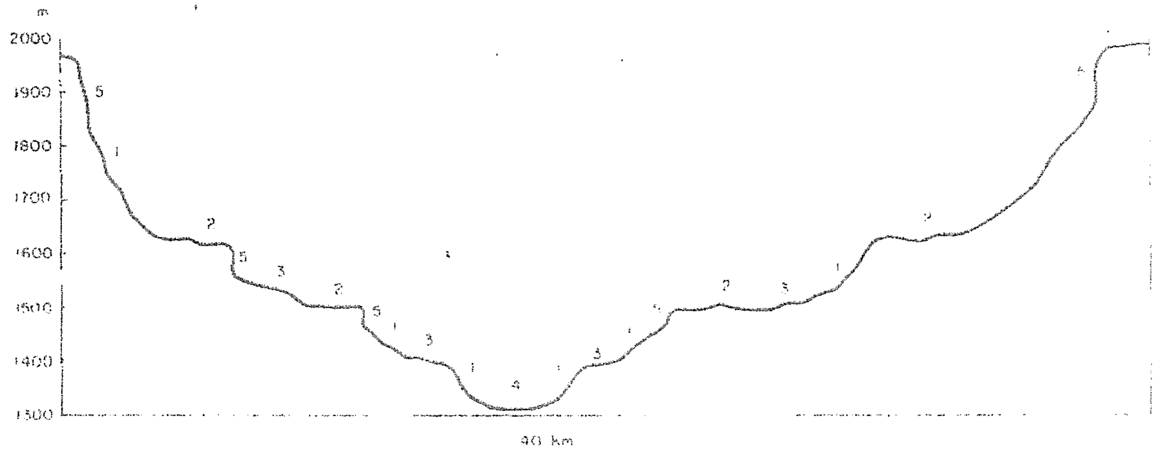
NUMBER	1	2	3	4	5	6
FACET	undulating plains	rolling plains	stony terraces	hills	dissected valleys	undulating basin
AREA (%)	30	30	10	10	10	10
SLOPE (%)	2-8	8-16	2-8	16-30	30-50+	2-8
SOIL	Calcic Xerosols (petrocalcic phase)	Calcic Xerosols (lithic phase)	Rubble land	Lithosols	Lithosols	Calcic Xerosols

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



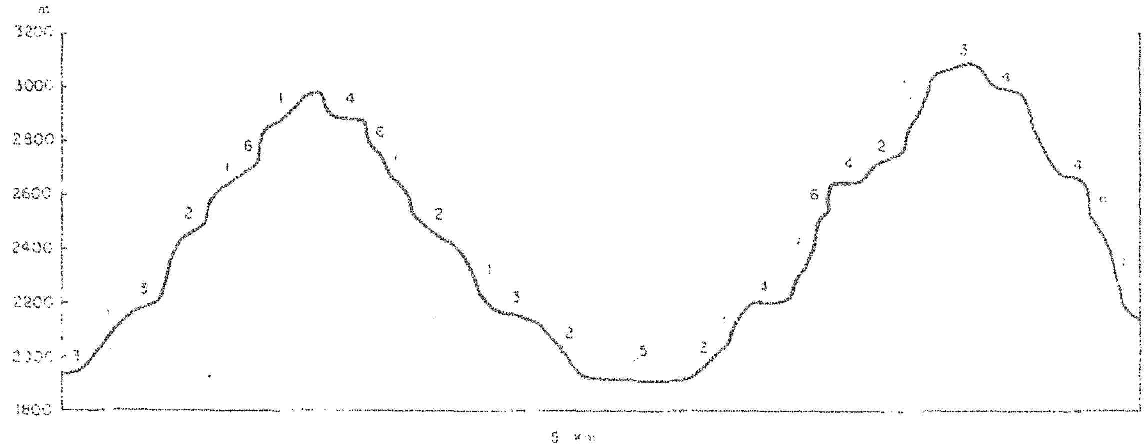
NUMBER	1	2
FACET	undulating sideslopes	low hills
AREA (%)	90	10
SLOPE (%)	2-8	8-16
SOIL		
Rf_v^1	Chromic Vertisols	Eutric Nitosols
Rf_v^2	Chromic Vertisols (stony phase)	Eutric Regosols (lithic phase)
Rf_v^3	Chromic Vertisols	Orthic Luvisols (stony phase)
Rf_v^4	Mollic Andosols	Eutric Cambisols
Rf_v^5	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.)



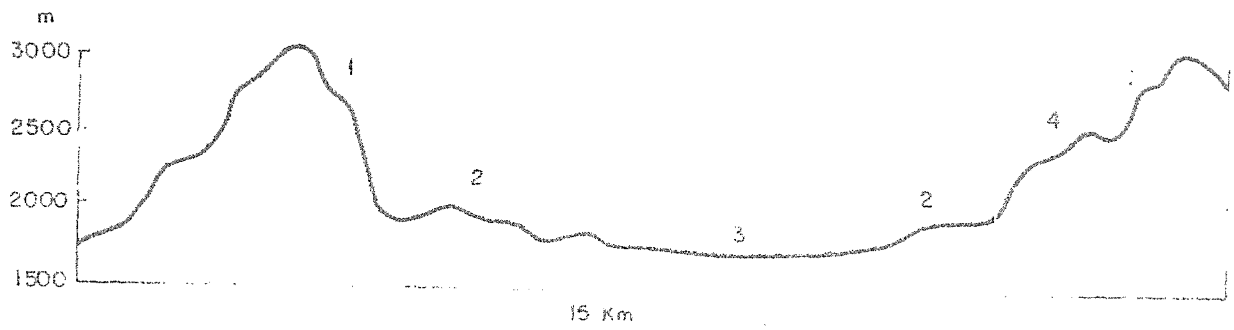
NUMBER	1	2	3	4	5
FACET	very steep sideslopes	plateau terraces	steep sideslopes	gorge's bottom	escarpments
AREA (%)	30	30	20	10	10
SLOPES (%)	30-60+	8-16	16-30	2-8	60+
SOIL					
Rg_v	Lithosols	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Rock surface
Rg_g	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



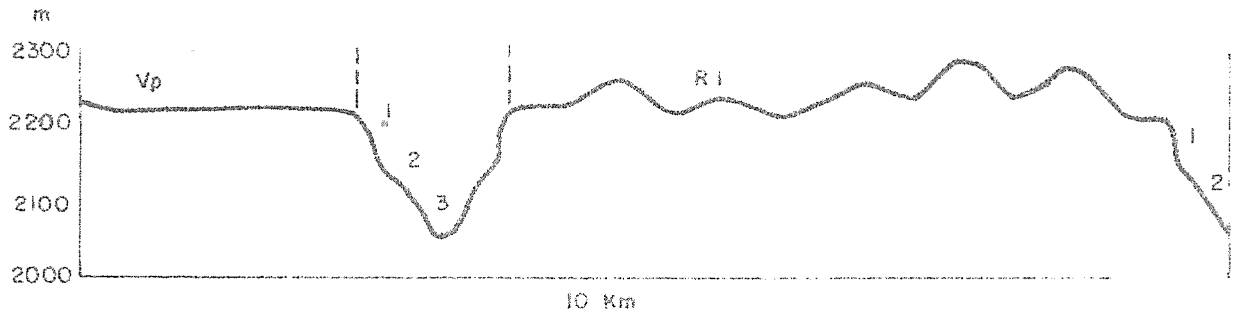
NUMBER	1	2	3	4	5	6
FACET	very steep sideslopes	steep sideslopes	moderate sideslopes	plateau terraces and gentle sideslopes	intermontane valleys	escarpments
AREA (%)	50	10	10	10	10	10
SLOPE (%)	30-50+	16-30	8-16	2-8	0-8	50+
SOIL						
Rh_v^1	Chromic Luvisols (stony phase)	Chromic Luvisols	Eutric Nitosols	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 [illegible]	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



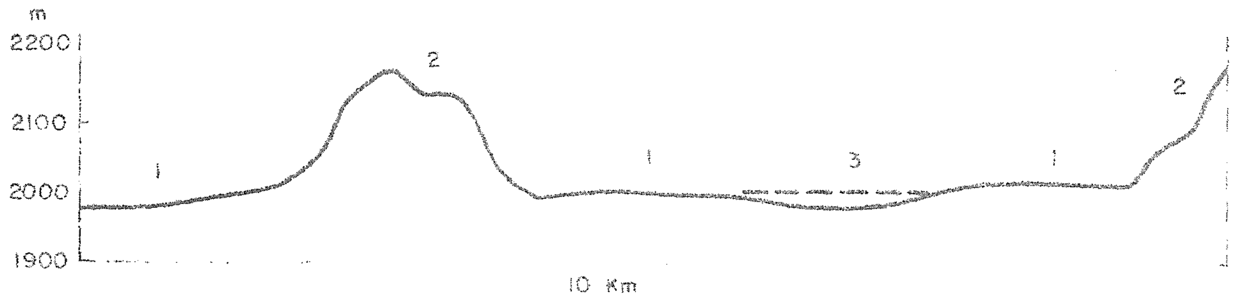
NUMBER	1	2	3	4
FACET	high relief hills and mountains	footslopes	valleys	high relief hills and mountains
AREA (%)	50	20	20	10
SLOPE (%)	30-50+	8-16	0-8	16-30
SOIL				
Ri_v	Lithosols	Eutric Regosols (lithic phase)	Vertic Cambisols (lithic phase)	Eutric Regosols (lithic phase)

Rj - Minor river gorges and ravines



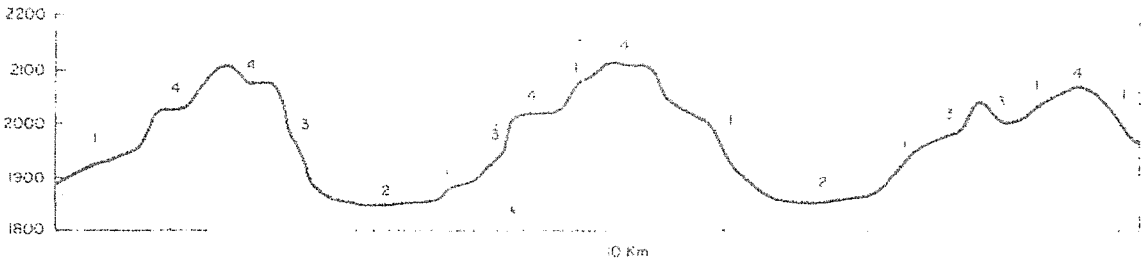
NUMBER			
FACET	very steep side slopes	escarpments	gorge's bottom
AREA (%)	50	40	10
SLOPE (%)	30-50	50+	2-8
SOIL			
Rj_v	Lithosols	Rock surface	Eutric Fluvisols
Rj_g	Lithosols	Rock surface	Eutric Fluvisols (stony phase)
Rj_c	Lithosols	Rock surface	Calcaric Fluvisols (stony phase)

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

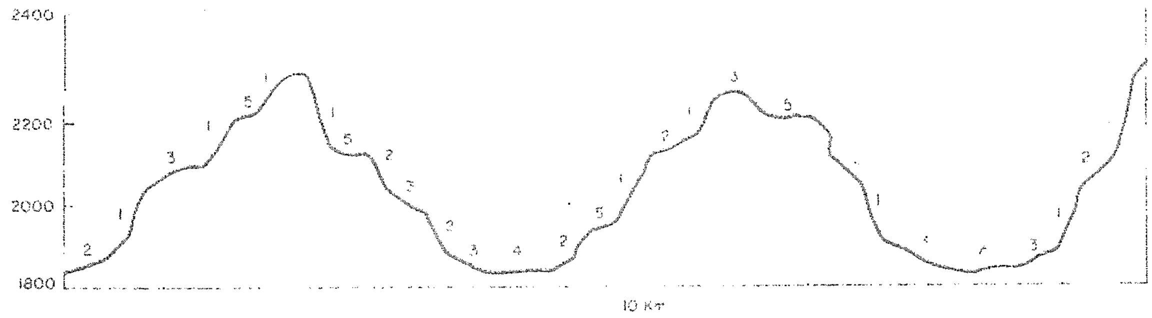


NUMBER	1	2	3
FACET	undulating plateaux	moderate relief hills	seasonal marshes
AREA (%)	50	30	20
SLOPE (%)	2-8	16-30	0-2
SOIL			
Rk_v^1	Dystric Nitosols	Dystric Nitosols	Dystric Gleysols
Rk_v^2	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)	Chromic Vertisols

Rl - Low to moderate relief hills

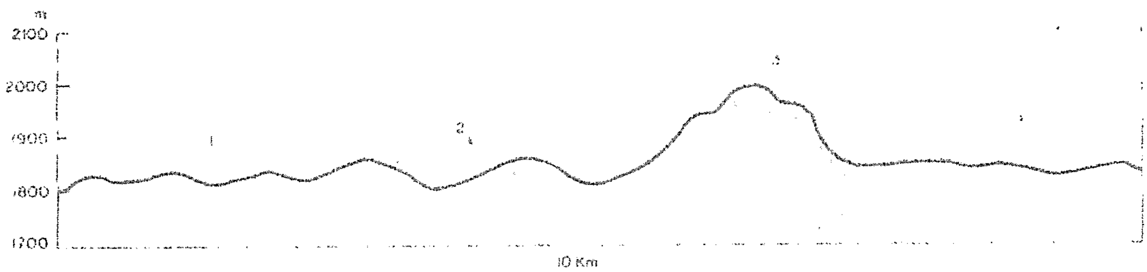


NUMBER	1	2	3	4
FACET	sideslopes	small valleys	steep sideslopes	plateau terraces and gentle sideslopes
AREA (%)	60	20	10	10
SLOPE (%)	8-16	0-8	16-30	2-8
SOIL				
Rl_v^1	Eutric Nitosols	Chromic Vertisols	Eutric Nitosols	Chromic Vertisols
Rl_v^2	Eutric Cambisols (stony phase)	Eutric Cambisols	Lithosols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



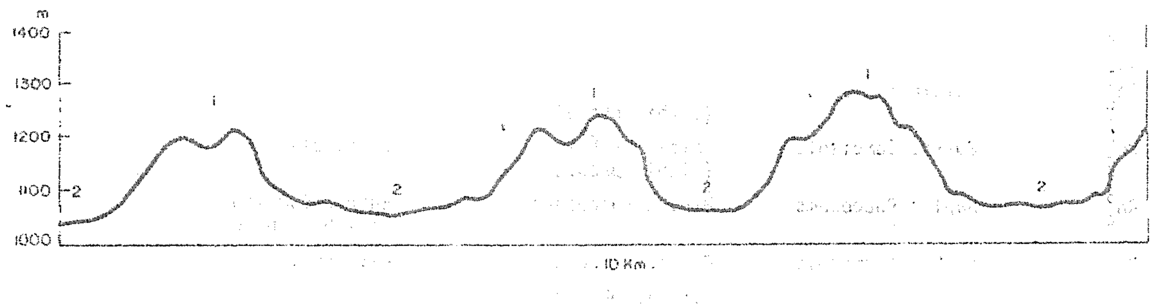
NUMBER	1	2	3	4	5
FACET	very steep sideslopes	steep sideslopes	moderate sideslopes	small valleys	plateau terraces and gentle sideslopes
AREA (%)	30	20	20	20	10
SLOPE (%)	30-50	16-30	8-16	0-8	2-8
SOIL					
Hm_v^1	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)	Chromic Luvisols	Chromic Vertisols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



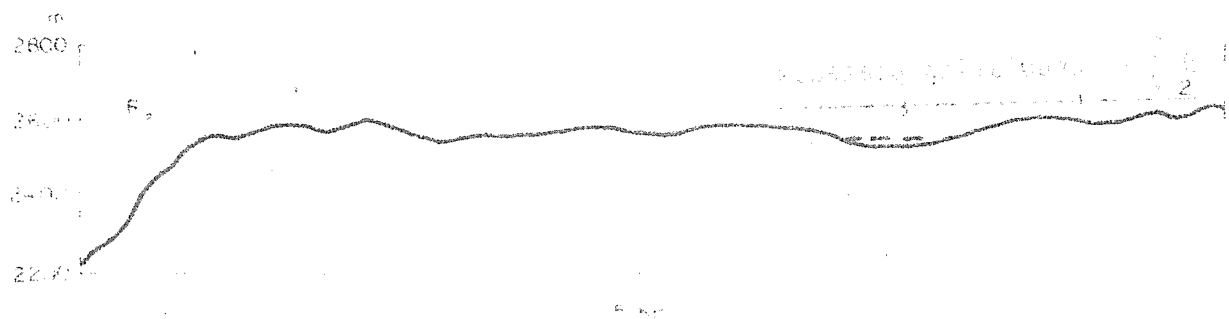
NUMBER	1	2	3
FACET	undulating plains and low plateaux	rolling plains and low plateaux	low to moderate relief hills
AREA (%)	60	20	20
SLOPE (%)	2-8	8-16	16-30
SOIL			
Rn_v^1	Eutric Nitosols	Eutric Nitosols	Chromic Luvisols
Rn_v^2	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Rn_v^3	Eutric Nitosols	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.

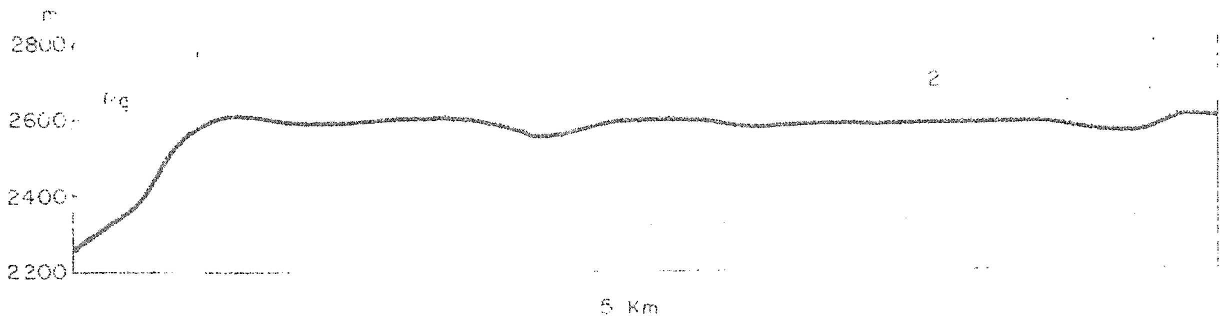


NUMBER	1	2
FACET	low to moderate relief hills	valleys
AREA (%)	60	40
SLOPE (%)	16-30	0-8
SOIL		
Ro_v^1	Nithosols	Eutric Regosols (stony phase)
Ro_v^2	Dystric Nitosols	Dystric Nitosols
Ro_v^3	Chromic Luvisols (stony phase)	Chromic Vertisols
Ro_v^4	Eutric Cambisols (stony phase)	Vertic Cambisols (stony 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

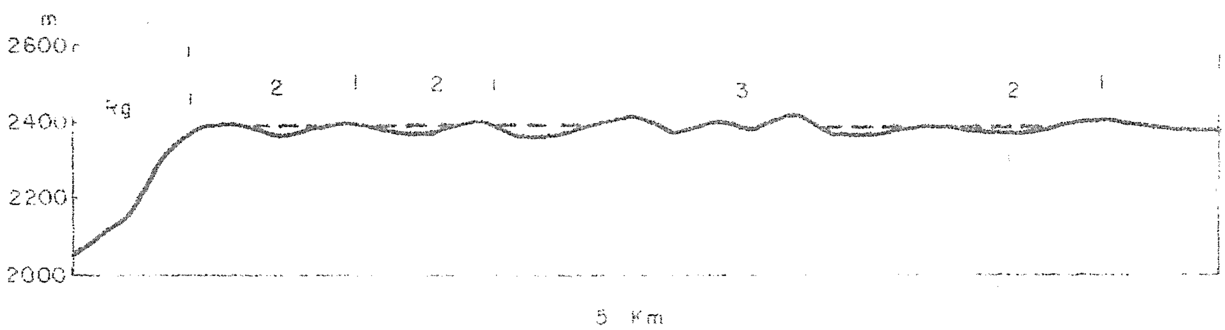


NUMBER	1	2	3
FACET	undulating plateaux	rolling plateaux	depressions with seasonal drainage deficiencies
AREA (%)	60	30	10
SLOPE (%)	2-8	8-16	0-2
SOIL			
Rp_v^1	Eutric Nitosols	Eutric Nitosols	Chromic Vertisols
Rp_v^2	Dystric Nitosols	Dystric Nitosols	Dystric Gleysols
Rp_g	Eutric Nitosols	Chromic Luvisols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



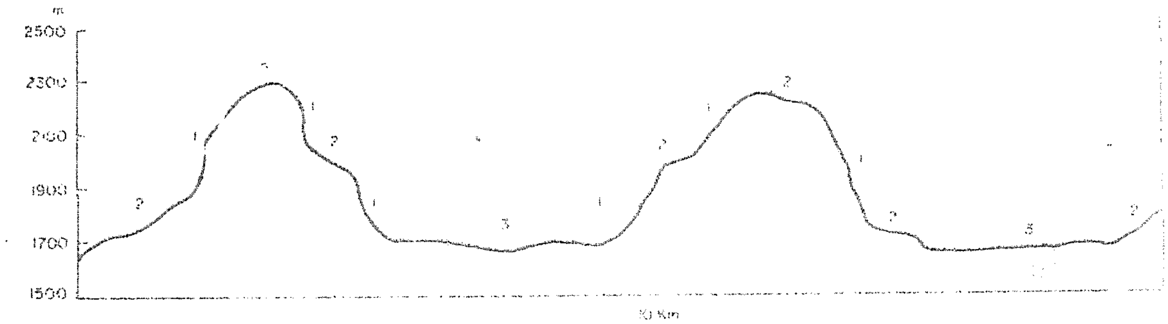
NUMBER	1	2
FACET	undulating plateaux	flat plateaux
AREA (%)	70	30
SLOPE (%)	2-8	0-2
SOIL		
Rp_V^3	Chromic Luvisols (stony phase)	Chromic Vertisols

Rp_V^4



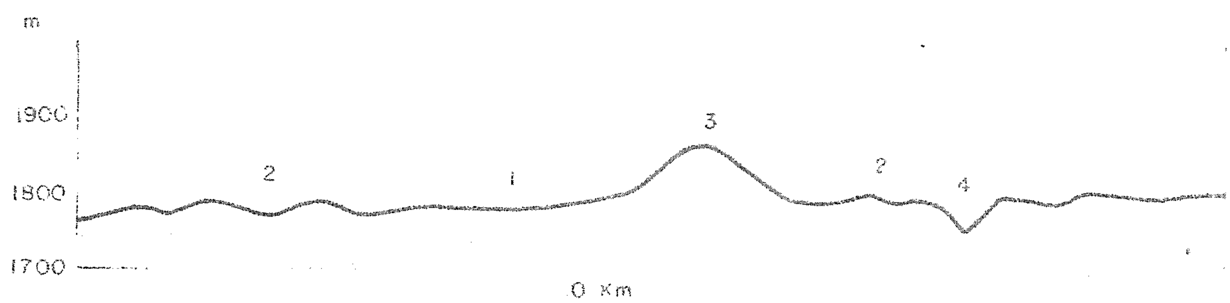
NUMBER	1	2	3
FACET	undulating plateaux	depressions with seasonal drainage deficiencies	rolling plateaux
AREA (%)	40	40	20
SLOPE (%)	2-8	0-2	8-16
SOIL Rp_V^4	Chromic Vertisols	Eutric Fluvisols	Dystric Nitosols

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



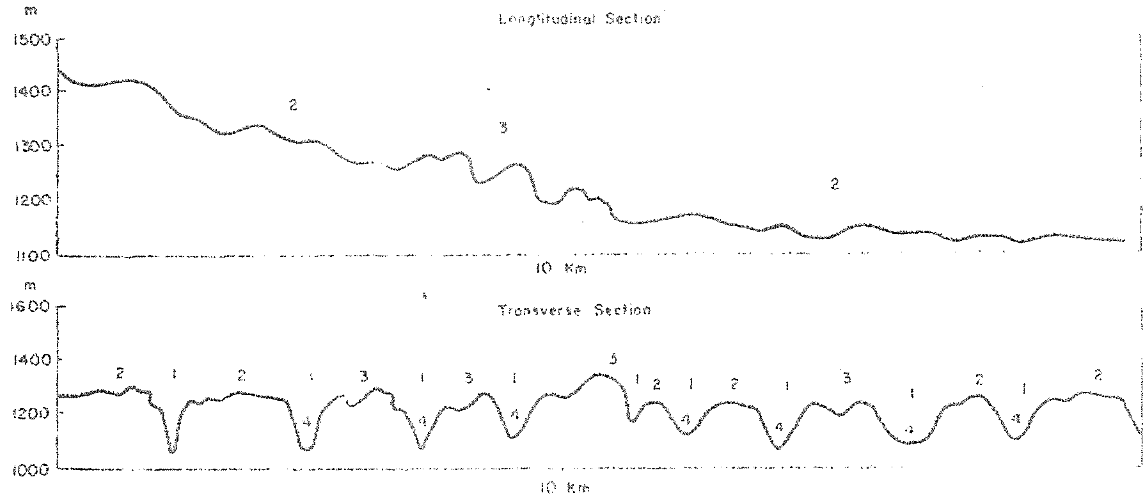
NUMBER	1	2	3
FACET	moderate to high relief hills	moderate to high relief hills	valleys
AREA (%)	40	30	30
SLOPE (%)	30-50	16-30	0-8
SOIL			
Rq_v^1	Lithosols	Eutric Regosols (lithic phase)	Vertic Cambisols (stony phase)
Rq_v^2	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols
Rq_v^3	Lithosols	Lithosols	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



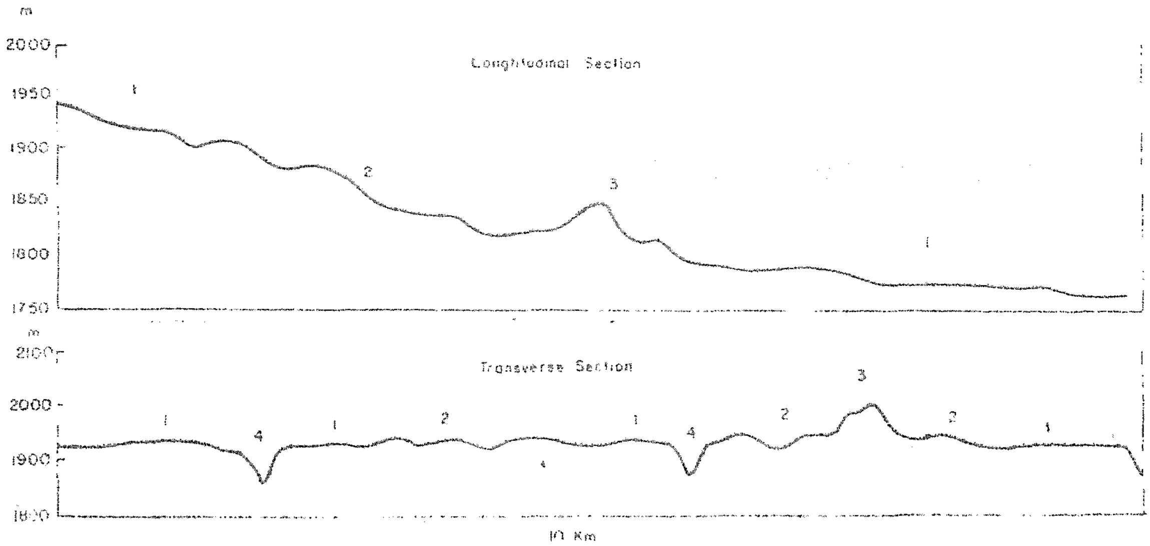
NUMBER	1	2	3	4
FACET	undulating plains	rolling plains	hills	incised valleys
AREA (%)	40	40	10	10
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Rr_v^1	Luvic Phaeozems (sodic phase)	Luvic Phaeozems (sodic phase)	Eutric Cambisols	Lithosols
Rr_v^2	Chromic Vertisols	Chromic Luvisols	Chromic Luvisols (stony phase)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

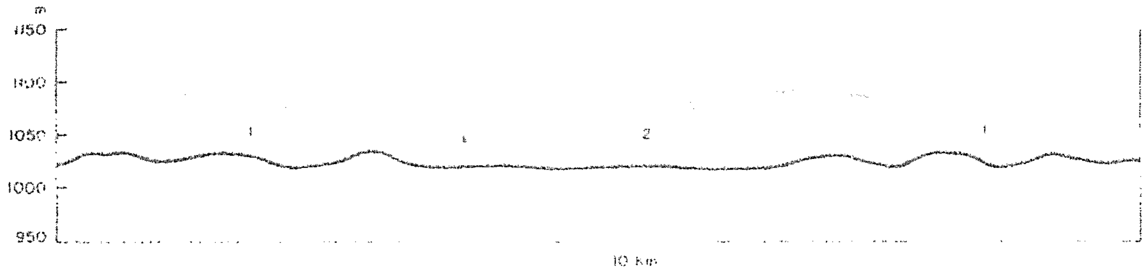


NUMBER	1	2	3	4
FACET	undulating sideslopes	rolling sideslopes	hills	incised valleys*
AREA (%)	40	40	10	10
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Rt_v^1	Chromic Vertisols	Eutric Nitosols	Chromic Luvisols	Lithosols
Rt_v^2	Dystric Nitosols	Dystric Nitosols	Orthic Acrisols	Lithosols
Rt_v^3	Chromic Vertisols	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

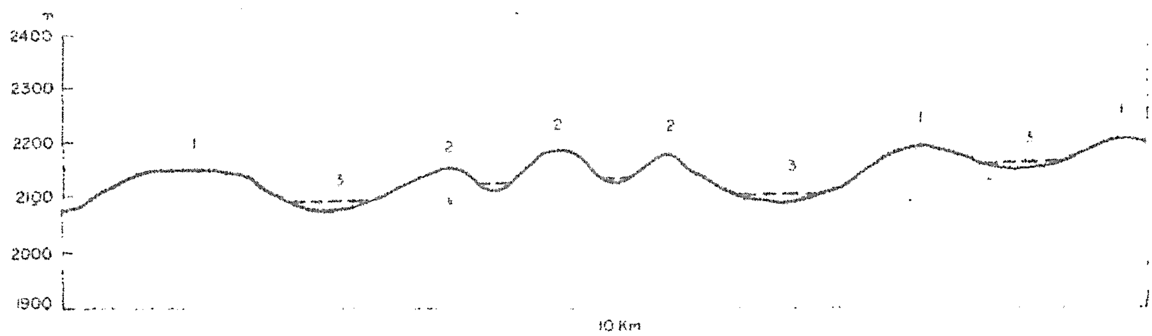
+ Incised valleys do not occur in unit Rt_c^3 and hills make up 20% of the unit

Ru - Flat to undulating lowland plains and low plateau



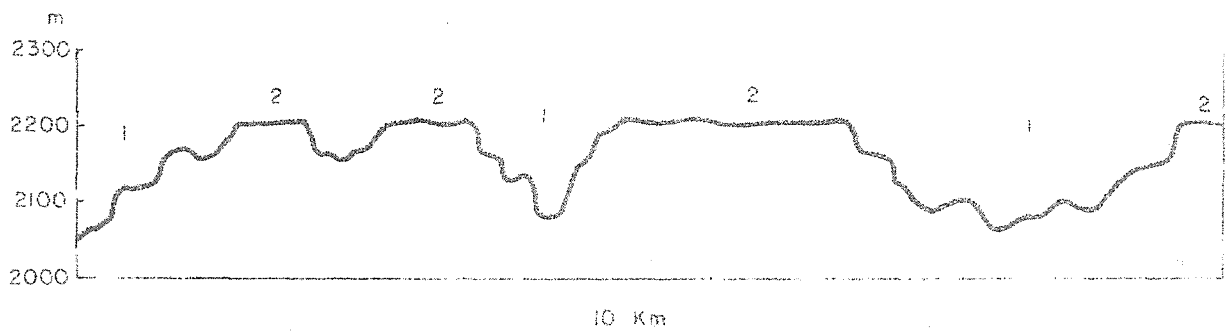
NUMBER	1	2
FACET	undulating plains	flat plains
AREA (%)	70	30
SLOPE (%)	2-8	0-2
SOIL		
Ru_v	Dystric Nitosols	Chromic Vertisols
$Ru_{v/g}$	Chromic Cambisols	Chromic Cambisols
Ru_g^1	Haplic Xerosols	Haplic Xerosols
Ru_g^2	Dystric Nitosols	Dystric Nitosols
Ru_g^3	Eutric Nitosols	Eutric Nitosols
Ru_g^4	Chromic 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



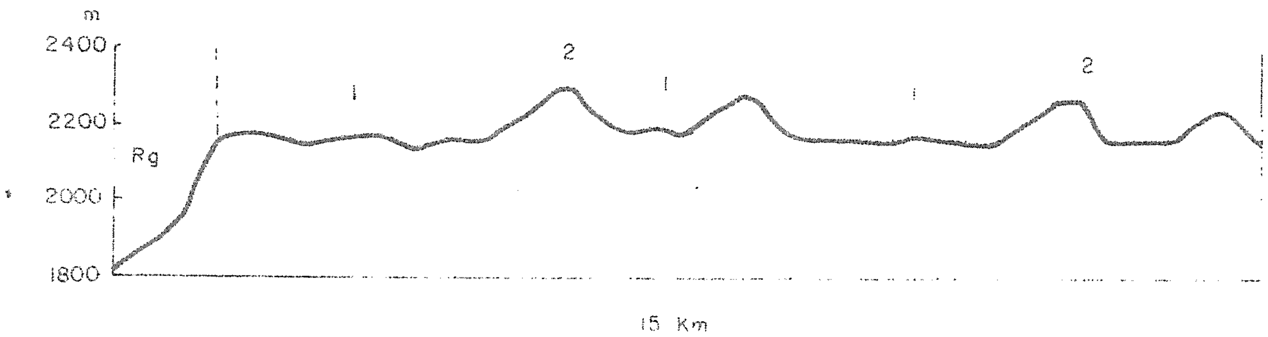
NUMBER	1	2	3
FACET	rolling plateaux	hilly plateaux	depressions with seasonal drainage deficiencies
AREA (%)	70	20	10
SLOPE (%)	8-16	16-30	0-2
SOIL			
Rw_v^1	Dystric Nitosols	Dystric Nitosols	Dystric Gleysols
Rw_v^2	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)	Chromic Vertisols
Rw_v^3	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)

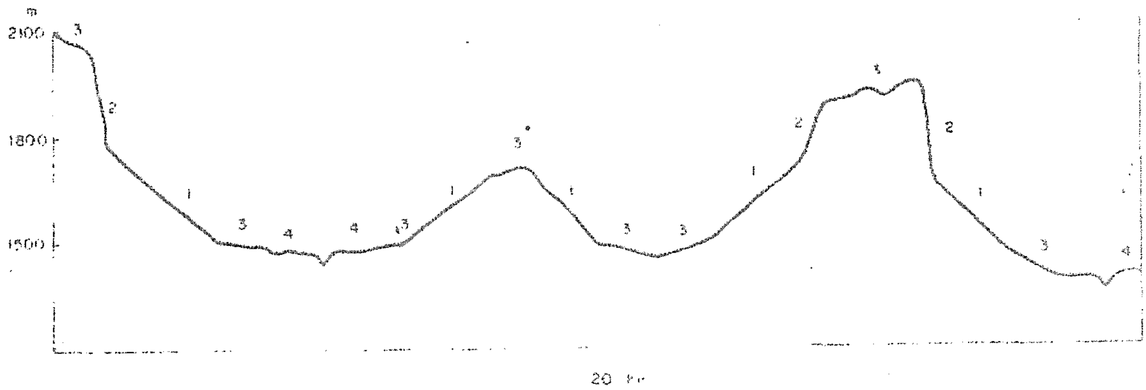
Ry - Undulating high plateaux with a substantial proportion of hills interspersed throughout



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)

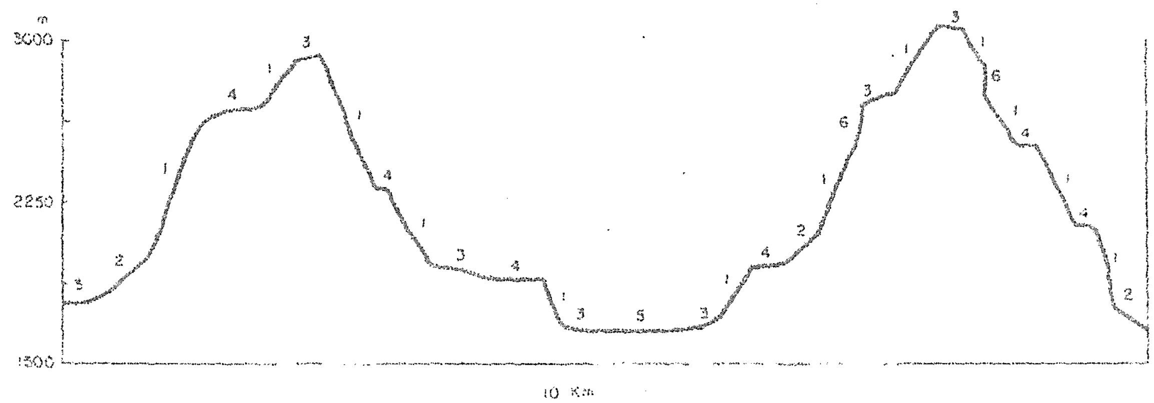
+ In Ry_v^4 volcanic plugs instead of moderate relief hills

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

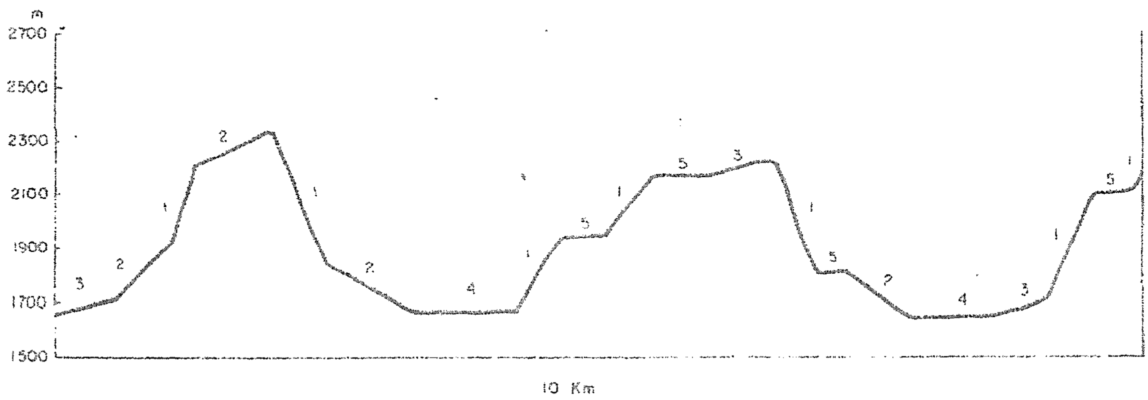
associated with extensive fault sets



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

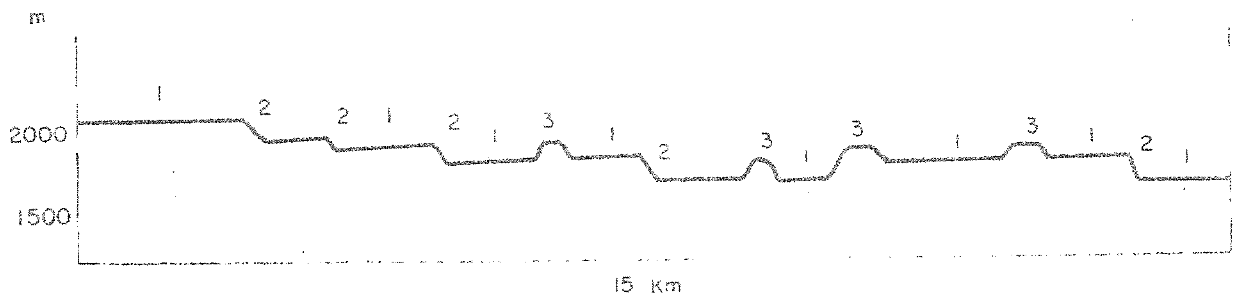
+ Steep sideslopes and moderate sideslopes make up each 20 percent in Sh_v^2; plateau terraces and gentle sideslopes and intermontane valleys are absent.

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



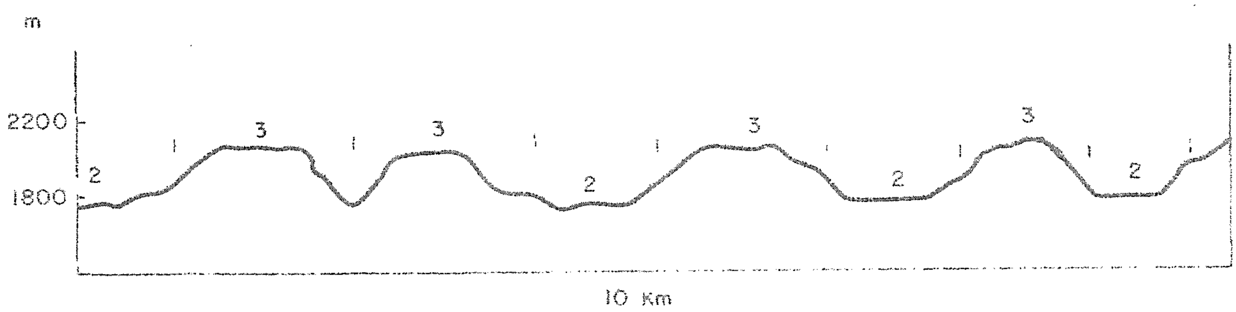
NUMBER	1	2	3	4	5
FACET	very steep sideslopes	steep sideslopes	moderate sideslopes	small parallel valleys	plateau terraces an gentle sideslop
AREA (%)	30	20	20	20	10
SLOPE (%)	30-50	16-30	8-16	0-8	2-8
SOIL					
Sm^1_v	Eutric Cambisols (lithic phase)	Orthic Luvisols (stony phase)	Orthic Luvisols (stony phase)	Eutric Nitosols (stony phase)	Eutric Nitosols (stony phase)
Sm^2_v	Lithosols	Eutric Regosols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)
Sm^3_v	Lithosols	Lithosols	Lithosols	Orthic Sonlonchaks (stony phase)	Eutric Regosols (lithic phase)
Sm^1_g	Orthic Acrisols (stony phase)	Orthic Acrisols	Dystric Nitosols	Dystric Nitosols	Dystric Nitosols
Sm^2_g	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols	Vertic Cambisols	Eutric Cambisol
Sm^3_g	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^1_m	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Gambisols	Orthic Luvisols
Sm^2_m	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Haplic Xerosols (stony phase)
Sm$^1_{m/g}$	Lithosols	Eutric Cambisols (lithic phase)	Eutric Cambisols (lithic phase)	Eutric Cambisols	Orthic Luvisol
Sm$^2_{m/g}$	Lithosols	Lithosols	Haplic Xerosols (lithic phase)	Haplic Xerosols (stony phase)	Haplic Xer... (stony ph...)

Sp - Step faulted plateaux of the Ethiopian rift margin



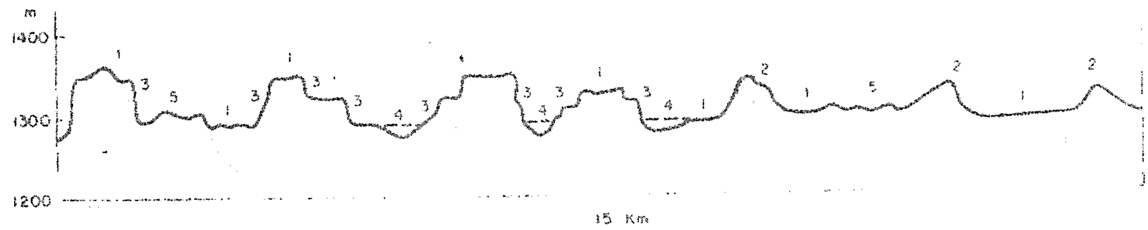
NUMBER	1	2	3
FACET	plateaux	fault scarps	horst crests
AREA (%)	70/50	20/30	10/20
SLOPE (%)	2-8	50+	2-8
SOIL			
Sp_v^1	Vertic Cambisols	Rock surface	Eutric Cambisols (stony phase)
Sp_v^2	Vertic Cambisols (stony phase)	Rock Surface	Eutric Cambisols (stony phase)

Sq - Linear ridges with wide intervening parallel valleys



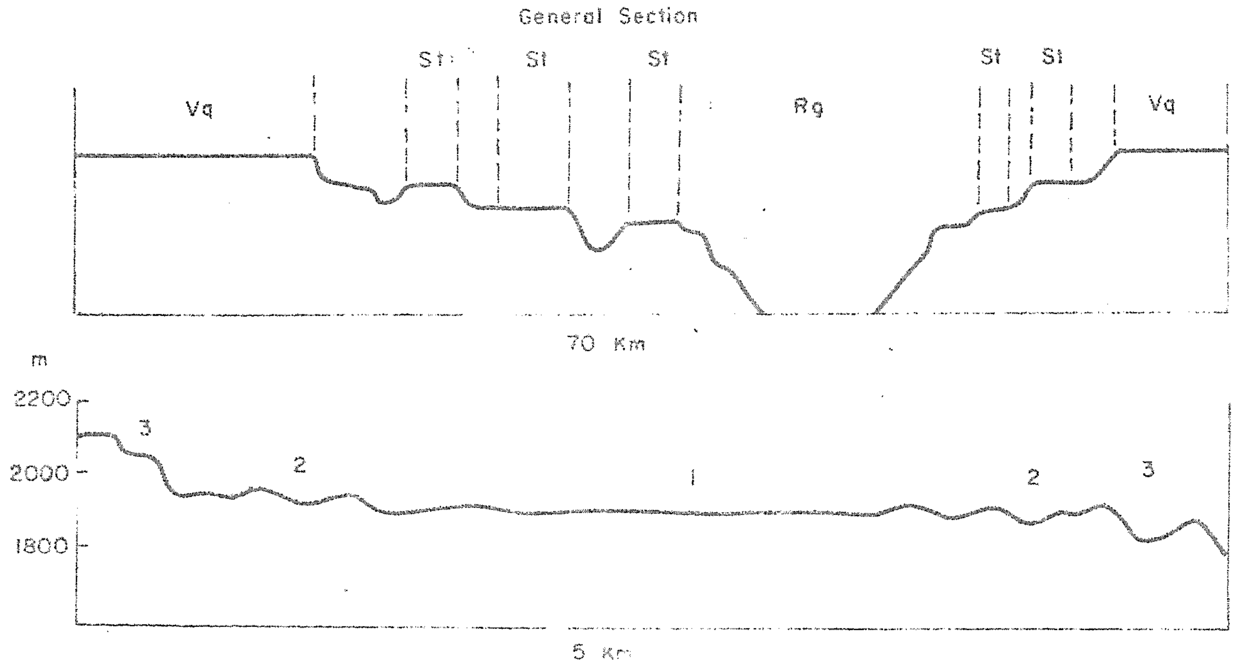
NUMBER	1	2	3
FACET	ridge sideslopes	broad parallel valleys	crests
AREA (%)	50	30	20
SLOPE (%)	16-30	0-8	8-16
SOIL			
Sq_v	Chromic Luvisols	Pellic Vertisols	Eutric Nitosols

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



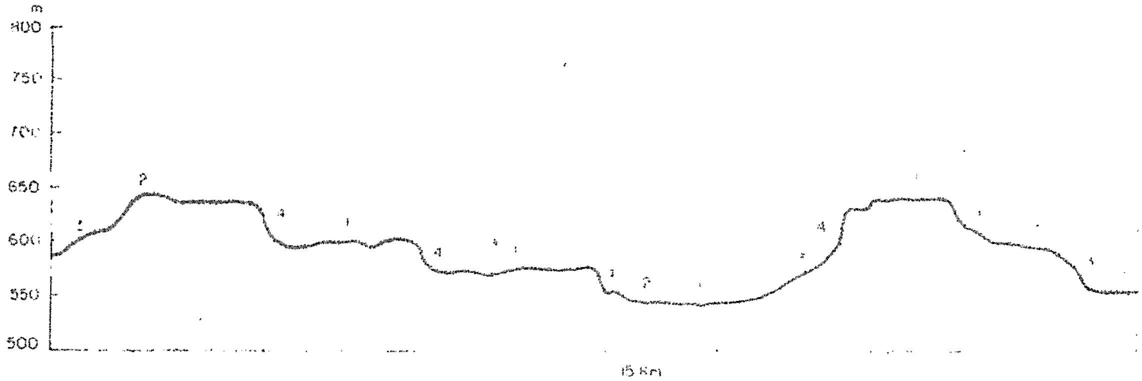
NUMBER	1	2	3	4	5
FACET	undulating plains and caldera floors	caldera rims and volcanic cones and plugs	fault scarps and very steep sideslopes	permanent marsh	rolling plain
AREA(%)	30	30	20	10	10
SLOPE (%)	2-8	16-30	30-50+	0-2	8-16
SOIL					
Ss_v	Mollic Andosols	Eturic Cambisols (lithic phase)	Lithosols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

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



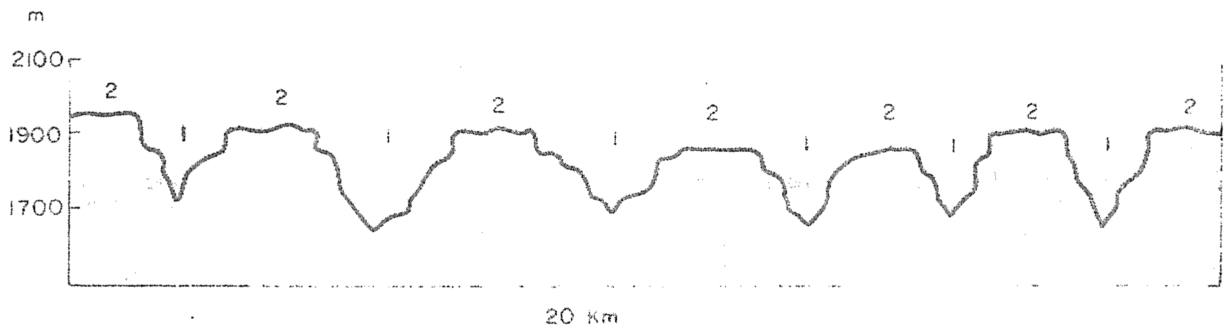
NUMBER	1	2	3
FACET	undulating plateaux	rolling plateaux	hills and steep sideslopes
AREA (%)	50	40	10
SLOPE (%)	2-8	8-16	16-30
SOIL			
St_v	Eutric Nitosols	Chromic Luvisols (stony phase)	Chromic Luvisols (stony phase)
St_c	Haplic Phaeozems	Haplic Phaeozems (stony phase)	Eutric Cambisols (lithic phase)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

Su - Intensively faulted lava platforms of the Afar lowlands



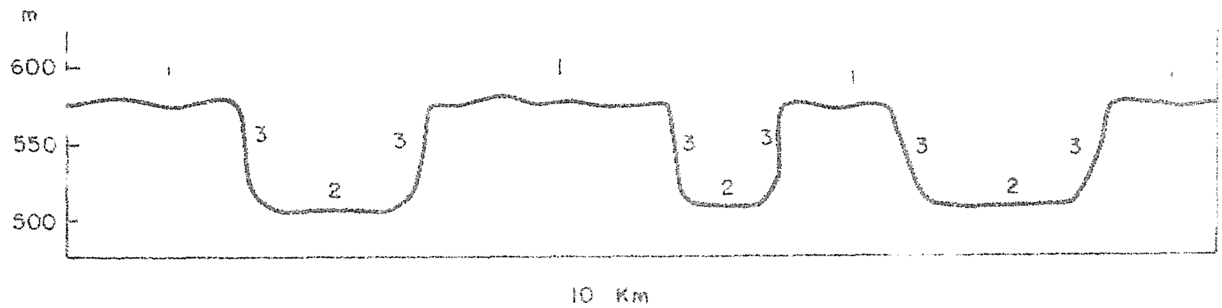
NUMBER	1	2	3	4
FACET	benches and valley bottoms	moderate slopes	steep slopes	very steep slopes and fault scarps
AREA (%)	40	20	20	20
SLOPE (%)	2-8	8-16	16-30	30-50+
SOIL				
Su_v^1	Eutric Cambisols (stony phase)	Eutric Cambisols (lithic phase)	Lithosols Lithosols	Rock outcrop Rock outcrop
Su_v^2	Orthic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

Sx - Severely dissected rift margins and fault



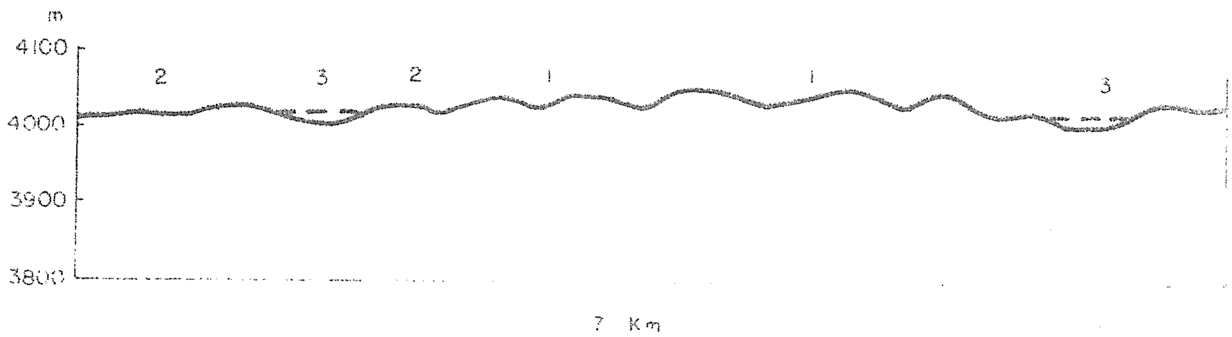
NUMBER	1	2
FACET	steep cut stream channels and escarpments	plateau remnants
AREA (%)	60	40
SLOPE(%)	50+	8-16
SOIL		
Sx_v	Lithosols	Eutric Cambisols

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.



