VARIATIONS IN SOILS AND THEIR MINERALOGY IN THE KULUBI AREA, HARAR, ETHIOPIA

A Thesis
Presented to
The School of Graduate Studies
of
Addis Ababa University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Geology

by
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July 1981

Abstract

The geology, geomorphology and soils of the Kulubi area, in eastern Ethiopia, are described.

The succession of rocks in the region comprises Precambrian rocks consisting of gneisses, granites, and migmatites overlain by a trachyte flow; Lower Sandstone Unit (Triassic to Lower Jurassic) consisting of a lower arenaceous and an upper calcareous sub-units; Limestone Unit (Lower Jurassic to Middle-Cretaceous) consisting of sandy and fossiliferous carbonate rocks; Upper Sandstone Unit (Middle Cretaceous) consisting of a cross-bedded, parallel-bedded, calcareous, and massive and laminated sub-units with Mesozoic volcanic intercalations; Tertiary basalts and Quaternary sediments.

The three stages in the geomorphological evolution of the area include a Late Cretaceous-early Cenozoic peneplatation; Trappean tectonics and formation of basin-plains; and renewed erosion associated with the rift tectonics.

The major soils in the region are Vertisols, Entisols, and Mollisols.

The Vertisols occupy depressions in alluvial plains and scattered spots on the uplands and are developed on basalt and alluvium. They are deep, clayey soils with low chromas and values. Chemically, they are very slightly alkaline, very low to medium in organic matter, low in total nitrogen, and very low to low in phosphorous. These are the least productive soils.

The Entisols occur on alluvium and on steep slopes of basalts, sandstones and gneisses.

They are dark grayish and reddish brown, shallow and discontinuous, loamy soils. They are slightly acid to very slightly alkaline, low to medium in organic matter and total nitrogen, and medium to high in phosphorous. Their occurrence on either actively eroding or flooding surfaces significantly reduces their agricultural productivity.

The Mollisols are the dominant soils occupying flat to gentle slopes on all theparent materials excepting the basalt. These are brownish-black and reddish-brown, shallow to deep, clay, clay loam, and sandy clay loam soils. They are strongly acid to slightly alkaline. The organic matter and available phosphorous contents differ widely. They have a low to medium total nitrogen. These are the most productive soils.

Comparison of these soils in terms of their textures, pHs, and organic-matter contents indicates that topography is the main soil-forming factor controlling the morphological, physical, and chemical properties of these soils.

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Acknowledgements

I would like to express my deep gratitude to my advisors Dr. Ludovico Branccacio and Dr. Aldo Cinque (Istituto Di Geologia E Geofisica, Napoli) for their constant guidance and assistance both in the field and laboratory works.

I gratefully appreciate the enthusiastic help given to me by the following persons from the land use planning and regulatory Department of the Ministry of Agriculture: Mr. Barry Henrickson, Miss Sussan Ross, Ato Berhanu Debele, Dr. Victor Odenyo and Ato Abebe Hailemariam.

My acknowledgement also goes to Dr. G.N. Saxena, for identifying fossils, Dr. Getaneh Assefa, for his help in organizing the manuscript and to Wzt. Aster Gebremariam for typing it.

Finally, I am highly indebted to the Swedish Agency for Research Cooperation with developing Countries (SAREC) which has given the financial assistance for this study.

1.1 Introduction

1.1.A Objective

The study of soils has a vast importance in agriculture. While this idea may have probably dwelt in the minds of many individuals and organizations, particularly little Pedological work has been done in Ethiopia. This has resulted not only in a loss of the agricultural productivity of the country but also the soil itself. Improper management of the soil has resulted in an extensive erosion of agricultural land, so extensive that the finding of solution to this urgent problem has become a top governmental priority.

The present study was undertaken in the light of the scantiness of soil studies made so far, with the view to characterizing the soils in terms of their morphological and chemical properties, in order to determine their productivity and to understand their genesis so as to provide a basis for prediction of soil types in the region for future works.

B Location

This study was undertaken in the Kulubi area, located in Harrarghe adminstrative region, 455 km east of Addis Ababa. The study arealies between longitudes 41°35'30" and 41°49'10" E and latitudes 9°20' and 9°30' N.

This area is well suited for such a study because of its physiographic position, marking the transition between the plateau and the rift, and its geological history which has resulted in the emplacement of different rock units.

C Physiography

The Ahmar mountains, the chain of highlands that runs east-west along the margin of the eastern plateau and the southern afar, have been classified into two distinct physiographic units, the Harrarghe highlands and the Chercher highlands (Tamirie 1974b). The Harrarghe highlands which include the studied area are characterised by a mean annual rainfall of less than or equal to 850 mm and a natural forest of Juniperus procera. The Chercher highlands have a mean annual rainfall of greater than or equal to 900 mm with a forest dominated by Podocarpus gracilior.

Topographically the area presently studied is highly rugged. North of the main Addis Ababa (A.A) - Dire Dawa (D.D.) road the area is entirely one of very steep valley and hilside slopes that lead to narrow sandy valleys. The divides and hilltops are characterized by undulating surfaces that stand tens of meters above the valley floors. South of the above mentioned road the area is characterized by smooth to gently undulating surfaces bounded by gentle to steep slopes and occasionally cliffs upto and over one hundred meters high. At the foot of these are found broad alluviated plains.

D Climate:

Climatic data gathered over a period of seven years (1960-67) for Alemaya and Kersa which are in the vicinity of the studied area, indicate a mean annual rainfall of 850 mm with an absolute minimum of 560 mm and an absolute maximum of 1260 mm. The rainy season extends from March to september, with over 60 mm monthly rainfall. Rainfall distribution is very erratic with two apparent peaks: a very irregular small rainfall during February, March, April & May and a regular maximum rainfall peak from July to September (Tamiria, 1974b).

The average yearly maximum temperature is 15.8°C. The average yearly minimum temperature is 7.8°C with an extreme minimum of -4°C, while the average yearly maximum temperature is 22.9°C with an extreme maximum value of 28°C.

E Vegetation

A distinction in the vegetal association of the study area may be made between parts of the area that lie to the north and south of the main A.A. - D.D. road respectively.

To the north of this road, that coincides with the escarpment and is low-lying, the vegetal association includes abundant _Acacia_ sp. and _Carrisa edulis_. On the plateau are found _Juniperus procera_ (dominant), _Podocarpus gracilior_, _Euphorbia_ sp. (typically found on the limestones), _Maytenus ovanus_, and _Croton macrostachys_. _Olea africanais_ appears occassionally.

Maize and sorghum are the dominant food crops grown by the farmers. Chat is the most important cash-crop. Barley, ground-nut, sugar-beet, and some other vegetables like potato, onions and green pepper are also grown.

1.2 Previous Works

The description, fertility status, and management practices on the soils of this region are given by Admassu and Tamire (1974), by Ayele and Tamire (1974) and by Tamire (1974a, 1974b, 1975). In addition to these works those of Murphy (1968) and of Gentry (1963) are also important.