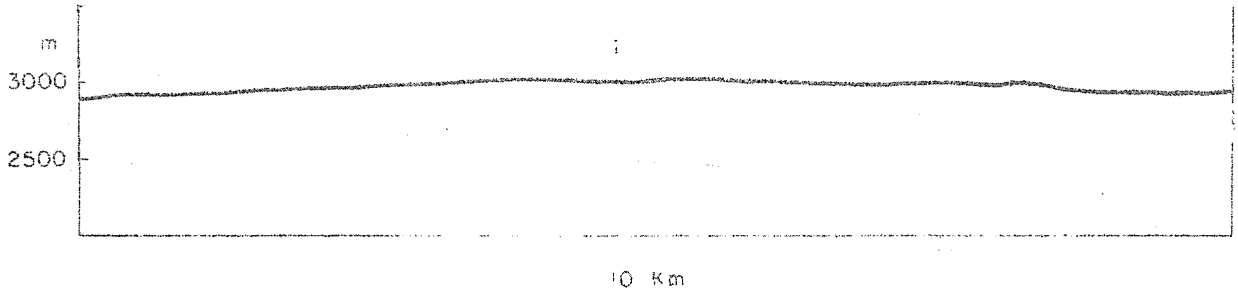
NUMBER	1	2	3
FACET	lava platforms and horst crests	grabens	fault scarps
AREA (%)	60	30	10
SLOPE (%)	2-8	2-8	50+
SOIL			
Sy_V	Lithosols	Orthic Solonchaks (petrogypsic phase)	Rock outcrop

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



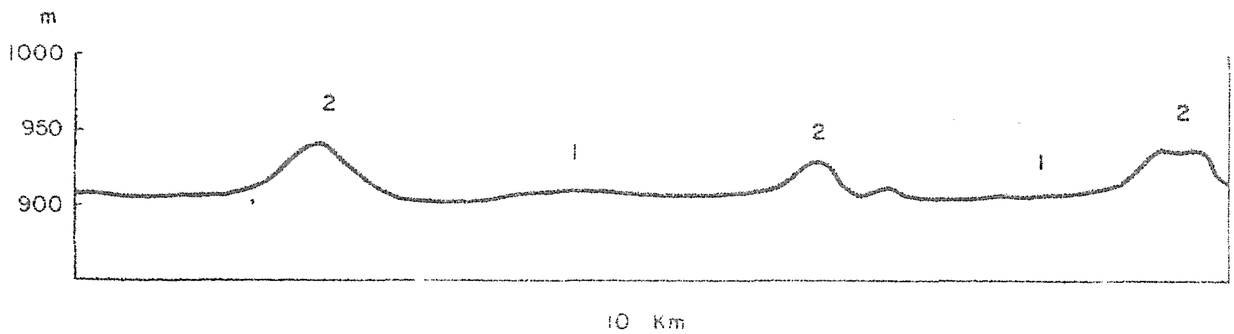
NUMBER	1	2	3
FACET	rolling slopes	undulating slopes	alpine bogs
AREA (%)	50	40	10
SLOPE (%)	8-16	2-8	0-2
SOIL			
Va[1]	Eutric Cambisols	Eutric Cambisols	Dystric Histosols

Va^2 - Afro-alpine summits



NUMBER 1
FACET n.a.
AREA (%) 100
SLOPE (%) 2-8
SOIL
Va^2 Eutric Cambisols

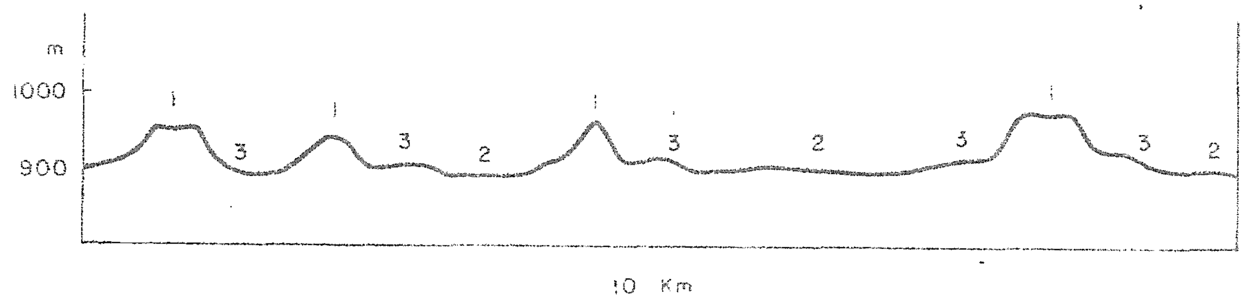
Vb - Low volcanic plains and piedmont zones of the Ethiopian rift



NUMBER	1	2
FACET	piedmont plains	stony outcrop and small cones
AREA (%)	80	20
SLOPE (%)	0-8	8-30
SOIL		
Vb^1	Vertic Cambisols	Rock outcrop and rubble land
Vb^2	Vitric Andosols (lithic phase)	Rock outcrop and rubble land
Vb^3	Eutric Regosols (lithic phase)	Rock outcrop and rubble land

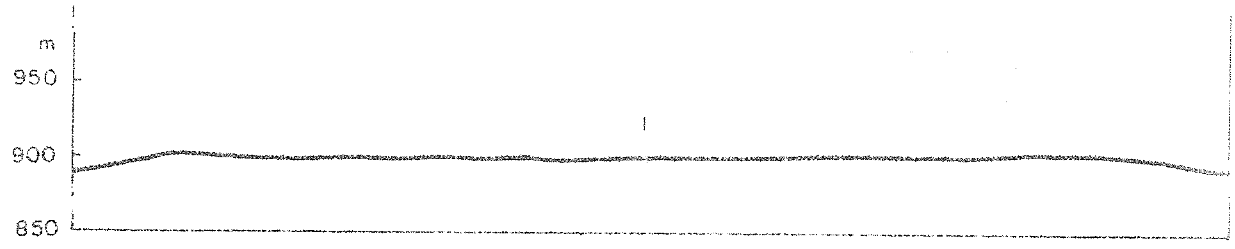
Vc - Complexes of small volcanic cones, vents, craters and other volcanic remnants

Vc^2, Vc^5



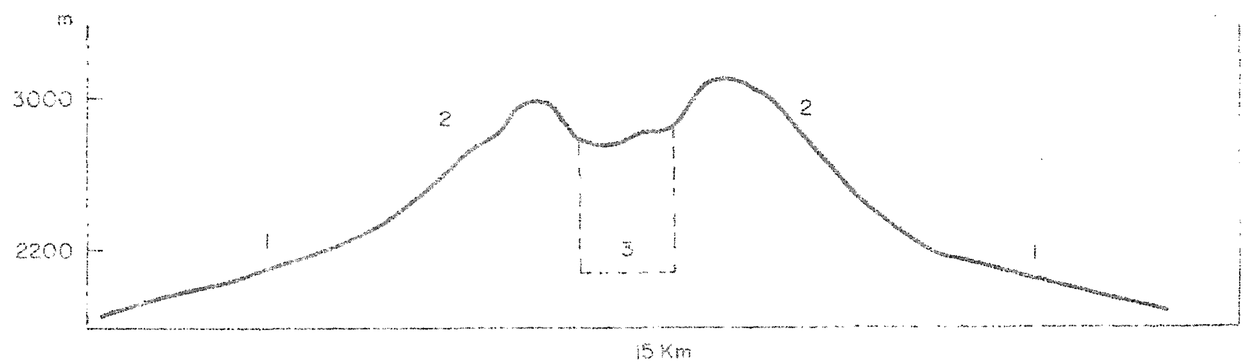
NUMBER	1	2	3
FACET	vent and cone remnants	undulating piedmont plains	lava flows and stony outcrop
AREA (%)	40	30	30
SLOPE (%)	16-30	2-8	0-8
SOIL			
Vc^2	Lithosols	Vitric Andosols (lithic phase)	Rock outcrop and rubble land
Vc^5	Lithosols	Vitric Andosols	Rock otucrop and rubble land

Vf - Lava platforms and plains



NUMBER	1
FACET	n.a.
AREA (%)	100
SLOPE (%)	0-2
SOIL	
Vf[1]	Vertic Cambisols
Vf[2]	Eutric Regosols (lithic phase)

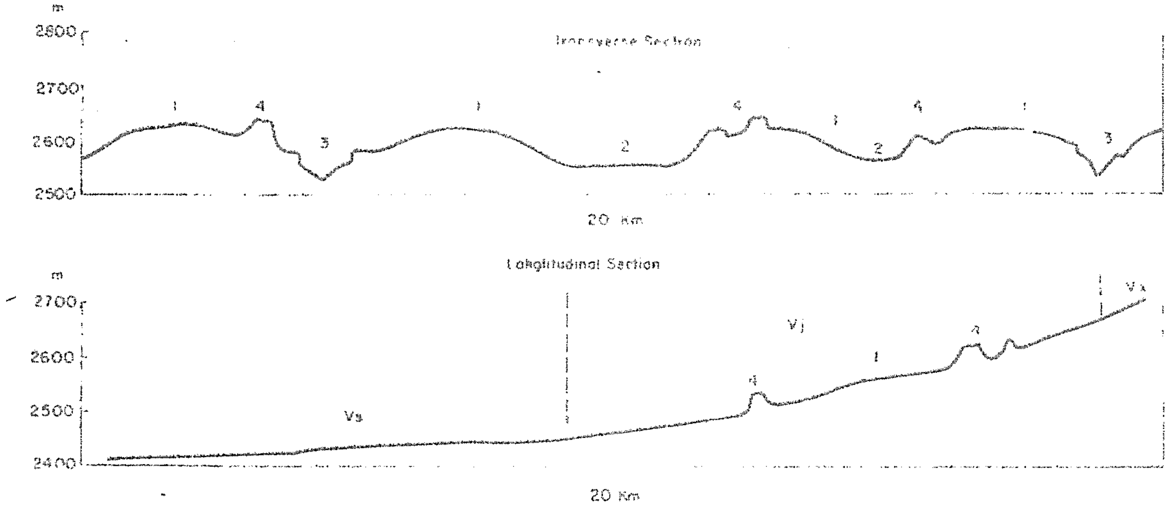
Vh - Degraded extinct central volcanoes, caldera remnants and associated forms of high to mountainous relief



NUMBER	1	2	3
FACET	steep sideslopes	moderately inclined sideslopes	crater floors
AREA (%)	50	40	10
SLOPE (%)	30-50+	16-30	0-8
SOIL			
Vh^{1+}	Chromic Luvisols (stony phase)	Chromic Luvisols	-
Vh^{2+}	Orthic Acrisols (stony phase)	Dystric Nitosols	-
Vh^{3}	Chromic Luvisols	Chromic Luvisols	Pellic Vertisols

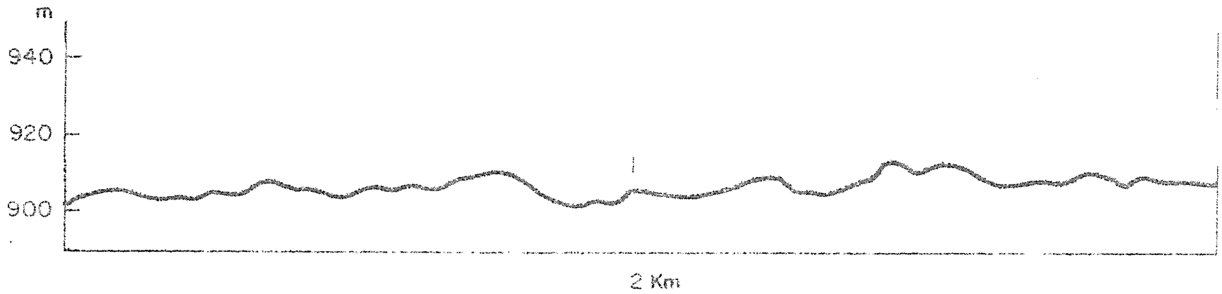
+ Crater floors make up less than 10% in Vh^1 and Vh^2

Vj - Moderately dissected sideslopes of extinct central volcanoes and other relic volcanic forms, often with small cone and vent remnants



NUMBER	1	2	3	4
FACET	convex hills	basins	steep cut stream channels	vent and cone remnants
AREA (%)	60	20	10	10
SLOPE (%)	8-16	0-8	50+	16-50
SOIL				
Vj^1	Eutric Nitosols	Pellic Vertisols	Lithosols	Chromic Cambisols (lithic phase)
Vj^2	Eutric Regosols (lithic phase)	Eutric Cambisols (stony phase	Lithosols	Eutric Regosols (lithic phase)
Vj^3	Dystric Nitosols	Dystric Nitosols	Lithosols	Orthic Acrisols (stony phase)
Vj^4	Eutric Cambisols (stony phase)	Vertic Cambisols (stony phase)	Lithosols	Eut[illegible] Cambisols (lithic phase)

V1 - Lava flows



NUMBER 1

FACET n.a.

AREA (%) 100

SLOPE (%) 2-16

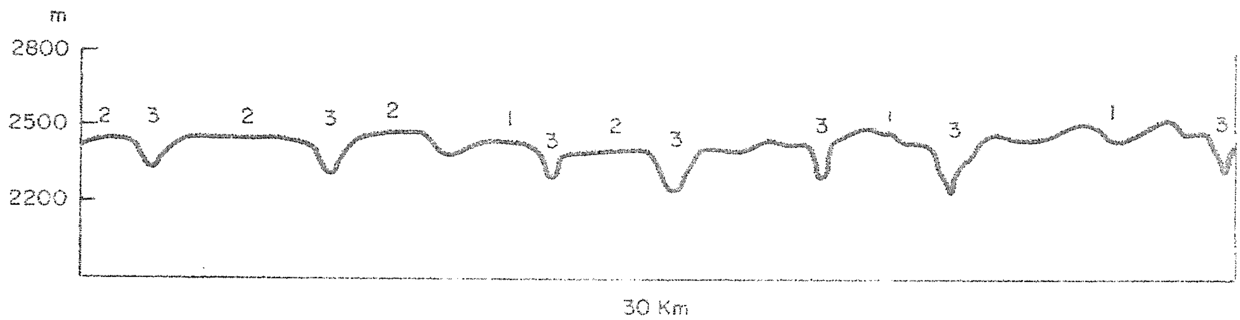
SOIL

V1[1] Rock surface

V1[2] Rock surface

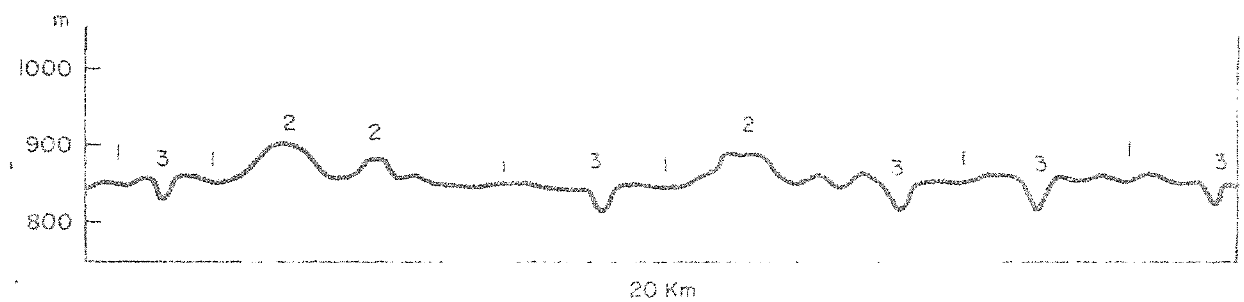
V1[3] Lithosols

Vn - Moderately dissected volcanic plateaux



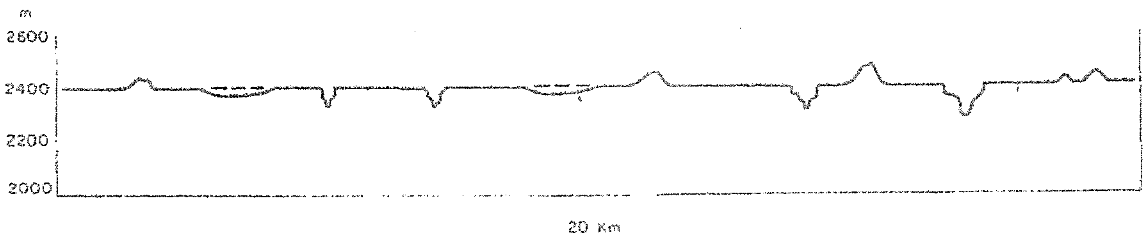
NUMBER	1	2	3
FACET	rolling plateaux	undulating plateaux	steep cut stream channels and dissected sideslopes
AREA (%)	40	30	30
SLOPE (%)	8-16	2-8	30-50+
SOIL			
Vn^1	Eutric Cambisols (stony phase)	Vertic Cambisols (stony phase)	Lithosols
Vn^2	Eutric Nitosols	Eutric Nitosols	Lithosols

Vo - Complexes of dissected volcanic piedmont plains, lava platforms and associated cones, vents and crater remnants



NUMBER	1	2	3
FACET	undulating plateau	low relief hills, volcanic cone remnants and lava flows	steep cut stream channels, dissected sideslopes and escarpments
AREA (%)	50	30	20
SLOPE (%)	2-8	8-30	30-50+
SOIL			
Vo^1	Eutric Regosols (stony phase)	Lithosols	Lithosols
Vo^2	Eutric Regosols (lithic phase)	Lithosols	Rock outcrop

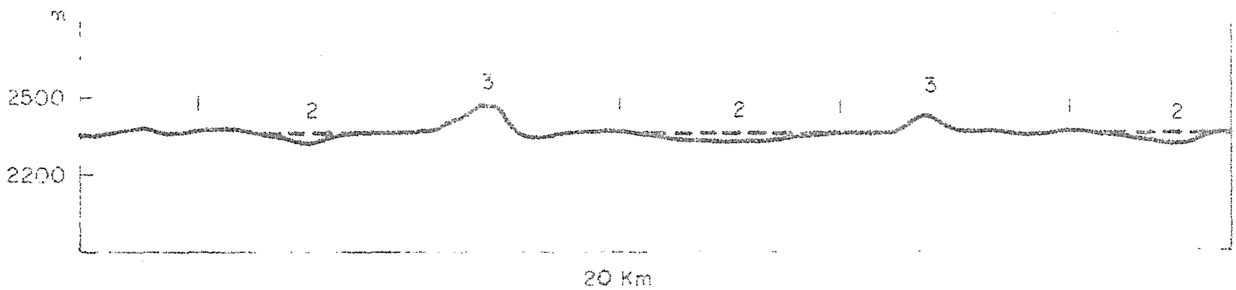
- Undulating high plateaux formed predominantly on pyroclastic deposits



BER	1	2	3	4
ET	undulating plateaux	small volcanic vent and cone remnants	depressions with seasonal drainage deficiencies	steep cut and/or severely eroded ravines
A (%)	70	10	10	10
PE (%)	0-8	16-30	0-2	50+
L				
	Pellic Vertisols	Chromic Cambisols (lithic phase)	Pellic Vertisols	Rock outcrop
+	Calcic Chernozems	-	Mollic Gleysols	-
	Vertic Cambisols	Eutric Cambisols (lithic phase)	Eutric Gleysols	Rock outcrop

In Vp^2 depressions with seasonal drainage deficiencies made up 30 percent; small volcanic vent and cone remnants and steep cut and/or severely eroded ravines are absent

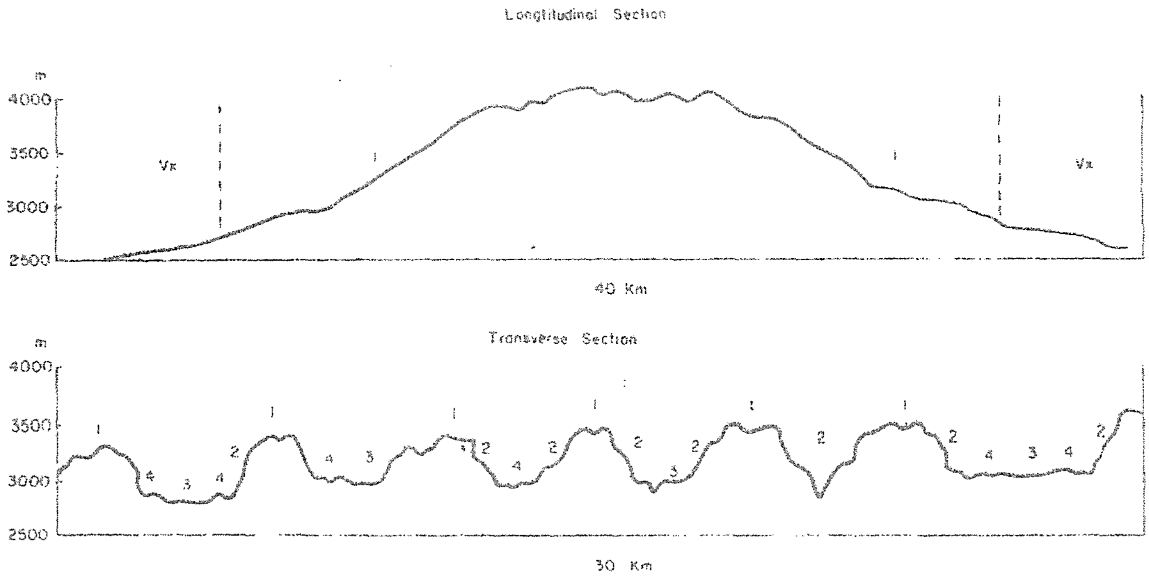
Vq - High volcanic piedmonts and lava plateaux
Vq^1, Vq^2



NUMBER	1	2	3
FACET	piedmont plains and lava plateaux	marshy depressions	low relief hills
AREA (%)	70	20	10
SLOPE (%)	0-8	0-2	8-16
SOIL			
Vq^1	Pellic Vertisols	Pellic Vertisols	Eutric Nitoosls
Vq^{2+}	Vertic Cambisols (stony phase)	Pellic Vertisols	Chromic Cambisols (stony phase)

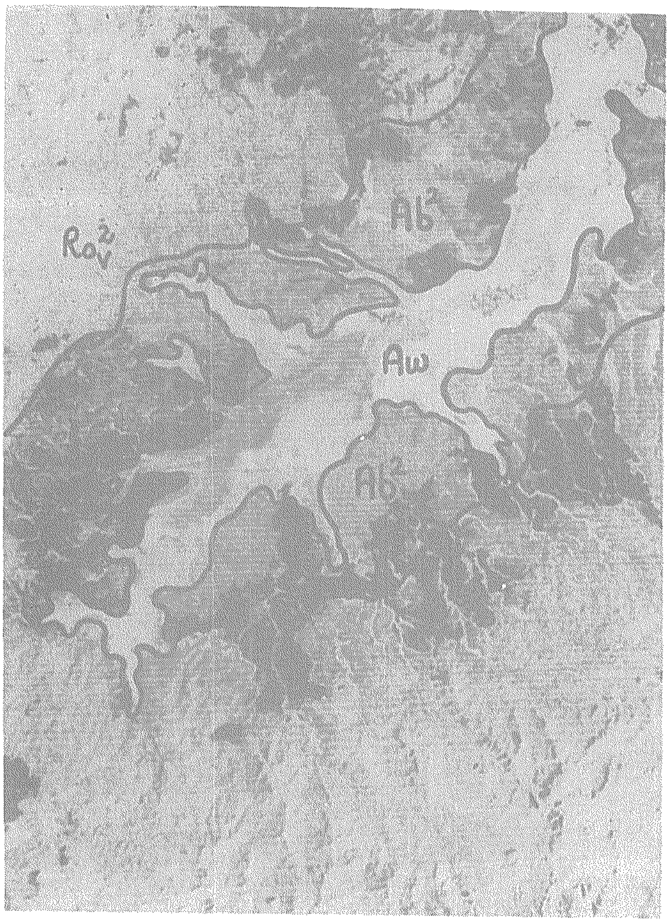
\+ In Vq^2 the low relief hills make up 20 percent

Vz^3



NUMBER	1	2	3	4
FACET	convex radial ridges	very steep valley sides and incised stream channels	valley bottoms	rolling intermontane valleys
AREA (%)	50	30	10	10
SLOPE (%)	16-30	30-50+	0-8	8-16
SOIL Vz^3	Chromic Luvisols (stony phase)	Lithosols	Eutric Nitosols	Chromic Luvisols

PLATE 1

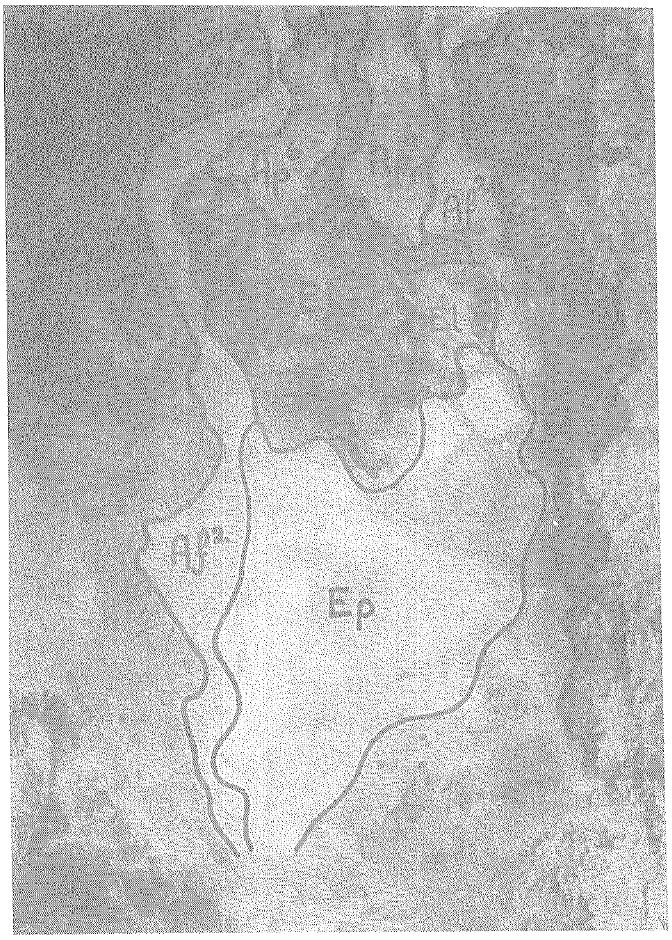


Landsat B & W Band 7 184-054

30 km

LANDSCAPE UNITS : Aw, Ab^2, Ro$_v^2$

PLATE 2

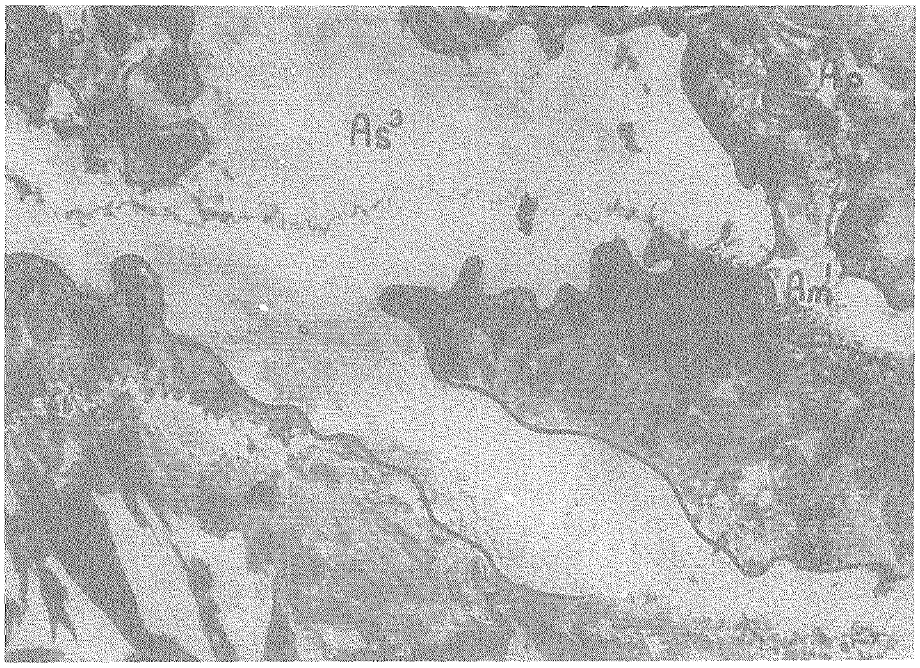


Landsat B & W Band 7 181-057

30 km

LANDSCAPE UNITS : Af^2, Ap^6, Am^4, El, Ep

PLATE 3

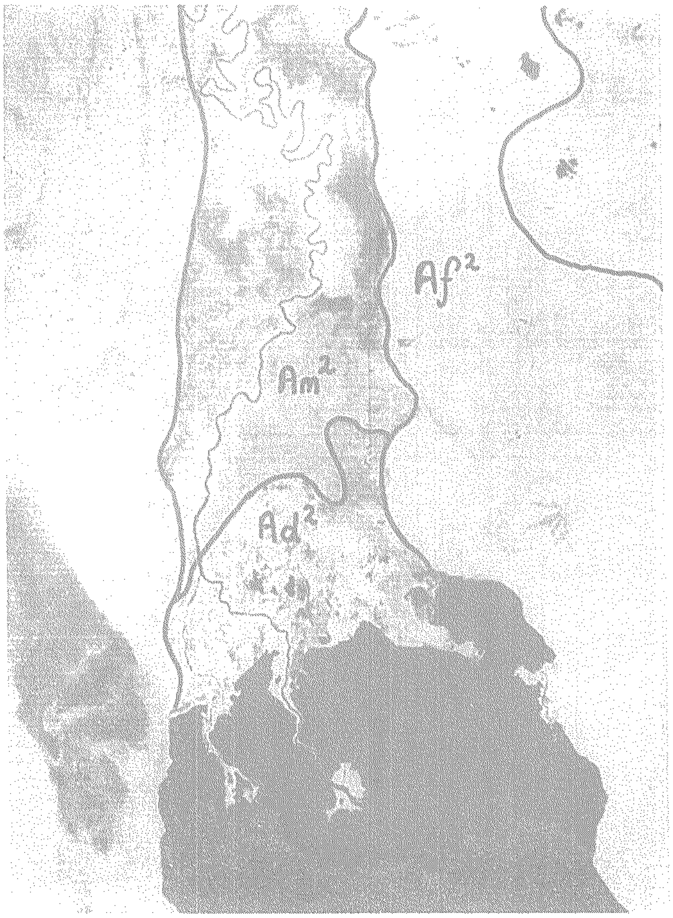


Landsat B & W Band 7 184-055

30 km

LANDSCAPE UNITS : Ap^1, As^3 , Am^1

PLATE 4

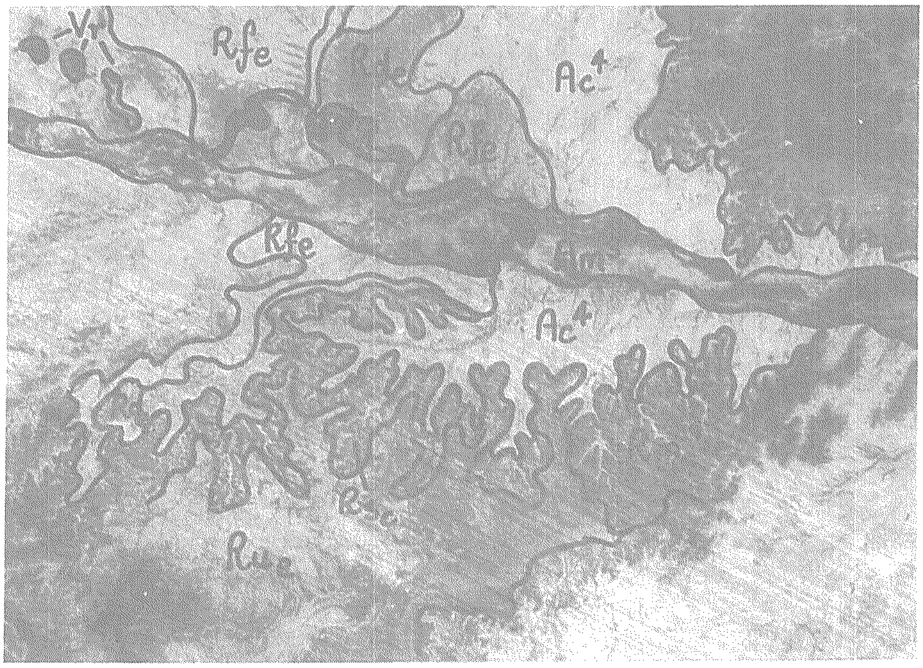


Landsat B & W Band 7 182-057

30 km

LANDSCAP UNITS : Ad^2, Af^2, Am^2

PLATE 5



Landsat B & W Band 7 177-056

30 km

LANDSCAPE UNITS : Am^3, Ac^4, Rd_e , Rf_e , Rm^1_c, Rs_c, Ru_e

PLATE 8

Landsat B & W Band 5 181-055

30 km

LANDSCAPE UNITS : Al^3 , Aw

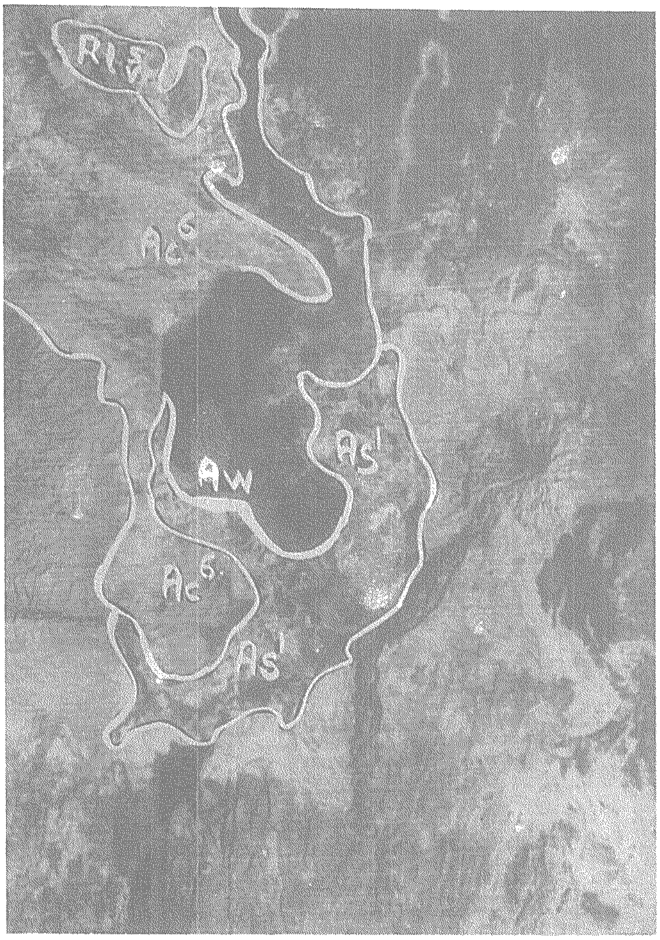
PLATE 9

Landsat B & W Band 7 182-053

30 km

LANDSCAPE UNITS: Ac^1, Rgs, V_q^3

PLATE 10

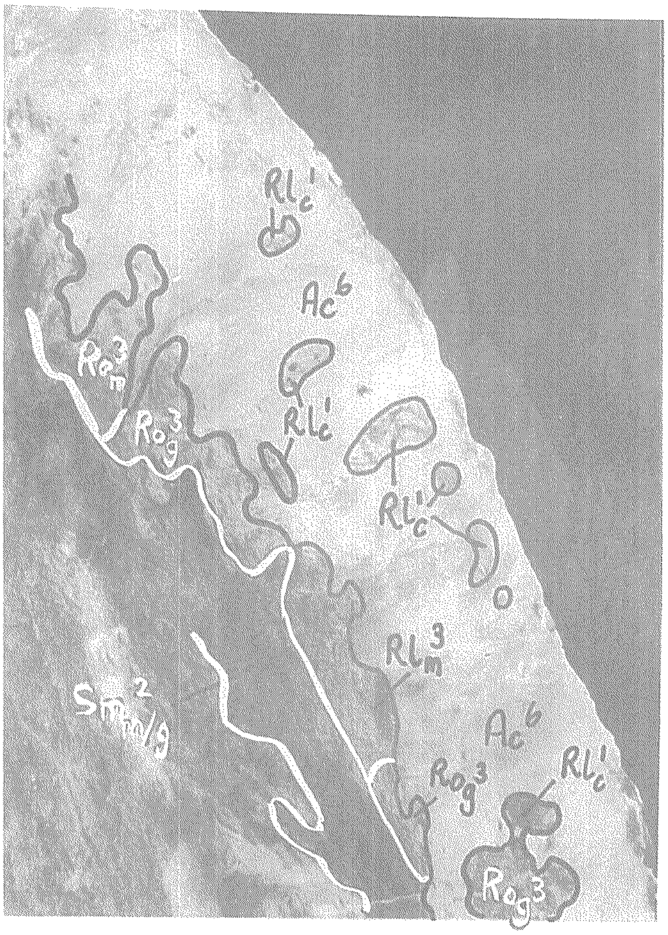


Landsat B & W Band 5 180-053

30 km

LANDSCAPE UNITS: Ac^6, As^1, Aw, Rl_v^5

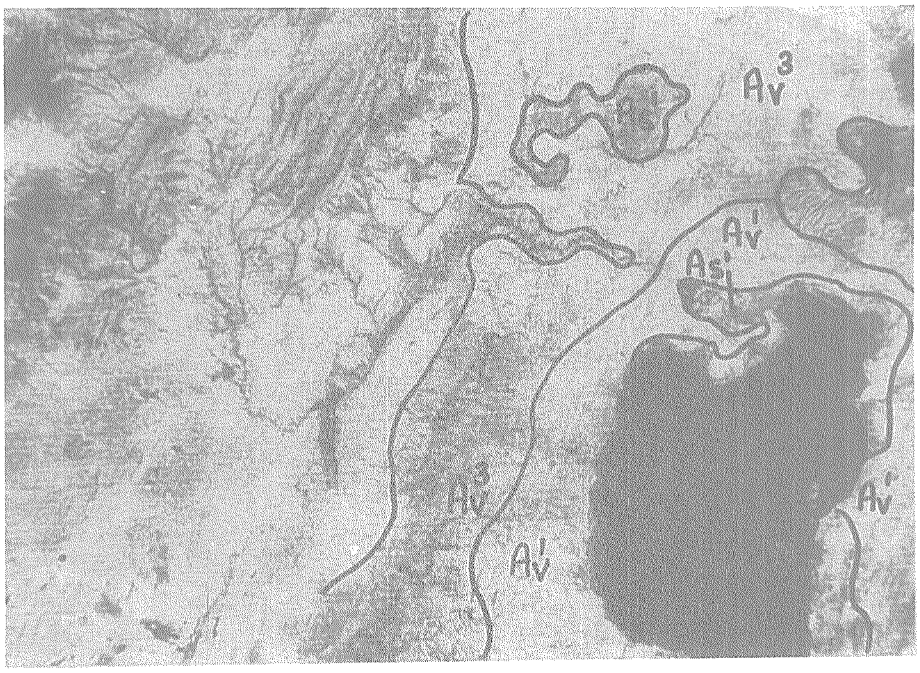
PLATE 11



Landsat B & W Band 5 182-048

30 km

LANDSCAPE UNITS: Ac^6 , Rl_c^1 , Ro_g^3 , Ro_c^1 , Ro_m^1 , $Sm^2_{m/g}$



Landsat B & W Band 7 181-054

30 km

LANDSCAPE UNITS: As^1, Av^1, Av^3

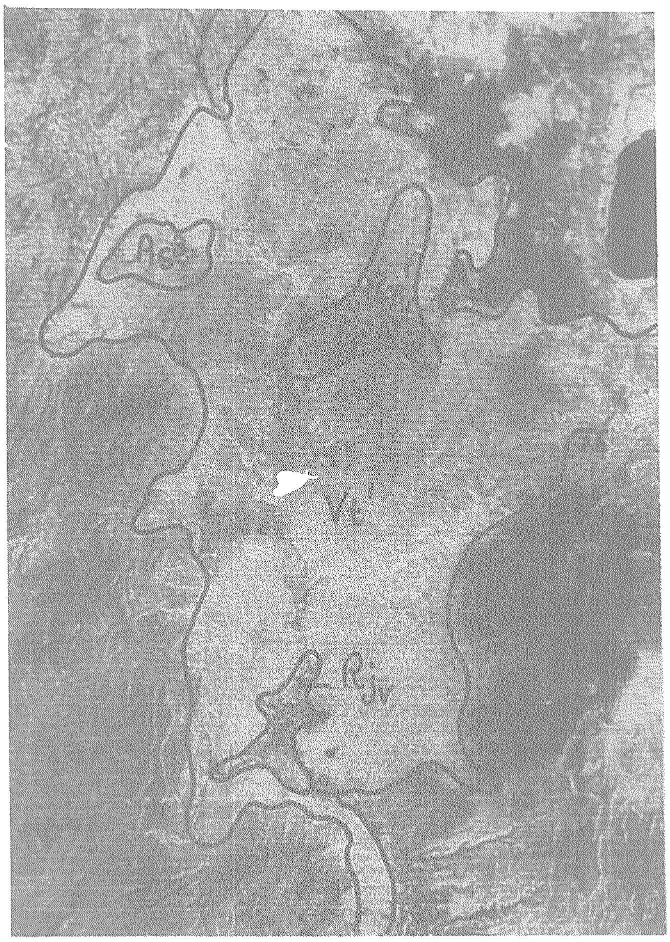
PLATE 13

Landsat B & W Band 7 181-057

30 km

LANDSCAPE UNITS : Vc^2, Vf^2, Vr , Vu

PLATE 15

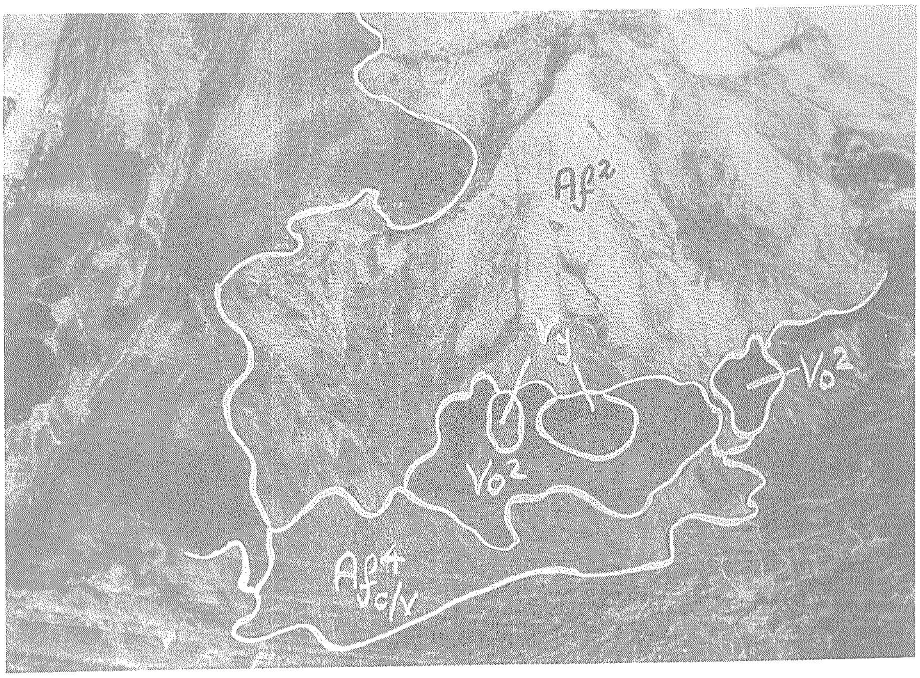


Landsat B & W Band 5 181-055

30 km

LANDSCAPE UNITS : As^3 , Rj_V , Rr^1_V , Vt^1

PLATE 16

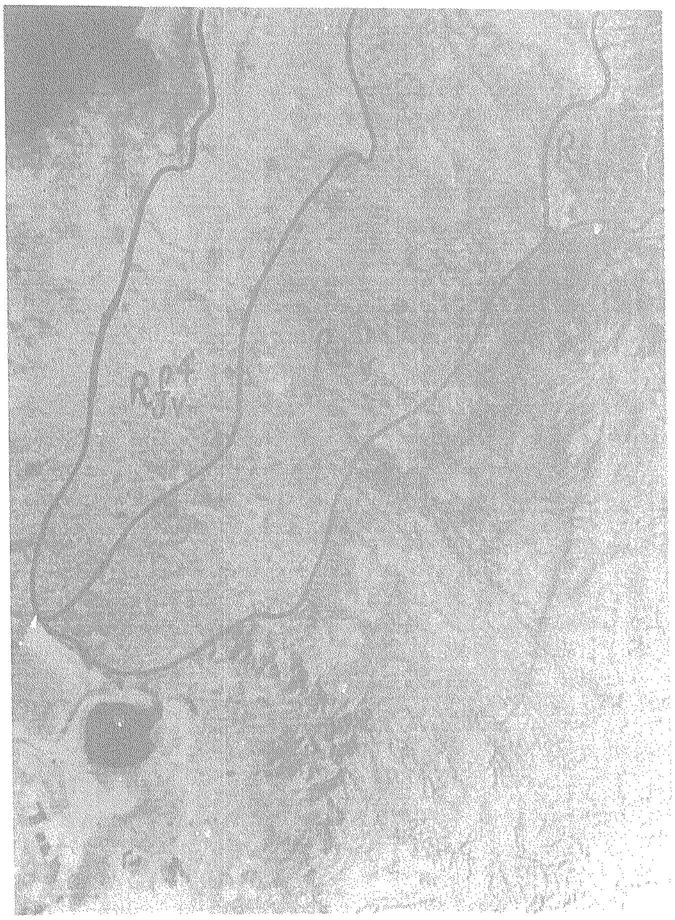


Landsat B & W Band 5 179-053

30 km

LANDSCAPE UNITS: Af^2, Af^4_{clv} , Vo^2 , Vy

PLATE 17

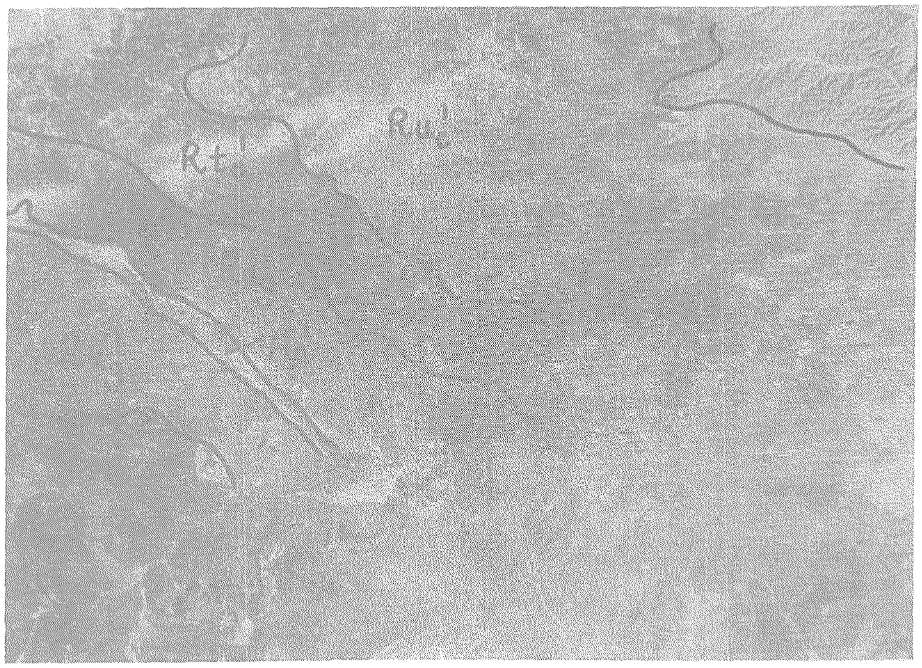


Landsat B & W Band 7 180-055

30 km

LANDSCAPE UNITS : Rf^{4}_{v} , Rs^{1}_{v} , Rt^{1}_{v}

PLATE 18

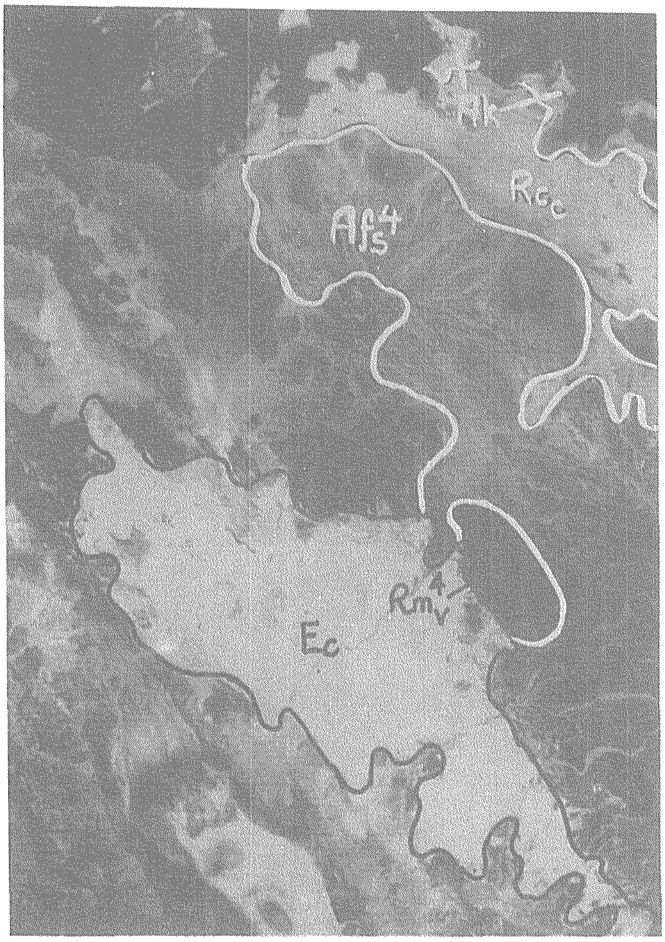


Landsat B & W Band 5 179-057

30 km

LANDSCAPE UNITS : An^1 , Rt^1_c , Ru^1_c, Ru^1_g

PLATE 19

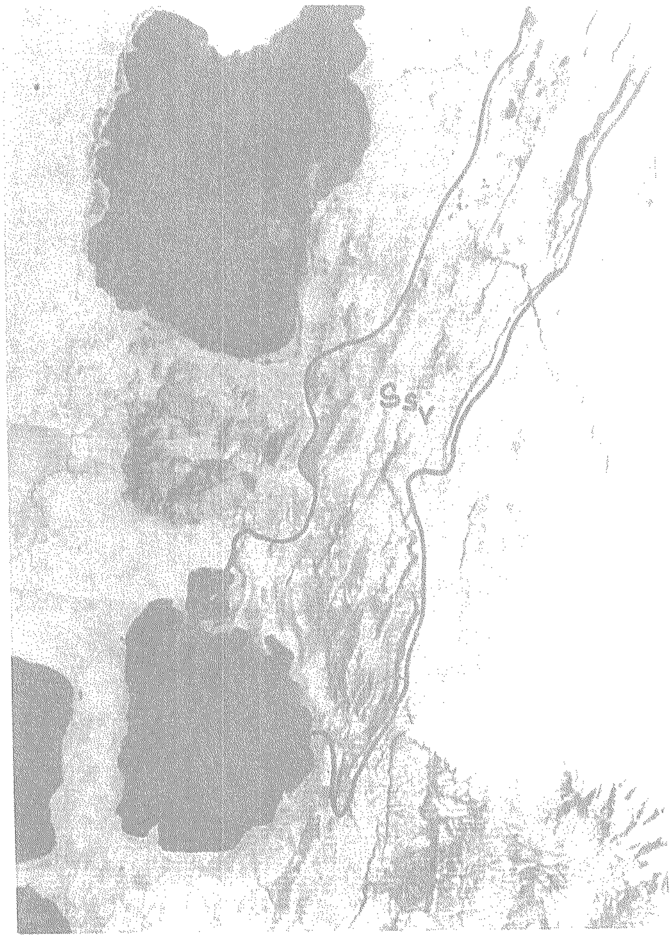


Landsat B & W Band 7 181-030

30 km

LANDSCAPE UNITS : Af_S^4 , Ak, E_C , Rc_C , Rm_V^4

PLATE 20



Landsat B & W Band 7 180-055

30 km

LANDSCAPE UNITS : S_{Sv}

PLATE 21

Landsat B & W Band 5 181-051

30 km

LANDSCAPE UNITS : Rd_g^5 , Ru_g^4 , Sk_c, Sl_m

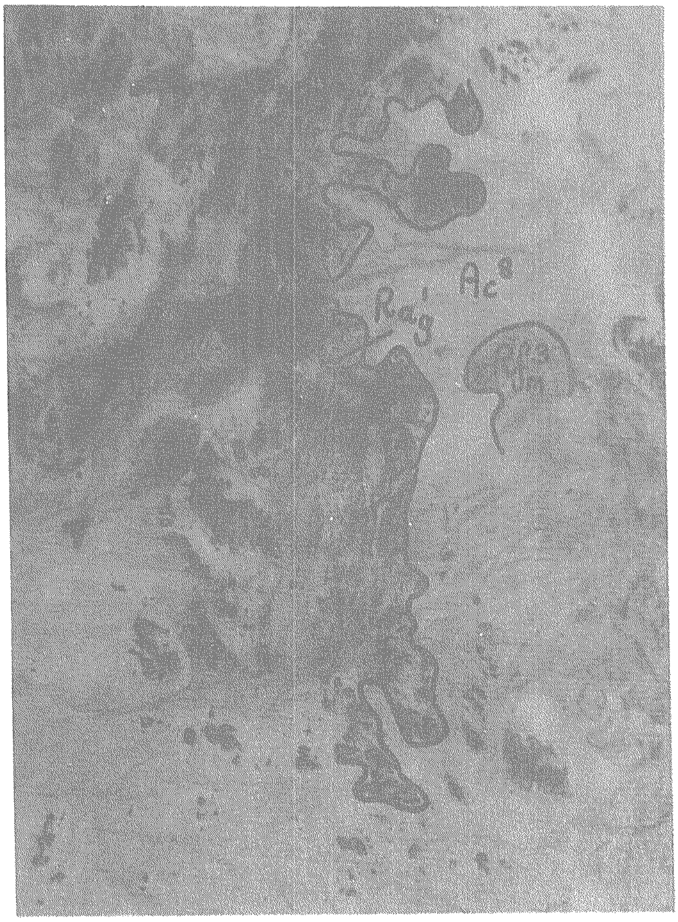
PLATE 22

Landsat B & W Band 5 180-057

30 km

LANDSCAPE UNITS: Ab^1 , An^1, Rb_g^1 , Rd_g^5 , Rn_g^3 , Ru_g^4, Sh_g^3

PLATE 23



Landsat B & W Band 7 180-057

30 km

LANDSCAPE UNITS : Ac^{8}, Ra^{1}_{g} , Rf^{3}_{m}

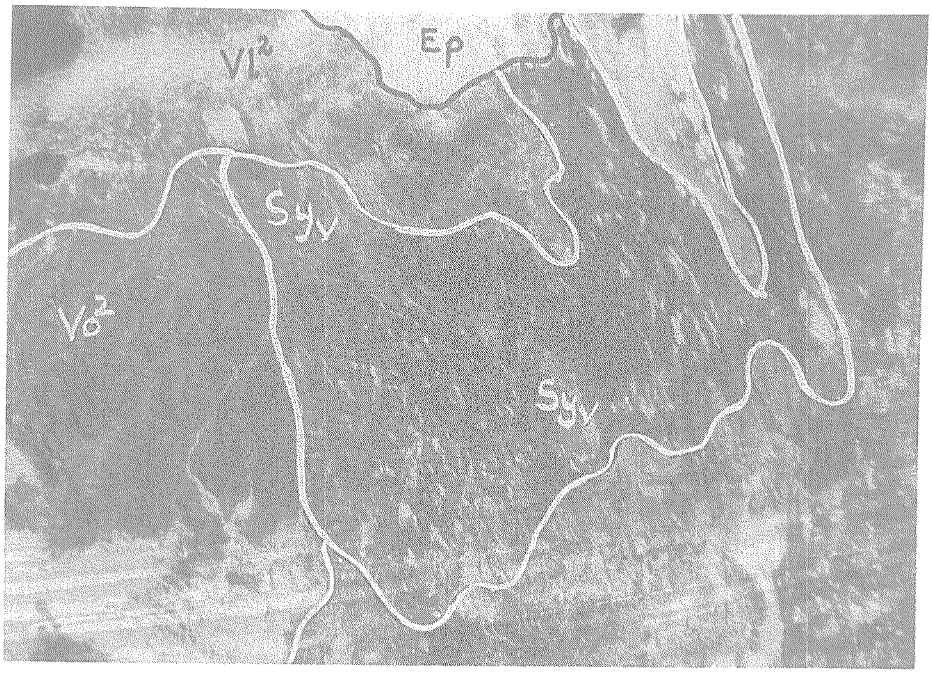
PLATE 24

Landsat B & W Band 7 180-057

30 km

LANDSCAPE UNITS : Rm^3_g , Sh^3_g , Vc^2

PLATE 25

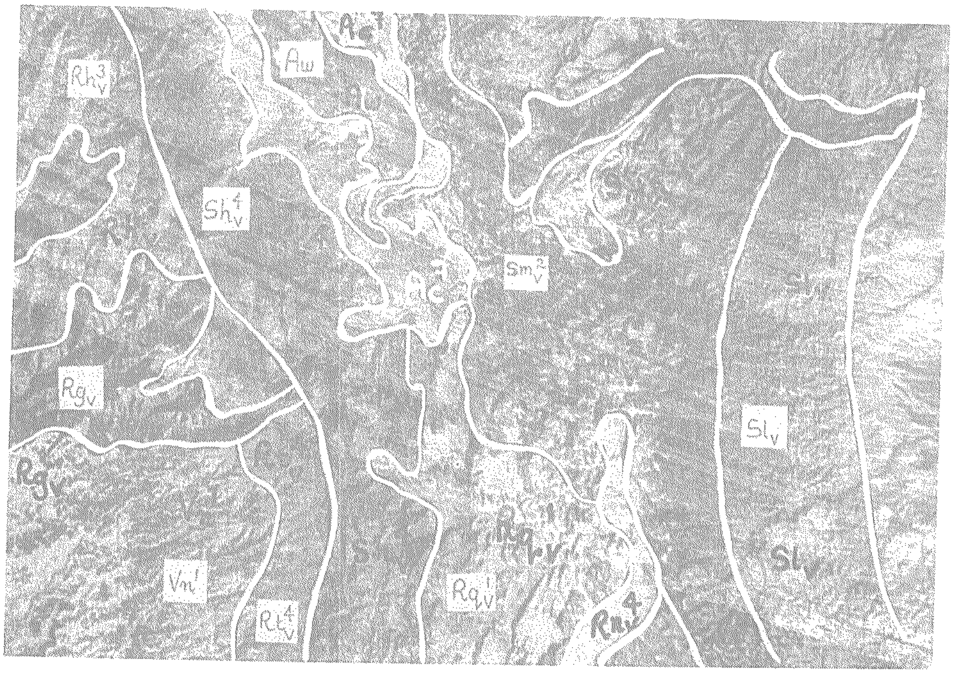


Landsat B & W Band 7 180-051

30 km

LANDSCAPE UNITS : Ep , Sy_v , Vl^2 , Vo^2

PLATE 26



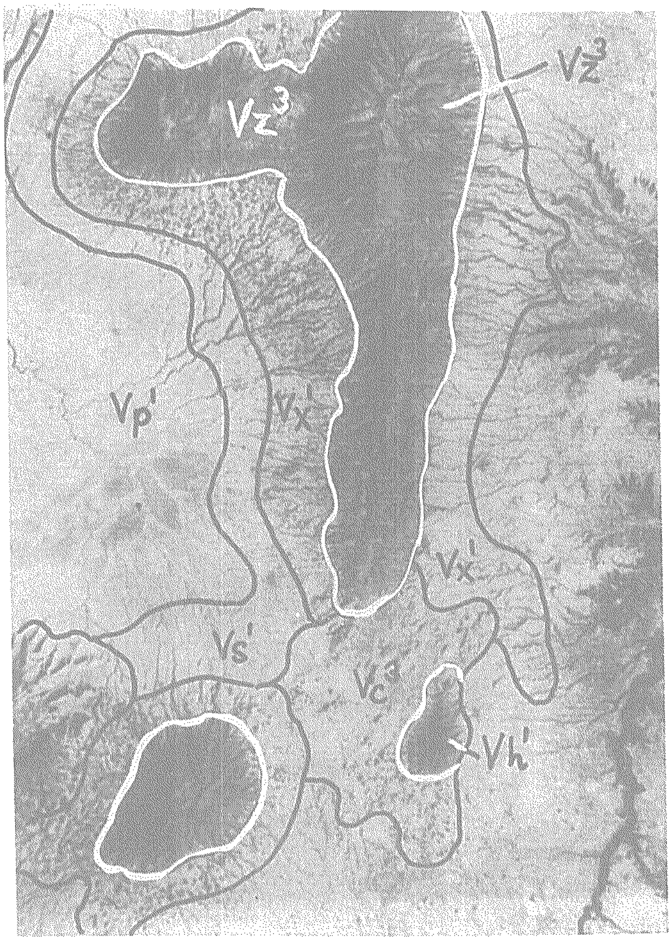
Landsat B & W Band 5 180-053

30 km

LANDSCAPE UNITS : Ac^7, Aw, Rg_V, Rh_V^3, Rq_V^1, Rt_V^4

Sh_V^4, Sl_V, Sm_V^2, Vn^1

PLATE 27

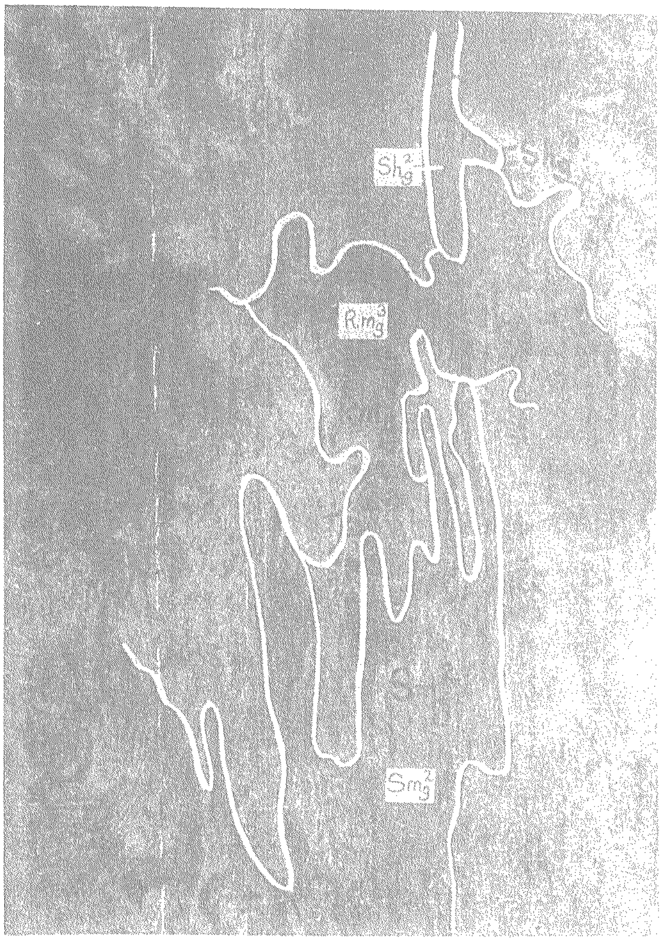


Landsat B & W Band 5 180-055

30 km

LANDSCAPE UNITS : Vc^3, Vh^1, Vp^1, Vs^1, Vx^1, Vz^3

PLATE 28

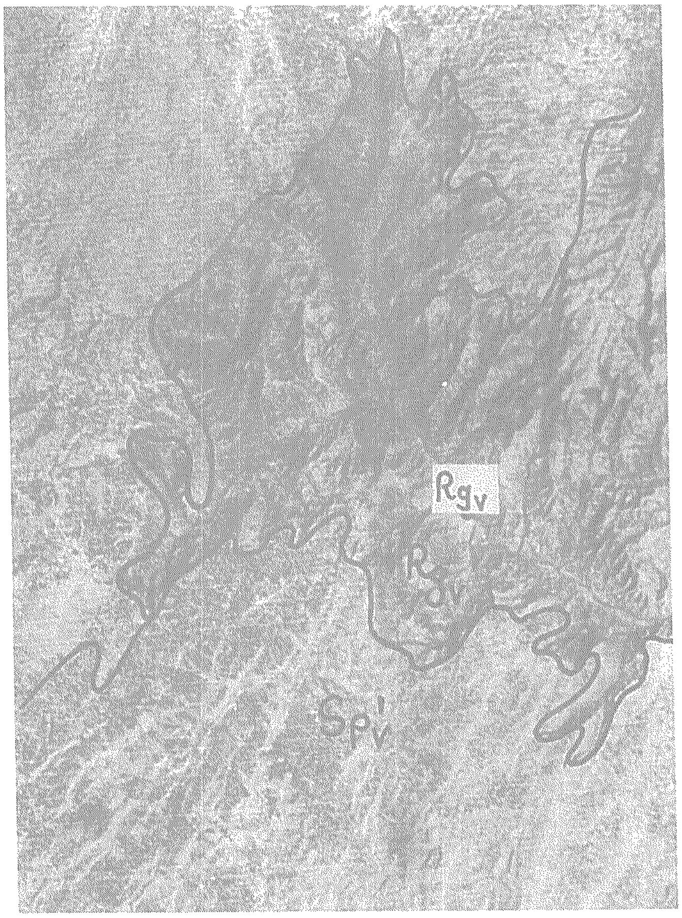


Landsat B & W Band 5 180-056

30 km

LANDSCAPE UNITS : Rm_g^3, Rh_g^2, Sh_g^2, Sm_g^2

PLATE 29

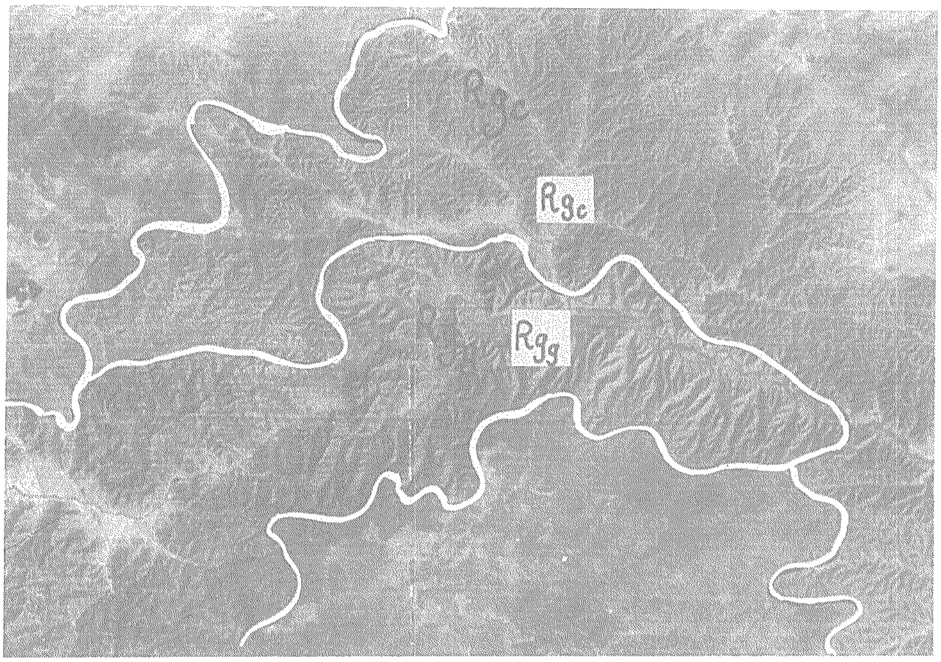


Landsat B & W Band 5 180-054

30 km

LANDSCAPE UNITS : R_{g_v} , Sp^1_v

PLATE 30

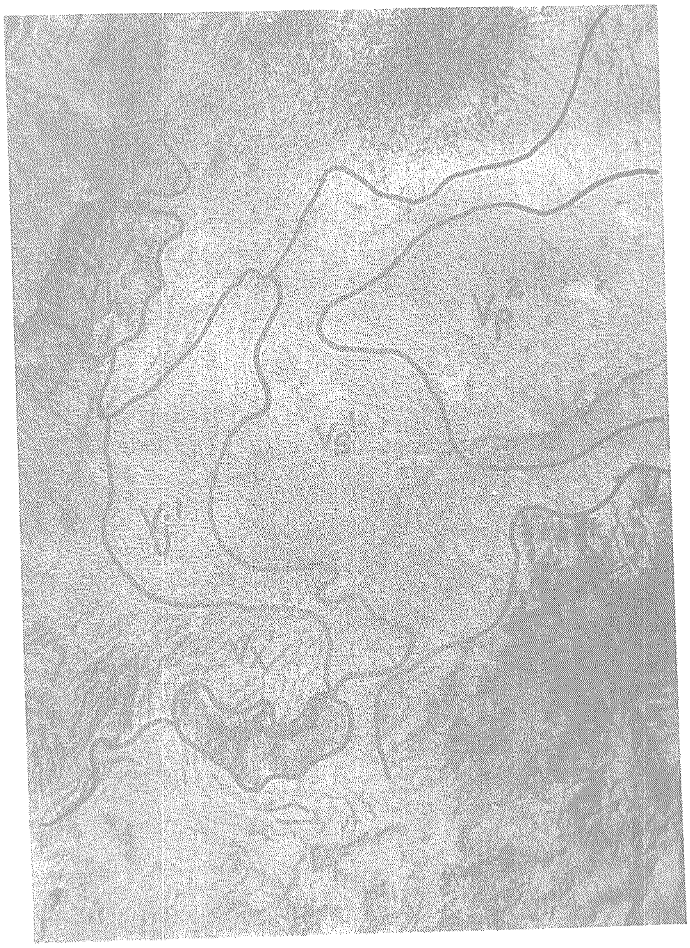


Landsat B & W Band 5 179-057

30 km

LANDSCAPE UNITS : R_{gc} , R_{g_g}

PLATE 31

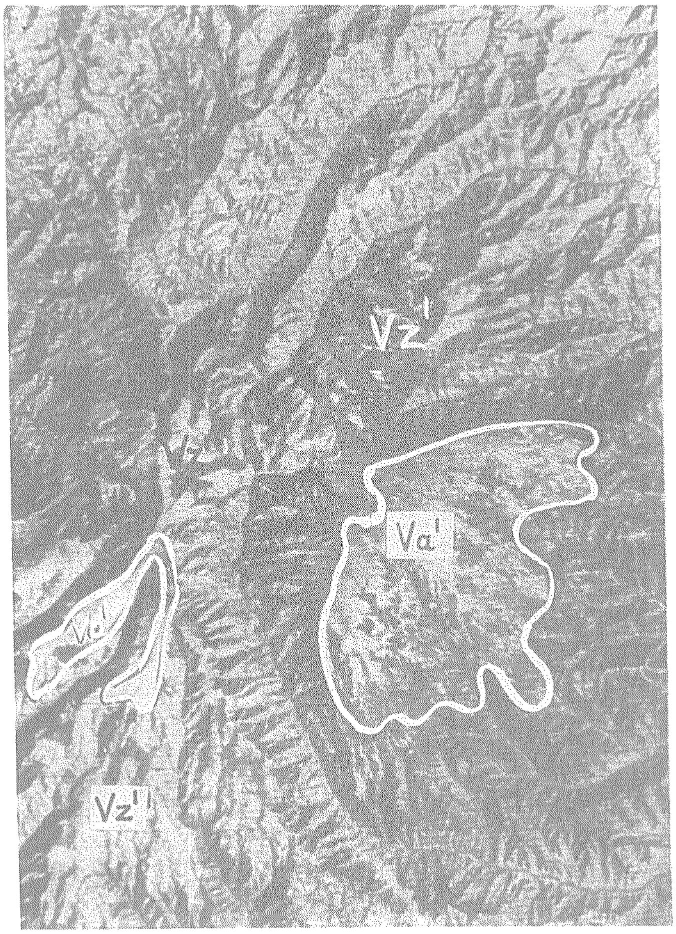


Landsat B & W Band 7 180-055

30 km

LANDSCAPE UNITS : Vh^1, $V_j{}^1$, $V_p{}^2$, Vs^1, Vx^1

PLATE 32

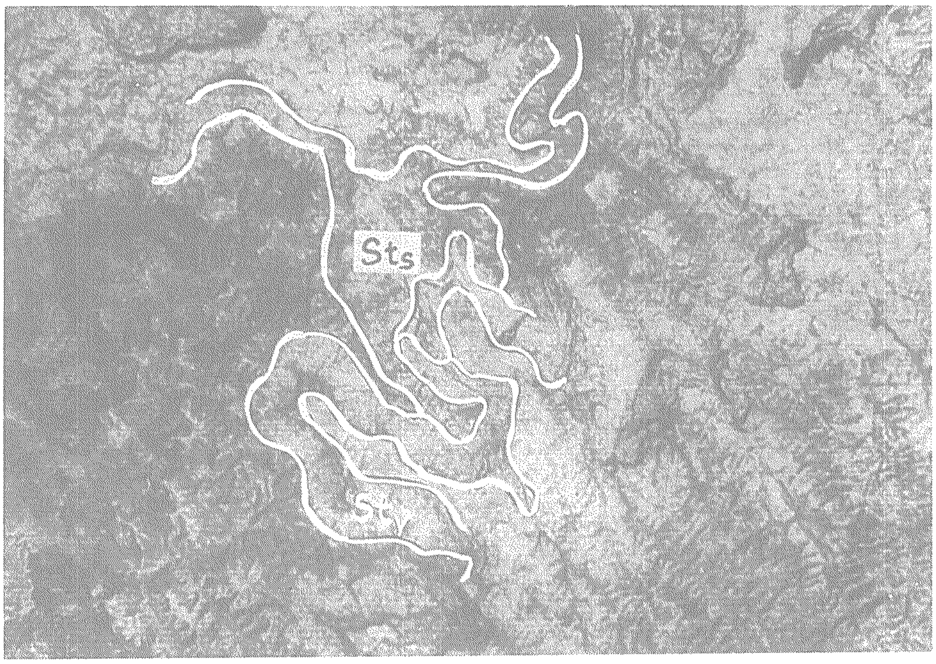


Landsat B & W Band 7 182-051

30 km

LANDSCAPE UNITS : V_a^{1} , V_z^{1}

PLATE 33

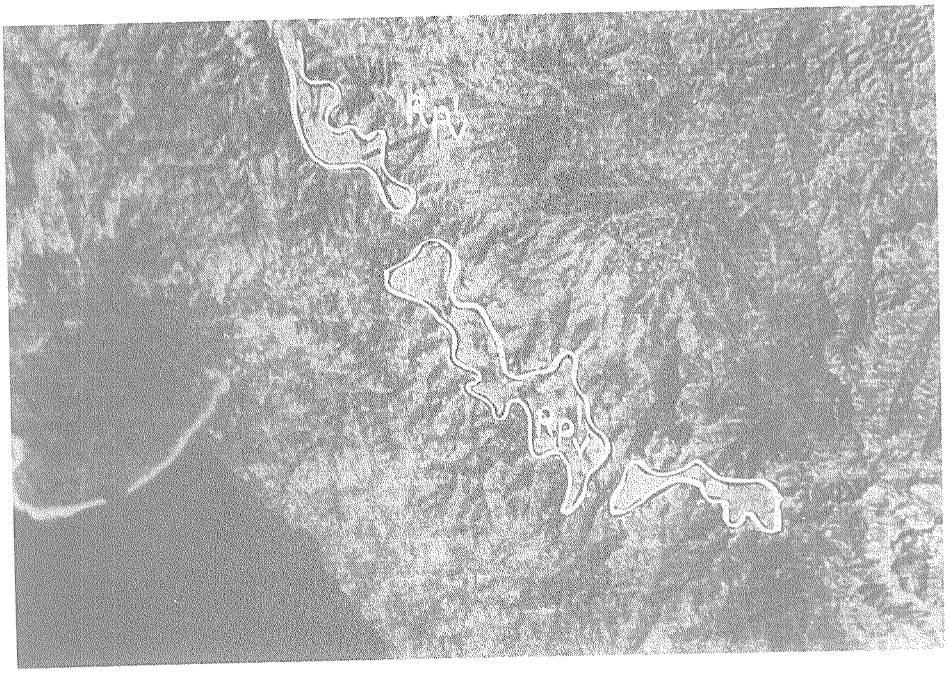


Landsat B & W Band 5 181-054

30 km

LANDSCAPE UNITS : St_S , St_V

PLATE 34

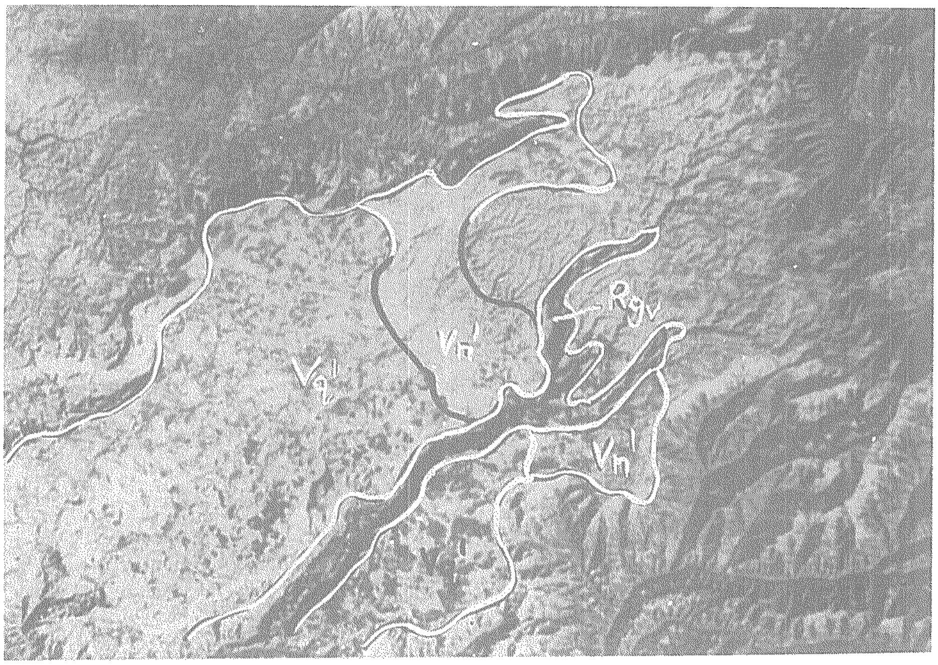


Landsat B & W Band 5 182-051

30 km

LANDSCAPE UNITS : $R_{p_V}^1$

PLATE 35

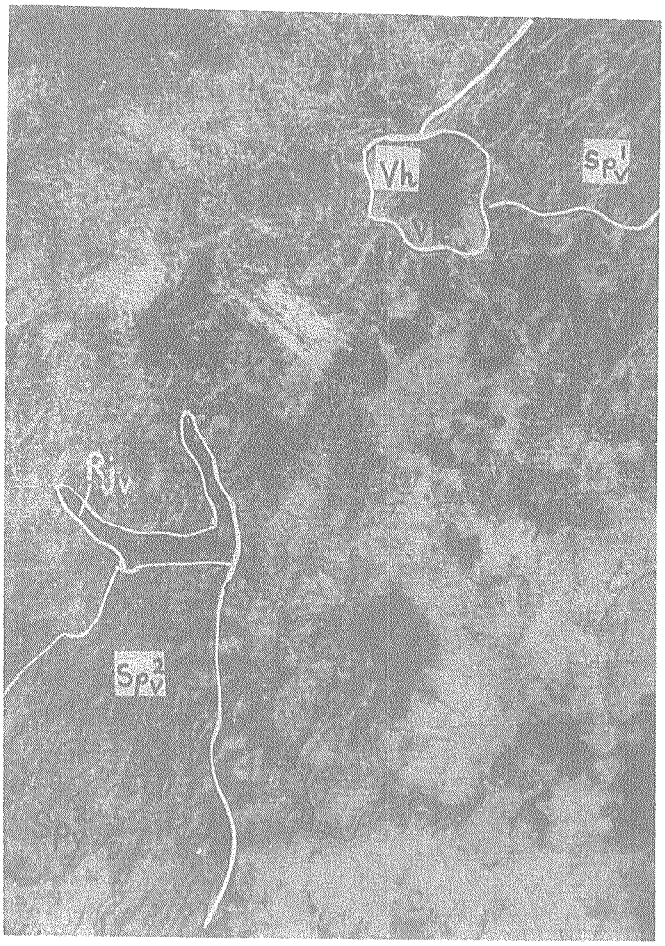


LANDSAT B & W Band 5 181-052

30 km

LANDSCAPE UNITS : R_{g_v} , V_q^1 , V_n^1

PLATE 36

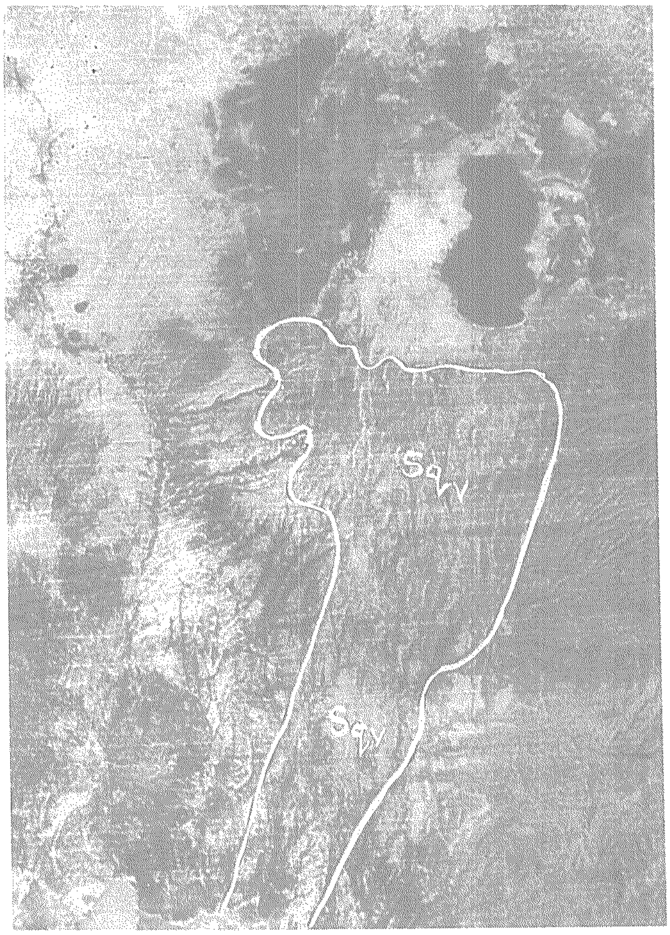


Landsat B & W Band 7 181-054

30 km

LANDSCAPE UNITS : $S_{p_V}^{1}$, $S_{p_V}^{2}$

PLATE 37

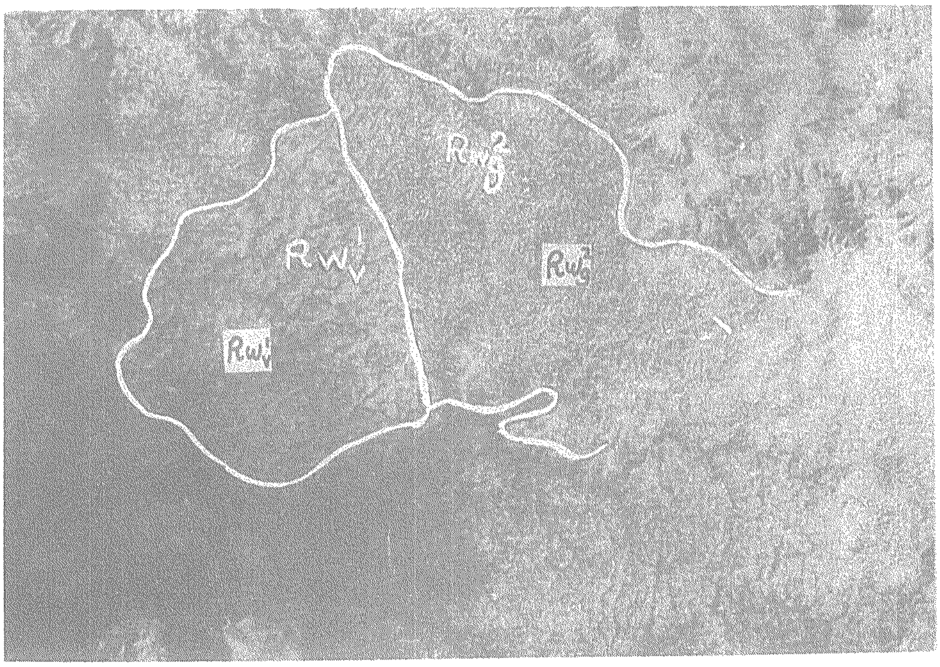


Landsat B & W Band 181-055

30 km

LANDSCAPE UNIT : S_{q_v}

PLATE 38



Landsat B & W Band 5 183-053

30 km

LANDSCAPE UNITS : Rw_g^2 , Rw_v^1

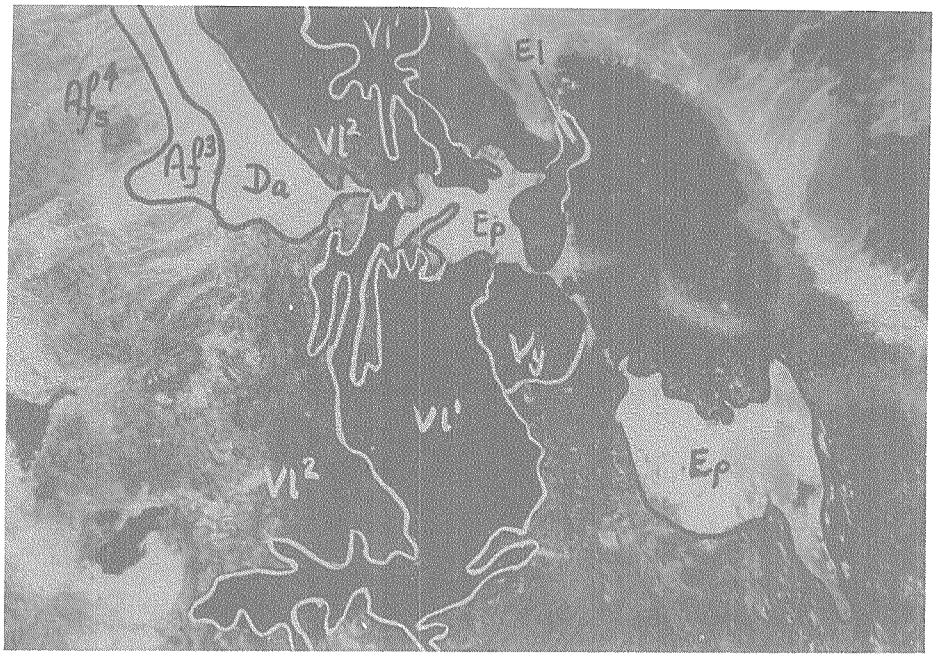
PLATE 39

Landsat B & W Band 5 182-052

30 km

LANDSCAPE UNITS: Rk_v^2 , $R{y_v}^1$

PLATE 40



Landsat B & W Band 5 180-051

30 km

LANDSCAPE UNITS : Af^3 , Af^4_S , Da, Vl^1, Vl^2

CHAPTER 5

SOILS

5.1 INTRODUCTION

This chapter describes the different soil units of the FAO classification occuring in Ethiopia: their general environment, characteristics, land use and natural vegetation, management and occurence.

For the soil types known to occur, a description of each major soil unit is successively given under the chapter sub-headings 5.2, 5.3 etc. Apart from the general characteristics of the various occuring soil types, details of field and laboratory characteristics are given where available.

As detailed studies are limited, especially in the north, northeast, west and southwest of the country, many soil types, although known to occur are not represented by profiles. Some other soil units may occur in Ethiopia, such as Rankers, Planosols and Ferralsols, but data are essentially un available.

Profile descriptions, test and laboratory data are taken from various existing studies, most listed in paragraph 2.5. As these studies do not all give similar kinds of data concerning soils, the quality and quantity of the soil data thus vary considerably. Also laboratory methods differ, so difficulties can arise in comparing profiles from different studies without first consulting the laboratory methods used.

5.2 HISTOSOLS

5.2.1 FAO classification

Histosols are soils having an Horizon of 40 cm or more (60 cm or more if the organic material consists mainly of sphagnum or moss or has a bulk density of less than 0.1) either extending down from the surface or taken cumulatively within the upper 80 cm of the soil; the thickness of the H horizon may be less when it rests on rock or on fragmental material of which the interstices are filled with organic matter.

Eutric Histosols are Histosols having a pH (H_2O, 1:5) of 5.5 or more at least between 20 and 50 cm from the surface; lacking permafrost within 200 cm of the surface.

Dystric Histosols are Histosols having a pH (H_2O, 1:5) of less than 5.5 at least in some part of the soil between 20 and 50 cm from the surface; lacking permafrost within 200 cm of the surface.

Gelic Histosols are Histosols having permafrost within 200 cm of the surface.

5.2.2 General environment

Permanent swamps and marshes provide the conditions under which Histosols develop their required organic matter contents. With two exceptions such swamps and marshes occur only locally and cover very limited areas in Ethiopia. These exceptions are the Asaita delta at the mouth of the Awash river near the Djibouti border and the Dabus river swamp in western Welega. A third huge swamp, at Fincha-a, is now a lake after the damming of the Fincha-a river.

Permanent swamps and marshes locally occur along major rivers and along lakeshores, in particularly poorly drained sites in the highlands, and along the Red Sea coast. Small bogs occur on the alpine plateaux on top of Mts. Ras Dejen and Batu. In total Histosols cover approximately .5% of Ethiopia.

5.2.3 Management

The severe drainage problems of Histosols, their frequent subsidence if drained, and their tendency, where brackish water collects on the Red Sea coast, to develop into acid sulphate soils, generally make these soils unfit for agriculture. In any case, swamps and marshes are often otherwise valuable as for example, wildlife preserves or flood damping areas.

5.2.4 Occurence

Gelic Histosols do not occur in Ethiopia. Dystric Histosols occur in alpine bogs and Eutric Histosols predominate elsewhere.

5.2.5 Profile descriptions

5.2.5.1 Eutric Histosols, Awash river

Because Histosols are not considered as potential agricultural soils in Ethiopia, they almost have not been surveyed. The following is simply an acknowledgement of their presence in the Awash river valley, and gives an indication of the conditions under which Histosols may develop along rivers.

Source: AWASH

Permanently waterlogged organic soils

The permanently waterlogged organic soils cover all the hollows bordering the Awash, where the water flows permanently in the numerous channels. The water often overflows and fills up the ground between the channels. Inside this complex network and are zones which running water reaches only during the floods. In the rainy season they form sheets of water of various depths, with frequently dense aquatic vegetation (water lilies, *Typhas*, *Phragmites*, etc.).

These soils exist especially on the left bank, between Dubti and Asaita, in the Asaita delta to the west of Lake Afembo and to the north of Lake Bario. Almost impenetrable, the zones offer little possibility of potential development, but serve as flood damping reservoirs for the Asaita delta area. Numerous aquatic animals live in this marsh region.

5.3 LITHOSOLS

5.3.1 FAO classification

Lithosols are soils which are limited in depth by continuous, coherent, hard rock within 10 cm of the surface.

5.3.2 General environment

Lithosols are probably the most common soils in Ethiopia covering over 16% of the country. They occur throughout the country, wherever, in combination or individually, slopes are too steep, climate too dry, or parent materials geologically too young -- as recent lava flows are -- to have permitted any significant degree of soil development. In Ethiopia, there is the additional factor of severe recent erosion on cultivated slopes creating Lithosols.

The largest extents of Lithosols in Ethiopia are in the Ogaden and in the Danakil, where such soils occur even on moderately sloping land, and in the Blue Nile, Tekezi, Gibe, Wabi Shebele, Genale and Dawa river gorges, where topography is extremely rugged. Lithosols also occur throughout the highland plateau wherever slopes are very steep, on the northeastern escarpment and in the Chercher highlands where both geological and man made erosion are severe, and on the young Quaternary landforms throughout the Rift Valley.

5.3.3 Characteristics

Occuring in all climates and on all parent materials, Lithosols are chemically and physically variable. They are very shallow, young, newly weathered and weathering soils, thus tend to coarse textures and extreme stoniness, and have comparatively good nutrient status.

5.3.4 Land use and natural vegetation

Most Lithosols in Ethiopia are under natural vegetation, which ranges from exposed soil surface in parts of the Ogaden where Lithosols are saline, to forest in the wetter climates. Where population pressure on the land is intense, Lithosols are cultivated and sometimes terraced. In the absence of terraces, such land may produce a good crop for one or two years but erosion soon results in the land being abandoned.

5.3.5 Management

With a 10 cm limit to depth, Lithosols are strictly speaking too shallow for agriculture and are better left to natural vegetation to conserve water in catchment areas, with perhaps some strictly controlled grazing or wood harvesting.

5.3.6 Profile descriptions

5.3.6.1 Lithosol, Ogaden

This profile was taken in southern Harerge. The mean annual rainfall is less than 200 mm and soils of significant depth only develop on colluvial and alluvial deposits on the flattest landforms. The chemical characteristics of this profile reflect the evaporite parent material.

Source: WABI SHEBELE

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

A) General

These soils are formed on the small "cockade shaped" gypsum hills of the main gypsum formation which occupies a very considerable area in all the lower Ogaden to the south of a line Dihun-Kebri Dahar. They are associated with alluvial and colluvial soils with a gypsum differentiation. The association stretches over 20 000 km^2 but the importance of the hills compared to the deposit zones varies according to the region.

South of the Wabi, particularly between El Kere and the Wabi, the gypsum hills are close to one another and water spreading zones are very limited. Temporary rivers flow deeply embanked in the gypsum which is very steeply cut by erosion. Conversely, north of the Wabi between Dihun and Denan and between Gode and Kebri Dehar and north of Imi, water spreading zones predominate, the gypsum hills only forming small grayish rounded peaks scattered in the midst of alluvial deposits and red to yellowish red colluvial deposits.

The gypsum hills present the driest pedoclimate in the lower Ogaden, hence there is particularly scanty vegetation consisting of a very loose bush, approximately 1.5 to 2 m high through which one may move easily when not hindered by the curved thorns of small acacias. The characteristic vegetation association of gypsum zones is represented by Boswellia and Jatropha rivae.

B) Profile description

0-10	AR	Yellowish grey (2.5 Y 8/4); silty loam; single grained structure; powdery; some rootlets; sudden transition to:
10 + cm	R	Greyish white translucent gypsum slab.

Consequently the soil layer is very thin and the gypsum slab often outcrops at the surface forming concentric lines around the hills and thus conferring a "cockade" aspect. The flashes of light, observed from planes are due to sunlight reflected on the gypsum sheets acting as mirrors. Colluvial local deposits may also be observed but these soils are deeper.

The upper horizon consists of a regular gypsum powder resting on the gypsum slab. Disaggregation and exfoliation in situ of the gypsum slab may be observed. Part of this gypsum is solubilized by rain water and accumulated in water spreading zones on colluvial or alluvial deposits located in lower positions and provides these soils with crusts but on the hills there is no neocrystallization of gypsum.

C) Physical and chemical characteristics

The yellowish grey to yellowish white superficial horizon therefore consists of very finely divided gypsum mixed with a small quantity of organic matter corresponding to less than 1 percent. pH is approximately 8.0 but the high conductivity of the saturation extract which varies from 10 to 15 mmhos/cm reveals the presence of a great quantity of soluble salts mainly composed of sodium chloride and gypsum.

D) Cultural and pastoral fitness

These soils are unsuitable for cultivation. During the rainy season they constitute meagre pasture grounds which are nevertheless relished by animals because of the high mineral element content (especially salt) of plants. These pastures would constitute a vast game reserve along the Wabi Shebele.

5.3.6.2 Lithosol, Addis Abeba

This profile comes from the hills surrounding Addis Abeba. The soil has a good inherent fertility and despite its depth, is cultivated. It should be noted that where Lithosols occur, soils are rarely consistently shallow. Bare rock and deeper soils occur with the uneveness of the terrain, and where deeper soils exist, crop growth can be quite good. On such very shallow soils, as on this one, ploughing often is done through the weathering parent materials. In some parts of the central highlands, the soil has been totally removed from the surface and crops are planted in the parent material, where this can be broken up. It is, of course, recommended that protective natural vegetation be established on this soil.

Source: LUPRD

A) Profile description:

- Information on the site

Profile no.:	0/37, Addis Abeba
Classification (FAO):	Lithosol
Date:	27 February 1974
Author:	Berhanu Debele
Location:	5 km west of Dire, Shewa

Elevation:	2810 m
Physiographic position:	hill slope
Surrounding landfprm:	hills and mountains
Microtopography:	complex terraces
General slope:	20%
Local slope:	40-50%
Natural vegetation:	Pennisetum, Hyparrhenia, Juniperus
Landuse:	60% cultivation (barley and lentils) and 40% under grazing,
Climate:	humid under temperate
Limitations and hazards:	topography, erosion, soil depth, stoniness and rock outcrop

- Information on the soil

Parent material:	basalt
Permeability:	moderate
Depth of groundwater:	not encountered
Drainage class:	excessive drainage
Moisture condition:	dry throughout
Stoniness:	exceedingly stony
Rock outcrop:	very rocky
Evidence of erosion:	very strong sheet wash and gullying

- Profile description:

0-10/15 cm	Very dark grayish brown (10 YR 3/2) moist; loam; weak very fine angular blocky; loose dry; 70% 10-15 mm stones; abundant fine and very fine roots; porous; clear wavy boundary.
10/15 + cm	Hard weathering basalt.

B) Laboratory data

	Depth (cm) 10/15+
Texture (%,mm)	
2-0.05	40
0.05-0.002	41
0.002	19
pH H_2O	6.0
KCl	4.6
Exchangeable cations (me/100g)	
Na	0.5
K	1.2
Ca	33
Mg	8
sum	42.7
CEC (me/100g)	47.7
Base saturation (%)	90

	Depth (cm) 10/15+
Organic C (%)	2.4
Total N (%)	0.25
C/N	10
Available P_2O_5 (ppm)	23

5.3.6.3 Lithosol, Mekele

This profile comes from near Mekele in Tigray. There are no data for this profile, but slightly deeper soils in the area on doleritic parent materials have neutral to slightly alkaline pHs and high Ca and Mg and low micronutrient contents. As for the soil above, it is recommended that protective natural vegetation be established.

Source: TIGRAI

Dindera series -- very shallow, excessively drained dark reddish brown soils which have sandy clay loam textures overlying in situ basic igneous rock.

A) General

- Environmental characteristics: The series occupies the very steep slopes on hills in the Mekele Plateau and the Adigrat Ridges. The relief is very varied and slopes range from 20 to 60 percent. The soils also occur within the complex of hilly dolerite terrain and occur locally on severely eroded sites on pediment slopes. The soils are rarely cultivated and are used for livestock browsing of the natural Acacia and Dodonaea vegetation. Some remnant juniper forest occurs at high elevation.

- Profile characteristics: The soils comprise a very shallow sandy loam to sandy clay loam, reddish brown (7.5 YR 4/4) horizon overlying hard fractured and weakly weathered igneous rock. Bare rock is exposed in many places. The soils are non-calcareous. Stones and boulders are abundant at the surface.

- Land capability characteristics: The lands are severely limited in potential by the bouldery surface, very shallow soil depth and steep slopes. They should be used for protective natural vegetation only.

B) Profile description

- Information on the site

Profile no.:	10, MS/15
Soil name:	Dindera series
Classification:	Lithosol
Date of examination:	27 March 1975
Author:	K.J.Virgo
Location:	15 km northwest of Mekele, Tigray
Elevation:	1,900 m
Physiographic position:	dolerite and limestone escarpment to west of dolerite and sedimentary plateau, above incised Giba River valley.
Surrounding landform:	steep north northeast facing escarpment
Microtopography:	uneven surface with dolerite boulders and regolith remnants to 25 cm
Slope	30-40%, locally 55%
Landuse:	grazing
Vegetation:	sparse bushes of _Dodonaea_ and _Aloe_, olive trees recently cut down
Rainfall:	650 mm

- Information on the soil

Parent material:	coarse to medium textured dolerite spheroidal weathering between columnar and horizontal joint systems
Drainage - profile:	excessive
Drainage - site:	very high runoff expected on steep poorly drained protected slopes
Moisture condition:	dry throughout
Flood hazard:	none
Depth of groundwater:	not encountered
Surface condition:	much bare rock weathered and corestones with thin soil cover, occasional protected soil cores behind bushes and boulders
Evidence of erosion:	great variation in soil cover, with maximum soil depth of 25 cm and bare rock

- Profile description soil depth of 25 cm and bare rock

Very shallow Lithosols with 10 cm (occasionally 25 cm of moderate subangular blocky reddish brown sandy clay loam over in situ and hard spherodial weathered dolerite. Root development is good in the soil, and a few large roots from old olives penetrate through the joints of the dolerite.

0-10 cm	Reddish brown 5 YR 4/4); sandy clay loam; moderate medium subangular blocky; many fine tubular pores; many fine roots; few soft weathered dolerite stones.
10 + cm	In situ hard weathered dolerite; limited topsoil and fine roots between fractures; residue of coarse sand from dolerite minerals.

5.4 VERTISOLS

5.4.1 FAO classification

Vertisols are soils having, after the upper 20 cm have been mixed, 30 percent or more clay in all horizons to a depth of at least 50 cm; developing cracks from the soil surface downward which at some period in most years (unless the soil is irrigated) are at least 1 cm wide to a depth of 50 cm; having one or more of the following; gilgai microrelief, intersecting slickensides, or wedge-shaped or parallelpiped structural aggregates at some depth between 25 and 100 cm from the surface.

Pellic Vertisols are Vertisols having moist chromas of less than 1.5 dominant in the soil matrix throughout the upper 30 cm.

Chromic Vertisols are Vertisols having moist chromas of 1.5 or more dominant in the soil matrix throughout the upper 30 cm.

5.4.2 General environment

Vertisols are found throughout Ethiopia, in all but the very driest climates and across the spectrum of parent materials, with the exception of evaporites. As to site they have in common only their topographic position on flat to undulating land. They cover approximately 10 percent of the country.

The largest extents of Vertisols are found in central Ethiopia on the volcanic plateaux, colluvial slopes and sideslopes of volcanoes, on the colluvial slopes and alluvial plains that line the Sudan border and on the vast limestone plateaux of central Harerge. They are also found in more limited extent in such varied sites as on granitic colluvium in basins with seasonal drainage deficiencies in southern Sidamo, on sandstone colluvium in valleys in Tigray, on the flood plains of the Wabe Shebele and Fafen rivers in the Ogaden and in basins in western Ethiopia where rainfall reaches 2 000 mm.

5.4.3. Characteristics

Beyond their defining characteristics, Vertisols can be extremely variable. Chemical, physical and behavioural characteristics vary widely. Very generally, they are dark, montmorillonitic clay soils which expand and contract with changes in moisture content and consequently show wide vertical cracks when dry and often develop slickensides, i.e. ped surfaces which appear polished, when moistened peds expand and slide across each other. Low permeability, high free calcium carbonate contents and gilgai microtopography are associated with Vertisols but do not invariably occur.

5.4.4 Land use and natural vegetation

Land use on Vertisols in Ethiopia varies widely, depending on climate, pressure on the land and local farming systems as well as on the particular characteristics of the Vertisols in a given location. Intensive rainfed peasant cultivation, often extremely productive, of teff and of legumes as a second crop grown on residual moisture after the rainy season, is typical of central Ethiopia. During the dry season, and in those areas where drainage problems are most severe, grazing is the predominant land use. Along the Sudan border Vertisols are irrigated for oil seed and cotton production. In central Harerge, grazing is most common, however there is some peasant dry farming. Where left to natural vegetation, grasses predominate, with some shrub and tree vegetation in drier climates.

5.4.5 Management

The limitations for agriculture of Vertisols center on their heavy texture which is unsuitable for many crops and can create workability problems for both hand tillage and mechanized farming; their expansion and contraction which can result in drainage difficulties when these soils are wet and expanded and in root damage when they are drying contracting and cracking and their severe erosion hazard. Also, in dry climates, low permeability aggravates salinity and alkalinity.

- Information on the soil:

Parent material:	alluvium/colluvium
Permeability:	slow
Internal drainage:	slow
Depth of groundwater:	not encountered
Drainage	poorly drained
Moisture condition:	slightly moist to 100 cm and wet below
Stoniness:	none
Rock outcrop:	none
Evidence of erosion:	none, deposition predominant
Presence of salt or alkali:	none
Human influence	none

- Profile description:

Deep heavy clay with strong iron mottling at the top and strong gley features and strong slickensides at the bottom.

0-10 cm	A_{11}	Very dark greyish brown (10 YR 3/2) dry and black to very dark brown (10 YR 2.5/2) moist; clay; strongly developed fine crumb aggregates; soft dry, friable moist; common fine, faint to distinct iron mottles; extremely porous; clear smooth boundary.
10-40 cm	A_{12}	Brown to dark brown (7.5 YR 4/2) moist; clay; well developed very coarse prismatic primary structures breaking into strongly developed fine angular blocky to crumb aggregates; hard dry, friable moist, plastic and sticky wet; many coarse prominent iron mottles; many micro, many very fine, common fine and very few fine pores; 4% 1 mm manganese nodules; clear wavy boundary.
40-95 cm	AC	Dark grey (10 YR 4/1) moist; clay; well developed very coarse primatic primary structures breaking into well developed medium angular blocky aggregates; extremely hard dry, extremely firm moist, very plastic and very sticky wet; many coarse distinct iron mottles; many micro, common very fine, very few fine pores; 4% 1 mm manganese nodules; clear wavy boundary
95-160/170 cm	C	Dark greyish brown (10 YR 4/2) moist; well developed medium to coarse angular blocky aggregates; extremely hard dry, extemely firm moist, very plastic and very few fine pores; 3% 2 mm manganese noddules; clear wavy boundary.