The overall account of the geology of the area is given by Mohr (1971). An account of the lithology, structure, and age of the basement rocks of the region is given by Kazmin (1975a). The Mesozoic sediments of the Harar and Dire-Dawa area have been studied by Greitzer (1970). The only study on the volcanics of the Kulubi area is that of Canuti *et* al (1971).

A number of studies made on the structural evolution of the Afar depression signficantly contribute to the understanding of the structure of the study area. These include the works of Black et al (1972), Juch (1975) and Morton and Black (1975).

The hydrogeology of the area is given by Greitzer (1970) and Tesfamichael (1974).

1.3 Materials and Methods

A survey of the geology and geomorphology of the area was made in order to determine the effect of these on soil properties.

As topographic maps at the required scale are not available for the study area field mapping of the lithological units was made on a base map prepared from aerial photographs, at the scale of 1:50,000. The topo-sheets available for the area are at the scale of 1:250,000. After having delineated the boundaries of the study area on these, contour lines were transferred to the geological map compiled from aerial photos by employing an opaque projector instrument.

As expected the contours of the topo-sheets did not fit exactly with the geological features mapped. The necessary corrections were made with reference to natural and man-made features common to both.

Similar procedures were followed in preparing the geomorphological map. In transferring the topo-sheet contours to the geomorphological map prepared from aerial photos certain details of small significance were generalized, like some limestone remnants that were included in foot-slopes. It was essential to transfer contour lines to both maps because of the high distortion inherent in the aerial photos and unavoidable distortion arising from overlapping of these for final compilation.

On the other hand, the soil map was prepared on the basis of the observed occurrences of the soils in field, as related to parent material vegetation and topography.

Wentworth's (1922) grade scale, Ingram's (1954) terminology of beds, and Folk's (1968) classification of rocks are followed in this thesis.

Field description of the soils was based on the FAO (1977) guidlines for soil descriptions. Selection of sampling sites was made on the basis of observed variations in topography and parent material. Soil color was described using the Munsell soil color chart (1975).

Chemical analysis of these soils was carried out in the soils laboratory of the Land Use Planning and Regulatory Department of the Ministry of Agriculture.

pH was determined by the electrometric method. Determinations of Organic matter, total nitrogen and available phosphorous were made respectively by the Walkley - Black, Kjeldahl and Olsen's methods. Available potassium was determined by precipitation as cobaltnitrite and evaluated by the colorimetric method, and exchangeable calcium and magnesium by the versante method after the soils have been extracted with ammonium acetate. Sodium was determined by flame photometer utilizing neutral ammonium extract. All these methods have been described by Jackson (1973). The descriptive terms applied to the values determined by these methods are those of Murphy (1968).

The mineralogy of the fine and very fine sand fractions of the soils were studied under the petrographic microscope. Thinsections were prepared both for total mineralogical analysis and heavy mineral concentrates. The soil mineralogical data shown in tables 4-5 and 4-6 should be regarded as more qualitative rather than quantitative data. This is due to the fact that some grains were always lost, probably depending on their shape and hardness, during the final preparation of the thin-sections:

The interpretation of the clay spectra obtained by the Perkin-Elmer, Infra-red spectrophotometer was made by comparison with atlas of spectra provided by Kommissionfur Spektroskopie (1966) and Van der Marel and Beutlespacher (1976).

2. GEOLOGY

2.1 Regional Stratigraphy

On the basis of the works of Gretizer (1970), Kazmin (1975 a), and Morton and Black (1975) the regional stratigraphic succession comprises the following:-

Alluvium Alkali olivine basalt	Holocene
Flood basalts Rhyolites	Pliocene - Pleistocene
Trap basalts	Eocene - Oligocene
Upper Sandstone * - massive and laminated arenaceous sub-unit - calceareous sub-unit - parallel-bedded arenaceous sub-unit - cross-bedded arenaceous sub-unit	Cretaceous
Limestone	Bajocian - Oxfordian
Lower Sandstone * - Calcareous sub-unit - Arenaceous sub-unit	Triassic - Lower Jurassic
Lower Complex	Archean

* Author's addition

In addition a discussion on the Mesozoic sedimentary sequence of the Ogaden region which differs markedly to that of this region is offered by Barnes (1976) and the Paleozoic sediments in the Ahmar mountains are described by Kazmin (1975 b).

2.2 Stratigraphy of the Study Area

The stratigraphy of the area given here is based on lithological units differentiated and mapped in the field. Eight lithological units were recognized and are described below.

2.2.1 Unit 1. Precambrian

The Precambrian rocks cover the northeastern part of the study area but are poorly exposed so the relationships between the various types of gneisses and any large-scale structural element that may be present remain obscrue. Stream courses running north-south afford but only the exposure of a single and the dominant lithotype of this unit which is a medium-grained feldspathic gneiss. A less commoner gneiss also outcropping along these stream sections is a quartzo-feldspathic gneiss in which mica flakes are neither large enough nor sufficiently abundant to produce a strong foliation in hand specimen. Isolated and unfoliated granite bodies also appear sporadically.

Sections exposed by road-cuts which extend east-west expose various high-grade gneisses comprising banded biotite-gneiss and migmatites. These occur along the main road A.A. - D.D. near the eastern flank of the studied area.

The predominantly exposed medium-grained feldspathic-gneiss does not have any other feature worth describing excepting that it bears occasional xenoliths of now highly weathered and friable amphibolite material. These are highly localized and not frequent either.

A distinct compositional banding is observed in the biotite-gneiss, comprising alternating bands of biotite and very coarse-grained feldspar and quartz. These segregational bands are involved in a tight isoclinal folding along a north-south fold-axis. Of the migmatite rocks, it is interesting to note that they occur in proximity to the banded biotite-gneiss suggesting that both may have resulted contemporaneously from the same agency.

The petrographic study of two thin-sections of the feldspathic-gneiss show that it is medium-grained, inequigranular, composed of 75% feldspar, 15% quartz, 5% biotite, 4% magnetite and hematite and 1% zircon and rutile.

The feldspars present are microcline, orthoclase and albite. The latter has been largely altered to secrictie mica.

A single thin-section studied indicates that the quartzo-feldspathic gneiss is coarse-grained, inequigranaular, being composed of 55% albite and microcline, 30% quartz and 15% biotite. Zircon, sphene, apatite, and chlorite occur in trace amounts. Quartz grains show graphic texture.

According to Kazmin (1975a) the Precambrian rocks exposed in this area form part of the lower complex and are of Archean age.

2.2.2 Unit 2. Trachyte

A single but continuous outcrop of this unit is found at the eastern flank of the mapped area a few hundred meters south of the main A.A. - D.D. road. This flow appears to have been abruptly truncated to the west where the Precambrian rocks outcrop a few meters beyond a high-standing cliff of this unit. The extent of this unit in the other geographic directions is not apparent although the presence of similar flows to the east of the area under consideration has been noted by Bonardi (letter commun.). Streams running to the south have exposed this flow until a point where a fault contact has truncated it, downthrowing the overlying Mesozoic rocks. A similar relationship to this is observed on the northern side. The trachyte flow does not apparently extend over a significant area as the Mesozoic sedimentary rocks are observed directly resting on the basement.