160/170-195 cm	Light brownish grey (2.5 Y 6/2) moist clay; well developed coarse angular blocky aggregates; extremely hard dry, extremely firm moist, very plastic and very sticky wet; common faint iron mottles; many micro, few very few fine pores; 3% 2 mm manganese nodules.

B) Laboratory data

	Depth (cm)				
	0-10	10-40	40-95	95-160/170	160/170-195
Texture (%, mm)					
2-0.2	7	4	6	3	2
2.2-0.05	6	3	2	2	1
0.05-0.002	21	13	3	12	3
0.002	67	79	89	83	93
pH					
H_2O	4.2	4.1	4.3	4.6	5.6
KCl	4.1	3.8	3.2	3.9	4.7
NaF	8.1	8.6	8.9	8.8	9.0
$CaCO_3$ (%)	6.0	6.0	6.0	7.5	4.0
Exchangeable cations (me/100g)					
Na	3.1	1.7	3.4	1.7	0.9
K	0.8	0.5	0.5	0.8	0.5
Ca	14	18	23	27	35
Mg	1	2	12	1	3
Mn	0.29	0.14	0.12	m	m
CEC (me/100g)	42.0	44.0	50.0	48.0	43.8
Base saturation (%)	45	51	78	64	90
Organic C (%)	2.5	1.8	0.8	0.6	0.6
Total N (%)	0.27	0.17	0.10	0.06	0.04
C/N	9	11	8	11	14
Organic matter (%)	4.4	3.1	1.4	1.1	1.0
Available P_2O_5 (ppm)	19	33	23	31	33

5.4.7.3 Pellic Vertisol, Akaki

This profile was taken at Akaki, just south of Addis Ababa. It is a Pellic Vertisol and typical of those which develop on the extensive pyroclastic plateaux, except in that, being eroded, it is much shallower than is common. With the exception of the absence of any concentration of $CaCO_3$ reported in the profile, the soil described here has all the classic characteristics associated with Vertisols, i.e. gilgai microrelief, slickensides, imperfect drainage despite a slope of 3% and surface cracking.

	Depth (cm)			
	0-10	10-75/80	75/80-100	100-130/135
$CaCO_3$ (%)	0	0	0.3	0.2
Organic C (%)	2.3	1.0	0.3	0.2
Total (%)	0.25	0.22	0.04	0.04
C/N	9	4	8	5
Available P_2O_5 (ppm)	10	9	16	11

5.4.7.4 Chromic Vertisol (sodic phase), Humera

This profile comes from Humera, in the very northwest of Gonder, on the Sudan border. The alluvium referred to is primarily of metavolcanic and volcanic origin but includes felsic materials as well. Rainfall is approximately 500 mm annually. Land use now is largely rainfed sesame production on state farms.

The climate of Humera is much drier than that for the areas of the profiles above, which is reflected in the laboratory data. pH is alkaline, raised even higher than would be typical for a Vertisol under 500 mm rainfall because of the high exchangeable sodium levels.

The data on clay mineralogy indicate montmorillonite to be dominant, but some kaolinite is present reflecting the varied origin and recent deposition of the alluvium. This will contrast with Vertisols developed on, for example, pyroclastic plateaux, which will have only traces of clay minerals other than montmorillonite.

Source: HUMERA

A) General

Humera soils are typic Chromusterts (USDA texonomy) occuring on nearly level to rolling alluvial clayey deposits under Acacia mellifera thornland. They are deep and characteristically have very dark greyish brown surface colours with soft mulch. The soils are self-mulching. Cracks are common and gilgai is generally weakly developed. The soils are typically mildly alkaline and slightly calcareous. Profiles lack distinct horizons and permeability is very slow when wet.

B) Profile description

Humera clay, 0 to 2 percent slope

Profile description: The following profile was examined in a specially prepared pit, B01, some 200 m southwest of the office buildings on the Humera Project Farm, about 4 km south of the Setit River (approximately 14°17' N and 36°41'E). The site was on a flat and level alluvial plain, under native vegetation of *Acacia mellifera* thornland. Elevation is approximately 590 m.

0-2 cm	A_{11}	Very dark greyish brown (10 YR 3/2) moist and very dark grey (10 YR 3/1.5) dry; clay; very fine and fine granular surface mulch; very sticky and very plastic wet, friable moist, hard dry; clear smooth boundary.
2-30 cm	A_{12}	Very dark greyish brown (10 YR 3/2) dominant and very dark grey (10 YR 3/1) both moist and dry; clay; very few fine sandgrains sloughing down in cracks; very coarse prismatic peds that break to moderate coarse and medium subangular blocky structure; common 3-4 cm wide cracks; very sticky and very plastic wet, friable moist, hard dry; very few small hard white $CaCO_3$ concretions, slightly calcareous; very few fine and very fine roots; gradual wavy boundary.
30-60 cm	A_{13}	Very dark greyish brown (10 YR 3/2) moist and very dark brown (10 YR 2/2) dry; clay; very coarse prismatic peds that break to moderate medium angular and subangular blocky structure; few 2-3 cm wide cracks; very sticky and very plastic wet, friable moist, hard dry; very few pressure faces; very few small hard white $CaCO_3$ concretions; slightly calcareous; very few fine and very fine roots; clear wavy boundary.
60-100 cm	AC_1	Very dark greyish brown (10 YR 3/2) moist and very dark brown (10 YR 2/2) dry; clay; massive structure with parallelepiped aggregates defined by frequent pressure faces and very few slickensides; no cracks; very sticky and very plastic wet, firm moist, hard dry; very few small hard white $CaCO_3$ concretions; slightly calcareous; roots as above; diffuse smooth boundary.

100-120 cm AC$_2$ Very dark brown (10 YR 2/2) both moist and dry; clay; massive structure with parallel-epiped aggregates defined by few pressure faces and few slickensides; very sticky and very plastic wet, firm moist; very few small hard white $CaCO_3$ concretions; slightly calcareous; roots as above; gradual smooth boundary.

120-200 cm C Very dark brown (10 YR 2/2) both moist and dry; clay; massive structure with few pressure faces; very sticky and very plastic, very firm moist; very few small hard white $CaCO_3$ concretions; calcareous; few termite burrows; very few fine roots (some decayed).

Note: (1) Cracks occupy about 12 percent of the surface area.

(2) Round gilgai have a diameter of 4-5m and a height of 5-8 cm.

C) Laboratory Data

	Depth (cm)				
	2-30	30-60	60-100	100-120	120-170
Moisture (%)	9.3	9.6	9.7	9.5	10.0
Texture (%,mm)					
2-0.2	1	1	1	2	1
0.2-0.05	7	5	6	6	5
0.05-0.002	45	43	39	35	33
0.002	48	50	54	58	61
$CaCO_3$ (%)	0.5	0.4	0.6	0.2	0.8
pH	8.4	9.0	9.1	9.1	9.2
EC (mmhos/cm 1.5)	0.1	0.1	0.2	0.2	0.3
Exchangeable cations (me/100g)					
Ca	38.6	38.2	37.1	35.9	33.9
Mg	20.0	21.8	23.7	25.4	27.4
K	0.5	0.4	0.4	0.4	0.4
Na	1.0	4.0	5.8	5.4	8.1
sum	60.1	64.4	67.0	67.0	69.8
CEC (me/100g)	71.0	73.6	71.3	71.1	76.4
ESP	-	5	8	8	11
Base saturation (%)	85	88	94	94	91

	Depth (cm)				
	2-30	30-60	60-100	100-120	120-170
Soluble cations (me/100g, 1.5)					
Ca	0.17	0.14	0.14	0.07	0.03
Mg	0.11	tr	tr	tr	tr
K	0.01	tr	tr	tr	tr
Na	0.25	0.47	0.47	0.68	0.68
sum	0.54	0.61	0.61	0.75	0.89
Soluble anions (me/100g, 1:5)					
CO_3	-	-	-	-	-
HCO_3	0.45	0.53	0.52	0.54	0.64
Cl	tr	tr	tr	tr	tr
SO_4	tr	0.03	0.07	0.03	tr
NO_3	tr	tr	tr	0.06	tr
sum	0.45	0.56	0.59	0.63	0.89
Organic C (%)	0.7	0.5	0.4	0.4	0.4
Total N (%)	0.08	0.05	0.03	0.04	0.03
C/N	8	10	15	11	15
Available P_2O_5 (ppm)	54	32	29	m	m
Available K_2O (ppm)	186	133	140	m	m

5.4.7.5 <u>Chromic Vertisol, Tigray</u>

This profile is notable in that it is developed on sandstone colluvium and alluvium. The clay content barely meets the requirements of a Vertisol. Drainage problems are indicated as more severe than the clay content would suggest, probably a result in part of excessive sodium content in the surface horizon and also in part of the topographic position of the profile.

Source: TIGRAI

Gormedo Series - Moderately deep, very grey profiles with sandy clay textures, overlying weathered sandstone.

A) General

- Environmental characteristics: The soils occupy the level depressions and lower sections of the lateral valleys of the undulating pediment plateau on Enticho Sandstone. The valleys and depression are generally flat, weakly concave and have slopes of less than two percent. The parent material comprises fine textured alluvium which overlies weathered sandstone. A thin layer of colluvium often covers the surface. The soils show prominent cracking and sink hole features during the dry season but are subject to prolonged flooding during the rainy season. The soils carry a dense sward of edaphic grassland vegetation which includes Pennisetum schimperi. Only the fringes of the depressions are cultivated.

- Profile characteristics: The surface horizon is usually very dark grey to dark brown (10 YR 3/2 to 3/3) with clay loam to sandy clay textures. This horizon is seldom deeper than 10 cm and overlies the very dark grey (10 YR 3/1-2) sandy clay B horizon, which shows prominent vertical cracking and slickenside faces to the coarse angular blocky peds. These cracking clay horizons extend down to at least 75 cm, often contain remnants of weathered sandstone fragments and are always mottled with yellow brown or strong brown colours. Below the cracking clay there is usually a transitional horizon of gleyed weathered sandstone and alluvium which has a stony sandy clay texture and olive colours (5 Y or 2.5 Y hues). This transitional horizon overlies in situ weathered sandstone which breaks down to sandy clay or sandy clay loam textures. Roots extend down into the B horizon but are often compressed along peds or stretched between them.

- Analytical characteristics: The soils are slightly acid and have medium to high base saturation, with calcium as the dominant cation. Sodium unusually ranges from low to very high in topsoil and constitutes a serious sodium hazard. Micronutrients are low in copper and zinc, but adequate for manganese.

- Land capability characteristics: The soils are severly limited in their agricultural potential by the prolonged inundation and waterlogging during the rainy season. On this basis they are recommended for continued use as grazing lands.

B) Profile description

- Information on the site

Profile no.:	14, QE/2
Soil name:	Gormedo series
Classification:	Chromic Vertisol
Date:	5 April 1975
Author:	R.N.Munro
Location:	10.5 km ENE of Hauziun, Tigrai 14°00'10" and 39°30'45" E
Elevation:	about 2 300 m
Physiographic position:	undulating pediment on plateau on Enticho Sandstones
Surrounding landform:	weakly concave valley floodplain
Microtopography:	smooth with slight gilgai relief and frequent sink holes 30 cm deep and 100 cm wide

Slope:	1 percent down to NW
Landuse:	intensive livestock grazing
Vegetation:	edaphic grassland, dense sward; Pennisetum, Echinochloe and Hyparrhenia.
Rainfall:	about 550 mm

Information on the soil:

Parent material:	alluvium from Enticho Sandstone
Drainage - profile:	Very poor
Drainage - site:	receiving site
Moisture condition:	dry to 75 cm and moist below
Flood hazard:	frequent prolonged flooding during the rainy season
Depth of groundwater:	not encountered
Surface condition:	surface cracking (15 cm wide) and frequent sink holes
Evidence of erosion:	none

- Profile description:

A moderately deep very poorly drained profile with very dark grey and olive grey colours. The upper horizon is formed in a shallow colluvial deposit: this overlies a sandy clay horizon in alluvium which shows strong vertical cracking and slickenside features. The profile is strongly gleyed below 35 cm, but mottles occur thought all the horizons. In situ weathered sandstone occurs at 94 cm depth. Roots are well developed in the profile, but are stretched between peds in the zones of cracking.

0-8 cm	Very dark grey (10 YR 3/1.5) with common fine distinct strong brown mottles; sandy clay; strong medium angular blocky structure; very hard dry; few vertical cracks; few fine pores; many fine and medium roots; clear smooth boundary.
8-75 cm	Very dark grey (10 YR 3/1.5) with few fine distinct strong brown mottles; sandy clay; strong medium to coarse angular blocky, extremely hard dry to very firm moist; vertical cracks 2 cm wide to base; few fine pores; weak slickensides; common fine and few medium roots; clear smooth boundary.
75-94 cm	Olive grey (5 YR 4/2.5) with many fine prominent yellow brown mottles; very fine sandy clay; massive; very firm moist; few vertical cracks; weak slickensides; few remnant weathered sandstone fragments; few fine roots; abrupt smooth boundary.

94-115 cm   Olive brown (2.5 YR 4/4) weathered sandstone with horizontal platy structure.

C) Laboratory Data

	Depth (cm) 0-8	8-75	75-94
Texture (%, mm)			
2	3	3	3
2-0.2	23	16	23
2.2-0.05	16	13	13
0.002	35	48	28
pH	7.2	7.8	7.8
Ec (mmhos/cm, 1:5)	m	0.1	0.1
Exchangeable cations (me/100g)			
Ca	20.4	17.2	17.5
Mg	6.9	6.1	2.6
Na	2.1	0.3	0.0
K	0.3	0.1	0.1
CEC (me/100g)	29.2	29.6	19.4
$CaCO_3$	0.0	m	0.5
Total K (ppm)	2150	2150	m
Available P_2O_5 (ppm)	7	2	m
Total N (%)	0.20	0.10	m
Organic C (%)	1.97	0.67	m
Soluble (ppm)			
Cu	2.2	1.5	1.1
Zn	1.5	1.2	1.3
Mn	122	30	10
Total (ppm)			
Cu	100	12	8
Zn	44	42	32
Mn	310	190	79

	Depth (cm) 0-8	8-75
Bulk density (g/cm^3)	1.29	1.48
Moisture (%)		
0.0 bar	42.6	32.4
0.1 bar	37.5	30.7
0.3 bar	29.8	28.4
1.0 bar	26.5	26.3
15. bar	16.3	18.8

	Depth (cm) 0-8	8-75
Available water capacity		
% weight	22.2	11.9
% volume	27.4	17.6
Porosity (%)		
total	46	38
aeration	6.6	2.4

5.4.7.6 Chromic Vertisol (mollic), Jijiga

The following profile was taken near Jijiga, Hararge. These Vertisols have a deep (30 cm) mollic A horizon which moderates the workability problems characteristic of Vertisols. The are particularly well adapted to dry farming.

Source: WABI SHEBELE

A) General

These Vertisols are largely extended in the north of the Wabi Shebele basin, at a mean altitude varying from 1 200 to 1 800 m where rainfall is approximately 600 mm. They stretch over 6 340 km^2 and are represented in particular in the Jijiga region, between Babile and Fik, Midegalola, between the Ramis and the Areri, between the Wabe and the Mojo, to the South of Boke-tiko, and between the Ungwata and the Siyanan where they spread on the vast, very flat or weakly undulated plateaux constituted by the geologic formation, of gramineae (Jijiga zone) or of a dense bush with a predominance of small acacias (north Fik.)

B) Profile description:

Location: 21 km south of Jijiga near the Degeh Bur track

- Profile description: Overgrazed gramineae with small acacias here and there

0-30 cm Brown (10 YR 5/3); very fine sandy clay; well-developed coarse, medium and fine crumbly structure; dry and very friable; very well developed root system; gradual and uniform transition to:

30-60 cm	Brown (10 YR 5/3); clay; vertical shrinkage cracks delimiting a weakly-developed prismatic structure with not very distinct slicken sides; very friable blocky fragments giving a subangular blocky structure to a well developed medium, fine or coarse granular structure; rather humid and friable; dense root system; some subangular limestone pebbles approximately 0.2 to 0.5 cm; gradual transition to:
60-100 cm	Dark brown (7.5 YR 3/2); clay; well developed medium prismatic structure with very distinct slickensides; rather humid; compact; looser root system; some 0.2 to 0.5 cm limestone pebbles; short transition to:
100-160 cm	Brown (7.5 YR 3/2) striped with red and brown (5 YR 5/3); clay; medium prismatic structure with distinct slickensides numerous white calcareous concretions, diameter approximately 0.5 cm; very friable giving a white powder; relatively humid; very compact; some rootlets; sudden transition to:
160+ cm	Hard calcareous crust of nodule type.

C) Laboratory data

	Depth (cm)		
	0-30	30-100	100-160
$CaCO_3$ (%)	20	22	20
Organic matter (%)	3.6	1.7	1.4
Total N (%)	0.20	0.10	0.06
C/N	15	10	13
pH	8.0	8.0	8.2
Exchangeable cations (me/100g)			
K	1.0	0.7	0.6
Na	1.7	2.6	3.0
CEC (me/100g)	57	62	57
Total P_2O_5 (ppm)	1400	1200	1000

Clay is predominant in these brown to dark brown soils. The loose granular horizon is 30 cm thick. The prismatic horizon at a 60 cm depth with distinct slickensides is very compact, and gradually changes into a transition horizon with a scarcely pronounced prismatic structure which however remains friable and well penetrated by the root system of gramineae.

Vertisols always present a calcareous crust with strongly cemented nodules visible either on the limestone slab in situ (Babile region, Fik, Midegalola), or on friable weathered limestone (Jijiga zone). Though the age of this crust is not exactly known, the observation of a horizon resulting from the weathering of the limestone in situ shows that pedoclimatic conditions are favourable in this zone for the present migration of calcium carbonate. Below this scarcely permeable crust a calcareous segregation may be observed in the form of friable nodules. All this soil contains calcium carbonate (approximately 20 percent).

Rainfall is consequently insufficent to decarbonate the upper horizons but friable nodules are formed owing to the presence during the rainy season of a perched groundwatertable above the crust.

The content of organic matter is high in the upper horizon with 3.6 percent and medium at depth with 1.4 percent; this is due to the importance of the graminea cover even when shrubby association are predominant. The high nitrogen content at the surface, and the C/N from 13 to 15, show that organic matter is well mineralized.

pH is approximately 8.0 The exchangeable capacity is high which characterizes a montmorillonitic clay type. The absorbing complex is base-saturated. The exchangeable potassium content is high at the surface and at depth. Conversely, the exchangeable sodium content is relatively high at depth but does not affect soil fertility. The phosphorus content is medium. The total N/total P_2O_5 ratio is approximately 1 or less and reveals an imbalance which is unfavourable for nitrogen.

D) Cultural fitness

These soils are particularly interesting for agricultural purposes, as they constitute the main category of soils liable to be used for dry farming and for the extention of cultivation from the north to the south. These soils are scarcely cultivated at present and though rainfall is relatively low, from 500 to 600 mm, they should be considered seriously because of i) their high water-holding capacity linked to a clayey texture; ii) the presence at the surface of a granular horizon facilitating cultural practices; iii) the need only of slight landclearing, especially in the Jijiga region where vegetation mainly consists of gramineae; and iv) the considerable extent of these soils suitable for large-sized mechanized farms.

5.4.7.7 Chromic Vertisol (saline phase), lower Wabi Shebelle

The following presents a mean profile description, mean physical and chemical data, and an indication of the variations existing for a range of Vertisols on the lower Wabi Shebele flood plain in the southern Ogaden, where rainfall is less than 200 mm.

Alkalinity is not a problem in these soils, but salinity is often excessive at depth in the profile, which in the climate of the southern Ogaden may produce difficulties for otherwise irrigable soils.

Source: LOWER VALLEY OF THE WABI SHEBELE

Vertisols and Vertic soils with a grumosolic structure

A) General

These soils are well represented in the lower valley of the Wabi Shebele and are formed on three types of clay alluvia from different origins: i) brown and reddish brown alluvia of basaltic origin (alluvia of temporary rivers to the northwest of Gode); ii) alluvia derived from Mustahil limestone (alluvia of Bu-Y temporary river northwest of Gode); and iii) brown alluvia of the Wabi Shebele spreading on the largest area.

B) Profile description:

Microrelief:	pronounced gilgai microrelief
Vegetation:	dense graminea vegetation

- Mean profile description:

0-15 cm	Brown to dark reddish brown (5 YR 3/2); clay to silty loam; medium to fine strongly developed subangular blocky structure; dry and very friable; numerous rootlets; gradual and regular transition to:
15-30 cm	Brown to reddish brown (5 YR 4/4); clay; medium to coarse strongly developed angular blocky structure; friable; numerous rootlets; distinct transition to:
30-80 cm	Brown to reddish brown (5 YR 4/4); clay; 0.5 to 3 cm wide subvertical shrinkage cracks (when dry), limiting a coarse prismatic structure with slickensides; dry and compact; rootlets; gradual transition to:
80+ cm	Same type of horizon with small gypsum crystals.

In this mean profile the structure is very divided up in the first horizon and more homogeneous in the second (15 to 30 cm). Both these horizons are described as "grumosolic" or friable, compared to the massive and dry, compact deeper horizon. The transition between these two horizons is very sudden. The deeper horizons are very compact and they present a prismatic structure. Prisms measuring 50 x 30 x 20 cm have often been separated from the profiles. Slickensides are very distinct in Vertisols and non-existent in vertic soils, but in both cases, shrinkage cracks are always numerous and from 1 to 5 cm wide. The gypsum accumulation is always powdery and can be observed at about 80 cm depth. It never becomes crusty.

C) Morphological and textural variations between series

The grumosolic horizon is very well developed on alluvia from basaltic and limestone (40 cm thick) origin, of the BU-Y and other nearly temporary rivers. In the Wabi plain it is only 20 to 30 cm thick. The prismatic horizon is well differenciated in all the series with distinct slickensides on prisms, except in vertic soils where only shrinkage cracks can be seen. The powdery gypsum accumulation of crystals is present at a more or less high level in the profile, depending on the pulsation level of watertable or of perched watertable. It reaches the base of the grumosolic horizon in series 10 and 12 and in other series it remains between 90 and 120 cm. The texture always consists of clay and heavy clay at depth. Conversely in the grumosolic horizon the texture is lighter in some series. (See below.)

	limestone alluvia	basalt alluvia		Wabi Shebele brown alluvia					
Series	9	10	11	12	13	14	15	16	17
Depth (cm)									
10									
20									
30	C	C-SiC	C	SiL	CSiL	CSiL	C	C	C
40									
50									
60									
70			C			C			
80	C							C	C
90					C		C		
100		C		C					
110			C			C		C	C
120									
130	C				C		C		

D) Laboratory data

	Depth (cm) 0-30	30-80	80+
$CaCO_3$ (%)	19	20	19
Organic matter (%)	2.4	1.0	0.8
pH	8.1	8.0	7.9
EC (mmhos/cm, sat. ex.)	2.0	4.3	7.4
Exchangeable cations (me/100g)			
K	1.4	0.9	0.7
Na	0.2	0.3	0.3
ESP	0.8	1.1	1.2
Soluble (%, of soil , sat. ex.)			
NaCl	0.009	0.027	0.092
SO_4Ca, $2H_2O$	0.070	0.106	0.170
Total P_2O_5 (ppm)	1900	1800	1800

In natural conditions, the content of organic matter is high for the region at 2.4% owing to the topographic position of Vertisols usually located in low and weakly flooded areas or in basins collecting rain water. These soils contain 19 to 20% of calcium carbonate and pH is approximately 8.0.

The exchangeable potassium content varies from medium to low whereas at depth a light increase of exchangeable sodium is invariable and in very low quantities, 0.2 to 0.3 me/100g. The ESP varies from 0.8 to 1.2 and shows no sign of alkalinization. Conductivity of the saturated paste remains low at the surface and is moderate at depth. Soluble salts can be divided into two groups: i) chloride (mainly sodium chloride) and ii) sulphate (mainly gypsum). The chloride content increases in the deeper parts from 0.2 to 0.5 g/1000 but is still low though not negligible. Without drainage, a toxity effect due to the concentration of chloride may be observed under irrigation in horizons at a medium depth. Gypsum also increases with the depth from 0.5 to 0.8 g/1000. The gypsum concentration indicates that the saturation extract dissolves all the gypsum in soils, the highest gypsum solubility being approximately 1.1 g/1000. Consequently gypsum accumulation is low in Vertisols and this is confirmed by observation.

E) <u>Chemical variation between series</u>

Variations mainly concern organic matter, exchangeable potassium, ESP and soluble salts.

The content of organic matter varies according to the extent of flooding and consequently to the degree of development of graminea vegetation in the series considered. For instance for horizon 0-30 cm, the content varies from 0.9% cm the alluvia of BU-Y temporary river to 7.8% in the Mustahil flood area.

Conductivity of the saturation extract increases with depth. At 80 cm depth and deeper, conductivity is high in some series and in other series it varies from medium to low. Exchangeable sodium exists in small quantities with a maximum of 0.8 me/100g and a minimum of 0.2 me/100g. The ESP is also very low with a maximum of 2.2 and a minimum of 0.4. Chloride concentration increases with depth and its maximum is 0.12% of soil and its minimum is 0.006%, these values being low. The chloride content enables the classification of these soils as scarcely saline soils at depth for some series and moderately saline soils at depth for others. The gypsum content varies from .017% to 0.15% of soil, which shows that the gypsum supply in these soils is poor.

Depth (cm)	Series	9	10	11	12	13	14	15	16	17
0-30	Organic matter (%)	0.9	2.0	1.1	1.2	3.0	1.1	2.4	7.8	2.6
30-80		0.7	0.6	0.9	1.0	1.0	0.6	1.2	0.9	0.6
80+		0.7	0.6	0.8	1.0	1.0	0.5	1.1	0.5	0.6
0-30	EC(mmhos/cm set.ex.)	1.6	0.5	1.6	2.6	2.0	3.1	2.1	2.0	5.0
30-80		9.0	0.7	3.2	2.2	5.0	3.3	3.1	4.0	8.0
80+		11.2	0.5	6.6	2.2	12.0	11.0	3.1	12.0	10.0
0-30	Exhangeable Na (me/100g)	0.2	0.3	m	0.1	0	0.4	0.3	0	m
30-80		0.2	0.3	0.8	0.15	0	0.2	0.3	0	m
80+		0.3	0.2	0.5	0.1	0	0.3	0.6	0	m
0-30	ESP	1.5	0.4	0	0.6	0	1.6	0.6	0	m
30-80		1.3	0.6	4.0	0.9	0	0.4	0.6	0	m
80+		1.3	0.6	2.2	0.4	0	1.6	1.2	0	m
0-30	Soluble Na (% of soil)	.023	.001	.010	.003	.004	.008	.002	.007	.023
30-80		.100	.006	.008	.003	.023	.004	.007	.014	.092
80+		.110	.001	.078	.004	.185	.116	.007	.185	.116
0-30	Soluble $CaSO_4$ (% of soil)	.044	.017	.034	.103	.058	.113	.075	.058	.137
30-80		.113	.020	.110	.079	.137	.099	.103	.106	.172
80+		.120	.014	.140	.079	.275	.200	.103	.275	.206

F) <u>Conclusion on Vertisols and vertic soils:</u>

Vertisols and vertic soils of the Wabe Shebele Valley present the following main characteristics: i) texture consisting of clay and occasionally of silty loam at the surface; ii) grumosolic topsoil, very well developed and moderately thick (30 cm); iii) a weak accumulation at depth of chloride which may concentrate when irrigated and insufficiently drained; iv) poor gypsum supply; and v) no profile alkalinization.

5.4.7.8 Pellic Vertisol, Degaga

This profile is situated in the highlands of the northeastern escarpment. Typical sites for this kind of soil are undulating plateaux and almost flat to gently sloping wide-valley slopes. Their surfaces are often stony.

Often the profile is truncated and $CaCO_3$ nodules are found at the surface. If present, the A horizon has a coarse granular structure.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.:	18, d, Borkena
Date:	9/12/83
Authors:	Fitzum F., Gebeyehu B., S. Paris
Location:	7.5 km ENE of Degaga, 10°49'15"N-39°41'50"
Classification FAO:	Pellic Vertisol
USDA:	Typic Pellustert
Physiographic position:	Undulating plateau
Slope:	3%
Elevation:	2450 m
Vegetation:	Cultivation of wheat, barley and pulses
Climate:	moist-subhumid cool tropical

- Information on the soil:

Parent material:	clayey residual material derived from basalt
Drainage:	moderately well
Moisture condition:	moist throughout
Rocky outcrop:	none
Evidence of erosion	gullies of 3-4 m deep

- Profile description:

0-30 cm	Very dark grey (10 YR 3/1) moist and dark grey (10 YR 4/1) dry, clay; strong coarse granular; very hard (dry), very firm (moist), sticky and plastic (wet); smooth and gradual and smooth on:

30-80 cm	Very dark grey (10 YR 3/1) moist and dark grey (10 YR 4/1) dry, clay; few medium faint mottles; strong medium angular blocky; very hard (dry), very firm (moist), very sticky and very plastic (wet); broken moderately thick clay cutans; few non-intersecting slickensides; diffuse and smooth on:
80-170 cm	Very dark grey (10 YR 3/1) moist and dark grey (10 YR 4/1) dry, clay; few medium faint mottles; strong coarse angular blocky; extremely hard (dry), very firm (moist), very sticky and very plastic (wet); broken moderately thick clay cutans; strongly developed large intersecting slickensides; clear and smooth on:
170-210 cm	Very dark greyish brown (10 YR 3/2) moist and dark greyish brown (10 YR 4/2) dry, clay; few medium faint mottles; strong coarse angular blocky; very hard (dry), very firm (moist), very sticky and very plastic (wet); broken thin clay cutans; common intersecting slickensides; many coarse $CaCO_3$ nodules; strongly calcareous.

B) Laboratory data

	Depth (cm)			
	0-30	30-80	80-170	170-210
Texture				
2-0.05	24	20	16	16
0.05-0.002	23	22	17	17
0.002	52	58	66	66
pH (1:1, H_2O)	6.0	6.0	6.1	7.3
Exchangeable cations (me/100 g)				
Na	0.4	-	0.9	0.9
K	1.0	0.8	0.5	0.8
Ca	17.0	16.6	24.1	m
Mg	3.0	5.9	7.0	m
CEC (me/100g)	33.0	31.0	37.0	31.6
Base saturation (%)	65	75	88	
Organic C (%)	2.2	1.5	0.8	0.3
Total N (%)	0.25	0.17	0.13	0.04
Available P_2O_5 (ppm)	10	12	8	17

5.5 FLUVISOLS

5.5.1 FAO classification

Fluvisols are soils developed from recent alluvial deposits having no diagnostic horizons other than (unless buried by 50 cm or more new material) an ochric or an umbric A horizon, a histic H horizon or a sulfuric horizon. As used in this definition, recent alluvial deposits are fluviatile, marine, lacustrine or colluvial sediments characterized by one or more of the following properties:

a) having an organic matter content that decreases irregularly with depth or that remains above 0.35 percent to a depth of 125 cm (thin strata of sand may have less organic matter if the finer sediment below meets the requirements);

b) receiving fresh material at regular intervals and/or showing fine stratification;

c) having sulfidic material within 125 cm of the surface.

Eutric Fluvisols are Fluvisols having a base saturation (by NH_4OAc) of 50 percent or more at least between 20 and 50 cm from the surface but which are not calcareous at the same depth; lacking a sulfuric horizon and sulfidic material within 125 cm of the surface.

Calcaric Fluvisols are Fluvisols which are calcareous at least between 20 and 50 cm from the surface; lacking a sulfuric horizon and sulfidic material with 125 cm of the surface.

Dystric Fluvisols are Fluvisols having a base saturation (by NH_4OAc) of less than 50 percent in at least a part of the soil between 20 and 50 cm from the surface; lacking a sulfuric horizon and sulfidic material within 125 cm of the surface.

Thionic Fluvisols are Fluvisols having a sulfuric horizon or sulfidic material, or both, at less than 125 cm from the surface.

5.5.2 General Environment

Fluvisols, like Vertisols, are found throughout Ethiopia but only have in common their occurence on flat or nearly flat land. They usually occur in limited extents, for example on lake margins in the Rift valley and a long the shores of Lake Tana, on deltas on Lake Abaya and Lake Turkana, on alluvial plains and along the meander belts of major rivers such as the Awash, the Baro, the Wabi Shebele and the Omo, in small intermontane valleys and in enclosed basins in the highlands of Ethiopia and along the Eritrean coast. However, large extents of Fluvisols do occur on the vast alluvial fans coming down off the highland plateau in northern Hararge, the southern Rift and western Ilubabor. In total, Fluvisols cover approximately 6% of Ethiopia.

5.5.3 Characteristics

The essentail defining characteristic of Fluvisols is that they occur on recent alluvial deposits. As such, their properties are largely controlled by deposition mechanisms and the origin of the alluvium rather than by pedogenetic processes. Very different texture and drainage characteristics will occur within the same climatic zone. In addition, because the mechanisms of deposition can be so complex and variable, Fluvisols can be extremely variable over very short distances, particularly with regard to texture.

The one characteristic all Fluvisols have in common is that they occur on flat or nearly flat land. High water tables and associated gleyic features often occur, although less often on alluvial fans. Particle size sorting and irregular chemical characteristics with depth often reflect the deposition of alluvium of different origin over time.

With the end of deposition, or in dry climates where deposition is possibly infrequent, pedogenetic processes may become evident. Accumulation of salts and sodium may occur as may leaching and redeposition of calcium sulphate at depth in the profile.

5.5.4 Land use and natural vegetation

Given the variety of chemical, physical and behavioral characteristics of Fluvisols, depending on the origin of the alluvium, the microtopography of the site of deposition, the mechanisms of deposition and, where these latter are not overwhelmingly dominant, the climate and associated pedogenetic processes, land use and natural vegetation cross the spectum of possibilities. Fluvisols provide some of the most productive agricultural land in Ethiopia as well as land where no natural vegetation will grow. Irrigated state farms on Fluvisols alternate along the Awash river between Metahara and Dubti, near the Djibouti border, with areas covered by Fluvisols which have no economic value due to salinization and/or alkalinization. These latter barely provide scrub vegetation for nomadic livestock grazing during very short rains. On the margins of Lake Tana and in the river valleys of the highlands, Fluvisols are flooded during the rainy season, but as water recedes intensive peasant cultivation of legumes on the residual moisture is common. The alluvial fans of northern Hararge and the southern Rift are under natural vegetation, which is sparse due to the climate. Nomadic livestock grazing is the main land use here. In western Ilubabor, the presence of Tse-Tse fly has restricted human settlement to such an extent that Fluvisols here are undisturbed under thick wooded grassland on the alluvial fans and under riparian woodland along the Baro river. Given the climate and natural fertility of these Fluvisols however, they are currently attracting attention as having high potential for state farm development.

5.5.5 Management

The major limitation to the agricultural use of Fluvisols is the frequent requirement for flood control and/or drainage, the latter particularly difficult due to an often high water table. Such problems are less serious on alluvial fans and on Fluvisols where deposition and flooding have recently ceased. In dry climates, infrequent flooding and the consequent patterns in the soil moisture regime commonly aggravate salinity and alkalinity. While such conditions are frequently removed through leaching, this approach is unsatisfactory on many Fluvisols due to the requirement of sub-surface drainage in the face of a high water table.

Fluvisols have a number of advantages for agriculture. They occur predominantly on flat land and on aggrading rather than eroding landforms. There is an associated source of water which ensures appropriate levels of soil moisture for at least a part of the year and may provide a continual supply of irrigation water for the whole year, allowing multiple cropping. In Ethiopia, except where salinity and alkalinity are excessive, these soils have a high natural fertility, the source of the alluvium being in most part the young volcanic soils of the highland plateau.

5.5.6 Occurence

The four types of Fluvisols defined above all occur in Ethiopia. Calcaric Fluvisols occur in the Awash and Wabe Shebele river valleys. Dystric Fluvisols occur in western Ethiopia, where the alluvium originates predominantly in acid soils and is deposited in equally high rainfall zones. Thionic Fluvisols, which are rarely usable due to extreme acidity (i.e. pHs of below 3.5), occur along the Eritrean coast. Eutric Fluvisols occur throughout the country. Saline and sodic phases are common in Eutric and especially Calcaric Fluvisols in Ethiopia.

5.5.7 Profile descriptions

Eutric Fluvisol, Wereta

This profile was taken on the eastern shore of Lake Tana, Gonder, approximately 10 m offshore. The area had just been reexposed with the retreat of the shoreline at a time well into the dry season. Depositional bedding, high irregular organic matter contents and prominant mottling indicative of a high water table are all characteristic of Fluvisols in such topographic positions.

The slightly acid pH, high potassium and very low available P_2O_5 contents are characteristic of the volcanic soils around Lake Tana, from which the alluvium of this soil originates.

The soils are used, as the lake recedes, for quickly maturing legume crops, with fair success. For although high in fertility, the land is exposed only during the dry season and the soils, are somewhat quickly divested of residual soil moisture due to a fairly coarse texture.

Source: LUPRD

A) Profile description

- Information on the site:

Profile No.:	P 34, Wereta
Classification (FAO)	Eutric Fluvisols
USDA taxonomy:	Typic Fluvaquent
Date:	7/12/81
Authors:	S. Ross, Fikru Abebe
Location:	shore of Lake Tana, Gonder, 11°56'N and 37°33' E

Elevation:	1810 m
Physiographic position:	plain
Surrounding landform:	flat
Microtopography:	none
Slope	less than 1%
Vegetation:	site on recently harvested teff field; 90% of area under niger seed, millet, chickpea, pepper and teff cultivation, depending on season; Cynodon dactylon the major grass
Climate:	mild tropical highland, koppen Cwb

- Information on the Soil:

Parent material:	actively aggrading lacustrine deposits
Drainage	moderately well drained seasonally flooded, water recedes in October/November
Moisture condition:	dry to 10 cm, barely moist below
Depth of groundwater:	150 cm
Surface stones	none
Rock outcrop:	none
Evidence of erosion:	none
Presence of salt and Alkali:	none
Human influence	no fertilizer, influence confined to plough layer

- Profile description:

Deep, moderately well drained dark reddish brown; texture highly variable in surface 60 cm, clay at depth; Fe and Mn mottling throughout, MnO_2 nodules throughout; weathered gra-el throughout.

0-25/35 cm	Dark reddish brown (5 YR 2.5/2) moist; loam; moderate fine granular; non-sticky and non-plastic wet; very friable moist; many very fine to medium interstitial pores; few weathered gravel; horizon gets slightly redder below 15 cm with few fine prominent sharp Fe mottles and few MnO_2 nodules; common fine to medium roots; clear irregular boundary; pH 6.0.

25/35-45 cm	Dark reddish brown (5 YR 2.5/2) moist with common fine distinct diffuse Fe mottles; clay loam; moderate coarse granular; slightly sticky and slightly plastic wet, friable moist; many very fine to medium interstitial pores; few weathered gravel; few MnO_2 nodules; few fine roots; very abrupt boundary; pH 6.0.
45-50/60 cm	Dark reddish brown (5 YR 2.5/2) moist; sand; incoherent structureless; non-sticky and non-plastic wet, loose moist; very many fine interstitial pores; few MnO_2 nodules; common weathered gravel; abrupt wavy boundary: pH 6.0.
50/60-75 cm	Dark reddish brown (5 YR 2.5/2)moist with common fine prominent sharp Fe and common coarse distinct clear Mn mottles; clay loam; moderate fine to medium subangular blocky; slightly sticky and slightly plastic wet, friable moist; many very fine to medium interstitial pores; few MnO_2 nodules; few weathered gravel; wavy boundary; pH 6.0.
75-150 cm	Dark reddish brown (5 YR 3/2) moist with many medium to coarse prominent clear Fe and Mn mottles; clay; strong medium subangular blocky; sticky and plastic wet; firm moist; common very fine to fine interstitial pores; common MnO_2 nodules; few weathered gravel; diffuse boundary; pH 6.5.
15-200+ cm	Dark reddish brown (5 YR 2.5/2) moist with common fine to medium faint diffuse Fe and Mn mottles; clay; beginning of ground water table; sticky and plastic wet; many MnO_2 nodules- few weathered gravel; pH 6.5.

Remarks : Pit to 85 cm, auger below

B) Laboratory data

	Depth (cm)					
	0-25/35	25/35-45	45-50/60	50/60-75	75-150	150-200
Texture (%, mm)						
2.0-0.05	45	35	93	17	19	23
0.05-0.002	42	36	2	48	30	36
0.002	12	29	5	35	51	41
pH	6.2	5.9	6.0	6.0	6.4	6.6
Exchangeable cations (me/100g)						
Na	1.7	0.9	0.4	0.9	0.9	0.9
K	1.5	2.9	0.5	0.8	0.5	0.5
Ca	35	20	20	20	38	40
Mg	5	5	1	10	11	5
sum	43.3	28.8	22.0	31.6	50.4	46.4
CEC (me/100g)	41.6	40.0	19.0	50.0	47.0	60.6
Base saturation	100	72	100	63	100	77
Organic C (%)	2.2	1.5	1.1	0.7	1.0	0.6
Total N (%)	0.20	0.18	0.13	0.15	0.14	0.11
C/N	11	8	9	5	7	5
Organic matter	3.8	2.6	2.0	1.3	1.8	1.0
Available P_2O_5 (ppm)	6	12	17	4	12	4

5.5.7.2 Eutric Fluvisol, Tigray

This profile comes from central Tigray, and again shows the depositional bedding and chemical properties of the soils from which the alluvium originated.

The site however slopes at an angle of 3%. Deposition and erosion both occur, the latter - during flash floding - both removing topsoil from the flooded land and cutting back the banks of the river.

The proximity of a water supply results in the use of this water for small scale peasant irrigation as is common in many parts of Ethiopia.

Source: TIGRAI

Lahama series - Deep well drained brown soils with stratified coarse and medium textures.

A) General

- Environmental characteristics: Lahama soils occur in the upper reaches of the narrow valleys of the Tigray escarpment. They are formed on alluvial deposits of mixed origin. The valleys are flat to weakly concave and slopes are normally less than five percent; the centres of the valleys are often deeply gullied. The soils are mostly under dryland cultivation or extensive grazing but locally they are irrigated.

- Profile characteristics: The soils have generally dark brown to brown colours throughout (10 YR 3/3 to 4/3) but have very varied textures and show pronounced stratification. Bands of sandy loam with moderately well developed angular blocky structure are interspersed with horizons of stony loamy sand with a silty clay loam texture or clay. Roots penetrate the soil to well below 100 cm depth. Stones occur in varied degrees; most Lahama soils are moderately stony at the surface and contain bands of alluvial stones within the profile.

- Analytical characteristics: Data from one profile of five horizons. The soils are moderately alkaline, with very high base saturation, dominated by high to very high calcium. The CEC of the clay fraction suggests montmorillonite clay mixed. In one horizon the Mg/K ratio is below 2.

- Land Capability characteristics: Although the soils have a moderate rooting depth and are topographically suitable for arable cultivation, they occur in a low rainfall area. They are therefore marginally suited to arable cropping but moderately suited to irrigated cropping. The lands also suffer from flash flooding, which causes severe erosion to the central stream ocurses.

B) Profile description

- Information of the site

Profile no.:	7, MS/11
Soil name:	Lahama series
Classification:	Eutric Fluvisol
Date of examination:	3/25/75
Author:	R.N. Munro
Location:	3 km SW of Akhaza, Tigrai, 13°25'00" N and 39°40'10" E
Elevation	about 2 100 m
Physiographic position:	alluvial valley between rolling (25% slope) limestone and shale hills
Surrounding landform:	gently sloping valley floor with river channel
Microtopography:	river channel 10 m wide, incised 2 m into slightly undulating alluvium
Slope:	3 percent
Landuse:	cultivation over most of alluvium; grazing along channel sides
Vegetation:	grass with scattered <u>Rumex nervosus</u>
Rainfall:	500 mm

- Information on the soil:

Parent material:	alluvium from calcareous sedimentary rocks and dolerite
Drainage - profile:	excessive
Drainage - site:	restricted in wet season
Moisture condition in the profile:	dry throughout
Flood hazard:	seasonally flooded
Depth to groundwater:	not encountered
Surface condition:	few limestone stones, no cracks
Evidence of erosion:	channel banks breaking off

- Profile description:

A deep excessively drained dark grey brown coarse textured alluvial soil. The texture changes rapidly from silt loam bands to gravel and stone lenses. Structure is weakly developed subangular blocky in the topsoil, with structureless stony, strong angular blocky fine textured and moderate subangular blocky textured layers in the subsoil. The rooting system is very well developed with as dense a network at one metre as at the surface.

0-15 cm	Dark brown (10 YR 4/3); heavy sandy loam; weak medium subangular blocky; dry and fine foots; few tubular pores and faunal (termite) pellets; clear smooth boundary.
15-30 cm	Dark brown (10 YR 4/3); fine sandy loam and silt loam striated bands; moderate medium angular blocky; dry and slightly hard; many fine tubular pores; many medium and fine roots; abrupt wavy boundary.
30-45 cm	Dark brown (10 YR 3/); gravelly heavy sandy loam matrix to stone and gravel bank; many medium and fine roots; abrupt smooth boundary.
45-65 cm	Dark brown (10 YR 3/3); sandy loam, moderate medium subangular blocky; dry and slightly hard; many medium and fine roots; many tubular pores; few limestone stones and gravel; abrupt smooth boundary.
65-75 cm	Dark brown (10 YR 3/3) gravelly heavy sandy loam matrix to stone and gravel band; many medium and fine roots; abrupt smooth boundary.
75-105 cm	Dark brown (10 YR 3/3); sandy loam; moderate medium subangular blocky; (rest of description as for 45-65 cm).
105-145 cm	Dark brown (10 YR 3/3); silt loam; few fine strong brown mottles; strong medium angular blocky; dry and hard; many medium and fine roots; few fine pores; stratified with thin sandy loam layers; abrupt smooth boundary.
145-160 cm	Dark brown (10 YR 3/3); coarse sand and gravel; structureless; many fine roots; many rounded limestone stones.

C) Laboratory

	Depth (cm) 0-15	15-30	34-45	45-64	65-105
Texture (%, mm)					
2	6	2	15	5	11
2-0.2	53	36	44	55	55
0.2-0.05	11	2	11	12	9
0.05-0.002	12	40	11	13	10
0.002	18	20	19	15	15
pH	8.1	8.2	8.1	8.1	8.1
EC (mmhos/cm)	0.2	0.1	0.2	0.1	0.1
Exchangeable cations					
Ca	16.5	24.1	15.4	18.1	13.6
Mg	1.2	2.0	1.4	1.6	1.0
Na	0.0	0.0	0.0	0.0	0.0
K	0.8	0.6	0.5	0.5	0.3
CEC (me/100g)	19.0	26.6	16.6	19.0	13.6
$CaCO_3$ (%)	13.9	10.0	20.6	10.8	4.6
Total K (mg/100g Soil	435	601	m	m	m
Available P	1.3	1.5	m	m	m
(me/100g soil)	1.3	1.5	m	m	m
Total N (%)	0.10	0.10	m	m	m
Organic C (%)	1.0	1.4	m	m	m
Soluble (ppm)					
Cu	0.1	0.1	0.1	0.1	0.2
Zn	0.2	0.2	0.3	0.3	0.3
Mn	456	328	168	256	192
Total (ppm)					
Cu	81	79	71	72	78
Zn	98	86	77	89	80
Mn	860	980	855	765	860

5.5.7.3 Eutric Fluvisol, Meki

This profile comes from the northern shore of Lake Ziway in the Rift Valley. Within the micro-relief of an alluvial plain or delta, coarser textured materials collect on levees, as is indicated by this soil on an old levee when compared to the heavier textured soils associated with it (see Meki report).

Much of the alluvial material around Lake Ziway is pumices and ash although this is mixed with volcanic alluvium orginating further upstream on the Meki river. With the exception of the loamys and horizon, the low bulk densities and high CEC when compared to clay content of the horizons reflect the presence of recent pyroclastic materials in the profile.

Source: MEKI

Sandy soils on old levee material

A) Profile description

Distribution:	Widespread in the central parts of the Meki delta on old levee ridges
Location:	5 km SE of Meki town
Landform:	Old levee, level
Landuse:	Previously under maize

- Profile description:

0-12 cm	Brown (10 YR 5/3); clay loam; cloddy hard consistence; common small roots gradual smooth lower boundary.
25-85 cm	Brown (10 YR 5/3); loamy sand with a thin layer of banded silt loam at 35 cm; structureless; loose consistence; common small roots; few pumice grains; few clay skins along root channels in top 10 cm; abrupt smooth lower boundary.
85-155 cm	Brown (10 YR 5/3); with dark brown and black organic stains between depositional layers; common distinct strong brown and yellowish red mottles; silty clay loam with bands and lenses of silt loam; banded structure (due to deposition of sand and silt) with well developed vertical cracks when dry; slightly hard consistence; common small roots; abrupt smooth lower boundary.
115-140 cm	Brown (7.5 YR 4/2); common prominent yellowish red mottles along old root channels; clay; moderate coarse vertical cracks; very hard consistence; few small roots; clear wavy lower boundary.

140-160 cm	Dark brown (7.5 YR 3/2); with common small brown patches; clay with areas of silty clay; weak medium to fine subangular blocky structure; hard consistence; for small fibrous roots; few small soft manganese nodules; abrupt irregular lower boundary.
160-200+ cm	as 85- 115 cm
12-25 cm	Greyish brown (10 YR 5/2); few small faint brown sandy mottles; clay loam; moderate medium subangular blocky; few weakly developed prismatic cracks; very hard consistence; common small roots; abrupt wavy lower boundary.

- Variations: The subsoil sand (or loamy sand) horizon may occur at depths between 20 and 75 cm and may vary in thickness from 1t to 60 cm. Thin silt loam layers. lenses and convolutions are commonly present within sand horizons. The dominant subsoil horizon is a mottled and banded deposit of silt loam or silty clay loam. Lensing and convoluting are common in this horizon and thin sand layers may also be present. Clay layers usually occur below 75 cm and attain thicknesses of up to 25 cm. An alkali phase below 50 cm has an ESP averaging 39.

B) Laboratory data

	0-12	12-25	25-65	68-115	115-140
Texture (%, mm)					
2	0	0	1.1	0.4	0
2-0.05	29	26	89	15	4
0.05-0.002	41	42	6	58	45
0.002	30	32	5	27	51
Organic matter (%)	3.9	2.5	0.3	1.0	1.4
Total N (%)	0.25	0.14	0.02	0.07	0.11
pH	7.0	7.1	7.3	7.5	6.0
EC (mmhos/cm)	0.12	0.09	0.08	0.15	0.12
$CaCO_3$ (%)	0	0	0	0	0
Exchangeable cations (me/100g)					
Na	0.1	0.2	0.2	0.8	0.9
K	3.3	2.5	0.9	0.7	1.0
Mg	5.6	6.9	3.5	7.7	9.4
Ca	23.8	23.2	10.0	21.7	20.8
Sum	32.8	31.8	14.6	31.9	34.1

	0-12	12-25	25-65	68-115	115-140
CEC (me/100g)	34.3	35.9	14.4	33.7	41.0
Base saturation (%)	96	89	100	95	83
ESP	1	1	1	5	7
Available P (ppm)	12	4	3	6	25
Total (ppm)					
P	570	470	330	430	530
K	7500	6950	2600	5450	6850
Mg	5850	6050	3800	6400	6650
Cu	30	30	20	30	40
Mn	1570	1630	1290	2220	1130
Zn	150	150	90	160	180
Bulk density (g/ml)	0.92	0.90	1.23	0.82	0.

C) Accumulated intakes and infiltration rates

Profile characteristics:	clay loam over layered loamy sand and silty clay loam
Soil conditions Prior to test:	cultivated, cloddy surface
Averaged accumulated intake after 9 hrs (mm):	633
Average final rate of infiltration (mm/hr:	45

D) Summary of available soil moisture

	Depth (cm)	
	0-20	35-85
Field texture:	clay loam	loamy sand
True density (g/ml):	2.536	2.605
Apparent density (g/m):	1.106	1.141
Porosity (%)	56.4	56.1
Moisture at field capacity (volume basis, %)*:	31.1	25.5
Moisture at wilting point (volume basis, %):	23.3	12.6
Available water (volume basis, %):	7.8	12.9
Air filled pore space at field capacity (volume basis %):	25.3	30.6
Texture (%, mm)		
2-0.05	28	87
0.05-0.002	41	6
0.002	31	7

* taken 1 day after irrigation or artificial saturation

5.5.7.4 Eutric Fluvisol, Awash

This profile represents those soils most intensively cultivated as irrigated state farms to fruit and cotton in the middle Awash river valley.

Source: AWASH

Alluvial soils on recent very slightly or non-calcareous deposits

A) General

- Typical features of these soils are their comparatively light colour and underdeveloped condition. They have formed over medium to heavy textured alluvia (sandy loam, silt loam, silt, clay loam) and are brown loam soils coloured 10 YR 4/2, 5/2 and 6/2. They do not contain any dark horizons, except occasionally a surface horizon very rich in organic matter. Their structure is weakly developed, usually platy, of varying fineness depending on the grain size of the deposit, and tending to develop into a blocky structure with block dimensions depending on local moisture conditions and clay content. Organic matter content may be as high as 10% but the average rate is about 2%. Lime content is low, generally below 5% although pH values are on the high side (7.5 to 8.5) without the exchangeable sodium rate ever exceeding 10% of the exchange capacity. These soils are found on the river levees in the middle valley, in the alluviation zones up-river from the plains and along them, and on alluvial zones of major tributaries. Recent deposits have sometimes formed over former swamp areas with fine to very fine textured darker soil. Wide drying cracks or holes are typical of the microrelief. Other differences refer to texture and its homogeneity in the soil profile.

- Water relations: Except where they occur over former swamp areas, these soils have adequate natural drainage with an average permeability of 1 to 2 cm/hr. Like most soils in the Awash valley, they have a low water holding capacity which is at most 10% by volume.

- Fertility: In view of the high proportions of plant nutrients they contain, the alluvial soils on recent deposits are very fertile. Total P_2O_5 rates exceed 1000 ppm. Considering the high pH values, nitrogen rates also appear to be adequate. Exchangeable K appears to be medium to high, generally over 2 me/100g.

- Land use: These are some of the best soils in the valley. There should be no major obstacle to their development under irrigation, nor are they likely to be subject to rapid salt concentration. Their organic matter content will require maintaining or increasing however, especially to prevent soil structure deterioration and a reduction in water holding capacity.

B) Profile description

Series:	dark coloured horizon with moderately fine texture at deeper levels
Profile No.:	MFS 52
Location	Melka Sedi plain
Relief and microrelief	flat, slightly wavy
Natural vegetation:	<u>Capparis</u> sp., <u>Sanseveria</u> sp., Gramineae. thorny plants
- Profile description:	
0-20 cm	Dark greyish brown to brown (10 YR 4/2 to 4/3); silty clay loam; dry; crumb structure; friable moist; many roots.
20-50 cm	Dark greyish brown (10 YR 4/2); silty loam; dry; tendency to crumb structure; friable moist; many roots.
50-70 cm	Transition horizon.
70-120 cm	Very dark brown (10 YR 2/2); silty clay; moderately dry; prismatic structure; hard vertical cracks 1 cm wide, few roots.

C) Laboratory data

	Depth (cm) 0-10	30-40	80-90
Texture (%, mm)			
2-0.2	1	1	1
0.2-0.05	5	17	5
0.05-0.002	57	64	50
0.002	37	18	44
pH	7.4	8.1	8.0
$CaCO_3$	0.2	2.5	1.2
Organic matter (%)	3.2	1.1	m
Organic C (%)	1.9	0.62	m
Total N (%)	0.16	m	m
C/N	12		
Exchangeable cations (me/100g)			
Sum	50	m	m
Ca	42.4	m	m
Mg	4.4	m	m
K	3.05	m	m
Na	0.13	m	m
CEC (me/100g)	51.6	m	m
ESP	0.25	m	m
Humidity of saturation extract	66	56	65
EC (mmhos/cm	0.64	0.55	0.35

D) Clay mineralogy

Sample UKK 002 (0-20 cm, 10 YR 4/2, 32% clay)

montmorillonite	fairly high
illite	high
kaolinite	nil
quartz	high
hematite	low

Sample UKK 002 (170 - 250 cm, 10 YR 7/2, 34% clay)

montmorillonite	low
illite	high
kaolinite	traces
quartz	fairly high
hematite	low

Sample UKK 001 (70 - 80 cm, 10 YR 5/3, 12% clay)

montmorillonite	fairly high
illite	fairly high
kaolinite	nil
quartz	low
hematite	low

5.5.7.5 Eutric Fluvisol (vertic), Weito

This profile was taken on the alluvial plain of the Weito river in Gamo Gofa. There is some overlap between Fluvisols and Vertisols, this is most notable in Ethiopia on the alluvial plain of the Baro river where Vertisols predominate despite annual flooding and deposition. The deposition on the Baro flood plain, however, is of very fine textured material.

This profile is transitional between Vertisols and Fluvisols, but still clearly possesses the textural stratification of a Fluvisol.

Source: WEITO

A) Profile description

Profile No.:	14, W-22
Classification (FAO):	Eutric Fluvisol
U.S. taxonomy:	Vertic Ustifluvent
Author and date:	K. Klinkenberg, 4/17/81
Landform:	flat
Vegetation/landuse:	shrub savanna

- Profile description:

0-33 cm	Dark brown (7.5 YR 3/3, moist); silty clay; weak to moderate medium subangular blocky structure; consistence moist friable; thin discontinuous cutans; many fine and very fine pores; clear and wavy boundary.
33-63 cm	Dark brown (10 YR 5/4 dry and 7.5 YR 3/3 moist); silty clay; weak to moderate medium subangular blocky structure; consistence dry slightly hard, moist friable;many fine and very fine pores; few fine and common very fine roots; clear and wavy boundary.
62-85 cm	Dark brown (10 YR 6/4 dry and 1.5 YR 3/3 moist); silty clay loam; weak to moderate medium subangular blocky structure; consistence dry slightly hard, moist friable; many fine and common very fine pores; patches with angular lumps of clayey material; few very fine roots; clear and wavy boundary.
85-117 cm	Very dark greyish brown (10 YR 3/2 dry and moist); clay; moderate fine angular blocky structure (lumps); consistence dry slightly hard, moist firm; thick cutans on lumps; many medium and few very fine pores; few pseudomycelia of calcium carbonate; few very fine roots; gradual and smooth boundary.
117-137 cm	Dark brown (10 YR 4/4 dry and 7.5 YR 3/3) moist; sandy clay loam; weak to moderate medium subangular blocky structure; consistence dry slightly hard, moist friable; thin patchy cutans; many fine and very fine pores; common fine mica; common pseudomycelia of calcium carbonate; very few very fine roots; gradual and smooth boundary.

137-165 cm	Dark brown (10 YR 5.5/4 dry and 10 YR 3/3.5 moist); sandy loam; few fine distinct yellowish brown mottles; weak to moderate coarse subangular blocky structure; consistence dry soft, moist friable; many fine and very fine pores; few pseudomycelia of calcium carbonate; very few very fine roots; gradual and smooth boundary.
165-185 cm	Dark brown (10 YR 4.5/3 dry and 10 YR 3/3 moist); loamy sand; massive structure; consistence dry soft; moist very friable many fine and very fine pores; very few very fine roots.

An auguring in the bottom of the pit showed silt loam from 185 to 270 cm

B) Laboratory data

	Depth (cm)			
	0-33	33-62	62-85	85-117
Texture (%,mm)				
2-0.05	13	13.5	11	19
0.05-0.002	39	42	58	24
0.002	49	45	32	58
pH	7.6	8.2	7.8	7.8
Exchangeable cations (me/100g)				
Ca	30.4	32.4	44.9	38.4
Mg	9.4	9.1	8.1	12.9
K	1.9	1.1	0.5	1.0
Na	0.5	2.7	0.8	1.0
Sum	42.2	45.3	54.3	53.3
CEC (me/100g)	50.8	49.6	41.6	56.0
Base saturation (%)	83	91	100	95
ESP	1.0	5.4	1.9	1.8
Organic C (%)	0.5	m	m	m
Total N (%)	00.08	0.08	0.05	0.06
Available P (ppm)	60	40	56	55
EC (mmhos/cm)	m	m	m	m

	Depth (cm) 0-33	33-62	62-85	85-117
Soluble cations (me/100g)				
Ca	m	m	1.65	m
Mg	m	m	0.44	m
K	m	m	0.01	m
Na	m	m	0.18	m
Soluble anions (me/100g)				
CO_3	m	m	0.11	m
HCO_3	m	m	0.11	m
Cl	m	m	0.11	m
SO_4	m	m	2.00	m
NO_3	m	m	0.58	m

C) Tests

- Infiltration rate over time (cm/hr)

Time in hours	Test 1	2	3
½	3.2	1.2	3.2
1	1.6	0.8	2.0
2	0.9	0.8	1.0
3	0.9	0.8	0.9
4	0.8	0.5	0.8
5	0.8	0.4	0.7
6	0.8	0.5	0.6
7	0.8	0.5	0.7
8	0.9	0.3	m

- Available water capacity

	Depth (cm) 13	14	15
Texture	SiC	SiC	SiCL
Moisture content (%)			
1/3 bar	46.6	46.6	51.5
15 bar	25.0	24.8	22.1
difference	21.6	21.8	29.4
Bulk Density	1.22	1.37	1.16
Available water capacity	26.4	29.9	34.1
Adjusted available water capacity*	20.1	23.5	28.1

* Adjustment made because determination of 1/3 bar values were done on disturbed sample

D) Limiting factors and land evaluation

	Limiting factors and land evaluation for furrow irrigation by state farm	cooperative settlers	flood irrigation
Topography	0	0	0
Wind erosion	1	1	1
Drainage	1	1	n.a.
Infiltration and available water Capacity	0	0	2
Workability	1	2	n.a.
pH	1	1	1
Salinity	1	1	1
Overall evaluation	S1	$S2_s$	$S2_s$

degree of limitation	land evaluation class	limiting factors
0: nil	S1: highly suitable	s: Soil
1: slight	S2: suitable	t: topography
2: moderate		

5.5.7.6 Eutric Fluvisol (Sodic phase), Omo river

This profile of a Eutric Fluvisol (sodic phase) is from the alluvial plain of the Omo river on the southern border between Gamo Gofa and Kefa. Although having ESP values high enough to meet the criterion for a Solonetz, irrigation potential is said to be high because the soils have a low clay content and drain well.

These soils are associated with Eutric Fluvisols, saline phase, Eutric Fluvisols, Chromic Vertisols and on older alluvium Mollic Solonetz and saline phase Mollic Solonetz. All these soils are of different textural classes and all are within the 200 km^2 of the study of a part of the alluvial plain along the Omo river, giving some indication of the extreme variability of Fluvisols and of the potential for pedogenetic processes to overtake deposition as the dominant factor in soil development on alluvial materials in drier climates. Rainfall in the lower Omo valley is less than 400 mm annually.

Source: WEITO AND OMO

Allkaline Eutric Fluvisols

A) General

- Because the morphological characteristics of the allkaline Eutric Fluvisols are closer to those of Fluvisols than to those of Solonetz, these soils have been kept in the Fluvisols class, in which they form a distinct sub-group. The Fluvisols classified in this sub-group are those in which one or more horizons show, on examination of the analysis results, an exchangeable sodium percentage (ESP) of the absorption complex of more than 15%. These soils are generally not saline. Depending on the proportion of saturated sodium in the complex, these soils can be considered as highly allkaline (ESP 20 %) or medium allkaline (ESP from 15 to 20%).

- Morphological and physical characteristics: The alkaline Fluvisols have a predominantly medium or fine texture throughout the profile. The colour ranges from 10 YR 4/4 to 7.5 YR 3/2 to 5/4 depending on whether their texture is medium or fine. Certain intermediate or deep horizons of the soils present traces of oxydation/reduction on the faces of the aggregates. These mottles are generally of colour 7.5 YR 4/4. The origin of these mottles may be attributed either to oscillating water levels in Lake Turkana, or to the period when the deposits were constituted, this being the more frequent case; the mottles are in this case fossile. The structure of these soils is of the grainy type on the surface to angular polyhedral in the intermediate and deeper horizons. In certain horizons, the polyhedral structure is associated with a lamellaer structure.

- Purosity, permeability and drainage: The alkaline Fluvisols with predominantly medium texture and an ESP of less than 20% percent can be developed for irrigation without any major difficulty. Indeed the low clay content means that these soils drain well and their ESP can easily be reduced by leaching. Basin irrigation, which is more suitable for leaching, is to be recommended for this type of soil. These soils at present classified as marginally suitable could soon reach the potential of highly suitable. The predominantly fine textured alkaline Fluvisols with an ESP of between 15 and 20% have been classified as currently not suitable on account of their alkalinity but more especially because this land forms part of the area that is periodically inundated by the rising water level of Lake Turkana.

B) Profile description

Profile no.:	598 0085
Classification (FAO):	eutric alkaline Fluvisol
Landform:	flood plain
Parent material:	alluvial deposit
Vegetation/landuse:	recently under food crops
Drainage:	moderately good

- Profile description:

0-10 cm	Very dark greyish brown (10 YR 3/2 moist with brown (7.5 YR 4/4) on ped surfaces, with other black mottles (10 YR 2/1) and non-directly detectable organic matter; moist; silty clay loam; blunt chipped coherent structure in peds; frequent fine and medium roots; diffuse boundary.
10-90 cm	Very dark greyish brown (10 YR 3/2) moist with few brown (7.5 YR 4/4) mottles on peds and iron elements in mottles; moist; silty clay loam; coherent blocky thin size structure in peds associated with platy structure; plastic; frequent fine and medium roots; distinct boundary.
90+ cm	Yellowish brown (10 YR 5/4) moist with many brown (7.5 YR 4/4) mottles on peds and iron elements in mottles; wet; silty clay; coherent blocky medium and thin size structure in peds; plastic; few fine and medium roots.

C) Laboratory data

	Depth (cm)		
	0-10	10-90	90+
Texture (%, mm)			
2-0.2	2	1	1
0.2-0.05	28	10	4
0.05-0.002	39	54	27
0.002	31	35	68
pH	7.5	8.3	8.4
Organic matter (%)	5.2	m	m
Total N (%)	0.27	m	m
Total P (ppm)	1320	m	m
Exchangeable cations (me/100g)			
Ca	18.6	16.1	19.6
Mg	8.0	10.5	15.4
K	3.2	1.2	1.2
Ka	2.5	5.0	1.7
Sum	32.3	32.8	43.9
ESP	8.0	15.0	17.0
EC (mmhos/cm, 1:10)	0.24	0.16	0.25
Moisture content (%)			
1/3 bar	47	53	57
1 bar	41	50	54
15 bar	25.6	40	16.3
Permeability (cm/hr)	m	0.93	m

5.5.7.7 Calcaric Fluvisol (saline phase) lower Awash

This profile is of a saline phase Calcaric Fluvisol in the lower Awash river valley. Although salinity is not extreme and the data indicate that leaching would be relatively straight forward, leaching is not considered worthwhile because of the proximity of the groundwatertable which necessitate subsurface drainage.

Source: AWASH

Saline soils on calcareous materials

A) General

- The salinity of these lower plain soils is generally due to concentration resulting from the evaporation of more or less strongly saline water. In the middle valley, salinity is mostly due to the existing warm salt water springs at Filwoha, or to former salt springs in the Metahara region.

- The soil texture is medium to moderately fine, nearly always with occasional crossbedded very thin clayey layers. Textures generally tend to become slightly heavier with depth (silty clay loam). The soil structure is platy and varies in development; the thin clayey horizons have a fine granular structure. Soil colour is fairly light ranging from 10 YR 4/2 to 5/2, and occasionally even to 10 YR 6/1 to 6/2 on the surface. Lime content is invariably over 5% but never exceeds 10%.

- Saturated extract conductivity is generally less than 8 mmhos/cm on the surface, but is apt to rise to 10 or 20 mmhos deeper down. It is very difficult to localize individual patches of soil with different salinity rates, as conductivity rates vary from one profile to the next. Salinity variations can also be observed in the same profile, with less saline horizons in the deeper layers than near the surface, although this is less frequent. White 'salt flowers' caused by irrigation are seen on the ridge tops in ploughed fields under cultivation and canal banks; saturated extract conductivities at the top and bottom of a ridge in this condition are 7.4 and 0.96 mmhos/cm respectively. This shows the effect of the high evaporation rates in the lower plains on the formation of saline soils. The conductivity of the profile is low (less than 2 mmhos/cm) because of a leaching process due to a nearby irrigation canal.

- Use: The soils are not very suitable for development under irrigation. Not only does their salinity restrict the number of possible crops but use of this land would imply substantial leaching water application to get rid of its dissolved salts, and hence a drainage system to prevent the watertable from rising. The limited water supplies should be allotted to land with more suitable chemical and physical properties.

B) Profile description

Series:	moderately fine texture and medium salinity at deeper levels
Profile no.:	TMF 17
Location:	Dubti plain
Relief and microrelief:	flat, very slight depressions
Natural vegetation:	*Salicornia* only

- Profile description:

0-16 cm	Greyish brown (10 YR 5/2); silty clay loam; dry; very coarse subangular blocky undeveloped structure; friable; some vertical cracks; many salicornia roots.
16-20 cm	As above but the structure is very platy.
20-33 cm	Brown (10 YR 4/3); silty clay; dry; subangular blocky structure; hard; some lime concretions; roots; some saccharoid salt crystals.
33-40 cm	Light yellowish brown (10 YR 6/4); silty clay loam; friable; platy structure; some saccharoid salt crystals.
40-60 cm	Dark grey (10 YR 4/1); silty clay loam; coarse prismatic structure with a tendency when crushed to coarse subangular blocky; some shells; vertical cracks; few saccharoid salt crystals.
60-75 cm	Brown (10 YR 4/3); silty clay loam to silty loam; dry; platy structure; friable; porous.
75-85 cm	Greyish brown (10 YR 5/2); silty clay to clay; dry; platy structure; slightly friable; rusty patches of hydromorphic iron; granules of polyhedral very hard clay; some salty mycelium on the surface of aggregates.
85-120 cm	Dark reddish brown (5 YR 3/2); clay; moderately dry; coarse prismatic and when crushed subangular blocky structure; slightly friable; some very thin beds of loam; salty patches; some granules of clay have black faces.
120-140 cm	Dark brown (10 YR 3/2); silty clay; moderately dry; the same structure and consistence as above.

C) Laboratory data

	Depth (cm) 0-10	50-60	120-140
Texture (%, mm)			
2.0.2	5	0	0
0.2-0.05	14	3	3
0.05-0.002	53	59	47
0.002	28	38	52
pH	9.4	7.9	8.0
$CaCO_3$	6.5	6.0	11.0
Basic saturation (%)	44	77	72
EC (mmhos/cm)	0.75	24.6	17.7
Soluble Na (me/l of the saturation extract)	6.2	145	100

D) Tests

- Leaching test

Before leaching	Depth (cm) 10-20	40-50	100-120
Natural moisture at 105 °C	16	19	19
Base saturation (%)	78	86	82
EC (mmhos/cm, sat. ex.)	23.0	15.6	9.5
Soluble anions (me/l, sat. ex.)			
Cl	108	76	18
SO_4	41.2	32.0	36.0
CO_3	0	0	0
HCO_3	3.5	4.0	10.0

	Depth (cm)		
NO_3	130	86	78
sum	282.7	198.0	142.0
Soluble cations (me/l, sat.ex.)			
Ca	142	90	54
Mg	18	25	15
K	1.2	0.9	0.7
Na	120	80	64
sum	281.2	195.9	133.7
pH	7.2	7.6	7.7

	Depth (cm)					
After leaching	0-5	20-25	40-45	60-65	80-85	100-105
Natural moisture at 105°C	42	43	45	42	31	11
Base saturation (%)	50	78	99	96	70	82
EC (mmhos/cm,sat.ex.	1.2	3.5	4.9	6.0	30.0	9.5
Soluble anions (me/l, sat. ex.)						
Cl	5.7	3.7	4.8	9.6	232.0	53.6
SO_4	10.1	41.6	74.0	84.0	24.0	29.6
CO_3	0	0	0	0	0	0
HCO_3	6.7	7.4	6.8	8.0	21.0	10.0
NO_3	m	m	m	m	236	58
sum	22.5	52.7	85.6	101.6	513.0	151.0
Soluble cations (me/l, sat. ex.)						
Ca	11.1	9.9	21.6	36.8	266	73.5
Mg	2.7	1.2	6.4	8.0	64	17.5
K	6.2	1.3	1.0	2.3	7.0	3.5
Na	8.4	37.8	49.2	54.8	58	69.2
sum	28.4	50.2	79.0	101.9	395.0	163.7
pH	8.2	7.9	7.6	7.8	7.3	7.0

- Infiltration rates

	Test 1	Test 2	Test 3
Duration (hrs)	93 1/3	197 1/4	64 1/2
Quantity of infiltration water (cm)	106.4	402.1	74.4
Infiltration rate (cm/hr)			
at end of test	1.08	2.22	1.14
mean	1.14	2.04	1.15
Wetted depth of soil (cm)	80	106	60
Mean moisture increase as % of saturation	26.6	24.3	25.8

5.5.7.8 Calcaric Fluvisols (saline and non-saline phase), lower Wabi Shebele

The following presents mean profile descriptions, mean physical and chemical data and an indication of the variations existing for Fluvisols on one type of alluvium on the lower Wabi Shebele floodplain in the southern Ogaden.

The three mean profile descriptions show again the possible textural and chemical variations over short distances. Although the mean chemical data show the unit as saline, as most Calcaric Fluvisols in Ethiopia are, the breakdown by series indicates that this saline phase does not always occur.

The present of gypsum in the soils of the Ogaden is due to i) the presence of the main gypsum formation, i.e. a huge source of gypsum and ii) the solubility of $CaSO_4$ in water in relation to $CaCO_3$. However only small amounts of this gypsum reach the alluvial plain of the Wabi Shebele because of this plain's topographic position in relation to the drainage system off the gypsum and because of the depth of the groundwatertable on the upper terraces of this plain, from which these soil series are taken.

Source: LOWER VALLEY OF THE WABI SHEBBLE

Modal soils with powdery gypsum on the brown alluvia of the Wabi Shebele

A) Profile descriptions
Three type profiles represent the most extended series of this group

- Series: 24
  Location: Gode plain, 2 km SW of Gode bridge

Profile description:

0-10 cm	Light brown (10 YR 6/3); silty loam; relatively well developed fine subangular blocky structure; very friable; many rootlets; uniform and distinct transition to:
10-30 cm	Light greyish brown (10 YR 6/4); silty loam; fine subangular blocky structue tending to a single grained structure; friable; numerous rootlets; distinct and steady transition to:
30-80 cm	Reddish brown (5 YR 5/4); silty clay; small shrinkage cracks giving prismatic fragments; friable; some gypsum crystals; some rootlets; distinct and steady transition to:
80+ cm	Yellowish brown (10 YR 5/4) and striped brownish black (7.5 YR 3/2); clay; subvertical shrinkage cracks giving prismatic and friable fragments with a mean well developed subangular blocky structure; many gypsum crystals with sodium cchloride.

- Series: 25
  Locations: Gode plain, 1 km S of Gode bridge

- Profile description:

0-15	Yellowish grey (10 YR 6/4); silty loam; subangular blocky structure tending to a single grained structure; friable and very powdery; few rootlets; distinct and steady transition to:
15-70 cm	Light brown (10 YR 6/3); clay with medium angular blocky fragments giving a medium relatively well developed subangular blocky structure; some subvertical shrinkage cracks 1 to 3 mm wide; friable; a few rootlets; distinct and steady transition to:
70-85 cm	Yellowish brown (10 YR 6/4); silty loam; single grained structure dry and loose distinct and steady transition to :
85-200 cm	horizon with 2 to 3 cm thick clay stratifications alternating with layers of light yellow fine sand 10 to 20 cm thick and single grained structure; powdery; whole horizon is very friable

- Series: 28
  Location: Gode

Profile description:

0-3 cm	Brown (10 YR 5/3); clay; very fine to fine angular blocky pseudo-structure; loose; soil mixed with leafmod composed of thorny mimosas; no rootlets; distinct and steady transition to:

3-20 cm	Brown (10 YR 5/3); clay; 0.5 to 2 cm wide shrinkage cracks in all directions delimiting medium to coarse and friable blocky fragments giving a fine angular pseudostructure; quite friable; many rootlets; distinct and steady transition to:
20-85 cm	Brown to reddish brown (10 YR 5/3 to 5 YR 5/4); clay streaked with white fine sand; 0.5 to 3 cm broad shrinkage cracks delimiting big and quite friable blocky fragments giving a medium to coarse angular pseudo-structure; firm; many root lets; distinct and steady transition to:
85+ cm	Brownish yellow (10 YR 6/6) streaked with brown; loam; single grained structure; very friable; numerous rootlets.

- Profile observations: The horizons above described are not real soil horizons but merely layers of non-weathered alluvial deposits. This is confirmed by the distinct limits observed between the different textural layers. Great differences in the composition of the various layers are consequences of the textural variations. Powdery gypsum accumulation can only be observed in horizons with clay textures.

B) Laboratory data

- Morphological and textural variations between series: The mean texture consists of silty loam 90 cm thick, with a basis of fine or clayey sand at depth. The profile is made up of stratifications of various textures. Clay type horizons predominate and give the whole profile a mean silty loam texture. The structure is directly linked to the texture. Sandy loose horizons have a single grained structure, whereas clay horizons are compact and present a weakly developed prismatic structure or cubic structure. Generally considered, the profile may be described as friable to firm. The gypsum accumulation is powdery, forms crystals and only exists in clay horizons.

The comparative profile data allow precision as regards the textural variations and depth of the gypsum accumulation (when the latter exists) for each soil series. Textural variations between series are important as the textural types are frequently inverted. Nevertheless, for 30-90 cm the sandy texture distinctly predominates with silty loam, loam and fine sand, and allows the series to be described as having a medium texture. At depth (80+ cm) variations are important; some series consist of fine sand and others of clay. These variations must be taken into consideration when studying the importance of the drainage system to be installed for irrigation purposes. A powdery gypsum accumulation is distinctly seen in most series.

Series Depth (cm)	23	24	25	26	27	28	29	34
10		SiL	Sil	SiC	CL	C		
20	SiC						fS+SiL	
30					SiL			fS
40								
50		SCL	C			C		
60	fS			SiL	L		SiL	
70								
80								
90								
100								
110		SiC-L						
120				C	CL	L	C	
130								SiL+C
140								
150								

- The content of organic matter is low, 1.0% is the content of most of the soils where no flooding occurs and no depression effects can be observed. The average calcium carbonate content of these soils is 20% and pH is slightly over 8.0. The content of exchangeable K and of total P_2O_5 is high. Conductivity of the saturation extract increases with depth and its mean value is 9.5 mmhos/cm below 90 cm. The soluble salt content is still low but under irrigation if drainage is insufficent sodium chloride may concentrate and have a toxic effect on plants.

Depth (cm)	Series	23	24	25	26	27	28	29
0-20	Organic	2.3	1.1	0.9	0.8	1.0	2.3	0.6
20-90	matter (%)	0.3	0.9	0.9	0.7	0.6	1.0	0.8
90+		0.3	0.6	0.4	0.8	0.3	0.6	0.5
0-20		10.0	1.0	0.8	1.0	1.0	2.0	3.0
20-90	EC(mmhos/cm sat. ex.)	3.0	0.7	4.1	2.0	3.0	3.0	2.8
90+		m	3.8	22.7	12.0	6.0	4.1	8.3
0-20	Soluble NaCl	0.140	0.003	0.002	0.003	0.002	0.005	0.070
	(% of soil)	0.005	0	0.0025	0.002	0.003	0.002	0.002
90+		m	0.014	0.460	0.185	0.050	0.023	0.104
0-20		0.170	0.036	0.027	0.029	0.031	0.051	0.020
	Soluble							
20-90	$SO_4Cl, 2(H_2O)$	0.103	0.024	0.120	0.068	0.103	0.103	0.096
90+	(% of soil)	m	0.123	0.344	0.206	0.170	0.120	

5.5.7.9 Calcaric Fluvisol (saline and sodic phase), lower Awash

This profile was taken in the lower Awash, however equally saline, and saline and alkaline soils occur in the middle valley as well. Extraordinarily high salinity and alkalintiy make leaching impractical thus the soils are not considered for agricultural development. Very little, particularly tolerant natural vegetation can grow on these soils during the very short rains.

Source: AWASH

Saline alkali soils on calcareous materials

A) General

- These soils are saline, and part of their exchange complex is saturated with sodium (ESP about 50%). Their surface textures are sometimes a little heavier than those of saline soils, but their general appearance is similar.

  Between depths of 40 and 60-70 cm they feature a horizon rich in gypsum above a heavier-texture horizon which is occasionally clayier. The gypsum occurs in fibrous or "saccharoid" form and its origin may be associated with warm saline springs or small volcanoes. A few volcanoes can still be seen in a group in the plain. Analysis shows a predominance of calcium and magnesium sulphates in the saturated extract, which seems to confirm the assumption.

Salinity near the surface is not very high. Below 40 to 60 cm however, the conductivity of the saturated extract rises to a high value, nearly always over 30 mmhos/cm. The exchange complex is saturated with sodium ions and ESPs are apt to vary between 20 and 60%. pH values vary between 9 and 9.5 in the deeper horizons and between 8 and 8.5 near the surface.

- Use: The soils are practically unfit for development. Very high salinity and the high sodium saturation percentage of their exchange complex rule out the great majority of crops. Only a few plants grow on them during the short rainy period, where they from a sparse covering grazed by camels. It is reasonable not to consider the development of this land under irrigation, but to keep it as grazing land and to use available water supplies for more suitable land elsewhere. Available water supplies, by no means unlimited, would certainly not suffice to irrigate all the land capable of development elsewhere is the Awash valley.

B) Profile description

Profile no.:	TT 37
Location:	part of the Dubti desert zone
Relief and microrelief:	flat
Erosion:	slight surface erosion
Natural vegetation:	Aristida, Salicornia, small acacias fringing the small wadis which spring from the basalt materials

- Profile description:

0-20 cm	very pale brown (10 YR 7/3); silt; dry granular structure; friable; some roots.
20-40 cm	Pale brown (10 YR 6/3); silty loam; dry; tendency to platy structure; friable to slightly hard; faces of aggregates have black streaks.

40-80 cm — Pale brown (10 YR 6/3); silty loam; dry; platy and subangular blocky structure; hard.

80-100 cm — Silty loam; dry; structure as above; very hard.

C) Laboratory data

	Depth (cm) 15	35	50
Texture (%,mm)			
2-0.2	2	2	0
0.2-0.05	3	2	2
0.05-0.002	77	84	82
0.002	8	12	16
pH	8.7	8.8	8.7
$CaCO_3$	9.1	8.0	9.5
Exchangeable cations (me/100g)			
Na	20.5	25.1	27.1
sum	38	41	46.2
ESP	54	61	59
Base saturation (%)	51	53	58
EC (mmhos/cm, sat. ex.)	31.2	60.5	49.0
Soluble and cations (me/l, sat. ex.)			
Cl	128	241	312
SO_4	292	m	m
CO_3	0	m	m
HCO_3	5	m	m
Ca	28	m	m
Mg	3.6	m	m
K	1.2	m	m
Na	15		

5.5.7.10 Eutric Fluvisol (Dystric Fluvisol), Baro river.

This profile comes from the base of a levee on the Baro river in Western Ilubabor. It is transitional to the Vertisols of the alluvial plain, with distinct stratification but also vertic properties of slight cracking and weak gilgai. Mottling throughout indicated the influence of the groundwatertable.

The profile chemical data show the soils to be Eutric Fluvisols, barely meeting the base saturation requirements of such. The soils appear to be very fertile, with the surprising exception of low potassium, but suffer drainage and flooding problems.

They are associated with Dystric Fluvisols of coarser texture on the upper levee, for which the GAMBELA report includes no data but only a short general description which is included below.

Source: GAMBELA

- Pullum Series

A) General

- Pullum soils are Fluvaqents occuring on the lower part of the levees along the Baro river. The soils are very dark brown and have a subangular blocky structure. Profiles are stratified; surface texture is dominantly clay loam; subsoil is generally clay. The soils are non-calcareous throughout and have a slight profile development. They are moderately well or imperfectly drained. Available water capacity is medium to high. Reaction is medium acid. Neither soluble salt content nor exchangeable sodium are present in harmful amounts. The organic matter and total nitrogen level are medium to high; available phosphate is high to very high; exchangeable potassium is low. Cultivation on these soils is restricted to the non-flooded parts of the levee. The natural vegetation is grass and shrubs; commonly occuring and hills carry trees.

B) Profile description

Profile no.:	A
Location:	Itang, 500 meters south of the Baro river
Vegetation:	grass, some shrubs and trees
Physiography:	lower levee
Topography:	almost flat
Elevation:	approximately 420 m
Drainage class:	imperfectly drained

- Profile description:

0-22 cm	Very dark grey (10 YR 3/1) when wet and dark grey (10 YR 4/2) when dry; common medium distinct diffuse brown mottles; clay loam; strong fine to coarse subangular blocky structure; slightly hard when dry, slightly sticky and slightly plastic when wet; many very fine to coarse pores; frequent fine to coarse roots; clear broken boundary.
22-50 cm	Very dark grey (10 YR 3/2) when wet and light brownish grey (10 YR 6/2) when dry; few fine distinct clear brown mottles along pores; loam; moderate coarse subangular blocky; slightly hard when dry, non-sticky and slightly plastic when wet; common fine and many very fine pores; common very fine to fine roots; clear broken boundary.
50-140 cm	Very dark greyish brown (10 YR 3/2) when wet and dark greyish brown (10 YR 4/2) when dry; common fine distict clear brown mottles; clay; weak coarse prismatic structure with few pressure faces; very hard when dry; few fine and very fine pores; few fine and very fine roots.

- Profile characteristics: The soil is non to slightly cracking. Infrequently micro-gilgai are weakly developed. Soil colours are caracterized by 10 YR hues, values range from 2 to 5 and chromas from 1 to 3. The soils are generally mottled below 20 cm. Most profiles are stratified with a clay content of 20 to 35 % for the topsoil irregularly increasing with depth to 50%.

- Environmental characteristics: The soil occurs on the slightly elevated recent Baro levees, of which it occupies the lower parts.

B) Laboratory data

	Depth (cm)			
	0-22	22-50	50-80	80-140
Texture (%, mm)				
2-0.2	7	19	13	5
0.2-0.05	16	24	15	23
0.05-0.002	41	31	21	25
0.002	35	26	52	47
Moisture (%)	2.5	1.5	3.5	3.1
$CaCO_2$ (%)	0	0	0.1	0.1
pH				
H_2O	6.0	6.4	6.6	.69
KCl	4.6	4.6	4.9	5.4
EC (mmhos/cm, 1:2.5)	0.09	0.04	0.06	0.07
Exchangeable cations (me/100g)				
Ca	9.2	8.1	8.3	11.9
Mg	3.9	3.2	5.4	9.2
K	0.4	0.2	0.3	0.3
Na	0.1	0.1	0.9	1.3
sum	13.6	10.5	14.9	22.6
CEC (me/100g)	27.2	15.9	28.4	27.9
Base saturation (%)	50	66	52	81
Organic C (%)	1.3	0.5	0.3	0.2
Total N (%)	0.15	0.05	0.06	0.03
C/N	9	10	4	6
Available P_2O_5	58	16	27	62

- Bulk density and water holding capacity

	Depth (cm)		
	2-7	30-35	60-65
Bulk density (gm/cm^3)	0.82	0.51	1.59
Moisture content (%)			
at pF			
0.4	60	45.4	49.9
1.0	52.9	42.0	49.2
2.0	36.1	31.6	45.7
2.3	34.4	29.9	45.0
3.4	26.7	22.7	41.0
4.2	16.7	16.6	31.3
Available water	19.4	15.0	14.4
Air capacity at			
pF 2.0	24.1	13.8	4.2

D) Mineralogical examinations of 50 to 200 micron fraction (%)

Light minerals	
quartz	39
org. SiO_2 (opal)	tr
orthoclase	24
albite	8
oligoclase	1
int. plagioclase	1
Heavy minerals	
chlorite	1
biotite	1
muscovite	tr
calcite	0
hypersthene	0
augite	0
enstatite	0
hornblende	4
titanite	0
epidote	1
zoisite	0
zircon	0
tourmaline	0
garnet	0
opaque (ore)	2

Weathering products	
alterites	5
weathered biotite	0
ferruginized material	13

Note: Alterites are mainly weathered feldspars. Ferruginized material mainly consists of compound silt and clay size material, cemented and coated iron gels and goethite.

- Baro Series

Baro soils are Ustifluvents occuring on slightly elevated levees along the Baro river. The soils are dark brown and have a weakly developed fine subangular blocky structure. Profiles are stratified; surface texture is dominantly loam; subsoil is clay loam or clay. The soils are non-clacareous throughout and have a slight profile development. They are well drained. Available water capacity is estimated to be high. Reaction is strongly to medium acid. Neither soluble salt content nor exchangeable sodium are present in harmful amounts. The organic matter and total nitrogen level are medium; available phosphate is high to very high, exchangeable potassium is medium. The major part of these soils is either under cultivation, used for villeges or being grazed. Common crops are maize and sorghum.

- Environmental characteristics: The soils occupy the upper part of the slightly elevated recent Baro levees.

5.6 SOLONCHAKS

5.6.1 FAO classification

Solonchaks are soils, exclusive of those formed from recent alluvial deposits, having a high salinity* and having no diagnostic horizons other than (unless buried by 50 cm or more new material) an A horizon, a histic H horizon, acamic B horizon, a calcic or gypsic horizon.

Orthic Solonchaks are Solonchaks having an ochric A horizon; lacking takyric features; lacking hydromorphic properties within 50 cm of the surface.

Mollic Solonchaks are Solonchaks having a mollic A horizon; lacking takyric features; lacking hydromorphic properties within 50 cm of the surface.

Takyric Solonchaks are Solonchaks showing takyric features; lacking hydromorphic properties within 50 cm of the surface.

Gleyic Solonchaks are Solonchaks showing hydromorphic properties within 50 cm of the surface.

5.6.2 General environment

Solonchaks occur only in drier climates, and thus are found in Ethiopia only in the Ogaden, in the Awash river valley and the Danakil, and in the extreme southern Rift valley in the area of Lake Chew Bahir. They are very extensive on the evaporite landforms in the Ogaden and to a lesser extent in the Danakil, where parent materials contain the salts. Elsewhere in the Ogaden and the Danakil and in the Awash river valley, Solonchaks generally occur on alluvial and colluvial slopes. Saline soils along river flood plains are generally classed as Fluvisols, saline phase.

* High salinity is defined as an electrical conductivity of the saturation extract of greater than 15 mmhos/cm within 75 to 125 cm of the surface depending on texture, or greater than 4 mmhos/cm within 25 cm of the surface if pH is greater than 8.5.

5.6.3 Characteristics

The major variations in Solonchaks in Ethiopia are related to the kind, amount and distribution of salts within the profile, to the presence or absence of sodium, or to profile morphology. Otherwise pHs are alkaline and organic matter contents very low.

The distinction between soils which are only saline at depth and those which are saline throughout the profile or at the surface is important from the point of view of their fitness for agriculture, as is the presence or absence of exchangeable Na. Problems associated with excess sodium are discussed under Solonetz soils.

5.6.4 Land use and natural vegetation

Virtually all Solonchaks in Ethiopia are under natural salt tolerant vegetation or, where salinity is extremely high close to the surface, are exposed soils. Where vegetation does occur, the land is used for nomadic livestock grazing, the vegetation with its high mineral and salt content being valuable pasture.

5.6.5 Management

The most severe limitation for the agricultural use of Solonchaks is the salinity. The soluble salt content of the soil moisture creates an osmotic gradient which effectively means plants suffer drought. In addition, chloride can be toxic at very high levels and boron toxicity is common.

However, Solonchaks with comparatively low salinity, and this only at depth in the profile, can be cautiously cultivated under special conditions. Given good internal drainage, a very deep water table, and a surplus of quality irrigation water, salts can be leached from the profile, and their return prevented. These conditions are, however, not frequently met where saline soils are found in Ethiopia and where they are met, it has not proven economic to so reclaim the Solonchaks. Also, as salts can be leached through good management, salts can be introduced into the rooting depth by poor management of irrigation water supply.

5.6.6 Occurence

The four types of Solonchaks defined above all occur in Ethiopia. Orthic Solonchaks are the more widespread, occuring in the driest parts of the Ogaden and northern Rift Valley. Where water supply is somewhat higher and where salinity is at depth and does not severely interfere with vegetation growth, Mollic Solonchaks occur, as in the southern Rift Valley and the middle Awash. Takyric and Gleyic Solonchaks have only very localized occurences, generally along major river courses. Lithic phases are very common on the gently to moderately sloping evaporite landforms of the Ogaden. Sodic phases occur particularly where recent volcanics form the parent materials, as in the Awash and the southern Rift valley.

5.6.7 Profile Descriptions

5.6.7.1 Gleyic Solonchak (sodic phase), Meka Sedi plain

This profile comes from Melka Sedi plain in the middle Awash valley. The high salinity and extraordinarily high ESP make them unfit for cultivation, even were they drained.

Source: AWASH

Alkaline hydromorphic soils

A) General

These are the soils in the warm spring marsh areas. Their hydromorphic features are due to their almost permanent salt waterlogged condition. In the upper horizons, these features mainly take the form of ochre stains and a high saturation percentage. Signs of alkalinity include pH values above 9 and ESPs exceeding 40%. The average conductivity of the saturation extract is only 8 mmhos/cm, which is comparatively low. The water from the warm springs and the saturated soil extract both contain a fairly high proportion of bicarbonates.

These soils are unfit for cultivation.

B) Profile description

Profile no.: Mal 4
Location: Melka Sedi plain
Microrelief: light microrelief lowland
Flooding: flooded by the Kadabilen hot spring
Water table: 65-70 cm
Natural vegetation: Thypas, Cyperus

- Profile description:

0-1 cm	Organic matter
1-15 cm	Greyish black; silty loam; wet; sticky; undeveloped structure; shells and roots, many decomposed; layers of organic matter.
15-25 cm	Greyish black with discoloured patches; silty loam; very wet; tendency to blocky structure; shells and decomposed roots.
25-50 cm	Grey; silty loam; very wet; tendency to fine blocky structure; many roots, some decomposed.
50-65 cm	Grey; silty loam with gravels and spots of clay; very wet; some roots.
65+ cm	Mixed basalt gravels, sand and loam.

C) Laboratory Data:

	Depth (cm)		
	0-10	23-25	50-60
Texture (%)			
2-0.2	1	1	46
0.2-0.05	3	2	28
0.05-0.002	79	15	11
0.002	17	26	17
pH	9.8	9.6	9.5
$CaCO_3$ (%)	9.2	11.0	16.0
Organic matter (%)	4.9	m	m
Organic C (%)	1.93	m	m
C/N	15	m	m
Total P_2O_5 (%)	1.33	1.22	m
Exchangeable cations (me/100g)			
Na	42.0	27.2	m
Sum	53.2	50.0	m
ESP	76	54	m

	Depth (cm) 0-10	25-35	50-60
Base Saturation (%)	87	60	31
EC (mmhos/cm, Sat.ex.)	11.8	8.8	2.26
Soluble anions and cations (me/l, sat. ex.)			
Cl	70	m	m
SO_4	71	m	m
CO_3	0	m	m
HCO_3	51	m	m
Ca	3	m	m
Mg+K	10	m	m
Na	136	100	

5.6.7.2 Orthic Solonchak (sodic phase), Melka Werer

This profile comes from near Melka Werer in the middle Awash. The extraordinarily high salinity and badland topography make these soils only useful for very limited grazing. The pH values of over 10 indicates extreme alkalinity.

Source: AWASH

Saline soils and Regosols on non-differentiated materials

A) General

These soils form the "badlands" in the rough broken semi-arid barren areas where intense erosion has made a dense and dry ravine network into the ground. The mounds between the ravines vary between rounded sharp spur or table shapes. The "badlands" lie down stream from Awash station, where they cover large areas between Gewani and Tendaho, and in the Mile and Logiya river basins.

The soil is highly saline silty clay loam (80-100 mmhos/cm at 25°C). This salinity is associated with sulphates and bicarbonates. Sodium accounts for nearly all the ions. pH values are above 9.

The land is totally unfit for agricultural development. It covers 4 500 km² in the Awash Valley.

B) Profile description

Profile No.:	KK 323
Location:	Kesem; Kebena plain
Microrelief:	stony hillocks bordering lower zones
Natural vegetation:	_Vetiveria_; usually in microdepressions, some gramineae

- Profile description

0-3 cm	Greyish brown (2.5 Y 5/2); sandy loam; dry; platy structure; hard; white salt efflorescences.
3-20 cm	Dark greyish brown (10 YR 4/2); silty loam; moist; single structure; hard; some gravel.
20-60 cm	Very dark greyish brown (2.5 Y 3/2); coarse sand; moist; without consistence.

C) Laboratory date

	Depth (cm) 0-3	3-10	50-60
Texture (%)			
2-0.2	38	15	m
0.2-0.5	17	15	m
0.05-0.002	36	59	m
0.00	19	11	m
pH	10.0	10.5	10.3
$CaCo_3$	2.9	7.7	0.80
Organic matter (%)	0.8	m	m
Organic C(%)	1.47	m	m
Base saturation (%)	20	40	28
EC (mmhos/cm, sat.ex.)	231	80	6.6
Soluble anions and cations (me/l, sat. ex.)			
Cl	4000	m	32.4
SO_4	m	m	9.0
CO_3	m	m	8.0
HCO_3	m	m	14.2
Ca	m	m	0.8
Mg	m	m	0.26
K	m	m	0.14
Na	7250	1280	75

5.6.7.3 Orthic Solonchak, Kelafo

This profile was taken in Kelafo, in southern Harerge. Surface salinity is not high, and the depressions where such soils occur are said to be cultivated periodically to salt tolerant crops. The soil has vertic properties.

Source: WABI SHEBELE

Vertic soils on red alluvial deposits derived from the Kebri Dehar limestone, from the main gypsum formation and from the Mustahil limestone.

A) General

These soils occupy the small depressions scattered in the lower Ogaden, mainly in the gypsiferous zones. These depressious often have formed in the wider parts of some valleys of temporary rivers or downstream from alluvial fans. Filled in with alluvial deposits derived from limestone and gypsum, these depressions present a real economic interest in this region since they are suitable for crop growth. In fact, they are periodically flooded but less than the soils which are represented in the Danan depression. This also accounts for less pronounced vertic features. The vegetation usually consists of small greyish thorny plants with a very dense gramineae cover.

B) Profile description

Profile no.:	50
Location:	4 km southwest of Kelafo
Microrelief:	rough, with broad shrinkage cracks

- Profile description:

0-20 cm	Reddish yellow brown (7.5 YR 5/6); silty loam; medium to fine relatively well developed subangular blocky structure; unstable aggregates; powdery; numerous small shrinkage cracks; friable; short and uniform transition to:
20-100 cm	Reddish yellow (5 YR 6/8); silty clay loam; large 1 to 3 cm wide subvertical shrinkage cracks delimiting big friable subangular fragments giving a single grained structure; the whole is compact; some gypsum crystals; still some rootlets; gradual transition to:

100+ cm — Yellowish red (5 YR 5/8); clay; small shrinkage cracks; small flat angular fragments; massive and very compact; numerous small gypsum crystals; few rootlets.

C) Laboratory data:

	Depth (cm) 0-10	10-60	60+
$CaCO_3$ (%)	32	32	27
Organic matter (%)	0.6	0.5	0.4
Total N (%)	0.03	m	m
C/N	20	m	m
pH	8.2	8.2	8.1
EC (mmhos/cm, sat. ex.)			
Exchangeable cations (me/100g)			
K	0.9	0.5	0.4
Na	0.1	0.1	2.6
Total P_2O_5 (%)	0.9	1.7	1.7

These reddish yellow to yellowish red soils have a silty loam to silty clay loam texture in the first 60 cm and become clayier at depth. The structure is characterized by a general cracking of the profile when dry with shrinkage cracks in all directions in horizon A1. At depth, the structure becomes massive with a prismatic trend but slickensides are seldom observed.

The gypsum accumulation appears below 60 cm depth in the clay horizon but always in a powdery form (separate crystals). These are very calcareous soils owing to the origin of alluvial deposits derived from limestone or gypsum. The content of organic matter is weak despite the considerable vegetative cover. In fact, vegetation is active only during a short part of the year and humus is soon mineralized.

The nitrogen content is low. pH is approximately 8.2 and conductivity of the saturation extract greatly increases with depth. There is a considerable accumulation of sodium chloride which represents approximately 6.3g/100g of soil in the profiles analysed. The exchangeable potassium content is high, as is the phosphorus content. Total N/total P_2O_5 shows a very distinct nitrogen deficiency.

D) Cultural and pastoral fitness:

In the arid context of the Ogaden, these depressions constitute interesting cultivation zones but owing to soil salinity at depth only some salt tolerant plants such as certain varieties of sorghum may be considered. Some of these depressions are periodically or episodically under cultivation.

A noticeable improvement of crop yields could be achieved through a combination of the flood effects of temporary rivers and of rainfall. To this end, it would be advisable to i) improve the efficaciousness of floods, the latter being distributed homogeneously in the depressions and ii) to prevent a loss of rain water through runoff by a system of small contour earth dykes compelling rain water to seep on the spot into the soil. Nitrogen carriers such as ammonium sulphate and lime nitrate are absolutely necessary at the end of the rainy season to obtain suitable crop yields.

5.6.7.4 Orthic Solonchaks (petrogypsic phase), Gode

These profiles taken from near Gode in southern Hararge are typical of the evaporite colluvial and alluvial deposits covering thousands of square kilometers in the Ogaden. Saline at depth, they nevertheless provide good pasture for nomadic livestock grazing.

Source: WABI SHEBELE

Reddish yellow to yellowish red soils derived from the main gypsum formation and from the Mustahil limestone

A) General

These soils cover all the colluvial or alluvial zones of the gypsum formation of the lower Ogaden. They are associated with eroded soils in an early stage of development on the gypsum hills, and with the soils of the sandstone plateau north or Imi. The total surface occupied by these soils is about 23 400 km^2, which is about 1/9 of the Wabi Shebele basin.

- The erosion of the retreating slopes of the sandstone plateaux of which very often only remnants are left as well as the erosion of the gypsum hills has provided a considerable quantity of weathered material, the latter being transported downstream by temporary rivers.

Alluvial deposits scarcely exist in the upstream part of temporary rivers finding their way with difficulty between gypsum hills which are yet hardly eroded. But, in downstream areas the landscape widens and alluvial deposits are more extended. The limit between alluvial deposits and the gypsum formations in situ is usually very distinctly seen in the field owing to a difference in the colouring. Alluvial deposits are yellowish red and soils on gypsum are yellowish grey. The temporary rivers end in alluvial fans the size of which varies according to the size of the river. In the alluvial parts along the temporary rivers or on the alluvial fans, depressed areas are covered with Vertisols or vertic soils with powdery gypsum which are suitable for agricultural purposes.

- The vegetation consists of a sparce bush with thorny (or not) shrubs approximately 2 m high and a plant association with dominant Cyrocarups habebensis. Among the beds of temporary streams a line of tall trees of the acacia type generally grows. The gramineae undergrowth is not dense and is only developed during the rainy season. On colluvial zones, bare areas may be observed in the field alternated with zones presenting a dense vegetation with a "striped bush" pattern seen on the aerial photographs.

B1) Profile description

Profile No.:	54a
Location:	Gode region
Parent material:	alluvial deposits

- Profile description:

0-30 cm	Reddish yellow (75 YR 6/6); clay loam; subangular blocky; trending to single grained structure
30-80 cm	Yellowish red (5 YR 5/8); clay; subangular blocky
80-120 cm	Dark yellowish red (5 YR 5/8); clay; compact.
120+ cm	Friable gypsum crust

B2) Profile description

Profile No.:	54b
Location:	northern Danan
Parent material:	colluvial deposits

- Profile description:

0-20 cm	Reddish yellow (7.5 YR 6/8); silty loam; scarcely developed crumb structure.
20-50 cm	Yellowish red (5 YR 5/8); clay loam; friable angular fragments.
50-70 cm	Reddish gypsum crust.
70+ cm	Gypsum slab in situ.

The forming process of the gypsum crust is different in alluvial deposits and in colluvial deposits. The alluvial deposits are usually very thick and the formation of the gypsum crust is due to the pulsation effect of the ground water table caused by variations of the hydrological conditions of temporary rivers. On the other hand colluvial deposits are not very thick and usually overlay a shallow gypsum slab. The latter plays the role of an impervious horizon which is favourable to the permanent existence of a small perched water table with abundant gypsum during the rainy season, and to the gradual formation of a gypsum crust.

In alluvial deposits, gypsum crusts are sometimes very thick and seem to depend on the importance of the height of bank dampened by flood waters which are practically always loaded with gypsum. Thus, for the Bu-Y temporary river the level of which may vary from 0-8m, a 6.5m thick gypsum crust may be observed as well as considerable saline efflorescences. In the alluvial fans of temporary rivers, the acumulation is often much weaker, approximately 20 to 50 cm thick, and sometimes is in a powdery form. In colluvial deposits, the gypsum shell is always thin and is often limited to discountinuous gypsum heaps.

C) Physical and chemical characteristics.

These reddish yellow to yellowish red soils present a silty loam to clay loam texture at the surface and are usually clayey at depth. The structure is generally scarcely developed. Surface horizons are very friable and powdery when dry, whereas at depth above the gypsum accumulation, soil becomes compact.

The calcium carbonate content is 25 to 35 percent. The content of organic matter is weak and approximately 0.9 percent in the surface horizon and 0.6 percent below. The nitrogen content is low to medium at 0.05 to 0.12 percent.

pH is approximately 8.1 but the low conductivity in the surface horizon (2 mmhos/cm) greatly increases in the gypsum crust (24 mmhos/cm). It shows a considerable increase of the sodium chloride content at this level which corresponds approximately to 5.6g/1000g of soil. This seems normal when one knows that gypsum accumulation is frequently accompanied by a sodium chloride accumulation. No alkalinization process may be observed owing to the presence of gypsum and calcium carbonate which prevent any considerable fixation of sodium on the absorbing complex.

The exchangeable potassium content is high, from 0.6 to 1.1 me/100g of soil. The phosphorus content is medium to high at 0.9 to 1.6%.

The analyses of the soils of the Gode region Showa high content of available boron, approximately 75 ppm, which is a very toxic concentration for most cultivated plants.

D) Cultural and pastoral fitness

These soils are unsuitable for crop growing. Apart from depressed areas, the alluvial and colluvial zones are nevertheless food pastures during the rainy season. Many antelopes and other animals live in these vast zones which may constitute interesting reserves for wild life.