The lower portion of this unit still occurs as a continuous flow while at the top it occurs in large sized patchy blocks. In outcrop it is intensively jointed, by both vertical and horizontal joints. Along the horizontal joints well-developed horizontally oriented slickensides are frequently encountered.

In hand specimen the trachyte rocks are light-colored, phaneritic, dense and compact with abundant black spots that are easily visible.

Petrographically the rocks are porphyritic, euhedral crystals of coarse alkali feldsaprs being embedded in a fine groundmass of alkali feldspars, pyroxenes, and amphiboles. The fedlspars show flow texture. Opaque minerals are also found.

Anorthoclase is the alkali feldspar present and constitutes 85% of the total composition of the rocks. Aeigrine grains constitute 5%, barkevikite 2% and hematite 8%.

The phenocrysts show strain effects such as wavy extinction and in some cases a complete breakdown of a single grain into two.

2.2.3 Unit 3. Lower Sandstone

A. Thickness and Distribution

This unit ranges in thickness from 10 to 55 m. The unit outcrops in the eastern part of the study area and continues farther to the east of the mapped area. To the west it is covered by younger sedimentary rocks, and its outcrops are restricted to the far northern edge of the study area.

B. Lithology

At the eastern flank of the mapped area, in a section exposed along the main road A.A. - D.D. , two subunits can be distinguished.

The lower sub-unit, unconformabily resting on the Precambrian rocks, has a thickness of 7 m. The sandstone immediately overlying the Precambrian rocks is light-yellowish in color, very coarse-grained and massive. This is followed upwards by a white colored, coarse-grained and thinly laminated sandstone which in turn is ovelain by a dark red, medium grained, cross-bedded sandstone, capped at the top by variegated shale upto 1 m thick. This same succession just described repeats itself twice, each time with a shale intercalation in between.

The top of the lower sub-unit is marked by the appearance of a thick (1 m) mud, that increases in thickness to the east. This mud fills fractures in the upper portion of this sub-unit.

Sedimentary structures observed in this sub-unit also include dessication cracks on the cross-bedded sandstone and sole marks on the shale intercalations.

The upper sub-unit has a thickness of 48 m. This sub-unit is calcareous and thickly bedded, with a lower portion of a red colored, fine-grained sandstone and yellowish limestone with fossil fragments. The middle succession is marked by the presence of a series of limestone beds with fine-sand laminations. At the top a white colored oolitic limestone appears above which a highly weathered, pebbly and massive sandstone occurs. The contact between the Lower Sandstone Unit and the overlying Limestone Unit is drawn above the latter bed.

C. Petrography

A total of thirteen thin-sections were studied for this unit. Out of these, the petrographic data for eight representative samples are listed in Table 2-1. Sample numbers S-2, S-3, and S-5-10 are representative samples of the lower sub-unit taken from bottom to top in the order listed. The rest of the samples studied are for the upper sub-unit with the same order of listing as for the lower sub-unit samples.

The thin-section study indicates that S-2 is silica cemented, probably by authigenic quartz, and the grains apparently constitute the whole rock mass. Sample 3 is composed of 10% iron oxide cement, 15% microcrystalline quartz matrix, and 75% of grains, while S-5-10 has 20% calcite cement, 20% microcrystalline quartz matrix and 60% grains.

In all the samples studied the grain shape is variable. This is marked by the presence of mostly angular to subangular, a few subrounded to rounded, elongated and irregular grains of quartz.

The surfaces of the quartz grains present are occasionally frosted, but otherwise are polished. Some of the quartzs also show strong undulose extincition and micaceous inclusions.

The feldspars usually occur as angular fragments. The feldspar present is dominantly fresh microcline, and subordinate plagioclase feldspars of albitle-oligoclase composition.

Table 2-1 Petrographic Data of the Lower Sandstone Unit.

Sub-unit	Sample no.	*Composition %														Rock clan
		Quartz	Feldspar	Rock fragment	Mica	Amphibole	Zircon	Iron-oxide	Intraclast	Oolite	Fossil	Pellet	Micrite	Sparite		
1	S-2	96	4													Quartzarenite
	S-3	84	9	1	4		1	1								Subarkose
	S-5-10	80	7		0.5	0.5	2	10								Subarkose
2	S-14	50	4				5	1					25	15		Subarkose
	S-18	23	1		1						5		70			Sandy fossil bearing Micrite
	S-12												20	80		Dismicrite
	S-1	32								57	1		2	8		Sandy Oosparite
	S-4	8								72			2	18		Sand bearing Oosparite

* The percent composition of the sandstones is only for the grains. For the limestone rocks the composition is for the whole rock mass.

Only in sample S-2 did occur some weathered feldspars.

In S-2 the rock fragment present is chert. In S-3 the exact nature could not be identified. The rock fragments in this sample are well rounded.

In most cases the mica present is muscovite which is distinctly bent. Biotite occurs in trace amounts. In sample S-3 chlorite was also observed.

The amphiboles present have been identified as hornblende and barkevikite. Most of the zircons occur in euhedral to subhedral grains, while a few are irregular.

The sand grains that are found in the calcareous sub-unit are all angular with a size range of 0.2 - 0.5 mm. The fossils present could not be identified on account of their fragmental nature.

2.2.4 Unit 4. Limestone

A. Thickness and Distribution

The Limestone Unit varies in thickness from 20-400m. In the eastern part of the mapped area the rocks of this unit mainly outcrop as isolated low-lying hills. To the west the exposures of the Limestone Unit owe their origin to faulting. Thus the rocks of this unit occupy fault scarps and generally hillslopes. The occurrences to this unit as depicted in map 1 are best explained by originally starting with a fault scarp along which limestones are exposed vertically. These are subsequently exposed in the upstream direction following the regressive erosion that advances headward on account of the new gradient created by faulting.ir

B. Lithology

This unit has a gradational contact with both the underlying and overlying sandstone units.

The portion of this unit immediately overlying the Lower Sandstone Unit comprises a lowermost horizon of white, sandy, fossiliferous and yellowish limestones with ripple marks and worm tracks.

Upwards in this succession appear, alternating beds of light gray limestone with abundant intraclasts, macro- and micro-fossils with a dark gray, fossiliferous limestone that becomes dominant near the top. The intraclasts showed a decrease in abundance and size from the bottom to the top of each bed.

The succession overlying the above mentioned alternating beds of limestone is a thickly bedded white and compact limestone that is replaced by beds of light yellowish, and white fossiliferous limestone with siliceous concretions at the top.

C. Petrography

Out of eleven thin-sections studied under the microscope, the petrographic characteristics of eight samples are given in table 2-2.

Samples K-1, K-2 and K-8 were obtained from the alternating layers of light and dark gray limestones, and the

YTable 2-2 Petrographic data of the Limestone Unit

Sample no.	Allochems				Others		Orthochems			Rock clan Rock clan
	Intra-clasts	Oolite	Fossil	Pellet	Quartz	Feldspar	Micrite	Dolomite	Sparite	
K-1			2				73	25		Coarsely crystalline Dolomicrite
K-2	50		25				10		15	Fossiliferous Intramicsparudite
K-8	10		15				60		15	Intraclast bearing Biomicrudite
3-B			6				80		14	Fossiliferous Micrite
6-B			2				20		78	Biosparite
10-B	5		80		10				5	Sandy intraclast bearing biosparudite
7-B							30		70	Dismicrite
4-B			23		2		60		15	Biomicrudite

rest from the overlying succession. The order of listing is from bottom to top.

In all the samples minute grains of angular quartz were observed and the percentage has been given when they occurred in significant amount.

In the samples obtained from the top of the Limestone Unit replacement veins and stylolites are present.

The fossils present include algae, bryozoa, foraminifera, molluscs and brachiopods.

2.2.5 Unit 5 Lower Basalt

This unit comprises the volcanics of the Mesozoic time which were for the first time studied and described by Canuti et al (1972).

The different basalt flows belonging to this unit are found to the west of Kulubi town and are exposed along the road cuts. In most places these are highly weathered and so it is very difficult to find fresh samples.

According to the above mentioned authors this unit consists of a lower portion of basalts and basalt agglomerates 20 m thick, an intermediate portion of predominantly tuffs and volcanic breccias about 37 m thick, and an uppermost portion of 2-3 m thick basalt flows. The part of the section in figure 1 depicting this unit is based on the above description of Canuti et al (1972). However, the stratigraphic position of this unit as depicted in figure 1-1, is doubtful.

In fact field observations clearly indicate the occurrences of volcanic intercalations at various levels within the Upper Sandstone Unit and not strictly limited between the Limestone Unit and the overlying Upper Sandstone Unit. Examples believed to be representatives of such occurrences as hinted above will be mentioned along with the description of the Upper Sandstone Unit.

As mentioned earlier, outcrops of this unit now visited are all weathered. The few samples that could be obtained show that these outcrops found along the main road A.A. - D.D. comprise various basalt flows that include porphyritic, vesicular aphanitic, and phaneritic types. Furthermore these outcrops are very much limited in extent, being significantly small (5 - 15 m) in the east-west direction which coincides with the strike direction of the sedimentary unit in which these flows occur. This occurrence is much like the Trappean dykes that are frequent and as extensive as the former, that the latter could easily be mistaken as flows.

Because of the above mentioned reasons more time and special attention is needed to initially differentiate between the Trappean dykes and Mesozoic flows and then to determine the stratigraphic levels at which the latter occur. It is emphasized here that the mere presence of sandstone dykes on top of the basalts and sandstone blocks embedded in some of the basalt occurrences in the area (Plate 1B) cannot be taken as exclusive evidences respectively indicating

Plate 1A Mesozoic Volcanic intercalation
Found at 1 km west of Kulubi town.

Mesozoic flows and Tertiary dykes. It is for this reason that this author urges the need for more time and special attention.

These flows and breccias are porphyritic alkali olivine basalts being composed of olivine, augite, plagioclase of 33-37% An, and nepheline and zeolites and iron oxides (Canuti et al, 1972). In the thin section of the upper basalt flow now examined, it was observed that serpentinized and chloritized olivine, titanium augite and some plagioclase feldspars occur as phenocrysts in a groundmass constituted by feldspar microlites and iron oxides.

The age of this unit is the same as that of the Upper Sandstone unit given in section 2.3.0.

2.2.6 Unit 6. Upper Sandstone

A. Thickness and Distribution

This unit has a thickness of 255 m. Extensive exposures of this unit are confined to the surrounding of Kulubi town and to the west beyond this town. To the east and north outcrops of this unit are isolated and very insignificant in thickness. Besides being completely absent to the east of Lange town, the outcrops of this unit that extend to this town all belong to the fourth sub-unit that would be described in the paragraphs below.

B. Lithology

Four sub-units have been recognized. The lower sub-unit is observed in a valley found south of the main road A.A.-D.D.

Plate 1B Sandstone blocks embedded in basalt. Only the exposure of the sandstone block at the left corner could serve to identify this basalt as a dyke. The Middle Upper Sandstone coincides with the top of this basalt and could easily but wrongly be taken as a sandstone dyke.

at the western end of the mapped area. A clear contact is observed between this and the underlying Limestone Unit at this place. Here it was observed that shale intercalations (30 cm thick) mark the boundary between the two units. The first of the shale intercalations appears directly above the Limestone Unit whereas the second comes above a sandy fossiliferous limestone. Above this latter intercalation appears a red coloured, medium-grained and uniformly cross-bedded sandstone bed. This lower sub-unit has a thickness of 20 m at the place of observation.

Above this lower sub-unit appears white, greenish, violet and red colored, medium-grained, thickly bedded sandstone with frequent lamination within each bed, and mud intercalations (Plate 1C) between the beds. This sub-unit has a thickness of 20 m and is found exposed along the road sections both to the east and west of Kulubi town.

The third sub-unit comprises a gray colored, sandy and fossiliferous limestone bed with a maximum observed thickness of 15 m. East of Kulubi town outcrops of this unit are characterized by the presence of abundant macrofossils of Nerenia sp. while to the west these are replaced by abundant lamelli branchs (Plate 1D).

The fourth sub-unit represents the bulk of the Upper Sandstone succession. This is a white, yellow, violet and red banded, very coarse-grained, massive and pebbly sandstone at the base. This sub-unit fines upwards with cross-lamina-

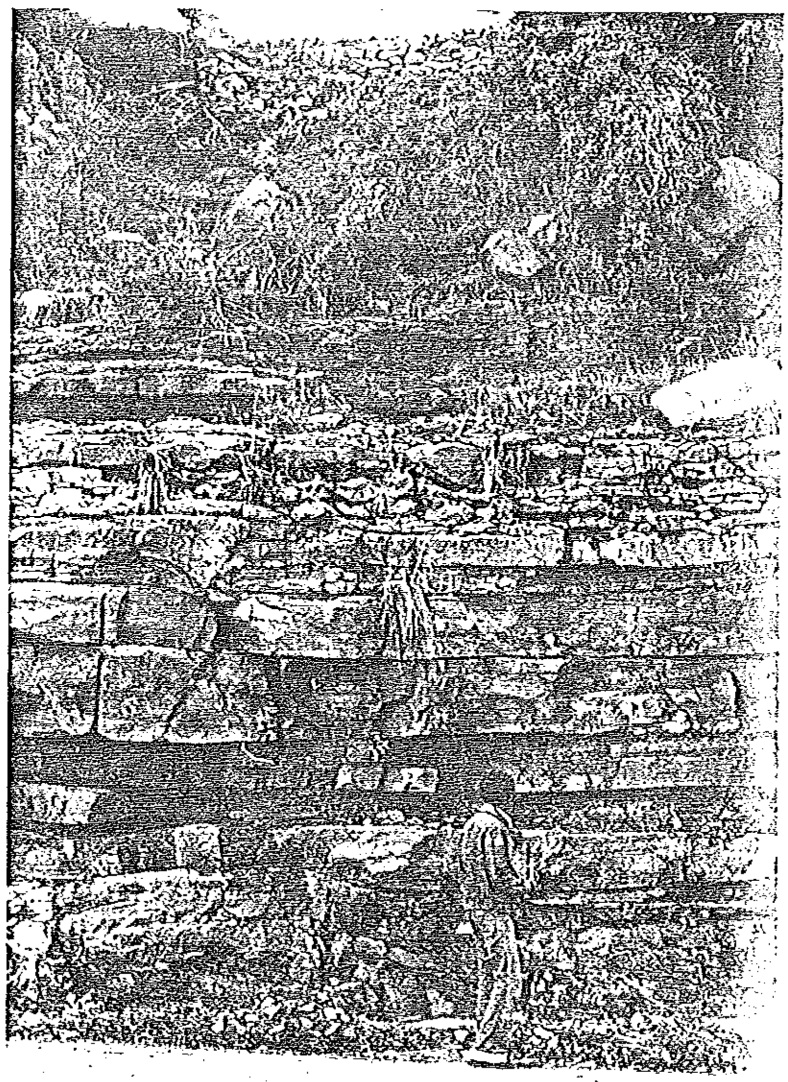


Plate 10 - Thickly bedded Upper Sandstone portion underlying the interbedded fossiliferous Limestone. Note load cast structure.