5.7 GLEYSOLS

5.7.1 FAO classification

Gleysols are soils from unconsolidated materials exclusive of recent alluvial deposits, showing hydromorphic properties within 50 cm of the surface; having no diagnostic horizons other than (unless buried by 50 cm or more new material) an A horizon, a histic H horizon, a cambic B horizon, a calcic or a gypsic horizon; lacking the characteristics which are diagnostic for Vertisols; lacking high salinity; lacking bleached coatings on structural ped surfaces when a mollic A horizon is present which has a chroma of 2 or less to a depth of at least 15 cm (soils showing these characteristics are grouped with Gleyic Greyzems).

Eutric Gleysols are Gleysols having a base saturation (by NH_4OAc) of 50 percent or more at least between 20 and 50 cm from the surface but which are not calcareous within this depth; having no diagnostic horizons other than an ochric A horizon and a cambic B horizon; lacking plinthite within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Calcaric Gleysols are Gleysols which have a calcic or a gypsic horizon within 125 cm of the surface and/or are calcareous at least between 20 and 50 cm from the surface; having no diagnostic horizons other than an ochric A horizon and a cambic B horizon; lacking plinthite within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Dystric Gleysols are Gleysols having a base saturation (by NH_4OAc) of less than 50 percent at least between 20 and 50 cm from the surface; having no diagnostic horizons other than an ochric A horizon and a cambic B horizon; lacking plinthite within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Mollic Gleysols are Gleysols having a mollic A horizon or a eutric histic H horizon; lacking plinthite within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Humic Gleysols are Gleysols having an umbric A horizon or a dystric histic H horizon; lacking plinthite within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Plinthic Gleysols are Gleysols having plinthite within 125 cm of the surface; lacking permafrost within 200 cm of the surface.

Gelic Gleysols are Gleysols having permafrost within 200 cm of the surface.

5.7.2 General environment

Gleysols are azonal soils depending for their defining characteristics on the seasonal presence of the groundwater table with its capillaryfringe within 50 cm of the surface, and the consequent hydromorphic properties. Thus Gleysols are found locally throught Ethiopia, irrespective of climate or parent material. Their extents are limited however, as most gleyed soils in this country are vertic, are saline or have developed on recent alluvial deposits and thus fall elsewhere in the FAO-Unesco classification. The likely exception to the above is in the west of Ethiopia where very high rainfall generally -- but not completely -- prevents the development of Vertisols and where salinity is not a problem. Otherwise Gleysols may be found on the alluvial plains of major and minor rivers where fluvial processes are not dominant, in basins in the central highlands where coarser textured parent materials predominate and under other anomalous - for Ethiopia - environmental conditions.

5.7.3 Characteristics

Beyond their hydromorphic properties, which may include the presence of a histic H horizon, dominant neutral hues, saturation by groundwater and/or mottling or other evidence of reduction, Gleysols may be extremely variable with regard to chemical and physical properties. Very generally, they are commonly relatively high in clay content and high in organic matter content and have good inherent fertility.

5.7.4 Land Use and natural vegetation

Land use on Gleysols is almost exclusively peasant or nomadic livestock grazing, due to difficulties in controlling the depth of the groundwatertable or flooding. Water loving grasses and shrubs are the predominant natural vegetation.

5.7.5 Management

The major limitation to agricultural use is the waterlogging of the profile, which must be controlled through subsurface drainage, the most common requirement, or occasionally through damming of rivers. Alkalinity, although not general, is a problem for Gleysols in the Awash valley, with leaching very difficult due to the high groundwatertable. Where Gleysols can be drained, or protected from flooding, their initial very high organic matter content and high nutrient status can result in very productive agricultural land.

5.7.6 Occurence

Plinthic and Gelic Gleysols do not occur in Ethiopia. Dystric and Humic Gleysols occur largely in the highest rainfall areas of western Ethiopia. Mollic Gleysols can be found in the central highlands where Vertisols have not developed, for example on the coarse textured pyroclastics around Mt. Batu. Eutric Gleysols are found throughout Ethiopia. Calcaric Gleysols occur along major rivers in the drier parts of the country, and commonly have sodic and/or saline phases.

5.7.7 Profile descriptions

5.7.7.1 Mollic Gleysols, Tigray

This profile comes from central Tigray. The site is an alluvial plain, but slow deposition of fine textured alluvium has prevented Fluvisol characteristics from appearing, while gleyic properties are very pronounced. The mottling, neutral hue of the subsoil, and saturation of the subsoil during the dry season when this profile was taken are typical of Gleysols.

Source: TIGRAI

Kesafi Series -- Deep poorly to very poorly drained brown to grey profiles, with loam to silty clay loam textures.

A) General

- Environmental characteristics: Kesafi series soils are formed on deep colluvium in valley centres on the Enticho Plateau. The drainage is restricted and standing water may occur throughout the year around seepages. The colluvium is fine grained, silty, and is derived mostly from a variety of basement rocks; it is weakly stratified. The land carries a dense grass sward throughout the year and is used only for grazing of livestock. The vegetation comprises grasses and sedges over much of the unit, but includes aquatic species around the perennial seepage sites. The groundwater seepages are derived from upslope at the Enticho Sandstone-Basement Complex boundary. The surface of the valley centres is concave to slightly undulating, with slopes of up to four percent. Erosion of the soils is slight and deposition of flood silt is a more important process.

- Profile characteristics: The topsoil in the Kesafi series is a porous very dark greyish brown (10 YR 3/2 to 4/2) loam strongly enmeshed in a thick root mat, and up to 20 cm thick. Mottles, if present, are many and faint, but they are usually masked by a high organic matter content. The subsoil is at least 100 cm thick, and has distinct horizons defined largely on the strength of mottling. Textures include silt loams, heavy loams and silty clay loams with dark brown and grey (10 YR 4/3 and 5/1) colours passing down the profile into olive grey (5 Y 3/2) and grey (N5) colours as the intensity of gleying increases. The mottles increase in contrast downwards from distinct to prominent. Roots are present to the base of the profile but especially in the upper 50 cm.

- Analytical characteristics: Data from one profile of four horizons. The soils are slightly acid in the topsoil to slightly alkaline in the subsoil, and have very high calcium dominated base saturation. Total and soluble micronutrients are all adequate, which probably reflects concentration of trace elements in alluvial sites under conditions of slow deposition.

- Land capability characteristics: The Kesafi soils are deep with medium textures and occur on slopes of less than five percent. However, they are seasonally or perennially wet.

B) Profile description

- Information on the site:

Profile No.:	18, QE/9
Soil name:	Kesafi series
Classification:	Mollic Gleysols
Date of examination:	29 April, 1975
Author:	R.N.Munro
Location:	200 m west of Mekele-Adigrat, 7 km north of Negash village, Tigrai, 13 56'30" N and 39 35'30" E
Elevation	about 2 400 m
Physiographic position:	undulating to rolling upland plateau
Surrounding landform:	minor floodplain of small stream between sloping valley sides
Microtopography:	flat, central stream channel incised about 50 cm
Slope at site:	1-2% down valley, 4% on lower slopes of valley sides
Landuse:	intensive grazing by livestock
Vegetation:	complete cover with dense sward of grasses and sedges.
Rainfall:	about 550 mm

- Information on the soil

Parent material:	valley alluvium derived from basement metavolcanics and metasediments
Drainage - profile:	very poor
Drainage - site:	receiving site, restricted drainage
Moisture condition:	moist to 80 cm, saturated below
Flood hazard:	subject to prolonged seasonal water-logging
Surface conditions:	complete cover of grass sward
Depth of groundwater:	120 cm
Evidence of erosion:	none

- Profile description

A deep very poorly drained profile with an upper soil of brown loam overlying grey silty clay loam. The soil is mottled throughout, indicating a fluctuating water table. The soil has moderate subangular blocky structure, with crumb structure under the dense grass mat at the surface. Roots are abundant down to at least one metre; the upper horizons have moderate levels of organic matter.

0-20 cm	Very dark greyish brown (10 YR 3/2) with many fine distinct strong brown mottles; loam, moderate fine crumb structure; friably moist; high organic matter content; very porous; abundant medium and fine roots; clear smooth boundary.
20-45 cm	Brown (10 YR 4/3) with many fine distinct strong brown mottles; heavy loam; moderate medium subangular blocky structure; friable moist; moderately porous, no cracks; mainy medium and fine roots; clear smooth boundary.
45-80 cm	Grey (10 YR 5/1.5) with many fine prominent strong brown mottles; silty clay loam; moderate medium subangular pores; few mica flakes; many fine and few medium roots; clear smooth boundary.
80-120 cm	Grey (N 5/0) with many fine to medium prominent strong brown mottles; silty clay loam; moderate fine subangular blocky; plastic and non-sticky wet; no pores visible; many mica flakes and few metavolcanic stones; many fine roots.

c) Laboratory Data:

	Depth (cm)			
	0-20	20-45	45-80	80-120
Texture (%,mm)				
2	6	3	0	1
2-0.2	17	14	7	8
0.2-0.05	6	7	12	8
0.05-0.002	53	53	53	50
0.002	18	23	28	33
pH	6.2	7.2	7.5	7.5
EC (mmhos/cm)	0.3	0.2	0.1	0
Exchangeable cations (me/100g)				
Ca	16.3	19.0	18.3	17.0
Mg	5.9	5.9	6.0	5.0
Na	0.2	0.1	0.1	0.1
K	0.2	0.2	0.1	0.1
CEC (me/100g)	28.2	25.0	21.7	17.6
Soluble (ppm)				
Cu	6.0	5.1	4.9	4.0
Zn	8.3	8.5	6.9	7.3
Mn	229	45	57	126
Total (ppm)				
Cu	46	51	56	57
Zn	153	160	89	91
Mn	765	450	1200	1290

5.7.7.2 Eutric Gleysol; Wereta

This profile was taken on the eastern shore of Lake Tana. Fluvisols and Vertisols are also present in the immediate area of this Gleysol. The profile is very dark coloured and typical gley dominant hues were not encountered, however the abundance of iron and manganese mottling is indicative of reduction processes.

This profile was taken 3 months after the end of the rains, however the soil was still saturated at 20 cm depth after the floods had receded and water holes for animals had been dug. The pH is higher than typical for soils in the area, indicative of the influence of alkaline ground water from Lake Tana.

A) Profile description

- Information on the site

Profile No.:	P 20
Classification (FAO):	Eutric Gleysol
Date:	November, 1981
Author:	S.Ross, Fikru
Location:	3 km northeast of Engormarkorios
Elevation:	1820 m
Physiographic position of the site:	seasonal marsh
Landform of surrounding country:	plain
Microtopography:	very small seasonal ponds
General slope:	nearly flat
Local slope:	nearly flat
Vegetation:	Eucalyptus, Acacia, Arundinaria around homesteads, sedges
Landuse:	100 % grazing land
Climate:	humid temperate
Limitations and hazards:	drainage, workability and flooding
Land improvement:	drainage and flood control

- Information on the soil

Parent material:	fluvio-lacustrine deposits
Permeability:	very slow
Depth of groundwater:	80 cm
Drainage class:	very poorly drained
Moisture conditions:	moist to 20 cm, wet below
Stoniness:	none
Rock outcrop:	none
Evidence of erosion:	none
Presence of salt or alkali:	none
Human influence:	small holes dug to get water for animals

- Profile description:

Very dary grey to very dark greyish brown profile with many grass roots, abundant mottling and groundwater table at 80 cm.

0-20 cm	Very dark grey (10 YR 3/1) moist; clay loam; slightly hard dry, friable moist and plastic and sticky wet; many very fine and few medium pores; moderately developed medium angular blocky secondary aggregates; many coarse and prominent iron oxide mottles; much organic matter; many fine roots; the top 3 cm is essentially grass remains; clear smooth boundary.

20-40 cm

Dark grey (10 YR 4/1) moist; clay loam; hard dry, friably moist and plastic and sticky wet; many very fine, many fine and few medium pores; moderately developed fine sized angular blocky secondary aggregates; many coarse and distinct iron oxide, and common coarse and distinct manganese oxide mottles; common very fine roots; animal activity by such as earthworm; clear smooth boundary.

40-80 cm

Very dark greyish brown (10 YR 3/2) moist; silt loam; hard dry, friable moist and plastic and sticky wet; many very fine, many fine and few medium pores; weakly developed fine angular blocky secondary aggregates; many coarse distinct iron oxide and common coarse distinct manganese oxide mottles; 10-15 percent 3 mm diameter manganese oxide nodules; common snail shells; common very fine roots; animal activity by such as earthworm.

B) Laboratory data:

	Depth (cm)		
	0-20	20-40	40-80
Texture (%,mm)			
2-0.05	29	17	21
0.05-0.002	42	46	54
0.00002	29	37	25
pH H_2O	7.3	7.7	7.8
KCl	6.3	6.3	6.4
NaF	8.8	9.5	9.4
Exchangeable cations (me/100g)			
Na	1.3	1.3	1.7
K	2.0	0.5	0.3
Ca	32	30	33
Mg	19	20	21
Sum	54.4	51.8	56
CEC (me/100g)	54.51	51	47
Base saturation (%)	100	100	100
Organic C (%)	6.61	0.9	0.7
Total N (%)	0.57	0.10	0.06
C/N	11	10	12
Organic matter (%)	11.3	1.6	1.2

5.7.7.3 Calcaric Gleysols, Wabi Shebele

This profile, from the flood plain of the Wabi Shebele river, is classified as a Calcaric Gleysol due to the presence of a gypsic horizon. Again, slow alluvial deposition has resulted in few Fluvisol characteristics being evident, while hydromorphic properties are pronounced.

Source: LOWER VALLEY OF THE WABI SHEBELE

A) General

This series consists of brown clay soils, and spreads over more than 10 000 ha to the north of the Shebele plain in a long-duration flood zone, downstream from Kelafo where the river divides into many never dry branches. Overflowing exceeds a 50 cm level during the floods but the water table is never below 1.5 cm depth during the minimum flow periods and the capillary fringe never less than 30 cm below the surface. Vegetation mainly consists of Cyperaceae of papyrus type but also of tall trees with ligneous thorns. The profile below is located 2 km from the old Kelafo-Mustahil track.

B) Profile description

0-15 cm	Very dark grey (5 YR 3/1); silty clay; very organic; plastic and wet; numerous small roots and rootles; short and slightly undulated transition to:
15-50 cm	Reddish brown (5 YR 4/3); clay; plastic and wet; angular fragments easily separated from the profile; some rootlets can still be found; short and uniform transition to:
50 + cm	Reddish brown (5 YR 4/3) with red stripes (2.5 YR 4/6); small very clayey gypsum crystals; plastic and wet; angular fragments which can be easily separated from the profile; some rootlets.

Texture is very clayey throughout the profile, due to alluvial deposition by slow flow. The structure is not well defined, the whole profile being usually wet. The soil is plastic and sticky. In some cases the pseudo-structure linked to the type of alluvial deposits gives the horizons a very friable character. Below 50 cm gypsum crystals can often be observed and in some places, brick red manganese blots.

C) Laboratory Data:

	Depth (cm)		
	0-15	15-50	50+
$CaCO_3$ (%)	14	17	16
Organic matter (%)	11.0	1.5	0.8
pH	7.9	8.0	8.1
EC (mmhos/cm, sat.ex.)	3.9	3.2	3.6
Exchangeable cations (me/100g)			
K	1.2	0.4	0.7
Na	0.8	0.9	0.7
Soluble salts (% of soil, sat. ex.)			
NaCl	0.4	0.7	0.9
$SO_4Ca, 2H_2O$	15.1	10.3	10.3
Total P_2O_5 (ppm)	2600	2000	2000

Accumulation of organic matter is high, 11% for the top 15 cm. But it suddenly falls to 1.5% and less at depth. This surface humus concentration is due to the quick mineralization of the latter which soon disappears under a large and permanent addition of organic matter. Calcium carbonate content is low and pH is close to 8.0. Exchangeable potassium content is medium to high. Total phosphorus is high. Conductivity of the saturated paste throughout the profile is less than 4 mmhos/cm. Sodium chloride content is low and the gypsum content shows that powdery gypsum supplies exist in the soil.

D) Cultural aptitude: These soils are suitable for land reclamation because of their high organic matter content and their low chloride concentration. However, many land clearing and levelling problems exist. Furthermore, flood control is necessary.

5.8 ANDOSOLS

5.8.1 FAO classification

Andosols are soils having a mollic or an umbric A horizon, possibly overlying a cambic B horizon, or ochric A horizon and a cambic B horizon; having no other diagnostic horizons (unless buried by 50 cm or more new material); having to a depth of 35 cm or more one or both of:

(a) a bulk density at 1/3 bar water retention) of the fine earth (less than 2 mm) fraction of the soil of less than 0.85 g/cm^3 and an exchange complex dominated by amorphous material;

(b) 60 percent or more vitric (including glass, crystalline particles coated with glass, and partially devitrified glass) volcanic ash, cinders, or other vitric phroclastic material in the silt, sand and gravel fractions;

lacking hydromorphic properties within 50 cm of the surface; lacking the characteristics which are diagnostic for Vertisols; lacking high salinity.

Ochric Andosols are Andosols having an ochric A horizon and a cambic B horizon; having a smeary consistence and/or having a texture which is silt loam or finer on the weighted average for all horizons within 100 cm of the surface.

Mollic Andosols are Andosols having a mollic A horizon; having a smeary consistence, and/or having a texture which is silt loam or finer on the weighted average for all horizons within 100 cm of the surface.

Humic Andosols are Andosols having an umbric A horizon; having a smeary consistence and/or having a texture which is silt loam or finer on the weighted average for all horizons within 100 cm of the surface.

Vitric Andosols are Andosols lacking a smeary consistence and/or having a texture which is coarser than silt loam on the weighted average for all horizons within 100 cm of the surface.

5.8.2 General environment

Andosols are azonal soils, their properties largely determined by the characteristics of the parent materials rather than other environmental factors and can occur wherever young, vitric pyroclastic deposits are found. Quaternary volcanic activity in Ethiopia is concentrated in the Rift Valley, the largest extents of Andosols in the country being between Lake Abaya and Metahara. However, Andosols do occur along the north-eastern escarpment and on large volcanic piles such as Mt. Ras Dejen and Mt. Batu. The history of the pyroclastic deposits in such locations is somewhat mysterious, it being hypothesized that wind blown ash has been laid down in such location after recent volcanic eruptions in the Rift, or alternatively, that the materials are older preserved deposits recently exhumed by erosion.

5.8.3 Characteristics

Andosols are generally dark, porous soils with very low bulk density. They have a high silt content, but textures range from fine to coarse depending on the relative proportions of ash and pumice in the parent materials. They have a high proportion of amorphous clay minerals, the most important consequences of which are, negatively, a high phosphorous fixing capacity and positively, a comparatively high cation exchange capacity in relation to texture.

5.8.4 Land use and natural vegetation

Because the largest extents of Andosols occur, in Ethiopia, in the drier climates of the Rift Valley, they are predominantly used for nomadic livestock grazing. However there are a number of exceptions. On the lakeshores of the Rift Valley lakes where irrigation water is available, horticultural far[illegible] have been developed.

Elsewhere in this region, where rainfall is highly variable but can be plentiful in some years, Andosols are planted to grains if the onset of the rains promises higher than average precipitation, and some of the highest peasant production levels of yield in the country are the result. On the north-eastern escarpment, Andosols are cultivated and grazed, depending on their topographic position and degree of erosion.

5.8.5 Management

Very coarse textured Andosols have a poor nutrient status and require large amounts of water to be productive. However, the finer textured Andosols, given an adequate supply of moisture, are some of the most productive soils in the world, in the absence of special limitations that are not general to this soil type. In Ethiopia, their predominant occurence in semi-arid areas has the result that many Andosols in this country are sodic, and saline phases are common. Their only other major limitation to agricultural use is a demand for high applications of phosphate fertilizers to overcome phosphorous fixation by amorphous clay minerals.

The finer textured Andosols have a number of advantages for agriculture. High infiltration rates, high available water capacity and free drainage simplify management of irrigation water, particularly if leaching is required. High available water capacity reduces difficulties implied by short term irrigularities in moisture supply under rainfed conditions. Andosols have a high natural fertility, which is continually renewed by the high proportion of weatherable minerals characteristic of young soils.

5.8.6 Presence

The four types of Andosols defined above all occur in Ethiopia. Ochric Andosols are typical in the drier parts of the Rift Valley. Mollic Andosols occur in the wetter parts of the Rift Valley and along the northeastern escarpment. Humic Andosols have been described on Mt. Ras Dejen. Vitric Andosols occur throughout the Rift and elsewhere in the country where coarser textured pyroclastics predominate. Sodic, saline and lithic phases are common in Mollic and Vitric Andosols in the Rift Valley, and lithic phases occur in the wetter highlands, on steep slopes.

5.8.7 Profile Descriptions

5.8.7.1/ Vitric and Mollic Andosols, Meki

5.8.7.2 These profiles are from the western shore of Lake Ziway, Shewa, and provide a good comparison between medium and coarse textured Andosols, particularly with respect to porosity and available water capacity. The parent materials are largely volcanic ash and pumice deposited subaerially, and soils still maintaining the characteristics of Fluvisols are found closer to Lake Ziway.

Bulk density is rather high in both soils, in the Mollic Andosols especially. Phosphorus is typically very low and potassium typically very high. Sodic phases are not present in the two profiles described here, but are widespread in the area. The high pHs are attributed to the presence of calcareous materials.

Source: MEKI AND GALANA

A) General

Andosolization in the area is related to the eruptive nature of the parent rock, basic volcanic ash and very broken pumic scoriae, and in particular to their non-crystalline 'glass' content. These young Andosols are not very developed but have a fairly well developed structural (B) horizon. The profile is thus of the A(B)C type and not AC as for typical Andosols. Given their recent nature, the Andosols are almost entirely Vitric Andosols. Only over a limited area are the more structured and finer textured Mollic Andosols found.

Where pH values of greater than 8 and even 8.5 are found, these high values are indicative of lateral calcareous inflows and 'calcareous impregnation' phase has been distinguished. As far as morphological characteristics are concerned, these soils are very heterogeneous. The following characteristics were nevertheless found:

- The surface horizon is 30 cm thick on average, although thickness varies considerably, from 15 to 55 cm. The colour is always the same, 10 YR 3/2. Texture is medium and medium and/or fine subangular blocky structure is strongly developed in peds throughout, and is locally associated with an angular structure. When dry the material is often fragile, especially in the Vitric Andosols. There is good fine tubular porosity. Root growth is dense and the transition to the underlying horizon is always regular.

- The underlying (B) horizon has an average depth of 50 cm although here again the thickness of the layer varies considerably, from 25 to 100 cm. Colour is more variable, often 10 YR 2/2 or 3/3, fairly often 10 YR 4/2 or 3/3 and occasionally 10 YR 4/4. In places where the horizon has been impregnated with limestone, the colour is either 10 YR 5/3 or 2.5 Y 5/2. The soil generally has a medium texture, rarely a coarse texture and occasionally a fine texture on the horizons with calcareous impregnation. There is fairly generalised subangular blocky strongly developed in peds structure, generally medium and fine, but otherwise medium or medium and coarse. The material is often fresh and friable, porosity is good, and rooting is satisfactory. Transition is regular in the Vitric Andosols and undulating in the Mollic Andosols.

The underlying deep horizon differs depending on whether the soil is a Vitric or a Mollic Andosol. In the Vitric Andosols (easily the more widespread) the colour varies considerably, 10 YR 5/3 or 5/2 generally, but otherwise 10 YR 4/3, 4/4, 3/3 or 3/4. This is a B/C horizon formed by weathering of volcanic ash and pumice. The texture is coarse with fine and medium sand. The horizon has a single-grain structure, the material is fragile and porosity is high. Root growth is very slight or zero. Gravels and/or unweathered pumice stones are frequently found in this horizon. In the Mollic Andosols, the colour is more homogeneous, 10 YR 5/3. Texture is finer, clay loam or sandy clay loam. The structure, locally strongly developed in peds, is still angular blocky. Pores are numerous and root growth remains satisfactory.

B1) ofile description.

Profile no.:	001 0052
Classification (FAO):	Vitric Andosol
Land form:	plain
Slope:	less than 1%
Parent material:	pumice
Vegetation/landuse:	high sparse woody vegetation and cultivation of food crops
Permeability:	Permeable soil; permeable subsoil

- Profile description:

0-15 cm	Very dark greyish brown (10 YR 3/2) dry with organic debris; silt loam; dry; moderately developed subangular blocky thin size structure in peds; common fine and medium random tubular slightly fragile pores; frequent fine and medium roots; smooth transition.
15-70 cm	Very dark brown (10 YR 3/3) moist with organic debris; silt loam; fresh; weakly developed medium subangular blocky associated with blocky structure; common fine random tubular friable pores; common fine foots; irregular transition.

70-180 cm	Greyish brown (10 YR 5/2) moist; sandy loam; fresh; single grain structure; very few gravel; very few weakly weathered stones; common very fine and fine random tubular friable pores; few fine roots.
180-270 cm	Brown (10 YR 5/3); sand loam.

C1) Laboratory data:

	Depth (cm)			
	0-15	15-70	70-180	180-270
Texture (%, mm)				
2-0.2	17	24	22	22
0.2-0.05	8	31	31	30
0.05-0.002	69	42	46	46
0.002	6	3	1	2
pH	6.9	7.8	8.8	9.8
Organic carbon (%)	2.4	1.4	m	m
Total N (%)	0.03	0.02	m	m
Available P_2O_5 (ppm)	5	5	m	m
Exchangeable cations (cm/100g)				
Ca	15	16.1	91.7	m
Mg	2.6	2.6	4.1	m
K	2.0	1.9	1.6	m
Na	0.2	0.3	0.9	m
Cation exchange capacity (me/100g)	57.2	38.8	16.7	m
Particle density	2.3	2.2	2.3	m
Moisture content (%)				
1 bar	38.8	33.3	36.1	m
15 bar	13.6	12.1	7.5	m

D1) Ranges and averages of laboratory data for Vitric Andosols in the study area:

	Minimum	Average	Maximum
pH a*	6.7	6.8	6.9
b*	7.7	7.8	7.8
c*	m	8.8	m

* a = surface horizon, b = intermediate horizon, c = deep horizon

	Minimum	Average	Maximum
Organic matter (%)			
a	3.42	3.78	4.14
b	1.44	1.89	2.34
c	m	m	m
Total N (%)			
a	0.19	0.22	0.25
b	0.08	0.11	0.15
c	m	m	m
C/N			
a	9.60	10.00	10.40
b	9.00	9.70	10.45
c	m	m	m
Exchangeable cations, sum (me/100g)			
a	15.41	17.64	19.87
b	20.09	20.52	20.96
c	m	25.08	m
Cation exchange capacity (me/100g)			
a	33.78	35.52	37.27
b	29.35	34.10	38.85
c	16.72	m	28.07
Base saturation (%)			
a	45.50	49.50	53.30
b	54.00	61.20	68.40
c	m	m	m
Assimilable P_2O_5 (ppm)			
a	4	4.5	55
b	5	5.5	66
c	m	m	m
Real specific gravity (g/cm^3)			
a	2.33	2.38	2.44
b	2.10	2.19	2.28
c	2.11	2.23	2.34

	Minimum	Average	Maximum
Bulk density (g/cm^3)			
a	0.95	1.02	1.09
b	0.95	0.95	1.00
c	m	m	m
Porosity (%)			
a	m	57.10	m
b	m	55.70	m
c	m	m	m
Moisture content at field capacity (%)			
a	38.20	38.50	38.80
b	33.30	35.30	37.20
c	m	36.10	m
Moisture content at permanent wilting point (%)			
a	13.60	13.90	14.20
b	12.10	15.00	18.00
c	m	7.60	m
Available water capacity (%)			
a	24.00	24.60	25.20
b	19.20	20.20	21.20
c	m	28.50	m

E1) Recommended quantities of irrigation water (m^3/ha):

for a root depth of 50 cm	800
for a root depth of 100 cm	1 500

B2) Profile description

Profile no.:	001 0001
Classification:	Mollic Andosol
Landform:	plain
Slope:	less than 1%
Parent material	scoria, pumice and ash
Vegetation:	very sparse high woody vegetation
Permeability:	permeable soil, very permeable subsoil
Microrelief:	termite mounds

- Profile description:

0-15 cm	Very dark greyish brown (10 YR 3/2)moist with humus; silty loam; dry; moderately developed medium subangular blocky associated with blocky structure; many fine and medium pores; coherent; frequent fine and medium roots; smooth transition.
15-60 cm	Very dark greyish brown (10 YR 3/2) moist with humus; silt loam; fresh; moderately developed medium and coarse subangular blocky structure; common fine and medium pores; coherent; common fine and medium roots; wavy transition.
60-90 cm	Brown (10 YR 5/3) moist; silt loam; fresh; moderately developed medium and coarse blocky structure; few limestone stones; common pores; coherent; few fine roots; wavy transition.
90-120 cm	Greyish brown (10 YR 6/2) moist; loam; fresh; massive structure associated with blocky structure; common pores; coherent; few fine roots; smooth transition.
120-140 cm	Greyish brown (10 YR 6/2) moist; loam; fresh; massive structure; common pores; light; no roots; smooth transition.
200-300 cm	Dark greyish brown (10 YR 4/2) moist; loamy sand with coarse sand; fresh; moderately developed massive structure common pores; light; no roots.

C2) Laboratory data:

	Depth (cm) 0-15	15-60	60-90	90-120
Texture (%, mm)				
0.0-2	13	12	18	21
0.2-0.05	19	25	21	22
0.05-0.002	51	53	52	47
0.002	14	10	9	10
pH	7.7	8.4	7.8	8.8
Organic carbon (%)	3.6	1.8	m	m
Total N (%)	0.03	0.08	m	m
Assimilable P_2O_5 (ppm)	9	4	m	m
Exchangeable cations (me/100g)				
Ca	31.2	65.8	m	m
Mg	2.9	2.8	m	m
K	2.5	1.5	m	m
Na	0.2	0.9	m	m
Cation exchange capacity (me/100g)	61.4	56	m	m
Particle density	2.5	2.4	m	m
Moisture content (%)				
1 bar	46.1	45.8	m	m
15 bar	18.4	19.5	m	m

D2) Ranges and averages of laboratory data for Mollic Andosols in the study area:

	Minimum	Average	Maximum
pH			
a*	7.7	7.9	8.1
b*	7.4	7.9	8.4
c*	7.8	8.2	8.6
Organic matter (%)			
a	4.42	5.36	6.25
b	2.87	2.95	3.03
c	m	m	m
Total N (%)			
a	0.26	0.30	0.35
b	0.20	0.50	0.79
c	m	m	m

* a = surface horizon, b= intermediate horizon, c= deep horizon.

	Minimum	Average	Maximum
C/N			
a	10.50	16.60	22.60
b	9.90	10.60	10.10
c	m	m	m
Exchangeable cations sum (me/100g)			
a	16.10	26.50	36.90
b	m	23.05	m
c	m	m	m
Cation exchange capacity (me/100g)			
a	m	42.98	m
b	m	51.57	m
c	m	m	m
Base Saturation (%)			
a	44.40	52.20	60.00
b	m	m	m
c	m	m	m
Assimilable P_2O_5 (%)			
a	0.09	0.23	0.37
b	0.04	0.04	0.04
c	m	m	m
Real specific gravity (g/cm3)			
a	m	2.53	m
b	m	2.4	m
c	m	m	m
Bulk density (g/cm^3)			
a	m	1.05	m
b	m	1.62	m
c	m	m	m
Porosity (%)			
a	m	58.70	m
b	m	32.50	m
c	m	m	m
Moisture content at field capacity (%)			
a	m	46.10	m
b	m	32.50	m
c	m	m	m

Moisture content at permanent wilting point (%)			
a	m	18.40	m
b	19.50	19.50	m
c	m	m	m
Available water capacity (%)			
a	m	27.40	m
b	m	26.30	m
c	m	m	m

E2) Recommended quantities of irrigation water (m^3/ha):

for a root depth of 50 cm	1 200
for a root depth of 100 cm	2 500

5.8.7.3 Mollic Andosol, Metahara

This profile was taken near Metahara in the middle Awash river valley. The soil described below is mapped as part of a group of eroding soils which are generally unfit for agriculture. However this particular profile is deep, is in a flat topographic position, and is not sodic as many Andosols in the Metahara area are. Such soils are productive when irrigated from the many flowing tributaries of the Awash river.

The weakly developed to inchorent structure is common in very young Andosols developed on unconsolidated ash.

Source: AWASH

A) Profile description

Profile no.:	MMH 3
Location:	Metahara plain
Relief:	flat
Erosion:	sheet
Matural vegetation:	groves of small acacias, occasional large acacias, patches of gramineae used for pasture, several Capparis

- Profile description:

0 - 1 cm	Greyish brown to pale brown (10 YR 5/2 to 6/3); loamy sand; dry; granular to powdery structure; friable; some roots.
0 - 15 cm	Light brown; loam; very fine single grained earth is held back by numerous rootlets; humid; "fluffy" talc-like consistence; distinct transition.;
15 - 60 cm	Blackish brown; fine sand; firmer single grained structure than above; still many rootlets; gradual transition.
60 - 100 cm	Reddish brown; fine sand; structure tending to single grained; still some rootlets with basalt gravels in the base.
100+ cm	Basalt slab in situ

The distinct differentiation between horizons A and (B) is linked to the colouring which is not variable although is sometimes bright red in the case of the (B) horizon. This is probably due to the individualization of ferrugineous constituents in relation to the deep weathering of basalt.

C) Laboratory Data:

	Depth (cm)		
	0 -15	15 -60	60 -100
$CaCO_3$(%)	0	0	0
Organic matter (%)	24.1	21.6	14.2
Total N (%)	1.06	0.92	0.59
C/N	13	13	13
pH	5.4	5.6	5.5
Exchangeable cations (me/100 g)			
Ca	8.6	7.5	5.4
Mg	1.9	1.5	0.05
K	1.1	0.9	0.4
Na	0.1	0.1	0.1
sum	11.7	10.0	5.59
Cation Exchange capacity (me/100 g)	69.3	69.5	54.6
Base saturation (%)	16.8	14.4	10.9
Total Fe_2O_3	7 0	7.4	10.2
Free Fe_2O_3	2.0	2.2	2.9
Free/total Fe_2O_3	0.28	0.29	0.28

These soils are mainly characterized by the abundance of amorphous material such as allophanes, which are easily revealed in the field by Fields and Perrott potassium fluoride test. The dark brown colouring of the soil when humid becomes light gray when dry. Although the texture is not easily determined, it seems to be loamy to fine sandy. The structure is mostly single grained. However, the soil consistence is characteristic and may be compared to that of a very fine and slightly compressed powder ("fluffy").

pH is very acid and scarcely varies with depth. The cation exchange capacity is very high but the base saturation is low. The exchangeable potassium percentage is high at the surface and medium at depth. The Free iron/Total iron ratio averages 0.28, hence there is no migration of iron.

D) Cultural fitness: Owing to the altitude and droughty climatic conditions, these soils are scarcely suitable for agricultural purposes. Nonetheless, some land clearing is now being undertaken on the western slope of Mt. Boraluku. Erosion is considerable on the steep slopes beaten by heavy rainfall. These zones should be kept as reserves for wild life.

5.8.7.4 Mollic or Humic Andosol, north-eastern escarpment

These soils are found on the north-eastern escarpment at high altitudes. Their parent material is probably mainly volcanic ash. They are associated with Haplic Phaeozems, often lithic phase (5. 7.) on lower cultivated slopes. These soils are dominantly under natural vegetation. pH values range from 4.8 to 5.2.

Source: LUPRD

A) Profile description

Profile no.:	210d, Borkena
Date:	16/12/82
Authors:	Fitsum F., Gebeyehu B., S. Paris
Location:	18 km NE of Rabel, 1 km N of junction Del Mikael road, along the road; 10°39'40"N - 39°42'55"E
Classification FAO:	Mollic or Humic Andosol, stony phase
USDA:	Typic Eutrandept or Hydric Dystrandept
Physiographic position:	high ridge in the highlands
Slope	40%
Elevation	3330 m
Vegetation/landuse	dwarf shrub grassland (Festuca abyssinica, Lobelia sp.
Climate	Humid cool tropical

- Information on the soil:

Parent material:	Colluvial deposit derived from volcanic rock (probably mainly airborn tuffaceous deposits)
Drainage:	well drained
Moisture condition:	moist throughout
Rock outcrop:	fairly rocky
Evidence of erosion:	none

- Profile description

0-20 cm An	Black (10 YR 2/1) moist and very dark greyish brown (10 YR 3/2) dry, loam; weak fine and medium crumb; loose (dry), friable (moist), slightly sticky and non plastic (wet); many pores; few gravel; many fine to medium roots; diffuse and amooth on:

20-65 cm AB	Black (10 YR 2/1) moist and very dark brown (10 YR 2/2) dry, clay loam to loam; weak coarse subangular blocky; soft (dry), friable (Moist), slightly sticky, non plastic and thixotropic (when wet); many pores; few gravel; many very fine and fine roots; diffuse and smooth on:
65-100 cm+ B	Black (10 YR 2/1) clay loam; weak coarse subangular blocky; slightly hard (dry), friable (moist), slightly sticky, non plastic and thixotropic (wet); many pores; few gravel; many very fine and fine roots.

B) Laboratory data

	Depth (cm)		
	0-20	20-65	65-100
Texture			
2-0.05	54	32	34
0.05-0.002	34	40	32
0.002	12	28	34
pH (1:1)			
H_2O	5.2	4.9	4.8
NaF	9.3	9.3	9.2
Exchangeable cations (me/100 g)			
Na	1.7	0.4	0.9
K	0.5	0.5	0.3
Ca	9.8	10.7	16.6
Mg	4.2	5.7	0.6
CEC (me/100 g)	34.2	29.2	35.8
Base saturation (%)	47	59	51
Organic C (%)	9.2	6.8	4.2
Total N (%)	0.92	0.42	0.56
Avaialable P_2O_5 (ppm)	8	10	6

5.9 ARENOSOLS

5.9.1 FAO classification

Arenosols are soils from coarse textured unconsolidated materials, exclusive of recent alluvial deposits, consisting of albic material occuring over a depth of at least 50 cm from the surface or showing characterstics of argillic, cambic or oxic B horizons which, however, do not qualify as diagnostic horizons because of textural requirement; having no diagnostic horizons (unless buried by 50 cm or more new material) other than an ochric A horizon; lacking hydromorphic properties within 50 cm of the surface; lacking high salinity.

Cambic Arenosols are Arenosols showing colouring or alteration characteristics of a cambic B horizon immediately below the A horizon; lacking lamellae of clay accumulation; lacking ferralic properties.

Luvic Arensols are Arenosols showing lamellae of clay accumulation within 125 cm of the surface; not consisting of albic material in the upper 50 cm of the soil.

Ferralic Arenosols are Arenosols showing ferralic properties; lacking lamellae of clay accumulation within 125 cm of the surface.

Albic Arenosols are Arenosols consisting of albic material to a depth of at least 50 cm from the surface.

5.9.2. General environment

In Ethiopia Arenosols occur on the steeper slopes and on coarse textured colluvium in the highlands where sandstones have been exposed -- largely in the gorges of southwestern Welo, at the base of Mt. Ras Dejen and in northeastern Bale. Clay content usually increases on the flatterlandforms and Arenosols give way to Cambiosls and Luvisols. Arenosols have also been identified on sandstones in the Ogaden and on wind blown materials where environmental conditions have subsequently permitted some maturing of the profile.

5.9.3. Characteristics

Arenosols essential characteristic is a coarse texture. Structureless horizons with very friable consistence, low cation exchange capacity and low organic matter content are consequent characteristics. Arenosols tend to be somewhat excessively to excessively drained, and as clays move very easily through the sandy textures, clay content usually increases with depth.

5.9.4. Land use and natural vegetation

In the Ogaden, natural végetation is grazed by nomadic livestock. In the highlands, Arenosols are frequently cultivated to cereals and pulses.

5.9.5 Management

Limitations for agricultural use include poor inherent fertility, low water holding capacity and excessive drainage. The advantages of Arenosols are restricted to easy workability, in the absence of stones, and moderate rooting conditions.

5.9.6 Occurence

Cambic Arenosols are the more common in Ethiopia, however on flatter landforms in higher rainfall areas Luvic Arenosols occur. Lithic and stony phases are common. Ferralic and Albic Arenosols do not occur in Ethiopia.

5.9.7. Profile descriptions

5.9.7.1. Cambic Arenosol, Tigray

This profile, from western Tigray, has all the typical characteristics of an Arenosol. Despite good topographic position for agriculture, their high permeability and fast drainage are a limitation. These factors also, however, significantly reduce the risk of erosion.

Source: TIGRAI

Mencheba series -- Moderately deep well drained soils having brown to yellowish brown profiles with sandy loam textures.

A) General

- Environmental characteristics: The series occurs on the upper slopes and convex ridge crests of undulating sandstone plateaux. Locally the soil occurs on middle slopes. The slopes range from one to five percent. The soils are formed in colluvial and in situ weathered Enticho sandstone material. Solid rock outcrops locally on the steeper ridge crests. The series is mostly under arable crops, including

Wheat, teff and linseed. There is little remaining natural vegetation apart from scattered low shrubs.

- Profile characteristics: The soils have coarse sandy loam textures in a zone of weathered sandstone. The plough layer is 10 to 15 cm deep, brown to yellowish brown coloured (10 YR 4/4 to 5/4) and has loamy sand to sandy loam textures. The horizon is porous and has a weak structure. The underlying B horizons have similar textures and structure but the colours are often brown (7.5 YR 5/4) and the soil is more compact, becoming hard when dry. These sandy loam horizons extend down to at least 50 cm from the surface, but in some profiles extend to 100 cm. The underlying horizons comprise in situ weathered Enticho Sandstone which retains its rock structure but has pockets of soil within the fractured rock. The texture of the weathered material is gravelly sandy clay loam, colours vary from brown to yellowish red (7.5 YR 5/4 to 5 YR 5/6). Many reddish mottles and black stains of iron and manganese are included. In many profiles solid sandstone is encountered at or below 15 cm. Roots are concentrated in the upper 50 cm of the profile but some penetrate deeper into the zone of weathered sandstone.

- Analytical characteristics: Data show the soils have variable base saturation with calcium and magnesium as the dominant cations.

- Land capability characteristics: The series occurs on sites which are topographically suited to arable cultivation. However, the coarse textures of the upper horizons result in the soils drying out rapidly after the rains and this reduces their capability rating. The soils have favourable infiltration characteristics and the erosion hazard is slight. Rocky outcrops are very limited in extent.

B) Profile description

- Information on the site:

Profile No.:	12, QE/1
Soil name:	Mencheba series
Classification:	Cambic Arenosol
Date of examination:	5 April 1975
Author:	R.N. Munro
Location:	9 km east northeast of Hauzien, Tigrai, 14°00'10" N and 39°30'30"E
Elevation:	about 2 300 m
Physiographic position:	undulating pediment on rolling plateau
Surrounding landform:	gently sloping convex ridges leading down to broad depression
Microtopography:	flat, plough ridges
Slope at site:	5 percent down to east northeast, in middle slope position
Land use:	cultivation of cereals (finger millet), oil seeds and pulses.
Vegetation:	scattered Rumex nervosus, Aloe along road, bare ground
Rainfall:	about 550 mm

-Information on soil:

Parent material:	colluvial and residual material of Enticho sandstone
Drainage-profile:	well
Drainage - site:	no restriction, shedding into depression
Moisture condition:	dry to 165 cm, moist below
Flood hazard:	none
Depth of groundwater:	not encountered
Surface conditon:	few sandstone stones; sandy surface
Evidence of erosion:	moderate rilling along paths and down plough lines; redeposition on surface and within fields

- Profile description

A moderately deep brown sandy loam soil overlying in situ weathered sandstones at 70 cm. The upper horizons have weak structure, with increasingly harder consistence down the profile. Below 70 cm the soil is very compact massive weathered sandstone with a sandy clay loam texture. Iron/manganese stains and weathering mottles are common in this lower zone. The sand fraction is coarse thoughout. Roots are concentrated in the upper 50 cm, but some penetrate through the weathered rock to 150 cm. The sequence of coarse sandy loam horizons overlying sandy clay loam weathered material is characteristic of the series.

0-10 cm	Brown (10 YR 4/3); loamy coarse sand; weak fine subangular blocky structure; loose dry; many fine interstitial pores; many fine and medium roots; abrupt smooth boundary.
10-45 cm	Dark brown (10 YR 3/3); coarse sandy loam; moderate fine to medium angular blocky; soft dry; many fine pores; many fine, few medium roots; gradual smooth boundary.
45-68 cm	Yellowish brown (10 YR 5/4); weak medium angular blocky; hard dry; many fine pores; narrow stone lines; few fine and medium roots; gradual smooth boundary.
68-100 cm	Dark brown (10 YR 3/3) with few medium prominent iron/manganese stains and yellowish red mottles; coarse sandy clay loam; massive blocky rock structure; very hard dry; few very fine pores; few fine and medium roots; diffuse boundary.

100-165 cm	Dark brown (10 YR 3/3) with many medium prominent yellowish brown mottles and iron/manganese stains; coarse sandy clay loam; massive rock structure; very firm moist; zone of weathered sandstone.
165-180 cm	Yellowish brown (10 YR 5/4) with few medium distinct yellow mottles; coarse sandy clay loam; very firm moist; weathered sandstone.

C) Laboratory Data:

	Depth (cm)				
	0-10	10-46	46-68	100-150	165-180
Texture (%, mm)					
2	9	8	7	m	m
2-0.2	69	68	67	m	m
0.2-0.05	8	6	6	m	m
0.05-0.002	6	8	5	m	m
0.002	8	10	15	m	m
pH	6.5	6.7	6.7	6.4	7.1
EC (mmhos/cm, 1:5)	0.1	0.1	0.1	0.1	0.1
Exchangeable cations (me/100 g)					
Ca	2.9	13.9	19.3	10.2	6.9
Mg	0.6	0.4	1	2.7	1.6
Na	0.0	0.0	0.3	0.0	0.0
K	0.2	0.0	0.1	0.1	0.1
CEC (me/100 g)	4.6	12.5	23.2	14.5	7.1
$CaCO_3$ (%)	0.0	0.0	0.0	0.2	0.1
Total K (mg/100 g soil)	81	101	m	m	m
Available P (mg/100 g soil)	2.4	0.4	m	m	m
Total N (%)					
Organic C (%)	0.5	0.4	m	m	m
Soluble (ppm)					
Cu	0.7	0.3	0.8	m	m
Zn	1.6	0.8	0.8	m	m
Mn	73	93	400	m	m
Total (ppm)					
Cu	5	5	6	m	m
Zn	15	15	13	m	m
Mn	155	235	835	m	m

5.9.7.2 Cambic Arenosol, southeastern Ogaden

This profile comes from the southern Ogaden. Some profile development is indicated by the concentration of $CaCO_3$ at depth.

Natural vegetation does not grow well, due to a combination of rapid drying of these soils in a rainfall regime of less than 200 mm annually.

Source; WABI SHEBELE

Red calcic soils derived from Gesoma sandstone

A) General

These soils are developed on the bright red sandy weathered material derived from the ferrugineous Gesoma sandstone, on a vast area of 5 450 km^2 in the farthest southeastern part of the Wabi Shebele basin.

The ferrugineous Gesoma sandstone is very coarse grained and easily disaggregated, thus providing a considerable quantity of weathered sandy material which covers the whole landscape. It rests directly on limestone with nodules forming small steps leading up eastward and separated by large sills covered with the weathered sandstone layer. The sandstone bluff is seen 18 km to the northeast of Shilavo and is only 4 m high, consisting of very brown and very ferrugineous sandstone. Small residual hills preceding the bluff present motley weathered sandstone facies. On the plateau these small steps consisting here of hard sandstone may also be seen with vast sills disappearing under the bright red sandy material. These plateaux form an entity in the lower Ogaden and must be considered completely apart from the rest of this region owing to their specific features, as follows:

i) there is no regular drainage system on account of the great permeability of sandstone. However, small depressions with grey soils which might be deferrated zones may be observed. Wells have been been dug in these depressions, the mean diameter of which is not more than 500m. They are located on the shilavo/Mustahil track and in the Bulaye and Gembari region.

ii) Numerous very bright red termitaries, often more than 4 m high present a particular shape. The base is in fact narrower than the top which gives them the aspect of a cone standing upside down.

iii) The vegetation consists of a thicket of Gardenieae and Cordia gharaf which is approximately 4 m high and not very dense near Warder but which becomes an impenetrable bush north of Shilavo. Unlike the striped bush pattern of the limestone plateaux, here the vegetation is uniformly distributed and presents a fine light grey dotted pattern on aerial photographs.

B) Profile description

Location:	5 km northeast of Shilavo
Vegetation:	dense cover of Gardeniea and Cordia gharaf
Relief:	undulating due to the action of wind

Profile description:

0-15	Red (2.5 YR 5/8); coarse and fine sand; single grained; loose; dense root system; gradual transition to:
15-120 cm	Red (2.5 YR 5/8); coarse and fine sand; single grained; loose; rootlets and numerous small roots; some big roots; gradual transition to:
120-cm	Red (2.5 YR 5/8); coarse and fine sand; numerous 1 to 4 mm friable concretionary masses consisting of sand cemented with a white calcareous cement; single grained structure; friable; still numerous rootlets.

The thickness of soil depends on the thickness of the weathered sand stone layer. For instance the thickness of soils decreases as one draws near the sandstone or limestone steps above described.

The profile is hardly differentiated. A calcareous accumulation of very small concretionary masses consisting of sands cemented with carbonates may be observed at depth. Also, small (1 to 2 mm diameter) round ferrugineous elements previously existing in the base rock may also be noted.

C) Physical and chemical characteristics

These soils are immediately identified in the field owing to their characteristic red to bright red colour. They are very sandy with a predominance of coarse sands. The structure is single grained. These soils are very friable to loose but a very slightly increasing compactness may be observed in the horizon with a nodule accumulation.

Fine earth is non-calcareous which is linked to the lack of carbonates in sandstone. The formation of nodules seems to be in relation to the fluctuations of the water table which is loaded with carbonates when in contact with the sub-jacent limestone formations.

The content of organic matter is very low and approximately 0.4 percent throughout the profile. pH is approximately 8. The absorbing complex is base-saturated. The exchangeable potassium and total phosphorus contents are weak.

D) Cultural and pastoral fitness

These soils are either scarcely or not at all suitable for crop growing. Nevertheless, a very considerable volume of soil is available to the root system which accounts for the developed shrub vegetation. Furthermore, coarse sand is a specific retention factor owing to the absence of capilarity, hence fruit trees could be adopted in these conditons.

In sandy soils the quality of pastures is poor even during the rainy season. However, in these red sandy zones a specific and diversified wild life exists, which is usually not seen in the other regions of the Ogaden, hence this region should constitute a reserve for wild life.

5.10 REGOSOLS

5.10.1 FAO classification

Regosols are soils from unconsolidated materials, exclusive of recent alluvial deposits, having no diagnostic horizons (unless buried by 50 cm or more new material) other than an ochric A horizon; lacking hydromorphic properties within 50 cm of the surface; lacking the characteristics which are diagnostic for Vertisols and Andosols; lacking high salinity; when coarse textured, lacking lamellae of clay accumulation, features of cambic or oxic B horizons or albic material which are characteristic of Arenosols.

Eutric Regosols are Regosols having a base saturation (by NH_4OAc) of 50 percent or more at least between 20 and 50 cm from the surface but which are not calcareous within this depth; lacking permafrost within 200 cm of the surface.

Calcaric Regosols are Regosols which are calcareous at least between 20 and 50 cm from the surface.

Dystric Regosols are Regosols having a base saturation (by NH_4OAc) of less than 50 percent at least between 20 and 50 cm from the surface; lacking permafrost within 200 cm of the surface.

Gelic Regosols are Regosols having permafrost within 200 cm of the surface.

Remark:

For the purposes of the Geomorphology and Soils Map of Ethiopia, Regosols are taken to also include severely eroded soils slightly deeper than the 10 cm limit for Lithosols and to include soils on terraced slopes.

5.10.2 General environment

Regosols so defined cover approximately 4 percent of Ethiopia. They occur on steep terraced and/or eroded slopes along the northeastern escarpment and at the eastern end of the

Chercher highlands. Regosols develop on largely windblown, but occasionally slope debris, materials on the flatter landforms throughout the Danakil and in the eastern Ogaden -- in this latter region, largely on sandstone parent materials.

5.10.3 Characteristics

Regosols on the northeastern escarpment are shallow, exceedingly stony clay loam soils with very low organic matter, neutral pH, medium CEC and very low available P contents. Water holding capacity of the solum is minimal, largely due to the shallowness of the soil. Terracing has been a fairly recent practice and has arisen largely in response to rapid erosion. Thus terraces are narrow and shallow, there not having remained much soil from which to build them.

Conditions are similar in the Chercher highlands, however where granitic parent materials predominate textures are coarser and where limestones occur, phosphorus deficiencies are not so dramatic and pHs are slightly alkaline.

Regosols in the Danakil are predominantly volcanic sands, and in the Ogaden sandstones and sandstones mixed with limestones provide the parent materials. These soils have much the same characteristics as Arenosols, being coarse textured and having the physical and behavioural characteristics consequent upon sandy textures. However, in contrast to the Arenosols, there is little evidence of pedogenetic processes, with the exception in the Danakil of some salinization. Chemical characteristics that can be attributed to the parent materials differ.