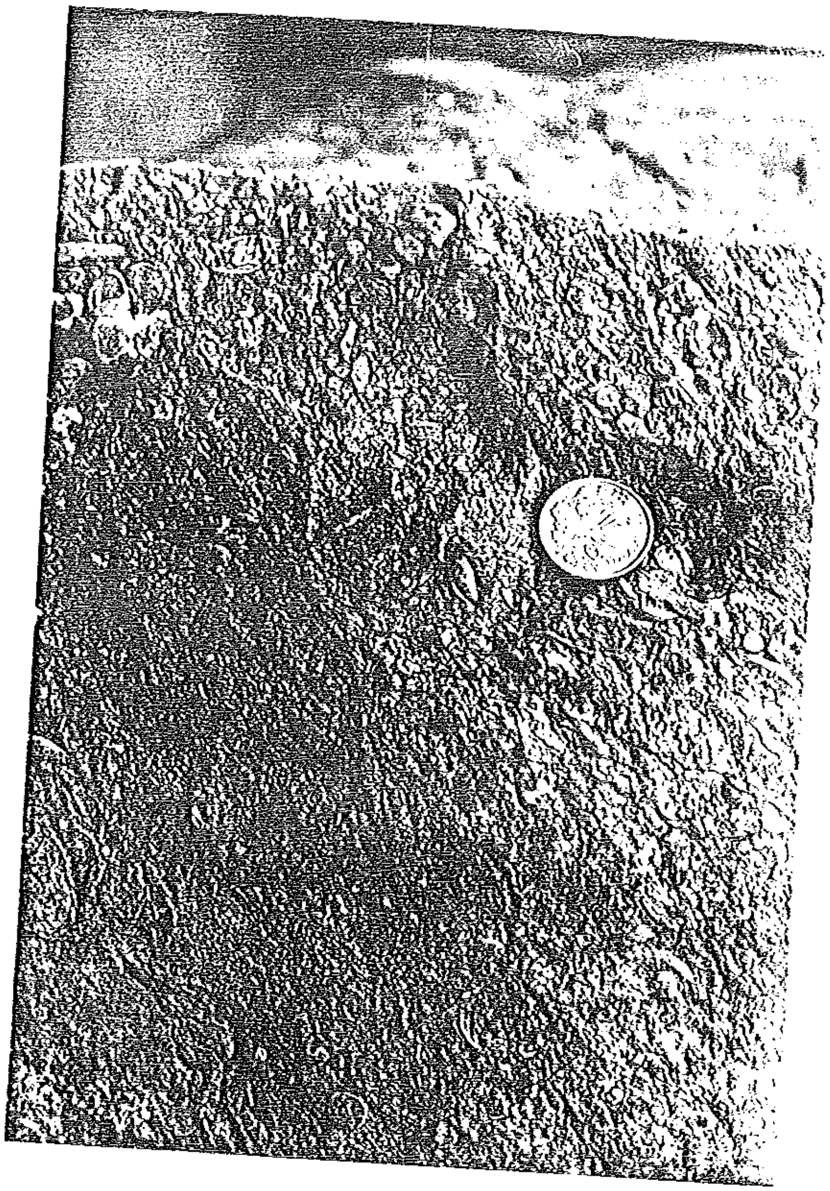


Plate 1D - A closer view of the interbedded fossiliferous Limestone.
The macrofossil assembalge observed here is different from the one observed to the east of Kulubi.

tion towards the top and at the top.

Plate 1B shows a Mesozoic volcanic intercalation 1 km west of Kulubi town. This intercalation at the point of observation occurs immediately below the fourth sub-unit described above. The columnar section given by Canuti <u>et</u> al (1972) confirms this situatuion. Another such occurrence as the type depicted in Plate 1B is found along the main road A.A. - D.D., just at the western flank of the study area, but this time it is restricted to the lowermost sub-unit. This flow is so completely altered that it is no more possible to find any rock. This observation points to the fact that the extrusion of these basalt flows and breccias may not have been a single and continuous process as has been hitherto contended, and also to the need for a better identification of the exact stratigraphic position of this unit.

C. Petrography

The petrographic data of all the samples obtained from the Upper Sandstone Unit areshown in table 2-3. In samples obtained from the lowermost sub-unit are found about 80% grains, 7% sparite and iron oxide cement, and 13% micrite and chert matrix in S - 011, and S - 013 respectively. In S-2-2 and S-2-3, there are found 70% grains, 30% iron oxide cement in the former, and 15% iron oxide cement and 15% chert matrix in the latter.

In samples obtained from the lowermost sub-unit, the quartz grains are highly irregular in shape (rounded to

Table 2-3 Petrographic Data of the Upper Sandstone Unit

Sub-unit	Sample number	Composition %													Rock clan
		Quartz	Feldspar	Rock-fragment	Mica	Amphibole	Zircon	Iron oxide	Intraclast	Oolite	Fossil	Pellet	Micrite	Sparite	
1	S-011	93	5			0.5	1.5								Subarkose
2	S-013	84	4			8	4								Quartzarenite
3	K-5										40		60		Biomicrudite
	K-51	3				1			66		15			15	Fossiliferous Intrasparudite
	K-52												80	20	Dismicrite
4	S-2-2	83	4			13									Quartzarenite
		96		4											Quartzarenite

angular) and the feldspars are all fragmental and mostly fresh, although some grains clearly show alteration to muscovite. In the immediately higher portion of this unit the grains start to show uniformity in shape and bedome dominantly subrounded. Minute crystals of hornblende, and acicular rutile and zircon in quartz are abundant. This same optical characteristic is obtained for the upper succession of this unit. The rock fragments in S-2-3 are chert.

The fossils found in the clacareous interbed include foraminifera, molluscs and brachiopods.

2.2.7 Unit 7. Upper basalt

The various flows grouped under this unit are extensive in the area to the south and west of Kulubi town. East of this town the basalt flows are highly localized. Basalt dykes, with a predominant n-s trend are numerous in the area. but are usually extensive to the west of Kulubi town.

In handspecimen these basalts are dark and compact and include aphanitic and porhyritic types.