5.10.4 Land use and natural vegetation

Regosols in the highland areas, having arisen from erosion consequent upon intensive cultivation are still wherever possible intensively cultivated. In the Chercher highlands, where the perennial crop Chat is traditional, effort is made to plant steep slopes and terraces to this crop, reserving flatter lands for grains and legumes. Increasingly, Regosols in the highlands are being planted to trees as a conservation measure.

Natural grass vegetation covers the Regosols of the Danakil and the Ogaden. In particularly dry areas, vegetative cover is sparse and much bare soil is exposed. The land is used for nomadic livestock grazing.

5.10.5 Management

Limitations for agricultural use of the highland Regosols are soil depth and stoniness. Shallow soils, beyond restricting plant rooting, have significantly lower water holding capacity than corresponding deeper soils. Regosols are rarely planted during the short rains, when deeper valley soils are lush with crop growth, for the former have little residual moisture to see a crop through even short dry periods.

The coarse textured Regosols in the Danakil and in the Ogaden are, as Arenosols are, severely limited agriculturally. Given their development on windblown deposits, wind erosion is an obvious limitation. Low available water capacity is a severe difficulty in dry climates with high evaporative moisture loss. Such soils are, however, often deep and can be productive where irrigation water is available and erosion can be controlled.

5.10.6 Occurence

Gelic Regosols do not occur in Ethiopia. Dystric Regosols have not been identified. Eutric and Calcaric Regosols, always with lithic and very often with stony phases, occur in the highlands; the Calcaric Regosols occur on the limestone of the Chercher highlands. In the Danakil, Eutric Regosols occur, often with saline phases. Eutric and Calcaric Regosols occur in the Ogaden, depending on the parent materials.

5.10.7 Profile descriptions

5.10.7.1 Eutric Regosol (stony phase), Metahara

The parent material of this Regosols from the foot of the escarpment on the western margin of the Rift Valley is volcanic debris washed down from above, which explains the comparatively high silt content and the stoniness.

Source: AWASH

Regosols resulting from erosion

A) General

At the western foot of the Awash Rift Valley, weathering debris which fell as rubble or has been washed down from the rocks on the high plateaux and hills further up river, forms a huge cone with an average slope of 10 percent. This heterogeneous formation suffered severe erosion and is covered with tree and shrub steppe vegetation, which gradually thickens to woods at higher altitudes nearer the humid zone.

B) Use

On the whole, this zone is unfit for agriculture because of the severe erosion affecting its slopes and its shallow soils. A few dozen hectares could be developed here and there under irrigation from the many permanently flowing tributaries of the Awash River.

C) Profile desc.ription

Parent material:	basalt gravel colluvial material
Location:	Metahara plain
Relief:	river cone with a medium slope
Microrelief:	clearly defined channels
Drainage:	good, fairly moist zone
Natural vegetation:	several large acacias, tufts of gramineae

- Profile description:

0-10 cm	Greyish brown (10 YR 5/2); sandy loam; dry; blocky, tendency to platy; friable; roots; basalt gravel.
10-35 cm	Brown (10 YR 5/3); sandy loam; dry; blocky; slightly hard; 1 cm basalt gravel; roots; porous.
35-100 cm	Brown (10 YR 5/3); loam; dry; blocky; slightly hard; not very porous; pumice gravel.
100-140 cm	Brown (10 YR 5/3); sandy loam to sand; moderately dry; blocky.

D) Laboratory data

	Depth (cm)	
	0-10	50-60
Texture (%)		
2-0.2	29	27
0.2-0.05	24	14
0.05-0.002	38	48
0.002	9	11
pH	7.7	7.6
$CaCO_3$ (%)	0.14	0.19
Organic matter (%)	1.70	m
Organic C (%)	1.00	m
Base saturation (%)	28	20
EC (mmhos/cm, sat. ex.)	0.55	2.3
Soluble Na (me/l, sat. ex)	0.43	2.0

5.10.7.2 Calcaric Regosol, Degeh Bur

This profile, from Degeh Bur in central Harerge, is developed on alluvial and colluvial deposits, but windblown materials also contribute as parent materials. Calcareous accumulation is due not to the parent material, which is non-calcareous, but to the effects of fluctuating ground water high in calcium carbonate. The absence of stones is an obvious characteristic of windblown soils.

These soils are cultivated, with poor results, as they rapidly dry out, and this in an area where rainfall is less than 400 mm annually. Protecting cultivated fields from wind erosion and evaporative soil moisture loss, through planting windbreaks, is suggested as a means to increase to productivity of these soils.

Source: WABI SHEBELE

Red calcic soils derived from Gesoma sandstone

A) General

These soils are developed on the red sandstone alluvial and colluvial deposits which spread at the foot of the scarp of the sandstone plateaux from east of Degeh Bur to the Jerer temporary river. They correspond to what is usually called the Degeh Bur basin and cover approximately 2 700 km^2.

The red alluvial and colluvial deposits are approximately 7 m thick on the Degeh Bur plain. They rest directly on the Kebri Dehar limestone in situ. In this zone, Gesoma sandstone is transgressive on this formation.

The natural vegetation is considerably degraded by cultivation near Degeh Bur and mainly consists of a dense savannah with tall acacias and a discontinuous gramineae carpet. Rainfall is approximately 400 mm. During the dry season a strong eastern wind blows and there is deep aeolian erosion on the plain.

B) Profile description

Location:	3 km east of Degeh Bur
Natural vegetation:	gramineae
Land use:	grazing

- Profile description:

0-40 cm	A11	Red (2.5 YR 4/6); coarse sand; friable medium subangular blocky fragments giving a single grained structure; loose to friable; dry; few rootlets; distinct and uniform transition to:
40-90 cm	A12	Red (2.5 YR 3/6); coarse sandy clay; friable subangular blocky fragments giving a subangular blocky structure tending to a single grained structure; small very white calcareous myceliums; dry and friable; some rootlets; gradual and uniform transition to:
90-300+cm	Bca	Red (2.5 YR 4/6); coarse sandy clay; flat medium fragments giving a medium subangular blocky structure with single grained trend; small very hard concretionary sandstone masses cemented together with lime and weathered sandstone pebbles, the average thickness of the whole being 0.5 cm; humid; scarcely friable; no rootlets.

These soils are deep and calcareous accumulation is progressive. Small myceliums are already observed at a 40 cm depth. Below 90 cm an horizon with abundant small lime concretions is present. The individualization of carbonates is surely linked to the fluctuations of the temporary ground water table which is located in the break between the alluvial and colluvial layer of weathered sandstone and subjacent Kebri Dehar limestone during the rainy season.

D) Laboratory data

	Depth (cm)		
	0-40	40-90	90+
$CaCO_3$	0	3.4	8.1
Organic matter (%)	0.9	0.8	0.4
Total N (%)	0.07	0.03	0.02
C/N	8.5	15	11
pH	8.5	8.4	8.9
EC (mmhos/cm, sat.ex.)	1.0	1.0	2.0
Exchangeable cations (me/100g)			
K	0.4	0.5	0.5
Na	0.1	0.1	1.0
Total P_2O_5 (%)	0.07	0.05	0.04

These red soils with dominant coarse sands become more clayey at depth but the structure remains scarcely developed and the soils are usually friable down to the subsoil.

The calcium carbonate percentage of the fine earth fraction is negligible from 0 to 40 cm and although it progressively increases with depth it remains weak. The content of organic matter is very low and gradually decreases with depth. The same occurs in the case of nitrogen. pH is high, being greater than 8.4 but the low conductivity of the saturation extract shows that the soil solution is scarcely loaded with salt and that exchangeable sodium is also low. The exchangeable potassium content varies from medium to high. The phosphorus content is low. The total N/total P_2O_5 ratio is approximately 1 or less, indicating severe nitrogen deficiency.

E) Cultural and pastoral fitness

The Degeh Bur plain is already largely cropped to sorghum. Considerable extensions to the north and south are possible but near the plateaux the existence of many runoff ravines prevents agricultural development. The sorghum plantations are at the present time affected by regular sand winds due to wind erosion itself, as well as by very strong mechanical actions and intense evapotranspiration conditions which considerably limit the crop yield in a region where rainfall is low.

Consequently it is absolutely necessary to plant wind screens if sorghum is to give a suitable yield. These wind screens could consist of Tamarix, which already occurs locally, or any other species enduring dry periods and with rapid growth. Trees should be placed every 200 m at right angles to the dominant wind direction.

Nitrogen carriers such as ammonium sulphate should be added to the soil.

Mechanized cultivation may be considered for these large flat zones with no coarse elements in the soil but it must be carried out carefully in order to avoid wind erosion of sandy surface horizons.

5.10.7.3 Calcaric Regosol (lithic, stony phase), Dire Dawa

This profile, from south of Dire Dawa, Hararge, is classed as a Regosol due to the absence of any profile development. The soil has recently been created with the construction of 2 m wide terraces, and rests on the stones and bedrock of the hill slope.

Few of the terraces in the immediate area are planted to trees, the land being required for the production of food crops.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.:	80
Classification (FAO):	Calcaric Regosol (lithic, stony phase)
Date of examination:	5 August 1982
Author:	H.Y. Wijntje-Bruggeman, Sultan Tilimo, S. Ross
Location:	10 km south of Dire Dawa on the Harer road
Elevation:	1650 m
Physiographic position:	terraced slope

Surrounding landform:	high relief parallel ridge and valley topography
Microtopography:	terraces
Slope:	terraces less than 1%, general slope 45-50%
Natural vegetation:	few scattered acacias, gramineae
Rainfall:	approximately 700 m

- Information on the soil:

Parent material:	Mesozoic limestone
Drainage:	well drained
Moisture condition:	dry throughout
Depth of groundwater:	not encountered
Stoniness:	exceedingly stony
Rock outcrop:	rocky
Erosion:	small gullies on terraces
Human influence:	terraced, land is cultivated to grains

- Profile description

Exceedingly stony, shallow dark yellowish brown sandy clay loam.

0-25 cm	Dark yellowish brown (10 YR 3/4) moist; sandy clay loam; weak fine subangular blocky and fine granular; very friable moist, slightly hard dry; common very fine and fine interstitial pores; very frequent angular fresh and slightly weathered limestone stones; common fine roots; gradual wavy boundary.
25 + cm	Fresh and slightly weathered limestone stones, boulders and bedrock.

B) Laboratory data

	Depth (cm) 0-25
Texture (mm, %)	
2-0.2	32
0.2-0.05	21
0.05-0.002	22
0.002	25
pH	8.1
$CaCO_3$ (%)	11.4
Exchangeable cations (me/100g)	
Na	0.3

	Depth (cm) 0-25
K	1.9
Ca	24
Mg	3
sum	29.2
CEC (me/100g)	26.4
Base saturation (%)	100
Total N (%)	0.038
Organic matter (%)	1.10
Available P_2O_5 (ppm)	0.0

5.11 RENDZINAS

5.11.1 FAO classification

Rendzinas are soils having a mollic A horizon (when the A horizon contains a high amount of finely devided calcium carbonate the colour requirements of the mollic A horizon may be waived) which contains or immediately overlies calcareous material with a calcium carbonate equivalent of more than 40 percent; lacking hydromorphic properties within 50 cm of the surface; lacking the characteristics which are diagnostic for Vertisols; lacking high salinity.

5.11.2 General environment

Rendzinas are found in wetter climates on fairly steep slopes, where soils are shallow but the development of a deep mollic A horizon is permitted. Thus they occur in Ethiopia on the moderate to steep sideslopes of limestone landforms in the central, northern and Chercher highlands. They are most extensive in the little cultivated gorges of the Wabi Shebele and, where limestone outcrops, of the Blue Nile. Rendzinas cover approximately 2% of Ethiopia.

5.11.3 Characteristics

As Rendzinas develop only in areas where a fairly limited range of environmental conditions coincide - i.e. sloping land on calcareous materials in moist climates: chemical, physical and morphological characteristics do not vary widely. The soils are often stony, and are shallow, the mollic A horizon directly overlying calcareous parent material. Reaction is neutral to slightly alkaline at the surface, which has often had any free calcium carbonate removed, and increases with depth. High organic matter content, an exchange complex dominated by calcium, high cation exchange capacity and excellent structure despite generally fine texture are characteristic.

5.11.4 Land use and natural vegetation

Rendzinas are predominantly under natural shrub and grass vegetation in Ethiopia, largely occuring as they do on steep slopes in the comparatively unpopulated gorges of the Wabi Shebele and the Blue Nile. Where population pressure is more intense, Rendzinas are cultivated as in the Chercher highlands. However, unless cultivation occurs on terraces or only slightly sloping land, such soils under cultivation quickly become Lithosols or lithic phase Cambisols.

5.11.5 Management

The agricultural potential of Rendzinas is severly limited by soil depth, frequent stoniness, and by their topographic position. Where soil depth permits, Rendzinas can be very productive for short periods, due to the excellent properties imparted to the soil by the mollic A horizon, but this is generally a very short lived phenomenon.

5.11.6 Profile descriptions

5.11.6.1 Rendzina, Harer

This profile was taken near Harer, Harerge. Under dense grass vegetation in an area with mean annual rainfall of over 800 mm organic matter is very high and all calcium carbonate has been leached from the A horizon.

Similar soils in the area are cultivated, but not very successfully because the soils are so shallow.

Source: WABI SHEBELE

Calcic rendzina soils

A) General

These soils only cover the limestone hills commanding the gently rolling landscape of the Harer plateau at a mean altitude of more than 2 400 m. Calcic rendzina soils are closely associated with brown calcic soils, the former developed on steep slopes and the latter on the flat eroded zones of hill tops.

These soils are close to carbonated soils from a morphological point of view, the only difference being that the A horizon does not react with hydrochloric acid.

B) Profile description

Location:	near Harer
Natural vegetation:	dense gramineae carpet, some bushes
Slope:	10%
Parent material:	Kebri Dehar limestone
Rock outcrop:	many outcroppings of the limestone in situ

- Profile description:

0-25 cm	A1	Very dark grey (10 YR 3/1); clay; medium and coarse crumb structure with very well developed granular trend; very dense root system holding back earth aggregates; dry; friable and non-calcareous; irregular and short transition to:
25-40 cm	A1R	Mingled calcareous elements from 0.5 to 10 cm thick and fine clay earth; dark brown (10 YR 3/3); fine granular structure; still dense root system; fine, non-calcareous earth; dry and friable; sudden transition to:
40 + cm	R	Sound limestone slab in situ.

This rendzina soil is considered as a calcic soil since a distinct decarbonation may be observed in the A1 horizon.

C) Laboratory data

	Depth (cm)	
	0-25	25-40
$CaCO_3$	0	40
Organic matter (%)	10.3	4.4
Total N (%)	0.45	0.20
C/N	13	13
pH	7.1	8.1
Exchangeable cations (me/100g)		
K	0.4	0.1
Na	0.2	0.1
sum	58	m
CEC (me/100g)	59	m
Base saturation (%)	100	m
Total P_2O_5 (%)	0.15	0.07

These brown to brownish black soils are clayey. They present a granular structure throughout the profile. The A1 horizon is friable.

There is no calcium carbonate except in the A1 horizon, which in fact consists of fine non-calcareous earth mingled with small dissolution calcareous elements which pass into the fine earth when analysed. The decarbonation of the profile results from very heavy rainfall from 800-1 000 mm combined with a high altitude determining a cool climate which is favourable to subsurface drainage and consequently to the washing away of calcium carbonate.

The content of organic matter is high with 10.3 percent in the A1 horizon. The nitrogen percentage is high and the C/N is medium to low. pH is practically neutral except at depth in the soil where it is 8.1 in the weathering horizon of the in situ limestone. The exchange capacity is high, the base saturation is approximately 100.

Exchangeable potassium content is medium. Phosphorus content is high at the surface and medium at depth. The total N/total P_2O_5 ration shows the nutritional balance to be correct.

D) Cultural and pastoral fitness

These soils are unsuitable for agricultural purposes owing to their thinness. They are at the present time under cultivation using the method of low contour dry stone walls in order to obtain an adequate thickness of soil, but the crop yield is very poor. The area dedicated to crop growing between two bunds is only about 2 m wide. Consequently these areas are progressively deserted but could be used for forest production combined with livestock breeding.

5.11.6.2 Rendzina, Mekele

This profile, taken near Mekele, is less typically an Ethiopian Rendzina. It has developed on a 2% slope and is cultivated. Organic matter is not high, although it is significantly greater than characteristic of cultivated soils in the Mekele region, where mean annual rainfall is less than 600 mm. The comparatively low rainfall has also not permitted the decarbonation of the A horizon, and the pH remains quite high.

Source: TIGRAI

Mosobo series -- shallow fine textured black soils directly overlying marl and limestone, well drained.

A) General

- Environmental characteristics: These soils occupy the upland plateau and dip slopes of the Antalo limestone. The terrain is generally flat to weakly undulating with parallel banding of flint and marl rock outcrop and the black soils of this series. The soils are usually cultivated for cereals, the intervening rocky areas being covered with low shrub.

- Profile characteristics: The soils are very dark in colour, usually 10 YR 3/1 in the upper horizon. The texture is clay and the structure coarse prismatic to strong angular blocky which cracks down to 25 cm when dry. Between 25 and 45 cm there is a zone of weathered mottled limestone and marl with silty clay textures, yellowish brown colours and weak structure. This directly overlays in situ hard blocks of limestone and intervening beds of marl. The soil is strongly calcareous throughout and contains soft remnants of limestone gravels. Roots penetrate freely to the limestone layer at about 45 cm. The surface is characterised by cracks and a coarse mulch.

- Analytical characteristics: The soils are slightly to moderately alkaline, with medium to high base saturation, dominated by very high exchangeable calcium. The CEC of the clay fraction suggests montmorillonite. The Mg/K ratio is below two for these horizons. Organic matter is high for a Tigray soil.

- Land capability characteristics: The soils usually occur on slopes of less than two percent but are limited in potential by their shallow depth and the occurrence of rock outcrop. In general the land is not arable and should be retained for controlled livestock browsing and grazing.

B) Profile description

Date:	8 October 1974
Location:	2 km W of Mekele micro-wave station
Parent material:	Antalo limestone overlain by thin marl layer
Landform:	dip slope of limestone
Slope:	2% maximum slope to north
Surface condition:	many cracks 1-2 cm wide and black clay mulch.
Landuse:	cultivation of wheat and livestock grazing

- Profile description:

0-10	Very dark grey (10 YR 3/1.5); clay; firm moist; moderate very coarse prismatic; few fine roots.
10-25 cm	Very dark grey (10 YR 3/1.5); clay; moderate medium subangular blocky; common fine roots; few flecks of soft $CaCO_3$.
25-45 cm	Yellowish brown (10 YR 5/4) with pale brown mottles; silty clay; friable moist; weak medium subangular blocky; soft remnant $CaCO_3$ gravels; common fine roots.
45-100 cm	Alternating bands of hard limestone and soft mottled marl with silt loam texture.

Comments: A shallow fine textured Rendzina. Cracks penetrate to the base of the profile at 45 cm. Soil is highly calcareous throughout with 49 percent $CaCO_3$ below 25 cm. Roots to 45 cm and deeper.

C) Laboratory data

	Depth (cm)		
	0-10	10-25	25-45
Texture (%, mm)			
2	0	2	4
2-0.2	8	10	9
0.2-0.05	11	14	6
0.05-0.002	41	30	40
0.002	40	44	41
pH	7.9	8.0	8.1
EC (mmhos/cm, 1:5)	0.1	0.1	0.1
Exchangeable cations (me/100g)			
Ca	40.0	36.1	11.0
Mg	1.6	1.3	0.4
Na	0.0	0.4	0.0
K	0.8	0.4	0.2
CEC (me/100g)	51.2	49.1	23.8
$CaCO_3$ (%)	7.3	7.8	49.0
Total K (ppm)	5330	2890	m
Total N (%)	0.22	0.19	m
Organic C (%)	2.8	2.2	m

5.12 SOLONETZ

5.12.1 FAO classification

Solonetz are soils having a natric B horizon; lacking an albic E horizon which shows hydromorphic properties in at least a part of the horizon and abrupt textural change.

Orthic Solonetz are Solonetz having a ochric A horizon; lacking hydromorphic properties within 50 cm of the surface.

Mollic Solonetz are Solonetz having a mollic A horizon; lacking hydromorphic properties within 50 cm of the surface.

Gleyic Solonetz are Solonetz showing hydromorphic properties within 50 cm of the surface.

5.12.2 General environment

Solonetz soils have very limited extent in Ethiopia, largely because soils with high exchangeable sodium usually fall within other soil groups whose defining characteristics taken precedence over high exchangeable sodium percentage (ESP) and whose morphology may not include a natric B horizon. Sodic phase Fluvisols, Gleysols, Solonchaks and Andosols -- with ESP values greater than the 15% required for Solonetz -- are more frequently encountered than Solonetz soils.

As with Solonchaks, Solonetz occur in drier climates, and in Ethiopia are usually associated with the Quaternary volcanic materials in the Rift Valley, although Solonetz have also been identified near the mouth of the Omo River. Solonetz also occur in areas influenced by sodium rich groundwater.

5.12.3 Characteristics

The important variations in Solonetz soils are related to the presence or absence of salt in the profile. Electrical conductivity (EC) may vary from none to very high levels.

providing in the latter case that a natric B horizon is present.

In the absence of soluble salts, Solonetz are characterized by very alkaline pHs, reaching 10 in some cases, and a distinctive columnar structure in the B horizon. Also, permeability is very low. The presence of even low amounts of exchangeable sodium causes deflocculation of clay particles when the soil is wet, i.e. the complete breakdown of soil aggregates. Large pore spaces thus disappear. This process limits water movement. For a given ESP this effect is more extreme the higher the clay content. In heavy textured soils, ESP values of less than 10 can have very negative effects, thus clayey sodic phase soils can suffer as severe problems as lighter textured Solonetz with high ESPs.

In Solonetz with ESPs at the lower end of the scale and high EC values, the effects of exchangeable sodium are to some extent counteracted by salinity. pHs are lower and permeability somewhat improved. There are in these soils however, the additional problems of excess salinity.

5.12.4 Land use and natural vegetation

Occuring in dry climates and being very difficult to reclaim, Solonetz soils in Ethiopia are almost exclusively under natural vegetation of grasses and scattered shrubs and trees. Land use is nomadic livestock grazing.

5.12.5 Management

Deflocculation of clay severely limits potential agricultural productivity, negatively affecting root penetration, soil aeration and permeability. This applies equally to Solonetz and to sodic phase soils, although where sodicity is at depth in the latter and management is careful not to permit the rise in the profile of exchangeable sodium, sodic phase soils can be successfully cultivated.

Reclamation of Solonetz is possible, if somewhat expensive and complicated due to the difficulties of leaching the sodium in viretually impermeable soils. If salinity is present, the effect of salts in counteracting deflocculation is to increase permeability, however efforts must be made to leach salts and sodium in common, and thus maintain levels of salts as required to counteract the effects of (diminishing) sodium.

5.12.6 Occurence

Orthic, Mollic and Gleyic Solonetz all occur in Ethiopia.

5.12.7 Profile descriptions

5.12.7.1 Mollic Solonetz (saline phase and non-saline), lower Omo river

These two profiles from the lower Omo River valley compare a Solonetz soil with a saline phase Solonetz. Both have vertic properties.

The effect of the presence of salts in counteracting the effects of high exchangeable sodium is not evident in comparing the two soils because the saline Solonetz has such a higher ESP than does the non-saline Solonetz, i.e. 84% as compared to 18% in the next to surface horizon. Thus despite high salinity in the saline phase Solonetz, permeability is lower and pH is higher, although not as high as would be expected for the ESP.

In addition, it is expected that the Solonetz can be leached, given adequate systems for drainage, whereas the saline phase Solonetz is regarded as non-suitable because of the especially high levels of exchangeable sodium.

Source: Weito and Omo

Solonetz

A) General

This class includes soils with an ESP of more than 15%. Given their good surface texture and the absence of hydromorphic conditions at less than 50 cm depth, these soils have been classified as Mollic Solonetz. They are either non saline or highly saline, and are designated typic Mollic Solonetz in the first case and saline Mollic Solonetz in the second case (electrical conductivity greater than 8 mmhos/cm).

The morphological characteristics of the Solonetz observed are very similar to those which characterise the Vertisols in the area. Only the analysis results, and especially the ESP, enabled these two soil classes to be distinguished.

The Solonetz have a predominantly fine texture throughout the profile. The clay content is generally between 40 and 60%. They are uniform in colour, 7.5 YR 3/2 or 10 YR 3/4 throughout the profile. There are no mottles in any of the horizons of these soils. In the saline Solonetz, highly saline white efflorescences are observed in the upper 50 cm of the profile.

The surface structure over the upper 10 cm is of the very fine grainy to friable type. The intermediate and deep horizons have prismatic and coarse polyhedral structure. In certain profiles, the presence of slickensides may be observed, generally at depths of more than 50 cm.

Given that the morphological characteristics of the Solonetz are very close to those of the Vertisols, their hydrodynamic characteristics are likewise very similar. The permeability values measured in laboratory indicate infiltration rates of between 2.13 and 3.40 cm/h, or $2.6x10^{-6}$ and $1.8x10^{-6}$ m/s, where the texture is silty clay loam and between 1.31 and 1.66 cm/h, or $3.6x10^{-6}$ and $4.6x10^{-6}$ m/s where the texture is clayey. As for the Vertisols, basin irrigation is preferable to gravity irrigation. At present, provision is made for irrigation of the typic Solonetz only, provided that an efficient drainage network is built and that the leaching water requirements are determined carefully. In view of their high rate of alkalinity and their high salinity, the saline Solonetz cannot be improved and have been classified permanently not suitable for irrigation.

B) Profile description

Profile no.:	596 0089
Landform:	flood plain
Parent material:	alluvial deposits
Natural vegetation:	low woody vegetation covering 5-10%
Drainage:	imperfect drainage

Profile description

0-5 cm	Dark yellowish brown (10 YR 3/4) moist with nondirectly detectable organic matter; silty clay loam; dry; moderate granular coherent thin size structure in peds; common very fragile pores; few fine roots; clear boundary.
5-45 cm	Dark yellowish brown (10 YR 3/4) moist with few brown (7.5 YR 4/4) mottles; silty clay loam; dry; moderate blocky coherent medium size structure in peds; few slightly fragile pores; few fine roots; clear boundary.
45-75 cm	Dark yellowish brown (10 YR 3/4) moist with many brown (7.5 YR 4/4) mottles; silty clay loam; dry; moderate blocky coherent medium size associated with a platy structure in peds; few non fragile fine pores; distinct boundary.
75+ cm	Dark yellowish brown (10 YR 3/4) moist with many brown (7.5 YR 4/4) mottles; silty clay loam; dry; strong blocky coherent medium and thin size associated with a platy structure in peds; few non fragile pores; no roots.

C1) Laboratory data

	Depth (cm)			
	0-5	5-45	45-75	75+
Texture (%, mm)				
2	2	0	0	0
2-0.05	7	2	2	2
0.05-0.002	66	68	72	68
0.002	26	30	26	27
pH	7.4	8.2	8.5	8.2
Organic matter (%)	2.4	2.0	m	m
Total N (%)	.12	.11	m	m
Total P (ppm)	960	800	850	870
Exchangeable cations (me/100g)				
Ca	22.8	21.3	m	m
Mg	9.0	9.6	m	m
K	2.5	1.1	0.9	0.9
Na	0.9	7.1	6.6	6.1
CEC (me/100g)	35.3	39.1	36.8	37.5
EC (mmhos/cm, sat.ex.)	0.99	2.25	3.54	1.92
ESP	3	18	m	m
Soluble cations (me/l, sat. ex.)				
Ca	3.00	1.95	2.25	2.10
Mg	1.60	1.02	1.90	1.10
K	0.8	0.3	0.3	0.2
Na	2.9	15.3	20.4	13.9
Soluble anions (me/l, sat. ex.)				
Cl	3.4	14.8	18.6	9.08
SO_4	3.42	2.24	7.17	6.32
CO_3	0.9	0.98	1.04	0.94
HCO_3				
NO_3				
Gypsum (%)	0.0	0.01	0.01	0.01
Moisture (%)				
1/3 bar	38	48	47	m
1 bar	35	44	42	m
15 bar	20.6	20	25.4	m
Permeability (cm/h)	m	2.95	2.95	m

B2) Profile description

Profile no.: 598 0092
Landform: flood plain
Parent material: alluvial deposits

Natural vegetation: herbaceous and low woody vegetation, covering 5-10%

Drainage: poor drainage

- Profile description:

0-5 — Dark brown (7.5 YR 3/3) moist with non directly detectable organic matter; silty clay loam; dry; moderate coherent granular thin and very thin size structure in peds; common fragile pores; no roots; clear boundary.

5-35 — Dark brown (7.5 YR 3/2) moist; silty clay; dry; strong coherent blocky medium size structure in peds; no pores; efflorescences; no roots; distinct boundary.

35 + cm — Dark brown (7.5 YR 3/2) moist; silty clay; dry; strong coherent blocky medium and thick size associated with a platy oblique structure in peds; no pores; non fragile slickensides; no roots.

C2) Laboratory data

	Depth (cm)		
	0-5	5-35	35+
Texture (%, mm)			
2	0	0	2
2-0.05	5	4	5
0.05-0.002	64	54	40
0.002	31	42	53
pH	8.9	8.1	8.1
Organic matter (%)	3.3	2.0	m
Total N (%)	.22	.21	m
Total P (ppm)	1310	850	m
Exchangeable cations (me/100g)			
Ca	4.2	7.7	10.9
Mg	8.5	6.5	5.0
K	4.0	2.0	1.3
Na	20	32	21

	Depth (cm)		
	0-5	5-35	35+
CEC (me/100g)	36.7	38.2	38.2
EC (mmhos/cm, sat.ex)	12.3	31.6	32.6
ESP	55	84	55
Soluble cations (me/l, sat. ex.)			
Ca	7.5	47	64
Mg	2.5	13.9	21.0
K	1.4	0.9	1.1
Na	10.3	260	250
Soluble anions (me/l, sat. ex.)			
Cl	82.2	249	310
SO_4	24.0	87.7	48.0
CO_3	1.22	0.60	0.36
Boron (ppm)	0.00	1.52	1.02
Moisture (%)			
1/3 bar	46	45	41
1 bar	41	42	38
15 bar	36	28	29
Permeability (cm/h)	m	2.13	0.25

5.12.7.2 Mollic Solonetz, Ziway

This profile from just west of Lake Ziway, Shewa, barely meets the criterion of a Solonetz, the natric horizon occuring at 40 cm. The soil is little represented in the area, most soils having high sodium only at depth in the profile. Peasant cultivation is relatively successful, for most of the rooting depth is unaffected by sodium however the area has been rejected for irrigation due to the presence of sodium.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.: 4
Classification (FAO) Mollic Solonetz
Date of examination: 17 March 1982

Author:	S. Ross, Gebeyehu B.
Location:	2.2 km west of Roma Gebrel, Shewa
Elevation:	1680 m
Physiographic position:	top of scarp
Surrounding landform:	flat
Microtopography:	none
Slope:	less than 1%
Natural vegetation:	scattered acacia
Rainfall:	about 700 mm

- Information on the soil:

Parent material:	lacustrine deposits, largely ash
Drainage:	well drained
Moisture conditions:	dry throughout
Depth of groundwater:	not encountered
Stoniness:	none
Rock outcrop:	none
Erosion:	none
Presence of salt and alkali:	Na concentration at 40 cm
Human influence:	influence confined to the plough layer, fertilizer applied irregularly

- Profile description:

Deep well drained, very dark brown over dark brown; clay loam over clay over silty clay loam; ash layer at 55 cm and worked into horizons just above and below; natric horizon at 40 cm; Mn segregation below 60 cm.

Profile description:

0-20 cm	Very dark brown (10 YR 2/2) moist, dark greyish brown (10 YR 4/2) dry; clay loam; moderate coarse granular: slightly sticky and slightly plastic wet, slightly hard dry; many fine to medium interstitial and few tubular pores; few fine to medium roots; diffuse wavy boundary.
20-40 cm	Very dark brown (10 YR 2/2) moist, dark greyish brown (10 YR 4/2) dry; clay; moderate medium subangular blocky crumbling to granular; slightly sticky

	and slightly plastic wet, slightly hard dry; many fine pores; few fine roots; gradual wavy boundary.
40-55 cm	Very dark brown (10 YR 2/2) moist, very dark greyish brown (10 YR 3/2) dry; clay; strong coarse columnar; sticky and plastic wet, hard dry; many fine interstitial pores; no roots; oriented clays on ped surfaces; clear straight boundary.
55-60 cm	Brown (10 YR 4/4) moist, pale brown (10 YR 6/3) dry; loam; weak coarse granular crumbling to incoherent structureless; none-sticky and non-plastic wet, soft dry; porous; abrupt straight boundary.
60-130 cm	Dark brown (10 YR 3/3) moist and dry; silty clay loam; moderate fine angular blocky; non-sticky and non-plastic wet, soft dry; many fine interstitial pores; oriented clays on aggregate faces; Mn segregation on aggregate faces; clear boundary.
130-150+ cm	Dark brown (10 YR 3/3) moist and dry; silty clay loam; common eathered gravel; stone line.

Note: Pit to 80 cm, auger below.

B) Laboratory data:

	Depth (cm)				
	0-20	20-40	40-55	60-130	130-150
Texture (%, mm)					
2-0.2	12	15	10	12	11
0.2-0.05	9	8	5	6	5
0.05-0.002	47	28	16	44	50
0.02	32	49	69	38	34
pH					
H_2O	6.2	6.5	7.2	7.9	7.9
NaF	8.5	8.5	9.1	9.3	9.0
Exchangeable cations (me/100 g)					
Na	0.4	0.9	7.4	7.8	9.6
K	3.8	2.6	4.9	5.1	5.1

	Depth (cm)				
	0-20	20-40	40-55	60-130	130-150
Ca	20	19	25	26	28
Mg	3	1	2	4	4
sum	27.3	23.4	39.3	42.9	46.7
CEC (me/100g)	37.8	33.0	38.4	28.4	m
Base saturation (%)	72	71	100	100	m
Organic C (%)	2.3	1.4	0.8	0.7	0.6
Total N (%)	0.25	0.10	0.07	0.06	0.02
C/N	9	14	11	13	20
Organic matter (%)	4.0	2.4	1.4	1.2	1.0
Available P_2O_5 (ppm)	12	10	4	8	10
EC (mmhos/cm, sat.ex.)	0.05	0.08	0.14	0.20	0.13

5.12.7.3 Gleyic Solonetz, Borkena

This profile occurs in a clayey outwash basin of the Borkena river. The source of the high sodium content is probably sodium rich groundwater, coming from a nearly spring. The soils are exceptionally to frequently flooded, depending on their topographic position. Vegetation is grassland with mainly Cynodon dactylon and Cyperus sp.

Source: LUPRD

A) Profile description:

- Information on the site:

Profile no.:	55d, Borkena
Date:	23/11/83
Authors:	Fitzum F., Gebayehu B,. S. Paris
Location:	3 km SW of Jimete along track, 10°35'40"N - 39°54'00" E
Classification FAO:	Gleyic Solonetz
USDA:	Typic Natragualf
Physiographic position:	marginal area of bottom lands in Borkena plain
Slope:	0-1%
Elevation:	1450 m
Vegetation/land use:	grassland with mainly Cynodon dactylon and Cyperus spec.
Climate:	dry-subhumid warm tropical

- Information on the soil:

Parent material:	clayey outwash basin deposits imperfectly to moderately well drained; flooded for short period during the rainy season
Moisture condition:	dry 1040 cm, moist below
Rocky outcrop:	none
Evidence of erosion	none

- Profile description:

0–20 cm A	Very dark greyish brown (10 YR 3/2) moist and dark grey (10 YR 4/1) dry, clay; moderate coarse subangular blocky; very hard (dry), firm (moist), slightly sticky and slightly plastic (wet);
20–40 cm Bt1	Very dark grey (10 YR 3/1) moist and dark grey (10 YR 4/1) dry, clay; moderate medium prismatic; friable (moist), sticky and plastic (wet); patchy moderately thick clay cutans;
40–80 cm + Bt2	Dark brown (7.5 YR 3/2) clay; moderate medium prismatic; friable (moist), sticky and plastic (wet); contiuous thick clay cutans.

B) Laboratory data

	Depth (cm)		
	0–20	20–40	40–80
Texture (%, mm)			
2–0.05	28	18	12
0.05–0.002	32	40	30
0.002	40	42	58
pH (H_2O, 1:1)	7.8	7.9	7.8
Exchangeable cations (me/100 g)			
Na	3.5	5.2	6.1
K	1.5	0.5	0.5
CEC (me/100g)	28.4	33.8	29.8
ESP	12	15	20
Organic C (%)	5.2	0.8	0.6
Total N (%)	0.42	0.13	0.13
Available P_2O_5 (ppm)	10	10	12
EC (1:5, mmhos/cm)	0.30	0.30	0.10

5.13 CHERNOZEMS

5.13.1 FAO Classification

Chernozems are soils having a mollic A horizon with a moist chroma of 2 or less to a depth of at least 15 cm; having one or more of the following: a calcic or gypsic horizon or concentrations of soft powdery lime within 125 cm of the surface; lacking a natric B horizon; lacking the characteristics which are diagnostic for Rendzinas, Vertisols, Planosols or Andosols; lacking high salinity; lacking hydromorphic properties within 50 cm of the surface when no argilic B horizon is present; lacking bleached coatings on structural ped surfaces.

Haplic Chernozems are Chernozems lacking an argillic B horizon, a calcic and a gypsic horizon; not showing tonguing of the A horizon into a cambic B or into a C horizon.

Calcic Chernozems are Chernozems having a calcic or a gypsic horizon; lacking an argillic B horizon overlying the calcic or gypsic horizon; not showing tonguing of the A horizon into a cambic B or into a C horizon.

Luvic Chernozems are Chernozems having an argillic B horizon, a calcic or a gypsic horizon may be present when underlying the B horizon.

Glossic Chernozems are Chernozems showing tonguing of the A horizon into a cambic B horizon or into a C horizon; lacking an argillic F horizon.

5.13.2 General environment

Chernozems are soils characteristic of humid temperate climates with pronounced dry seasons, for it is under these conditions that the characteristic high organic matter contents can be maintained. Chernozems have vast distributions in the grassland areas of North America and Russia. In Ethiopia, they have been reported on the flat pyroclastic plateaux just south of Mt. Chilalo, in Arsi.

5.13.3 Characteristics

Chernozems are some of the most productive soils in the world, the excellent properties of these soils largely attributable to a deep mollic A horizon, Chernozems in Ethiopia are no different. Loamy texture, excellent structure, slightly acid pH, high organic matter content and good nutrient status are all characteristic. Chernozems also have some accumulation of $CaCO_3$ or $CaSO_4$ at depth in the profile.

Chernozems in this one location in Ethiopia are developed on ash and thus have some properties related to their origin, most importantly a very high exchangeable potassium content and low phosphorus. Neither of these properties are generally characteristic of Chernozems.

5.13.4 Land Use and natural vegetation

Land use on these soils is intensive peasant cultivation of grains with associated peasant livestock grazing during the dry season. Increasingly, land is being given over to state farm cereal production, largely wheat and barley.

5.13.5 Management

Chernozems have no serious limits with regard to agricultural use, however the Chernozems in Arsi do have some phosphorus deficiencies.

Advantages include loamy texture, excellent structure and high organic matter content, all of which contribute to high water holding capacity, good soil aeration and good drainage, excellent rooting conditions and high nutrient retention. The soils are very fertile.

5.13.6. Occurence

Of the types of Chernozems defined above, only Calcic Chernozems have been reported in Ethiopia

5.13.7 Profile Description

5.13.7.1 Calcic Chernozem, Guedeb plain

This profile represents the only reported occurence of Chernozems in Ethiopia. The climate is typical of that under which Chernozems develop in more northern latitudes. No special measures need be recommended to improve fertility other than such as are applicable to all soils, essentially increased use of fertilizers and improved farm management.

Source: WABI SHEBELE

Chernozems derived from volcanic tuff

A) General

These soils are only represented in the Guedeb plain where they occupy the largest part covering 983 km. This plain is in fact a double gently sloping glacis where the Wabi Shebele in the centre occupies the lower part, and which joins on the outskirts the hills of Dodola and Adaba in the south, the sides of the Kaka and Enkolo mountains in the north and the rolling land of Kofele in the west. To the east, the plain becomes narrower and ends on the level of Malka Wacana falls.

This plain has a volcanic origin, the cross section of the Asasa ford shows in fact a succession of usually calcareous tuff and ash with a rhyolitic layer at an elevation of 30+ m compared to the level of the Wabi Shebele. This formation rests on basalt.

The rhyolitic layer is in a way the framework upholding the Guedeb plain. It is overlain with approximately 15 m of andesitic ash resulting from eruptions in the Rift Valley. This ash with abundant glass constitutes the base material of the Chernozem soils.

The climate is characterized by a mean annual rainfall of 800 mm, a pronounced dry period from November to January and a low mean annual temperature of approximately 13°C. The vegetation mainly consists of gramineae since this zone is under cultivation, and trees only remain in some small valleys.

B) Profile description:

Location:	7.5 km away from Dodola towards Asasa
Natural vegetation:	Pennisetum

- Profile description:

0-7 cm	A_{11}	Dark brown (7.5 YR 4/4); loam; well developed medium crumb structure; dry and friable; numerous rootlets; distinct and uniform transition.
7-35 cm	A_{12}	Dark brown (7.5 YR 4/4); silty loam; well developed medium granular structure; dry and friable; numerous rootlets; gradual transition.
35-75 cm	A_{13}	Brown (7.5 YR 5/4); silty loam; subangular blocky structure with trend to well developed granular; friable; many rootles; short and uniform transition.
75-105 cm	(B)	Yellowish brown (10 YR 5/6); sandy clay loam; scarcely developed coarse subangular blocky structure; dry and friable; some rootlets; distinct transition.
105-140 cm	Cca	Yellowish white calcareous accumulation; soft powdery lime with calcareous heaps amd nodules (lime puppet); gradual transition.
140+ cm	R	Greyish yellow non-calcareous tuff with abundant pumice.

The A horizon is therefore considerable since it is 75 cm thick. However, its thickness varies in relation to its position. The gentle folds of the Guedeb plain present a convex aspect and soils are thicker on the upper part of these foldsbut they are very thin at the foot of slopes.

C) Laboratory data

	Depth (cm)				
	0-7	7-35	35-75	75-105	105-140
$CaCO_3$ (%)	0	0	0	tr.	15.6
Organic matter (%)	6.2	2.7	1.9	1.0	0.4
Total N (%)	0.28	0.13	0.07	0.06	0.03
C/N	13	12	15	9	7
pH	6.6	6.6	7.3	7.6	9.0

	Depth (cm)				
	0-7	7-35	35-75	75-105	105-140
Exchangeable cations (me/100g)					
K	2.3	1.9	0.5	0.8	3.6
Na	0.1	0.2	0.3	0.7	2.1
sum	20.6	23.6	28.6	29.3	m
CEC (me/100g)	24.0	25.0	27.0	30.0	m
Base saturation (%)	86	94	100	98	m
Total P_2O_5	0.090	0.080	0.075	0.080	0.080

These dark brown soils have a usually light texture, loam to silty loam. The clay percentage is very low unlike in the neighbouring Vertisols formed on basalt.

Two features have been observed enabling the classification of these soils as Chernozems: i) the strongly developed granular structure of a considerable thickness averaging 75 cm and becoming a subangular blocky structure deeper down and ii) the presence of an horizon with calcareous accumulation (15.6 percent) at depth, in the form of soft powdery lime with a fluffy consistency and in the form of big lime puppets, while the A and B horizons are noncalcareous.

The content of organic matter is high and averages approximately 6 percent and steadily decreases with depth. It gives the A horizon its brown colouring (melanic horizon). The nitrogen content is high at the surface and medium at depth. The C/N ratio is approximately 12 and indicates a calcic mull. Organic matter which is linked to mineral matter is one of the favourable elements for the formation of a granular structure.

The exchangeable capacity is medium throughout the profile. The absorbing complex is weakly desaturated at the surface but is saturated below 35 cm depth. The content of exchangeable potassium is high, approximately 2 me/100g of soil. Exchangeable sodium comparatively increases at depth owing to the weathering of andesitic material. Total phosphorus is medium. The total N/total P_2O_5 ration is approximately 3 which means that the nutritional balance between these two elements is correct.

D) Cultural fitness

These soils with a comparatively dry moisture regime due to their very well developed granular structure and consequent excellent drainage are particularly suitable for the cultivation of cereals. The Guedeb plain has been entirely under cultivation for the last thirty years using a traditional crop growing system based on cereals, generally wheat or barley alternating with long fallow periods during which gramineae are used for grazing.

The cereal yield combined with livestock breeding would considerably increase if i) cultural practices were improved by using modern instruments for field work; ii) more productive crop varieties tested beforehand were grown; iii) fallow land was replaced with cultivated meadow; and iv) nitrogen carriers such as urea, ammonium sulphate and ammonium nitrate and phosphate carriers (lime superphosphate) were added. By planting wind breaks, at 400 to 500 m intervals and at right angles to the wind, evaporation would be decreased, the moisture condition in the soil improved and yield increased.

5.14 PHAEOZEMS

5.14.1 FAO classification

Phaeozems are soils having a mollic A horizon; lacking a calcic horizon, a gypsic horizon and concentrations of soft powdery lime within 125 cm of the surface; lacking a natric and an oxic B horizon; lacking the characteristics which are diagnostic for Rendzinas, Vertisols, Planosols or Andosols; lacking high salinity; lacking hydromorphic properties within 50 cm of the surface when no argillic B horizon is present; lacking bleached coatings on structural ped surfaces when the mollic A horizon has a moist chroma of 2 or less to a depth of at least 15 cm.

Haplic Phaeozems are phaeozems lacking an argillic B horizon and which are not calcareous between 20 and 50 cm of the surface.

Calcaric Phaeozems are Phaeozems which are calcareus at least between 20 and 50 cm of the surface; lacking an argillic B horizon.

Luvic Phaeozems are Phaeozems having an argillic B horizon; lacking hydromorphic properties within 50 cm of the surface.

Gleyic Phaeozems are Phaeozems having an argillic B horizon and showing hydromorphic properties within 50 cm of the surface.

5.14.2 General environment

Phaeozems are widespread on the northeastern escarpment, often in association with Andosols on the higher uncultivated slopes. In the central highlands and in the Chercher highlands Phaeozems occur locally, mainly developed in calcareous parent material. In the Rift valley and in the south of the country, Phaeozems are found developed in volcanic ash.

5.14.3 Characteristics

Phaeozems are characterized by a dark coloured humus-rich basic topsoil and containing little or no calcium carbonate.

In the northeastern escarpment Phaeozems are mainly stony and shallow, as they occur on rather steep slopes. They can have an argillic B horizon and show hydromorphic properties.

In the Rift valley the Phaeozems are deep soils with a very thick topsoil and often having a high sodium content.

Elsewhere in the country Phaeozems can be deep or shallow and stony, mainly depending their topographical position.

5.14.4 Land use and natural vegetation

Phaeozems, when they occur in areas with a high population density, are intensively cultivated or, when the slope is very steep, are used for peasant livestock grazing.

In the semi-arid regions they are mainly moderately cultivated or provide good grazing grounds for peasant and nomadic livestock. The vegetation is mainly composed of grasses with some trees.

5.14.5 Management

Phaeozems, when they are deep, can constitute excellent agricultural land. However, in the northeastern escarpment the Phaeozems are mainly shallow and stony. In the Rift valley the Phaeozems are deep, but often have a high exchangeable

Sodium percentage on the absorption complex. To diminish the sodium content in these soils, they have to be leached, taking care of proper drainage. However leaching and drainage are hindered by impermeabilisation of the soil related to the high sodium content.

5.14.6 Occurence

All four types of Phaeozems are present in Ethiopia.

5.14.7 Profile descriptions

5.14.7.1/ Phaeozems occuring in the Rift valley

5.14.7.2/

5.14.7.3 Haplic Phaeozem
Luvic Phaeozem (sodic phase)
Calcaric Phaeozem

In the Rift valley several types of Phaeozems occur, often in the proximity of each other. Luvic Phaeozems, sodic phase are most widespread. Haplic and Calcaric Phaeozems only occur locally.

Source: MEKI & GALANA

A) General

The climate in the area is of the hot semi-arid type; rainfall is insufficient and the dry season too long to allow development of a dense forest, but promotes the growth of a spiny grass vegetation. The parent material is or inherited, by colluvial deposition from the red soils of the mountains which were formed in a more humid climate and were subsequently transported by surface runoff to the depressions subjected to a drier climate (Haplic Phaeozem) or colluvial material mixed with volcanic ash (Luvic and Calcaric Phaeozems)

B) Profile descriptions

B1) Haplic Phaeozems

Landform:	Plain
Slope:	less than 1%
Land use:	cultivation

Profile description:

0-15 cm	10 YR 3/2 (moist); clay; strong medium and fine blocky; slightly friable moist; few pores; frequent fine and medium roots; smooth transition to:
15-45 cm	10 YR 3/2 (moist); clay; strong medium blocky; slightly friable moist; few pores; frequent fine and medium roots; smooth transition to:
45-90 cm	7.5 YR 3/2 (moist); clay to clay loam; strong medium and fine subangular blocky; very friable moist; many pores; common fine and medium roots; smooth transition to:
90-220 cm	7.5 YR 3/2 (moist) with many oxido-reduction mottles 2.5 YR 3/6 (moist); clay; moderate coarse subangular blocky; non friable moist few pores; no roots
220-300 cm	7.5 YR 3/2 (moist) with many oxido-reduction mottles 2.5 YR 3/6(moist).

On the surface, the Haplic Phaeozems have a fine texture and a well developed angular blocky structure. Permeability is low.

The deep horizon has a clay loam, silty clay loam to clay texture with a well developed subangular blocky structure. They are more permeable than the surface horizons.

B2) Luvic Phaeozems, sodic phase

Landform:	glacis
Slope:	2%
Land use and vegetation:	high and low woody vegetation, with livestock grazing.

Profile description:

0-30 cm	7.5 YR 3/2 (dry); sandy loam; moderate medium subangular blocky; common pores; common roots; smooth transition to:
30-45 cm	7.5 YR 3/2 (moist); loam; moderate cubic-blocky; few fine pores, non friable; common fine and medium roots; smooth transition to:
45-70 cm	7.5 YR 2/2 (moist); sandy loam; moderate cubic blocky; few fine pores, non friable; few fine roots; smooth transition to:
70-100 cm	7.5 YR 3/2 (moist); iron-manganese elements in diffuse forms and in concretions; sandy loam; moderate angular blocky; few fine pores, slightly friable; few roots; smooth transition to:
100-125 cm	7.5 YR 3/2 (dry); sandy loam; $CaCO_3$ with few limestones; massive.

In this soil a natric horizon with a cubic structure is developed, resulting in a permeability in the structural elements of virtually zero. The total permeability, equal to about 2 or 3 mm/hr in the dry soil, becomes very low in the saturated soil (destructivation and impermeabilisation). Similarly, it is likely that the root penetration observed in dry conditions in the structural interstices becomes very small in wet conditions.

The above-mentioned horizon generally overlies a ferromanganic accumulation horizon which is shown by blackish spots and coatings which are not fragile and rarely indurated.

B3) Calcaric Phaeozem

Landform:	Plain
Slope:	2%
Vegetation	high sparse woody vegetation

Profile description:

0-50	10 YR 3/2; silt loam; moderate medium and fine subangular blocky; porous; common fine and medium roots; $CaCO_3$
50-105 cm	10 YR 3/2; sandy loam; strong medium and coarse angular blocky; slightly porous; few fine roots; $CaCO_3$
105-135 cm	10 YR 3/3; sandy loam; moderate subangular medium blocky; porous; few fine roots; $CaCO_3$
135 + cm	$CaCO_3$; sandy loam; massive.

C) Laboratory data

C1) Haplic Phaeozem

	Depth (cm)			
	0-15	15-45	45-90	90-220
Texture (%, mm)				
2-0.2	2	4	12	5
0.2-0.05	9	9	7	5
0.05-0.02	9	10	17	12
0.02-0.002	29	22	24	23
0.002	51	55	30	55
pH	6.8	7.1	7.2	7.9
Organic C (%)	5.0	4.0		
Total N (%)	0.45	0.41		

	Depth (cm)			
	0-15	15-45	45-90	90-220
Cation Exchange Capacity (me/100g)				
Ca	37	38		
Mg	15.7	15.1		
K	2.9	0.4		
Na	0.4	0.5		

C2) Luvic Phaeozem, sodic phase

	Depth (cm)				
	0-30	30-45	45-70	70-100	100-125
Texture (%, mm)					
2-0.2	13	17	6	5	2
0.2-0.05	30	27	14	23	11
0.05-0.02	22	19	34	21	18
0.02-0.002	26	25	38	41	42
0.002	4	12	8	10	27
pH	7.5	7.5	8.1	9.1	9.5
Organic C (%)	1.4	1	0.8		
Total N (%)	0.16	0.09	0.08		
Cation Exchange Capicity (me/100 g)					
Ca	17.5	12.1	20.6		
Mg	4.8	3.0	6.9		
K	1.9	2.0	6.2		
Na	0.7	1.5	6.5		

C3) Calcaric Phaeozem

	Depth (cm)	
	0-50	50-105
Texture (%,mm)		
2-02	7	22
0.2-0.05	30	33
0.05-0.02	35	24
0.02-0.002	25	20
0.002	3	1
pH	7.5	8.3
Cation Exchange Capacity (me/100 g)		
Ca	12.1	
Mg	2.8	
K	1.9	
Na	0.4	

D) Tests

	Haplic Phaeozem	Luvic Phaeozem	Calcaric Phaeozem
- Field capacity (%)			
Hs*	31.2	43.0	39.2
Hm*	42.2	39.9	25.0
- Permanent Wilting Point (%)			
Hs*	13.0	18.0	14.2
Hm*	20.5	19.9	10.0
- Available Moisture (%)			
Hs*	18.2	24.8	25.0
Hm*	21.7	17.9	15.0

*Hs = surface horizon
Hm = intermediate horizon

5.14.7.4 Calcaric Phaeozem, Harar

These soils occur on the vast limestone plateaux of South Chercher and of Harar at an altitude varying from 1 000 to 2 000 m. They occur in association with Rendzinas (profile 15.116.1) and Vertisols (profile 15.4.7.6)

Source: WABI SHEBELLE

A) Profile description

0-20 cm	Very dark greyish brown (10 YR 3/2); silty loam; medium granular; scarcely calcareous.
20-90 cm	Very dark greyish brown (10 YR 3/2); clay loam; medium granular; calcareous
90-120 cm	Yellowish brown (10 YR 3/4) to dark reddish brown (5 YR 3/3); fine sub-angular blocky structure; calcareous clay.