In thin-sections these flows are porphyritic and show typical flow textures. They are composed of olivine, that occurs both as phenocryst and in the groundmass, titanium-augite, feldspar laths, and iron oxides all occurring in the groundmass.

These basalt flows are Tertiary in age (Merla et al 1979).

2.2.8 Unit 8. Quaternary Sediments

This unit crmprises sediments accumulated in localized grabens along the margin of the plateau. The lithological description is given in section 3.2.4.

2.2.9 Depositional conditions for the lithological units

The optical characteristics of both the Lower and Upper Sandstone Units are similar, among other things, being marked by constancy of mineralogy, which is taken as an indicator of uniform proveneance in each case: a mixed metamorphic-sedimentary provenance for the Lower Sandstone Unit, and a mixed sedimentary-volcanic for the Upper Sandstone Unit.

The presence of quartz grains that are elongated and that show undulose extinction indicates a metamorphic provenance for the Lower Sandstone Unit, while the chert fragments are indicative of a sedimentary source area for this unit. On the contrary the presence of highly irregular grains of quartz with capillary rutile and zircon indicate a volcanic source area, while chert fragments and rounded quartz grains indicate a sedimentary provenance for the Upper Sandstone Unit.

Further the highly irregular shape of quartz and the fresh and fragmental nature of feldspars observed at the base of these units. imply a rapid transportation over short distances. The fresh nature of the feldspars and ferromagnesian minerals coupled with the long standing stability of the region in the Paleozoic, exclude a humid climate of weathering.

Sub-unit 1 of the Lower Sandstone Unit and Sub-unit 4 of the Upper Sandstone Unit are deposited in a fluviatile environment. This is indicated by the fining-upward of grainsize, by the presence of gravels at the base, and lamination, cross-bedding and dessication cracks at the top. Further the lower sub-unit deposits are cyclic, a feature common to fluvial deposits (Selley, 1976).

The microfacies, micrites, dolomicrites, oosparudites, intrasparudites, biosparudites, and quartzarenites that are erratically arranged, and structures such as lamination, parallel- and cross-bedding indicate an environment of deposition ranging from open marine to shelf for the bulk succession of the sedimentary units found between sub-unit 4 of the Upper Sandstone Unit and sub-unit 1 of the Lower Sandstone Unit.

2.3.0 Age of the Lithological Units

A Triassic to Lower Jurrasic age may be assigned to the Lower Sandstone Unit on the basis of the presence of a similar succession in Harar and Dire-Dawa areas with this same age (Greitzer 1970). The lower age limit of the Limestone Unit is the same as the upper age limit of the underlying unit. A Middle-Cretaceous upper age limit has been assigned to this unit by Canuti et al (1972). This latter age is however doubtful for two reasons. The first reason is that a Middle - Createceous age has been reported by Merla et al

(1979) for a calcareous interbed of the type found in the Upper Sandstone Unit and most probably the same unit as this latter one, in Garamulata region (Map 1) south of Kulubi. The second reason is that in the columnar section given by Canuti et al (1972), the interbedded limestone unit is not indicated. It is worthwhile to add here that the part of the area in which thevolcanic intercalations occur coincide with the maximum observed thickness of this sub-unit. The age of the Upper Sandstone Unit, on the other hand, may conveniently be taken as Aptian - Cenomanian on the basis of age determinations made and reported by Merla et al (1979) on similar units in Garamulata region.

2.4 Tectonics

The tectonics of the area is characterized by changes in the style of deformation from tensional to compressional and back to tensional.

Excluding the tectonic events that have left their marks on the Precambrian rocks and that have been discussed by Kazmin (1975 a) the evidences for tensional displacements consist in the presence of extensive predominantly north-south trending fractures within the Precambrian rocks that have later been intruded by Tertiary basalt dykes, and the well developed slickensides found on the Trachyte flow. This flow itself may have been the resultof tensional tectonics. The thickness of this unit is uniform in the east-west direction and abruptly decreases in the north-south direction. This observation shows that this flow was extruded from an east-west extending fracture.

A shift to the compressional style of deformation is indicated by the presence of an early Mesozoic folding along a north-south axis, such as indicated in plate 1A. This deformation came accompanying the early stages of subsidence of the region as can be deduced from the fact that its effect is restricted to the lowermost bed of the Lower Sandstone Unit.

During and after the sea transgression the tectonic style in the region has remained and still remains to be tensional. The presence of Mesozoic volcanic intercalations that are extensive along north-south directions may be used as indicative of remobilization of Precambrian north-south trending structural elements.

After the emergence of the land and the following peneplanation that is discussed in the geomorphological part of this paper, faults of similar trend as that of early structural elements bounded narrow grabens that subsequently broadened. The displacements associated with these faults measured upto a hundred meteres. This type of faulting was common in Tertiary times. The evidences for this are brought into light in the discussion of the geomorphology of the area.