120 + cm Limestone blocks in situ

B) Laboratory data

	Depth (cm)		
	0-20	20-90	90-120
Texture	SiL	CL	C
$CaCO_3$(%)	1.0	14.0	15.0
Organic matter (%)	4.6	2.3	1.1
Total N (%)	0.24	0.09	0.05
C/N	11	14	12
pH	8.0	8.1	8.2
Total P_2O_5(ppm)	600	500	400

The content of organic matter is relatively high and well distributed in the topsoil. The nitrogen percentage is high and C/N is medium, showing that humus is deeply mineralized. Organic matter of 'mull' type is closely related to mineral matter through calcium links. This is favourable to the formation of a very well-developed granular structure characterizing these soils. pH is distinctly basic and approximately 8.1 owing to the presence of calcium carbonate.

C) Cultural fitness

These soils are very suitable for agricultural purposes. However, because of a strongly developed granular structure, these soils are very well drained and the pedoclimate is relatively dry. Besides, their close imbrication with rendzina soils is the reason why arable areas are generally small and may not be used for mechanized cultivation. These soils are already largely cultivated in the North but in the South, owing to a decreasing rainfall, the crop-growing possibilities are very low.

5.14.7.5 Luvic Phaeozem, Borkena

This profile is situated in an almost flat stable alluvial fan slope in the Borkena plain. This site is not receiving any more new material. Depths of the soils is highly variable in this fan, as well as stoniness. The parent material of this soil is dark coloured and has a low chroma.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.:	B20a, Borkena
Date:	9/6/1983
Authors:	Abebe H/M, J.Bruggeman
Location:	3.5 km WSW of Milamile, 3 km W of the main road, 10°46' 10" N-39°48'20"E
Classification FAO:	Luvic Phaeozem
USDA	Udic Argiustoll
Physiographic position:	stable alluvial fan
Slope:	0-1%
Elevation:	1445 m
Vegetation/landuse:	cultivation of teff, sorghum and maize
Climate	dry-sub humid warm tropical

- Information on the soil:

Parent material:	silty sheetflood deposits
Drainage:	well drained
Moisture condition:	moist throughout
Rock outcrop:	none
Evidence of erosion:	none

- Profile description:

0-10 cm	Ap1	Very dark greyish brown (10 YR 3/2) clay loam; strong coarse subangular blocky; very firm (moist), sticky and plastic (wet); many very fine to medium pores; clear and smooth on:
10-35 cm	Ap2	Very dark greyish brown (10 YR 3/2) clay loam; moderate coarse subangular blocky; firm (moist), sticky and plastic (wet); many fine to medium pores; many fine roots; clear and smooth on:
35-85	Bt1	Dark brown (7.5 YR 3/2) loam to silt loam; moderste coarse subangular blocky; firm (moist), sticky and plastic (wet); broken moderately thick clay cutans; many fine and medium pores. few very fine and fine roots; gradual and wavy on:

85-130 cm	Bt2	Dark brown (7.5 YR 3/2) loam; weak coarse angular blocky; friable (moist), slightly sticky and slightly plastic (wet); patchy thin clay cutans; many fine and medium pores; few very fine and fine roots; clear and smooth on:
130-170 cm	BC	Very dark greyish brown (10 YR 3/2) loam; few faint mottles; moderate medium angular blocky; friable (moist), slightly sticky and slightly plastic (wet); common fine and medium pores; few very fine and fine roots; clear and smooth on:
170-190 cm	Cg	Dark brown (10 YR 3/3) sandy loam; few fine distinct mottles; weak medium subangular blocky; loose, non sticky and non plastic (wet); common fine pores; few fine roots.

B) Laboratory data

	Depth (cm)				
	0-10	10-35	35-85	85-130	130-170
Texture (%, mm)					
2-0.05	27	30	29	43	49
0.05-0.002	42	42	50	40	28
0.002	31	29	21	17	23
pH (1:1)					
H_2O	65	6.4	6.3	7.2	7.4
KCl	5.5	5.3	5.5	5.3	5.9
Exchangeable cations (me/100g)					
Ca	0.9	0.4	0.4	0.9	0.9
K	2.0	1.5	0.5	0.3	0.5
Organic C (%)	1.9	1.3	0.4	0.2	0.8
Available P_2O_5 (ppm)	8	6	6	8	4

5.14.7.6/ Haplic Phaeozem (lithic phase) and Gleyic Phaeozem,
5.14.7.7 northeastern escarpment

These profiles are both situated in the highlands on the northeastern escarpment. The Gleyic Phaeozems occur in association with Luvic Phaeozems on the broad convex ridges above 3 000 m; the Haplic Phaeozems, lithic phase are found in association with Lithosols on the steep slopes. Parent material for the Gleyic Phaeozems is residual material derived from basalt with some possible ad-mixture of more recent tuffaceous materials. The Haplic Phaeozems, lithic phase are developed in colluvium from this material.

The Gleyic Phaeozem considered when under natural vegetation at very high altitudes sometimes becomes so acid and leached that base saturation is under 50 percent and the soils have to be classified as Humic Gleyic Acrisols, as is the profile described.

Source: LUPRD

A1) Profile description

- Information on the site:

Profile no.:	B65a, Borkena
Date:	2/7/1983
Authors:	Fitsum F., Legesse Y., Melesse H.
Location:	1 km S of May Bar along the road, 10°58'10" N-39°39'15"E
Classification FAO	Haplic Phaeozem, lithic phase
USDA	Lithic Haplustoll
Physiographic position:	steep mountainslope
Slope:	35%
Elevation:	2320 m
Vegetation/landuse:	shrubs and some cultivation (maize)
Climate:	dry-subhumid cool tropical

- Information on the soil:

Parent material:	slope deposit derived from basalt
Drainage:	somewhat excessively
Moisture condition:	moist
Rock outcrop:	fairly rocky
Evidence of erosion:	moderate sheet erosion

- Profile description:

0-20	Dark brown (10 YR 3/3)loam; weak medium crumb; friable (moist), slightly sticky and slightly plastic (wet); common very fine and fine pores; many gravel; many very fine to medium roots; abrupt and broken on:
20 cm +	Weathered basalt.

B1) Laboratory data

	Depth (cm)
	0-20
Texture (%, mm)	
2-0.05	51
0.05-0.002	33
0.002	15
pH (1:1)	
H_2O	6.1
KCl	5.0
Organic C (%)	3.0
Available P_2O_5(ppm)	10

A2) Profile description

- Information on the site:

Profile no.:	217d, Borkena
Date:	17/12/83
Author:	J.Bruggeman, S.Paris
Location:	13 km NE of Rabel along road, $10^o37'25''N - 39^o41'10''E$
Classification FAO:	Humic Gleyic Acrisol
USDA:	Tropaqualf or Typic Umbraqualf
Physiographic position:	broad convex ridge
Slope:	6%
Elevation:	3200 m
Vegetation/landuse:	cultivation of barley and pulses
Climate:	moist-subhumid to humid cool tropical

- Information on the soil:

Parent material:	residual material derived from basalt with possible admixture of recent tuffaceous material
Drainage:	moderately well
Moisture condition:	moist throughout
Rock outcrop:	none
Evidence of erosion:	none

- Profile description:

0-45 cm	Ap	Dark brown (7.5 YR 3/2-4) moist and (dark) brown (7.5 YR 4/2-4) dry, clay; moderate medium to coarse subangular blocky; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); smooth and clear on:
45-80 cm	Btg	(Dark) brown (7.5 YR 4/2) clay; common medium faint and distinct mottles; weak to moderate medium subangular blocky; very hard (dry), very firm (moist), sticky and plastic (wet); patchy thin clay cutans; smooth and clear on:
80-120 cm	Bt	(Dark) brown (10 YR 4/3) moist and brown (7.5 YR 5/2) dry, clay; strong coarse angular blocky and prismatic; extremely hard (dry), very firm (moist), sticky and plastic (wet); continuous thick clay cutans; few slickensides.

Remark: Commonly the soils with hydromorphic properties in this unit are less well developed and less leached; they are classified as: Gleyic Phaeozem.

B2) Laboratory data

	Depth (cm)		
	0-45	45-80	80-120
Texture (%,mm)			
2-0.05	18	14	14
0.05-0.002	24	26	22
0.002	58	60	64
pH (1:1, H_2O)	4.8	4.9	5.0

	Depth (cm)		
	0-45	45-80	80-120
Exchangeable cations (me/100g)			
Na	1.7	0.9	0.4
K	0.5	0.5	1.0
Ca	9.6	11.5	16.1
Mg	1.8	0.5	1.5
CEC (me/100g)	29.2	31.8	31.6
Base saturation (%)	47	42	60
Organic C (%)	1.5	0.7	0.4
Total N (%)	0.14	0.13	0.06
Available P_2O_5 (ppm)	8	4	8

5.15 XEROSOLS

5.15.1 FAO Classification

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

Haplic Xerosols are Xerosols having no diagnostic horizons other than a weak ochric A horizon and a cambic B horizon.

Calcic Xerosols are Xerosols having a calcic horizon within 125 cm* of the surface; lacking an argillic B horizon overlying the calcic horizon.

Gypsic Xerosols are Xerosols having a calcic horizon within 125 cm* of the surface; lacking an argillic B horison overlying the gypsic horizon.

Luvic Xerosols are Xerosols having an argillic B horizon; a calcic or a gypsic horozon may be present if underlying the B horizon.

The depth requirement varies with the weighted average textural class.

5.15.2 General environment

Xerosols are extensive in the semi-arid areas of Ethiopia, including the Ogaden, Afar triangle and northern Eritrea, occuring on various parent materials. Weathering is slow in dry climates, thus soils rarely develop significantly on the steep landforms. Xerosols therefore are generally found on flatter landforms, in association with Lithosols as slope angles increase.

5.15.3 Characteristics

Xerosols most importantly differ from soils in more humid environments in the consequences to the profile of accumulation rather than leaching as the predominant pedogenetic process. pHs are neutral to alkaline, even on acidic parent materials and accumulation of $CaCO_3$ and $CaSO_4$ are common. In addition organic matter is low, rarely above 1%. Soils are shallower than soils of corresponding topography and parent material in more humid climates, and textures coarses. Both these tendencies are attributed to slow weathering in semi-arid environments. Structure is often weak.

Xerosols may however be quite variable chemically and physically, within the limits set by the climate, depending on parent material. pH varies from neutral to alkaline, textures from medium to coarse and exchangeable cation ratios can differ widely.

5.15.4 Land use and natural vegetation

Xerosols in Ethiopia are predominantly under natural vegetation or grassland and trees or shrubs, however some areas are given over to dryland farming. This latter exercise is a tenuous business, given rainfall variability and resultant recuring crop failures.

5.15.5 Management

In the absence of very coarse textures, high salinity, and/or shallow petrocalcic or petrogypsic horizons, Xerosols are potentially productive. However a reliable supply of irrigation water is required and applications of phosphorus and micronutrients may be needed, as these nutrients become unavailable at high pHs.

Where large accumulations of $CaCo_3$ or $CaSO_4$ occur, limitations to agriculture, even given adequate moisture supply, become more serious. Macronutrient imbalances may have to be redressed. Where such calcium accumulations become concretized close to the surface, rooting may be interfered with. Salinity is also a frequent phenomenon, and Xerosols with high silt contents are susceptible to severe wind erosion in the absence of complete vegetation cover.

5.15.6 Occurence

Of the four kinds of Xerosols defined above, all occur in Ethiopia. Calcic and Gypsic Xerosols are the most common, covering large areas in the lower Ogaden and in the northern Rift Valley Lithic, saline, petrocalcic and petrogysic phases are very common. Haplic Xerosols, largely developed on granitic materials, occur in northern Eritrea and in southeastern Sidamo. Luvic Xerosols occur probably in southern Sidamo.

5.15.7 Profile descriptions

5.15.7.1 Haplic Xerosol (saline phase), east of Mekele

This profile, from the edge of the northeastern escarpment east of Mekele, has developed under a rainfall regime of less than 400 mm annually. The alluvium is of volcanic origin.

In the study of Tigray soils, these Xerosols were discovered to have the highest index of erodability (using Wischmeier's nomograph) as a result of heavy silt and fine sand content and of low organic matter. In dry climates, such soils are particularly subject to wind erosion.

Although the electrical conductivity values barely qualify this soil as a saline phase, the boron level at 10 cm depth is toxic to some plants.

Source: TIGRAI

A) Profile description

Profile No.:	GA/5
Date of examination:	30 October 1974
Location:	northern end of Kalla plain
Parent material:	outwash alluvium
Landform:	almost flat terrace
Slope:	slight slope to the east
Surface:	compact with no cracks
Landuse:	livestock browsing on _Salvadora_ and _Cadaba_ spp., low scrub

- Profile description:

0-10 cm	Brown (10 YR 4/3); very fine sandy loam; soft dry.
10-60 cm	Dark brown (7.5 YR 4/2); very fine sandy loam; soft dry; very weak structure.
60-100 cm	Dark yellowish brown (10 YR 4/4) very fine sandy clay loam; slightly hard dry.

Comments: Deep medium to fine textured Haplic Xerosols; weak structure but friable consistence; no visible salt concentrations; salinity levels range from 2.75 to 4.10 mmhos/cm, qualifying the soil as a saline phase.

B) Laboratory data

	Depth (cm) 0-10	10-60	60-75	75-100
Texture (%, mm)				
2	0	1	0	1
2-0.2	5	2	3	7
0.2-0.05	16	10	10	15
0.05-0.002	67	72	57	45
0.002	12	15	30	32
pH	7.7	7.7	7.6	7.6
EC (mmhos/cm, 1:5)	2.75	4.10	3.60	3.50
Exchangeable cations (me/100g)				
Ca	16.4	11.6	14.6	15.6
Mg	1.7	1.6	3.1	3.3
Na	0.0	0.0	1.3	0.7
K	1.0	0.6	1.0	1.0
CEC (me/100g)	16.5	20.3	28.3	28.3
Total K (ppm)	5620	2890	m	m
Available P (ppm)	5.0	3.0	m	m
Total N (%)	0.10	0.08	m	m
Organic C (%)	1.1	1.0	m	m
Soluble (ppm)				
Cu	0.2	0.2	0.2	0.2
Zn	0.3	0.3	0.3	0.2
Mn	292	304	390	326
Total (ppm)				
Cu	13	13	11	11
Zn	6	5	5	5
Mn	580	560	680	580
Boron (ppm)	2.16	5.00	2.10	1.62

C) Estimates of soil erodability index (K)

	Depth (cm) 0-10	10-60
Texture	SiL	SiL
K	0.470	0.455
Contributing factors		
organic matter	mod	mod
silt+very fine sand	v. high	v. high
medium sand	v. low	v. low
other	v. weak structure	compact

5.15.2 Gypsic Xerosols (saline and lithic phase), lower Ogaden

These profiles, from the area around the lower reaches of the Wabi Shebele, are typical of vast areas of the lower Ogaden, on flatter landforms where salt accumulation is not extreme. These soils have relatively low salinity levels and thus are saline phase Xerosols. Depths vary, the first profile is in fact a lithic phase, depending on topographic position and thus on any influx of colluvial material.

The second profile must be classed as a Xerosol, for organic matter content is over 1%. In the immediate area of these profile sites rainfall is less than 200 mm annually and Yermosols are also well represented. Perhaps the first soils is better classed as such, however without more complete laboratory data, it is difficult to tell.

Neither is it absolutely clear that these soils are gypsic, rather than calcic Xerosols. The profile descriptions refer to accumulations of gypsum, however it is also reported that calcium carbonate is 21% in the upper horizon. Where calcium carbonate accumulation is above calcium sulphate accumulation, soils are classed as Calcic Xerosols.

Source: LOWER VALLEY OF THE WABI SHEBELE

Xeric soils in early stage of development

A) General

They spread over large gypsum zones between Kelafo and Mustahil and beyond, on the southern bank of the Wabi Shebele and from Kugno to Imi on the northern bank.

The yellowish grey (2.5 YR 8/4) upper horizon consists of a fine gypsum powder, the real texture of which cannot be easily determined and seems to be composed of loam to silty loam resting on a gypsum slab. The depth of the latter varies according to local colluvial depositions and leads to the distinguishing of two types of soils.

B1) Profile description, in situ

0-5	Yellowish grey (2.5 Y 8/4); silty loam; single grained powdery structure; no rootlets; distinct transition to:
5-25 cm	Multi-coloured gypsum stones and yellowish brown (10 YR 7/6) or light yellow (5 Y 8/3) gypsum crystals mixed with a yellowish grey (2.5 Y 8/4) material; silty loam; single grained structure; dry and compact; no rootlets; sudden transition to:
25+ cm	Gypsum slab.

B2) Profile description, colluvial type

0-20 cm	Yellowish grey (2.5 Y 8/4); silty loam; single grained structure; dry, friable and powdery; no rootlets; distinct transition to:

20-70 cm	Yellowish grey (2.5 Y 8/4); silty loam; single grained structure; powdery, flattened and friable angular fragments; no rootlets; sudden and regular transition to:
70+ cm	Greyish gypsum slab.

C) Laboratory data

The surface soil consits of disintegrated gypsum, nevertheless low grade reprecipitation is observed when vertical movement of water occurs during the rainy season. These soils are composed of 21% calcium carbonate in the upper horizon but of less than 10% in the horizon resting on the gypsum slab.

pH is approximately 8.0. The average content or organic matter is 1.1% but in the colluvial type the content is high at 1.5% than in the in situ type (profile description 2) at 0.8%. Conductivity is high at 1.9 to 2.8 mmhos/cm of the 1:10 extract corresponding to the abundance of gypsum and to the presence of sodium chloride in large quantities , of up to 21 me/100g soil, or 1.2%.

5.15.7.3 Haplic Xerosol (petrocalcic saline phase), middle Awash

This profile was taken in the middle Awash valley. The soils have good behavioural characteristics-- attributable to medium texture, are said to be fertile and do not have excessive salinity, however there are difficulties in supplying the necessary irrigation water to make them agriculturally productive. The soil also meets the requirements, although just barely, of a saline phase.

Source: AWASH

Semi-arid brown soils on soft calcareous materials with a local limestone crust

A) General

Soils in this unit can form over old alluvial material or over non-stony old colluvial material.

The characteristic features are their colour (brown to light brown, 10 YR 4/2, 5/2, 5/3, 6/2 or 6/3) and fine lime mycelia or lime cemented gravel, or less often, calcareous crust. These are mainly found in the plain west of Awash Station. The plain is of ancient origin, and more often than not in a very broken-up condition. The present soils have probably formed from former eroded soils.

Lime content is variable, usually between 5 and 10% although lower values may be found where the lime occurs in the form of concretions over 2 mm in size or in the form of crusts.

The soils are medium textured, of the silt or silty loam type with a comparatively weakly developed structure which tends to granular on the surface and to blocky deeper down.

Organic matter rates seldom exceed 2%. pH values generally range between 8 and 8.5 and conductivities are low, i.e. less than 4 mmhos/cm. Soils backing against basalt hills, however, show some signs of salinity, with slightly higher conductivity values in the deeper horizons. Their pH values may be as high as to denote alkalinity.

Due to their higher altitude than the alluvial materials, these soils are not flooded by the Awash river. They receive water only from runoff from the higher lying ground. Their moisture regime is dryer than that of the alluvial materials in the plains, so that they are more sparsely overgrown with vegetation. They can be expected to have satisfactory water holding capacities and permeabilities.

These fertile soils are irrigable but their use is severely restricted by ground features, state of erosion and the difficulty of irrigating them. Lime or gravel crusts or salinity occasionally affect their irrigability.

B) Profile description

Profile no.:	MMS 314
Location:	Melka Sedi plain
Natural vegetation:	very few green trees, some bare spots with gramineae

- Profile description:

0-25 cm	Greyish brown (2.5 Y 5/2); sandy loam; dry; single grained structure; no consistence; fine roots.
25-40 cm	Greyish brown (2.5 Y 5/2); coarse sand; moderately dry; single grained structure; no consistence; small round shaped limestone concretions; fine roots; gravel from 1 to 2 cm.
40-90 cm	Light brownish grey (2.5 Y 6/2); silt; dry; powdery structure; friable; some limestone concretions; not hard
90-95 cm	Greyish white limestone crust; dry; after 95 cm this horizon is powdery (like ash) without structure and consistence; the upper part is hard and cemented with lime.

C) Laboratory data

	Depth (cm)			
	0-10	60-70	90-100	90-95 (crust)
Texture (%, mm)				
2-0.2	21	2	m	m
0.2-0.05	39	17	m	m
0.05-0.002	35	79	m	m
0.002	5	2	m	m

	Depth (cm)			
	0-10	60-70	90-100	90-95 (crust)
pH	8.4	8.1	8.9	m
$CaCO_3$ (%)	3.1	4.5	9.4	47.0
Organic matter (%)	0.8	m	m	m
Organic C (%)	0.5	m	m	m
Base saturation (%)	m	45	m	m
EC (mmhos/cm, sat. ex.)	m	4.2	m	m
Soluble Na (me/1,sat.ex.)	m	15.2	m	m

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	0.05	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: 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.

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 high-lands, 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.

75-130 cm	strong brown (mixed 7.5 YR 5/4 and 7.5 YR 5/8) gritty sandy clay loam; crystalline rock structure dominant; dry and hard; rare fine roots; soil from 15-75 layer down fractures.
130 + cm	Hard in situ weathered dolerite, with fresh solid corestones.

C) Laboratory data

	Depth (cm)		
	0-15	15-75	75-130
Texture (%, mm)			
2	0	1	8
2-0.2	23	18	49
0.2-0.05	21	17	13
0.05-0.002	43	31	20
0.002	15	33	10
pH	7.0	7.3	7.5
EC (mmhos/cm, 1:5)	0.1	0.1	0.1
Exchangeable cations (me/100 g)			
Ca	12.8	23.3	17.8
Mg	4.3	7.3	5.1
Na	0.1	0.2	0.1
K	0.2	0.1	0.1
sum	17.4	30.9	23.1
CEC (me/100g)	18.1	31.7	19.0
Base saturation (%)	96	97	100
$CaCO_3$	0	0	0
Total K (ppm)	1250	900	m
Available P (ppm)	38	15	
Total N (%)	m	m	m
Organic C (%)	0.6	0.8	m
C/N	m	m	m
Soluble (ppm)			
Cu	0.8	0.6	0.6
Zn	1.8	1.2	1.7
Mn	400	400	322
Total (ppm)			
Cu	20	23	24
Zn	190	165	145
Mn	1275	1575	1150

	Depth (cm) 0-15	15-75	75-130
Bulk density (g/cm^3)	1.33	1.43	1.42
Moisture (%)			
0.0 bar	36.4	34.7	33.3
0.1 bar	26.9	30.7	23.9
0.3 bar	19.6	26.7	18.9
1.0 bar	14.9	24.3	16.1
15 bar	8.6	15.6	3.7
Available water capacity			
% weight	18.3	15.1	20.2
% volume	24.4	21.6	28.7
Porosity (%)			
total	54	51	51
aeration	12.6	5.7	13.3

5.19.7.3 Vertic Luvisol, Harer

This profile was taken on a concave valley side along the road Dire Dawa - Harer. In this area the valleysides have Vertic Luvisols, the convex hillsides have Chromic Luvisols, sometimes Eutric Nitosols.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no:	70, Harer
Classification:	Vertic Luvisol
Date:	6 August 1982
Author:	H.Y. Wyntje- Bruggeman, S.Ross
Location:	200 m NE of the road Dire Dawa-Harer; 2.5 km S from junction Dire Dawa-Harer, Asbe Teferi-Harer
Elevation:	2080 m
Physiographic position:	lower sideslope to depression
Surrounding landform:	rolling to undulating plateau with depressions

Microtopography:	1 m deep gullies
Slope:	1 percent
Land use:	intensively cultivation, sorghum
Climate:	humid temperate

- Information on the soil:

Parent material:	colluvium from granites with calcareous intercalations
Drainage:	moderately well
Moisture condition:	moist to 50 cm, dry below
Depth of groundwater:	not encountered
Stoniness	none

- Profile description:

Deep, moderately well drained, dark brown, clay; clay content increasing with depth; cracks open below 40 cm; cutans, increasing in number with depth.

0-40 cm	Very dark brown (10 YR 2/2) moist; clay; strong medium granular and fine subangular blocky; sticky and plastic wet, friable moist; no cutans; common fine and very fine interstitial pores; frequent fine and very fine roots, common medium and coarse roots; clear wavy boundary.
40-65 cm	Very dark greyish brown (10 YR 3/2) moist; clay; strong coarse prismatic structure subdivided into moderate medium angular blocky; sticky and plastic wet, firm moist, hard dry; few cutans; cracks 5 to 10 cm apart, 1 cm wide; common fine and medium tubular pores exped; common roots; clear wavy boundary.
65-80 + cm	Dark greyish brown (10 YR 4/2) moist; clay; strong very coarse prismatic structure; very firm moist, very hard dry; common broken thick

cutans, very dark greyish brown (10 YR 3/2) moist, on ped surfaces; cracks 2 cm wide 10-20 cm apart; very few fine pores; few roots.

B) Laboratory data

	Depth (cm)		
	0-40	40-65	65-80
Texture			
2-0.2	15	18	10
0.2-0.05	16	12	7
0.05-0.002	20	22	19
0.002	50	47	65
pH	7.8	7.5	7.4
CEC (me/100g)	45.8	52.2	53.8
Organic matter (%)	1.7	1.9	1.7
Available P (ppm)	0	0	0

5.19.7.4 Chromic Luvisol, Babile

Source: WABI SHEBELLE

Reddish brown modal soil types, derived from granite and sandstone

A) General

These soils are developed in the region of Harar, Babile-Fugnanbira, on rolling plateaux and on slopes where the weathering of granite or the colluvia derived from sandstone and granite are the most considerable. They are easily known owing to their reddish-brown to red colouring contrasting with the light grey of soils in early stage of development on granite. On these plateaux, isolated granite outcroppings are frequently seen. West of the Harar-Dire Dawa road they also exist on relatively steep slopes the top of which consists of limestone remnants with brown calcic soils.

B) Profile description

0-40 cm. Brown (7.5 YR 5/4); coarse sand; medium and fine crumb structure; friable.

40-100 cm	Reddish-brown (5 YR 5/4); fine sandy clay; subangular blocky; stone-line of scarcely worn quartz gravels; abundant yellow mica; friable.
100-180 cm	deeply weathered granite in situ; mottled white and red with some pockets of red clayey earth; friable.
180 cm +	decayed granite with black mica; friable.

Variations are mostly observed in horizon A1. Very frequently, owing to weathering, the stone-line of horizon B is very near the surface (Hadow region, Fugnanbira track).

C) Laboratory data

	Depth (cm)		
	0-40	40-100	100-180
Texture	cS	cSC	CS
pH	7.1	7.5	8.0
$CaCO_3$	0	0	0.8
Organic matter (%)	2.1	1.2	0.6
Total N (%)	0.12	0.08	0.05
C/N	10	9	8
Exchangeable cations (me/100 g)			
Ca	7.1	11.8	m
Mg	4.0	6.0	m
K	0.5	0.3	m
sum	11.8	18.4	m
CEC (me/100 g)	10	18	m
Base saturation	100	100	m
Total P_2O_5 (ppm)	600	400	400

These reddish brown and red soils are very sandy at the surface (coarse sand) and more clayey at small depth. In the weathered granite horizon (C) some traces of calcium carbonate may be observed. The content of organic matter is medium to low as well as the nitrogen content. C/N is very low and shows that humus is quickly mineralized. The absorbing complex is saturated but the exchangeable capacity is very weak owing to the scarcely clayey soil texture. The phosphorous content is medium. The Total N/Total P_2O_5 ratio is approximately 2 and indicates a nutritional unbalance detrimental to nitrogen.

D) Cultival fitness

Soils are generally largely cropped in Harar owing to the density of population and there are practically no fallow lands. On this type of soil the main crops are sorghum, groundnuts and sweet potatoes as well as vegetables. Chat (Catha edulis) is grown on the terraces built on steep slopes.

Though the farmers regularly add manure to the soil, the latter is very poor in nitrogen as well as in potassium and phosphorus. The nitrogen deficiency is easily observed on sorghum and chatt. The addition of a complete mineral fertilizer: NPK before cultivating the land and a fractional adding of nitrogen during the vegetative cycle would considerably increase the crop-yield. However, as on the one hand the soil is very well-drained and on the other hand it has a very weak exchangeable capacity hence a low retention of fertilizers, the fractional addings of nitrogen carriers should be calculated judiciously in order to avoid losses due to leaching.

5.19.7.5 Gleyic Luvisol, Borkena

This soil occurs in the clayey backswamp deposits of the Borkena river, in association with Calcaric Gleysols. The soils are exclusively used for grazing. The soils are flooded for 2 to 3 months during the rainy season.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.:	B 106, Borkena
Date:	10/4/1984
Authors:	J.Venema, Fitsum F., S.Paris
Location:	2.3 km SSW of Babile, 2 km W of main road, 10°43'40"N-39°49'.5'E
Classification FAO:	Gleyic Luvisol
USDA:	Aeric Tropaqualf
Physiographic position:	Backswamp of Borkena river
Slope:	0%
Elevation:	1420 m
Vegetation/landuse:	grassland with Cynodon dactylon and Cyperus sp., grazing
Climate:	dry - subhumid warm tropical

- Information on the soil:

Parent material:	clayey backswamp deposits
Drainage:	imperfectly drained; on the spot protected from seasonal flooding by dike
Moisture condition:	slightly moist throughout
Rock outcrop:	none
Evidence of erosion	none

- Profile description

0-8 cm A	Very dark brown (10 YR 2/2) moist and very dark greyish brown (10 YR 3/2)dry, clay; few fine distinct mottles; strong fine to medium angular blocky; very hard (dry); few pores; common fine and medium roots; abrupt and smooth on:
8-20 cm Btg 1	Very dark brown (10 YR 2/2) clay; many medium distinct brown and black mottles; strong fine and medium angular blocky; very hard (dry); thin patchy clay cutans; few pores; common very fine and fine roots; clear and smooth on:
20-45 cm Btg 2	Dark brown (7.5 YR 3/2) clay; common medium distinct brown mottles; moderate coarse subangular blocky; very hard (dry), very firm (moist); broken thin clay cutans; very few pores; few to common fine roots; clear and smooth on:

45 - 85 cm Bg	Dark brown (7.5 YR 3/2) silty clay; common medium distinct mottles; weak to moderate coarse prismatic; hard (dry); very patchy clay cutans; few pores; few very fine and fine roots; clear and smooth on:
85 - 95 cm 2Bg	Dark brown (10 YR 3/3) moist and (dark) brown (10 YR 4/3) dry, loam; common medium faint mottles; weak coarse subangular blocky; slightly hard (dry); common very fine and fine pores; very few roots.

B) Laboratory data

	Depth (cm)				
	0 - 8	8 - 20	20 - 45	45 - 85	85 - 95
Texture (%, mm)					
2-0.05	14	10	12	16	28
0.05-0.002	24	20	14	42	46
0.002	62	70	74	42	26
Ph (H_2O, 1:1)	6.2	6.3	6.6	6.6	7.0
$CaCO_3$(%)			4.6	4.8	4.6
Exchangeable cations (me/100 g)					
Na	0.9	0.9	1.7	0.9	0.9
K	2.0	1.5	1.0	1.0	0.5
Ca	21.2			19.2	
Mg	15.2			11.2	
CEC (me/100 g)	41.6	36.0	42.4	34.2	25.8
Organic C (%)	5.0	4.6	2.1	1.7	0.9
Total N (%)	0.42	0.27	0.20	0.18	0.14
Available P_2O_5(ppm)	10	3	7	7	3

5.19.7.6 Orthic Luvisols (stony phase), Degaga

These soils are developed in colluvial deposits derived from porphyritic basalt. The soils are medium to coarse textured soils with a very stony surface. They are intensily cultivated.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.:	B74 a, Borkena
Date:	8/7/83
Authors:	Legesse Y., J. Breggeman
Location:	5 km S of May Igir Hayk and 6.5 km N of Seny O, 0.2 km W of road 10°56'00" N - 39° 38'50"E

Classification FAO:	Orthic Luvisol, stony phase
USDA:	Udic Haplustalf
Physiographic position:	colluvial slope
Slope:	10%
Elevation	2490 m
Vegetation/landuse:	cultivation of teff, wheat, barley, maize and pulses
Climate:	dry - subhumid cool tropical

- Information on the soil:

Parent material	colluvial deposite derived from porphyritic basalt
Drainage:	well drained
Moisture condition:	moist throughout
Rock outcrop:	none
Evidence of erosion:	none

- Profile description

0 - 15 cm Ap	Dark brown (10 YR 3/3) moist and yellowish brown (10 YR 5/4) dry, sandy loam; moderate coarse subangular blocky; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many pores; common gravel; few fine roots;
15 - 45 cm Bt1	Dark brown (10 YR 3/3) loam; moderate coarse angular blocky; friable (moist), sticky and plastic (wet); patchy thin clay cutans; many very fine and fine pores; many gravel; few very fine roots; clear and wavy on:
45 - 60 cm Bt2	(very) dark (greyish) brown (10 YR 3/2-3) sandy clay loam; moderate coarse prismatic; friable (moist), sticky and plastic(wet); patchy thin clay cutans; many very fine and fine pores; few gravel; no roots; abrupt and smooth on:
60 - 125 cm C	Dark yellowish brown (10 YR 3/4) sandy loam; weak coarse prismatic; very friable (moist), slightly sticky and non plastic (wet); many very fine and fine pores; many gravel; no roots; abrupt and smooth on:
125 - 180 cm 2B	Dark reddish brown (5 YR 2.5/2) clay loam; strong coarse prismatic; friable (moist), sticky and plastic (wet); common slickensides; many fine pores.

B) Laboratory Data

	Depth (cm)				
	0 - 15	15 - 45	45 - 60	60 - 125	125 - 180
Texture (%, mm)					
2-0.05	55	47	49	51	33
0.05-0.002	30	30	28	28	32
0.002	15	23	21	23	35
pH (1:1)					
H_2O	6.4	6.3	5.9	6.1	6.3
KCl	4.5	4.4	4.3	4.1	4.7
Exchangeable cations (me/100 g)					
Na	0.4	0.9	0.4	0.4	0.9
K	0.5	0.3	0.3	0.3	0.3
Organic C (%)	0.8	0.9	1.4	1.1	1.4
Available P_2O_5 (ppm)	6	12	12	10	8

5.19.7.7 Orthic Luvisol (stony phase), Borkena

These soils are found in the hill east of the Borkena plain. The climate is semi-arid warm tropical. The soils are developed in colluvial deposits derived from basaltic rock. The soils are cultivated.

Source: LUPRD

A) Profile description

- Information on the site:

Profile no.:	B55 a, Borkena
Date:	27/6/83
Authors:	Legesse Y., Neizgi A., Fitsum F.
Location:	5 km WNW of Bora, appr. 23 km E of Kemise; 0.2 km W of the Kemise Bora road; 10°43'40"N - 40°64'05"E
Classification FAO:	Orthic Luvisol, stony phase
USDA:	Udic Haplustalf
Physiographic position:	Slope of wide valley in Afar flootdhills
Slope:	2%
Elevation:	1680 m
Vegetation/landuse:	cultivation teff, sorghum and pulses
Climate:	semi-arid warm tropical

- Information on the soil:

Parent material:	colluvial-fluviatile deposits
Drainage:	well drained
Moisture condition	dry to 20 cm, moist below
Rock coutcrop:	none
Evidence of erosion:	gullies up to 5 meters deep

- Profile description:

0 - 15 cm Ap — Dark yellowish brown (10 YR 3/4) moist and brown (10 YR 4-5/3) dry, clay loam; moderate coarse angular blocy; very hard (dry), firm (moist), sticky and plastic (wet); many very fine and fine pores; common very fine and medium roots; clear and smooth on:

15 - 33 cm AB — Dark brown (7.5 YR 3/4) clay loam; strong medium angular blocky; hard (dry), friable (moist), sticky and plastic (wet); broken moderately thick clay cutans (5 YR 3/3-2); many very fine to medium pores; common fine roots; gradual and smooth on

33 - 50 cm Bt1 — (Dark) brown (7.5 YR 4/4) moist and brown (7.5 YR 5/4) dry, clay loam; moderate medium prismatic; hard (dry), friable (moist), sticky and plastic (wet); broken moderately thick cutans; common very fine and fine pores; abrupt and smooth on:

50 - 120 cm Bt2 — (Dark) brown (7.5 YR 4/4) moist and brown (7.5 YR 5/4) dry, clay; strong medium angular blocky; very hard (dry), firm (moist), sticky and plastic (wet); continuous thick clay cutans; common very fine to medium pores; few very fine and fine roots; gradual and wavy on:

120 - 160 cm+ Bt3 — (Dark) brown (7.5 YR 4/4) moist and brown (7.5 YR 5/4) dry, clay loam; moderate medium angular blocky; friable (moist), sticky and slightly plastic (wet); broken thick clay cutans; common very fine and fine pores; no roots.

B) Laboratory data

	Depth (cm)				
	0-15	15-33	33-50	50-120	120-160
Texture (%, mm)					
2-0.05	31	27	31	17	29
0.05-0.002	34	36	38	42	36
0.002	35	37	31	41	35
pH (1:1)					
H_2O	6.7	7.0	7.5	7.6	7.4
KCl	5.5	5.6	6.0	6.1	5.9
Exchangeable cations (me/100 g)					
Na	1.3	0.9	0.9	1.7	2.6
K	0.5	0.5	0.5	1.0	0.5
Organic C (%)	0.3	0.4	0.4	0.3	0.3
Available P_2O_5 (ppm)	6	6	8	12	14

5.20 CAMBISOLS

5.20.1 FAO classification

Cambisols are soils having a cambic B horizon and (unless buried by more than 50 cm or more new material) no diagnostic horizons other than an ochric or an umbric A horizon, a calcic or a gypsic horizon; the cambic B horizon may be lacking when an umbric A horizon is present which is thicker than 25 cm; lacking high salinity; lacking the characteristics diagnostic for Vertisols or Andosols; lacking an aridic moisture regime; lacking hydromorphic properties within 50 cm of the surface.

Eutric Cambisols are Cambisols having an ochric A horizon and a base saturation (by NH_4OAc) of 50 percent or more at least between 20 and 50 cm from the surface but which are not calcareous within this depth; lacking vertic properties; having a cambic B horizon not strong brown to red; lacking ferralic properties in the cambic B horizon; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Dystric Cambisols are Cambisols having an ochric A horizon and a base saturation (by NH_4OAc) of less than 50 percent at least between 20 and 50 cm from the surface; lacking ferralic properties in the cambic B horizon; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Humic Cambisols are Cambisols having an umbric A horizon which is thicker than 25 cm when a cambic B horizon is lacking; lacking vertic properties; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Gleyic Cambisols are Cambisols showing hydromorphic properties below 50 cm but within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Gelic Cambisols are Cambisols having permafrost within 200 cm of the surface.

Calcic Cambisols are Cambisols having an ochric A horizon and showing one or more of the following: a calcic horizon, a gypsic horizon or concentrations of soft powdery lime within 125 cm of the surface; calcareous at least between 20 and 50 cm from the surface; lacking vertic properties; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Chromic Cambisols are Cambisols having an ochric A horizon and a base saturation (by NH_4OAc) of 50 percent or more at least between 20 and 50 cm of the surface but which are not calcareous within the same depth; having a strong brown to red cambic B horizon; lacking ferralic properties in the cambic B horizon; lacking vertic properties; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Vertic Cambisols are Cambisols having an ochric A horizon; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

Ferralic Cambisols are Cambisols having an ochric A horizon and a cambic B horizon with ferralic properties; lacking vertic properties; lacking hydromorphic properties within 100 cm of the surface; lacking permafrost within 200 cm of the surface.

5.20.2 General environment

Cambisols occur wherever conditions are not favourable for other soil processes than weathering to take place. Such conditions are relief, erosion and climate.

In the humid areas in the west of the country and at high altitudes Dystric and Humic Cambisols are found on very steep slopes. They occur mainly in association with Dystric Nitosols and Acrisols.

In the northern highlands Cambisols are widespread in areas where, due to intensive cultivation over several hundreds of years, the soils are eroded. Here Eutric, sometimes Chromic Cambisols are found in colluvial material and on moderate to steep slopes. They occur in association with Lithosols on the steep to very steep slopes and Vertic Luvisols and Vertic Cambisols on the flat land.

In the central highlands Vertic Cambisols are found on some pyroclastic plateaux where stoniness prevents the formation of Vertisols.

In the semi-arid areas of eastern,southeastern and southern Ethiopia Cambisols are found on sloping to moderately steep land. Calcic Cambisols occur in association with Vertisols, Rendzinas and Lithosols in the limestone areas of eastern Ethiopia; Eutric Cambisols in association with Luvisols and Lithosols in southern Ethiopia.

Gleyic Cambisols occur throughout the highlands in depressions

5.20.3 Characteristics

As Cambisols occur under quite variable environmental conditions, their characteristics may vary accordingly. Generally they have a texture of loamy very fine sand or finer in the B horizon,and show evidence of alteration. This alteration can be in the form of oxidation/reduction processes - Gleyic Cambisols- , or can be weathering or some evidence of removal of carbonates. Also soils with a thick umbric A horizon without further diagnostic horizons or properties classify as Humic Cambisols.

Due to their topographical position in Ethiopia, Cambisols are often shallow and stony. On flatter land Cambisols can be deep.

5.20.4 Land use and natural vegetation

As these soils are often chemically rich, although shallow soils, they will be intensively cultivated in areas with a high population pressure. In areas with a moderate to low population, these soils are mainly under natural vegetation, the type of vegetation varying depending the climatic zone they occur in. Land use then will be mainly peasant or nomadic livestock grazing.

5.20.5 Management

The major limitation to agricultural use is their topographical position. As these soils often occur on steep slopes, they are shallow and stony. Intensive cultivation, as in eastern Tigray, aggravates erosion and very little soil is left. In flatter positions they will have a rather high agricultural potential, as these soils are chemically rich soils.

5.20.6 Occurence

Gelic Cambisols do not occur in Ethiopia. Ferralic Cambisols are not reported to exist in Ethiopia. Dystric and Humic Cambisols, lithic and stony phase are found on the steep slopes in the high rainfall areas. Calcic Cambisols are found in the semi-arid limestone areas in Hararge and Bale. They have petrocalcic or lithiphases. Vertic Cambisols, stony phase occur on the flat to sloping areas in the highlands. Gleyic Cambisols can be found in depressions. Eutric and Chromic Cambisols, lithic and stony phase are found in the highlands on steeper slopes.

5.20.7 Profile descriptions

5.20.7.1 Gleyic Cambisol, Dabus

This profile is situated in the west of the country. Rainfall is over 1 000 mm a year. The site is moderately well to poorly drained.

Chemical data are not available for this profile, but several physical test results are given. Especially the surface infilteration rates are very low for this soil.

Source: DABUS

A) Profile description

Profile no.:	K51
Classification FAO:	Gleyic Cambisol
USDA:	Aquic Ustropept
Author	K. Klinkenberg
Date:	14 November 1980
Landform:	Upper to middle slope in gently undulating terrain, slope 1 to 2 percent; slight micro-relief
Vegetation/Landuse:	Open savanna woodland, *Terminalia* spp common

- Profile description:

0-15	Very dark brown (10 YR 3.5/2, dry; 10 YR 2/2, moist) clay; moderate medium subangular blocky structure; consistence dry hard, moist friable; many very fine, fine and medium pores; few to common fine round iron concretions; many very fine and fine and common medium roots; clear and smooth boundary.

15-43 cm	Olive brown (10 YR 5/2.5, dry; 2.5 Y 4/3, moist) clay; common fine distinct strong brown mottles; moderate coarse subangular blocky structure; consistence dry hard, moist friable; thin discontinuous cutans; many very fine and fine and common medium pores; common fine round iron concretions; many very fine and common fine and medium roots; gradual and smooth boundary.
43-76 cm	Dark greyish brown (10 YR 5/3, dry; 10 YR 4/2.5, moist) clay; common fine distinct strong brown mottles; moderate coarse subangular blocky structure; consistence dry (very)hard, moist friable; thin continuous cutans;many very fine, fine and medium pores; few fine round iron concretions; common very fine and fine and few medium roots; gradual and smooth boundary.
76-120 cm	Dark grey (10 YR 4/1, dry and moist) clay; common medium distinct reddish yellow and few fine distinct dark red mottles; moderate to strong very coarse angular blocky structure; consistence dry very hard, moist friable; moderate continuous cutans; common very fine and few fine and medium pores; common fine iron concretions; few very fine and fine roots; gradual and smooth boundary.
120-162 cm	Grey (10 YR 5/1, dry and moist) clay; many medium prominent red mottles; moderate very coarse angular blocky structure; consistence dry very hard, moist friable; moderate continuous cutans; common fine and few very fine and medium pores; many medium soft iron concretions; few very fine and fine roots; gradual and smooth boundary.
162-206 cm	Grey (10 YR 5/1, dry and moist) clay; many medium distinct dark brown mottles; moderate coarse angular blocky structure; consistence dry very hard, moist firm; weakly developed slickensides, thick continuous cutans; common fine and few very fine and medium pores; many medium soft iron concretions; few fine and very fine roots.

Augering in the bottom of the profile showed the same material continuing till a depth of 240 cm, after which the iron concretions become very many. The augering stopped at 300 cm.

B) Tests

- Available water capacity

	Depth (cm)		
	0-23	23-65	65-100
Water retained (%)			
1/3 bar	21.2	21.5	23.0
15 bars	13.9	15.0	16.2
Bulk Density	1.49	1.55	1.63

- Surface infiltration rates (cm/hr)

	Test	
	a	b
Day 1		
IR*	1.7	1.4
HRS*	9	9
Day 2		
IR		1.1
HRS		14

IR = final infiltration for each test day

HRS = cumulative hours of testing

- Hydraulic conductivity (m/day)

	Depth (cm)	
	46-120	144-207
hydraulic conductivity	0.087	0.0053

5.20.7.2 Eutric Cambisol, Tigray

These soils are found on slightly sloping land, with parent material derived from acid igneous rocks. These soils are intensively cultivated.

Source: TIGRAI

Yemad series: Moderately deep to deep, well drained brown profiles with gritty sandy day loam textures.

A) General

- Environmental Characteristics: The series occupies much of the arable land within the undulating terrain. It is formed on stratified alluvium and colluvium derived from acid igneous granite and diorite, and locally from basement metavolcanics. There is a very sharp contrast between bare rock outcrops of the granite tors and the cultivated Yemad soils. In valley centres, where the Yemad series alluvium overlies a finer textured, poorly drained and weathered granite subsoil the land is reserved for grazing but gullies are developing on these sites. Locally, the valley centres are irrigated for maize, but the main arable use is for teff, barley, wheat and finger millet.

- Profile Characteristics: The Yemad soils are moderately deep to deep, with up to 150 cm depth in valley centres. The plough layer is typically a coarse textured sandy loam or loamy coarse sand 10-15 cm thick, with a weak subangular blocky structure and dark brown colours (10 YR 3/3 and 4/3 to 7.5 YR 4/3). The subsoil is a heavier textured medium to coarse sandy clay loam with moderate angular blocky structure and dark brown colours (10 YR 3/3 and 3/2.5, 7.5 YR 4/2). On the valley sides this passes into weathered granite at about one metre, but in the valley centres there often occurs a basal-layer of medium to coarse sandy clay, very dark grey in colour (10 YR 3/1.5), occasionally mottled, derived in situ from granite and an older buried soil. A few roots pass down into the very dark grey sandy clay layers.

- Analytical Characteristics: The soils are slightly acid and have medium to very high base saturation, dominated by Calcium. Total Potassium is high, probably due to Mica derived from the Granite. The C/N ratio is higher in the subsoil, reflecting the older buried soils. Available Phosphorous is higher in the subsoil and the CEC clay suggests Montmorillorite in subsoil.

- Land Capability Characteristics; The soils occur on slopes of less than 5 percent and have coarse textured topsoil over medium textured subsoils,

- Associated Series: Yemad soils lie downslope of coarser textured soils which are freely draining and are probably derived mainly from diorite colluvium.

B) Profile description

- Information on the site:

Profile no.:	PG/1
Soil name:	Yemad Series
Classification FAO:	Eutric Cambisol
Date:	29 April 1975
Author:	R.N. Munro
Location:	5 km NW of Negash village, Tigray 13°58'40"N-39°34'10"E
Elevation:	2 375 m
Physiographic position:	plateau with concentrically orientated valleys and rocky ridges
Surrounding landform:	weakly undulating valley floor
Microtopography:	smooth, low cultivation terraces
Slope:	3%, SW
Landuse:	cultivation of cereals
Vegetation:	occasional _Rumex nervasus_ bushes; _Euphorbia abyssinica_ and _Tarconanthus_ sp. on adjacent rocky tors
Rainfall:	about 550 mm

- Information on the soil:

Parent material:	colluvial and alluvial material derived from acid igneous rocks
Drainage-profile:	well drained
Drainage-site:	no restriction
Moisture condition:	moist below 15 cm
Flood hazard:	none
Depth of groundwater:	not encountered
Surface condition:	few rounded granite stones; sandy surface
Evidence of erosion:	moderate rilling locally

- Profile description:

A deep well drained brown colluvial soil with medium textures and a high quartz grit content in the upper profile. The subsoil has a heavy sandy clay loam texture and overlies a very dark grey sandy clay at 122 cm which probably represents a buried alluvial Vertisol. The upper profile is porous and moderately well structured. Roots extend to the base of the profile but are commonest in the upper 15 cm. The upper 100 cm is characteristic of the series.

0-14 cm	Dark brown (10 YR 3/3) medium sandy loam; weak fine subangular blocky structure, soft dry; many fine and medium roots; porous; abrupt smooth boundary.
14-70 cm	Dark brown (10 YR 3/3)gritty sandy clay loam; moderate fine to medium angular blocky, firm slightly moist; porous; many mica flakes, few fine roots; clear smooth boundary.
70-122 cm	Very dark greyish brown (10 YR 3/2.5) heavy gritty sandy clay loam; moderate medium angular blocky, friable moist; few granite stones, much mica; very few fine roots; clear smooth boundary.
122-144 cm	Very dark grey (0 YR 4/1.5) sandy clay; moderate coarse angular blocky, very firm moist to plastic wet;few granite stones and gravels; very few fine roots along cracks.

C) Laboratory data

	Depth (cm)			
	0-10	10-30	30-50	122-144
Texture (%,mm)				
2-0.2	11	11	13	7
0.2-0.02	42	49	50	21
0.02-0.05	13	11	7	10
0.05-0.002	26	15	11	32
0.002	8	14	19	30
pH	6.4	6.4	6.5	7.0
EC (sat.ex.mmhos/cm)	m	m	m	0.1
Exchangeable cations (me/100g)				
Ca	5.2	5.7	6.6	16.7
Mg	1.2	0.9	1.4	4.0
Na	0.0	0.0	0.0	0.1
K	0.2	0.2	0.2	0.3
CEC (me/100g)	12.5	9.6	13.1	22.2
Organic C (%)	0.6	0.5	m	0.7
Total N (%)	0.10	0.10	m	0.10
Available K (ppm)	246	406	m	562
Available P (ppm)	6.5	11.0	m	0.8

	Depth (cm)			
	0-10	10-30	30-50	122-144
Soluble (ppm)				
Cu	5.2	5.7	6.6	16.7
Mg	1.2	0.9	1.4	4.0
Na	0.0	0.0	0.0	0.1
K	0.2	0.2	0.2	0.3
CEC (me/100g)	12.5	9.6	13.1	22.2
Organic C (%)	0.6	0.5	m	0.7
Total N (%)	0.10	0.10	m	0.10
Available K (ppm)	246	406	m	562
Available P (ppm)	6.5	11.0	m	0.8
Soluble (ppm)				
Cu	0.6	0.6	0.2	2.2
Zn	0.6	0.6	0.2	3.0
Mn	8.8	43	82	49
Total (ppm)				
Cu	3	5	9	33
Zn	3	3	4	103
Mn	m	m	m	530

D) Estimates of Soil Erodiability Index -K

Texture	SL
Index of erod-ibility a	0.250
b	0.17
Organic matter	low
Silt + very fine sand	moderate
Medium sand	high
Weak structure but permeable	

5.20.7.3 Vertic Cambisol, Tigray

These soils are found around the partly drained sites on the undulating plateau around Hausien. The soils are intensily cultivated

Source: TIGRAI