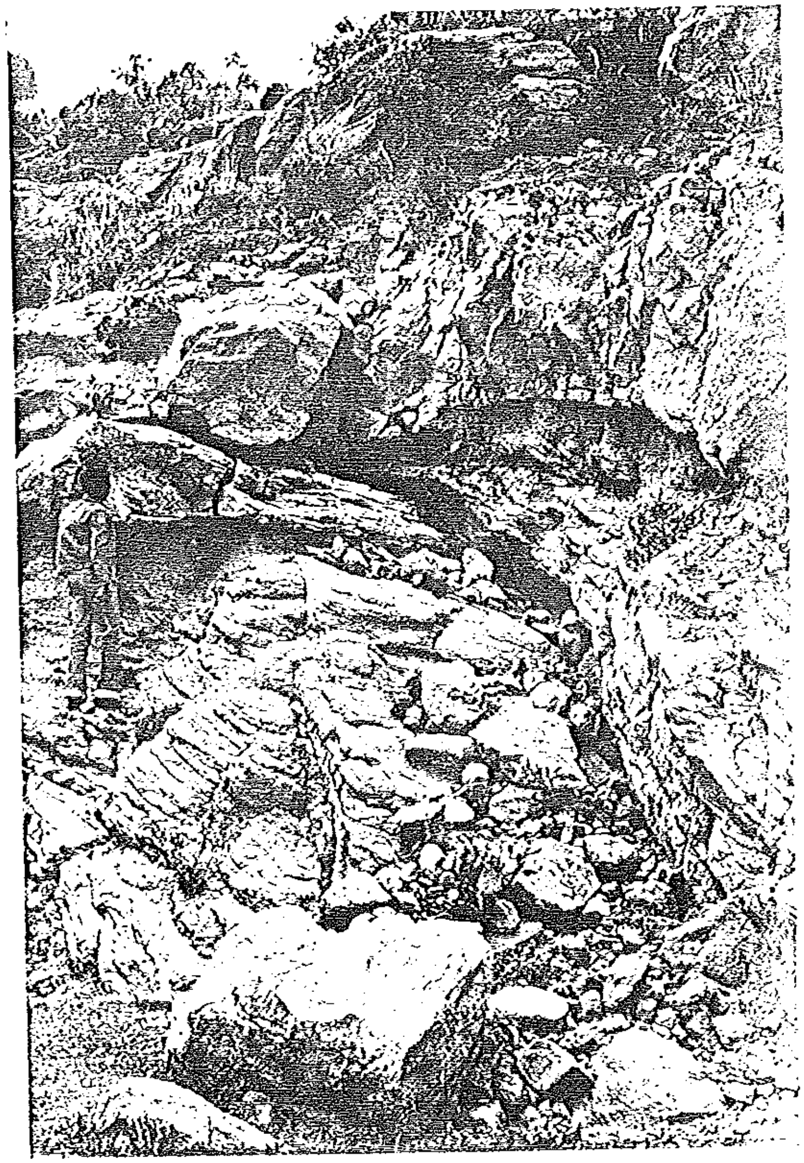


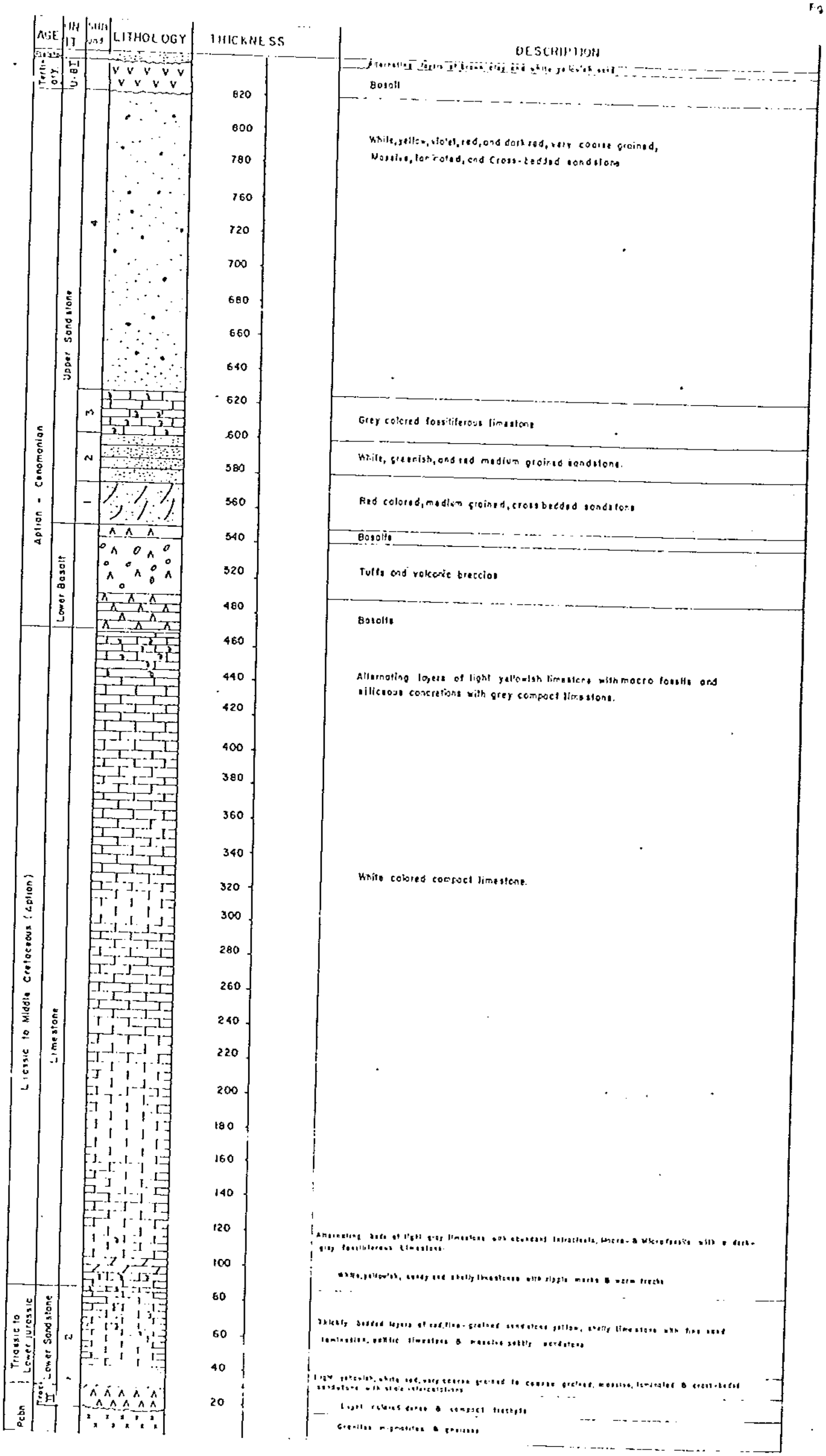
Plate 1E. Reverse faulting affecting the lower sub-unit of the Lower Sandstone and Precambrian rocks.

Following the tectonic event mentioned above faulting became predominant along east-west directions with vertical displacements occasionally exceeding 300 m. A Pliocene- Pleistocene age has been suggested by Kazmin and Seife (1978) for this type of faulting.

Within the last tensional tectonic phase that ensued after the compressional style of deformation, differences in style are suggested by the extensive development of both basalt units to the west of Kulubi town and the change in the dip of sedimentary beds from south to the east of the above mentioned town to the north, west of this town. These differences coincide and in part are explained by the style of déformation indicated to exist in the area by Juch (1975) and Canuti <u>et</u> al (1972). These styles are block faulting to the east of Kulubi town and warping to the west of this town. Ancient Precambrian trends still continue to be remobilized as transverse structures.

STRATIGRAPHIC COLUMN OF THE KULUBI AREA

Fig I-I



T - Upper Basalt

3. GEOMORPHOLOGY

3.1 General

On a regional basis four geomorphological provinces may be recognized:

1) The Plateau
2) The Marginal Highlands
3) The Escarpment
4) The Rift

The studied area lies on the east-west extending chain of highlands known as the Ahmar mountinas (map 2). These mountains rise from a lowermost elevation of 1500 m at the base of the escarpment to a level of 3000 m above sea-level on the plateau.

3.2 Description of Geomorphologic Units

3.2.1 Structural surfaces

One of the characteristic morphological features of the studied area is the existence of flat surfaces at topographic culminations which are generally at 2500 m above sea-level.

These surfaces have their maximum dimensions along the north-south direction, and are bounded by scarps that are connected with low-lying morphologic units by foot-slopes. This latter fact shows that these surfaces are in no way related to the current base-level and that they are remnants of a paleosurface. In fact, field investigations indicate that these surfaces correspond to the established top of the Upper Sandstone Unit, which formed the topmost stratigraphic unit at the time of this phase of the geomorphologic evolution of the area. Associated with these surfaces are found hematite concretions that are probably the only remnants of a paleosol of lateritic origin. These surfaces can now be interpreted as a structural surface, i.e., determined by a geological plane, corresponding to the top of the Upper Sandstone Unit in this case.

The maximum extension of this structural surface along a north-south direction lays the ground for an assumption to be made on the understanding of the manner of its preservation. This direction of maximum extension coincides with the trends of ancient north-south structural elements whose remobilization might have determined the stream courses that initially cut-down their channels upto the prevailing base-level and shifted to lateral planation upon reaching that base-level. Thus this surface is bounded by retreating slopes and its preservation has been possible by the creation of new base-level by the tectonic activity that resulted in the Trappean Volcanism. Evidences for the presence of faulting prior to the onset of the geomorphic processes of this phase are presented in the following section.

As described above, this surface has undergone but only an insignificant amount of erosion so that it can be considered as corresponding to the original topographic surface after the emergence of the land in the late Cretaceous. In parallel to the preservation of this structural surface a morphological surface, that is, an erosional surface was formed and this is described next.

3.2.2 Ancient Erosional Surface

Another characteristic morphological feature of the studied area is the presence of concordant summits usually at elevations of 2300 m and 2000 m above sea-level.

These summits are generally well preserved in the eastern part of the study area and farther to the east out of the mapped area. In the northern part of this area these summits have been intensely faulted and are being fast eroded. Where they are well preserved these summits make smooth and flat surfaces.

These surfaces uniformly form the flat divides of the present-day streams. It is also observed that they are carved on different lithologies which include the lower sub-units of the Upper Sandstone Unit, the Limestone Unit, the Lower Sandstone Unit, and the Precambrian rocks, although all these surfaces are not mappable at this scale. Further, basalt flows uniformly covering these surfaces and the structural surface described in the preceeding section are common.

The above mentioned features of these surfaces indicate that these surfaces correspond to an ancient base-level of erosion that is not more operating. It is not clear whether this base-level was controlled by some regional structural element or by the sea-level.

The interpretation of these isolated surfaces as an ancient erosional surface implies that the occurrence of these surfaces at elevations of 2300 and 2000 m is the result of a post-erosional tectonic episode, while the carving of these surfaces on different lithologic units is a clear evidence for the presence of faulting prior to the onset of this erosional phase.

Detailed field investigations indicate that this surface is predominantly carved on the Limestone Unit and the lower sub-units (1-3) of the Lower Sandstone Unit in the eastern and north-western part of the study area respectively. This fact coupled with the account given in section 2.2.6, on the distribution of the Upper Sandstone Unit, serves to reach the conclusion that the thickness of rock units eroded by this phase of erosion does not very much exceed 200 m which is the thickness of that of sub-unit 4 of the Upper Sandstone Unit. This conclusion is in good agreement with the already mentioned 2300 m elevation of this erosional surface, when considered along with the structural surface that at present stands at

2500 m above sea-level. This fact may be used to consider the erosional surface found at 2300 m elevation as remnant of an ancient topographic surface that has not been significantly displaced by tectonics.

It is true that such an extensive erosion requires a significant period of time. The fact that there are basalt flows covering both the structural and morphological surfaces indicates that these basalts were not affected by this erosion. It means that this erosion happened during the time between the deposition of the Upper Sandstone Unit and the Trappean volcanism. The lower age limit of this erosion is determined by the age of the Upper Sandstone Unit and the upper by the age of the basalts. The available absolute age determinations for the basalts in the region do not exceed 26 m years. (Juch, 1975; Merla et al, 1979).

It is possible then that this erosional phase has occurred over a period of time extending from post - Aptian times to the end of Oligocene. This age limit is in a good agreement with that of the erosional period reported for central Ethiopia where it extended from Lower Createaceous to Oligocene (Merla et al, 1979).

3.2.3 Trappean Tectonics and Basin-Plains

Following the erosional surface, the Morphological features that developed subsequently are all assoicated with intensive tectonism. A series of localised basins bounded

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3.2.3 Trappean Tectonics and Basin-Plains

Following the erosional surface, the Morphological features that developed subsequently are all assoicated with intensive tectonism. A series of localised basins bounded by faults were formed. These faults with northwest southeast trends extend from a few hundred meters to 3-5 kms. The retreating scarps broadend the basins that were originally narrow and also provided the sediments that were acumulated in these basins.

An example of these plains is the Water valley (map 2). The Water valley is an alluviated plain through which is flowing the Water river with some meandering traces related to a very low gradient and alluvial fans derived from the valley sides. Detailed surveying domonstrates that this valley has its origin as a graben that was later filled by sediments.

There are convincing evidences that show the tectonic origin of the valley side slopes. These include the presence of well preserved fault scarps and basalt dykes aligned to the foot of the valley sides.

The occurrence of these dykes is a useful clue to an understanding of the age of these basins. As faults provide the conduits for lava outpouring, it may be said that the formation of these basins in the area coincided with the tectonism that gave way to the Trappean volcanism.

The present-day position of the valley sides does not in general coincide with the fault planes. This is due to the fact that slope recession has occurred to the extent that in some cases like the Lange plain, Paleozoic erosional surfaces are exhumed. The presence of a Paleozoic peneplanation all over Ethiopia has been reported by Merla et al (1979).

The evidences for this phase of Post-trappean geomorphologic evolution are foundall over the highlands. The presence of broad plains occupied by ephemeral lakes at Kersa, Adele and Alemaya that show a certain alignment in a northwest-southeast direction with that of the Lange plain clearly demonstrates that the former are landforms associated with this phase of geomorphological evolution.

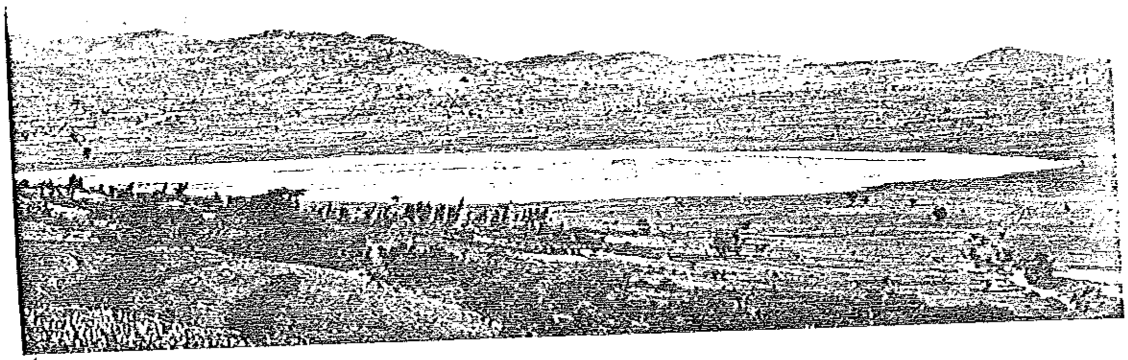
As already mentioned the age of this erosional phase begins with the Trappean volcanism in the Miocene while its landforms still characterise a large part of the plateau bordering the rift.

3.2.4 Rift Tectonics and Current Erosion

The last phase of the geomorphological evolution started with the developmentof extensive east-west trending faults with important desplacements. Whatever the age of these faults may be, it is established that they are associated with a stage or more of rift opening (Juch, 1975 ; Kazmin and Seife , 1978).

The morphological evidences for this new phase of erosion include the presence of suspended land surfaces immediately bordering the rift, like the case of the Kerra and Lange plains that are actively cut by recent regressive stream erosion, the occurrence of narrow valleys of tectonic origin, superaggradation in antecedent streams, and reversal of stream courses on the plateau. These are

A



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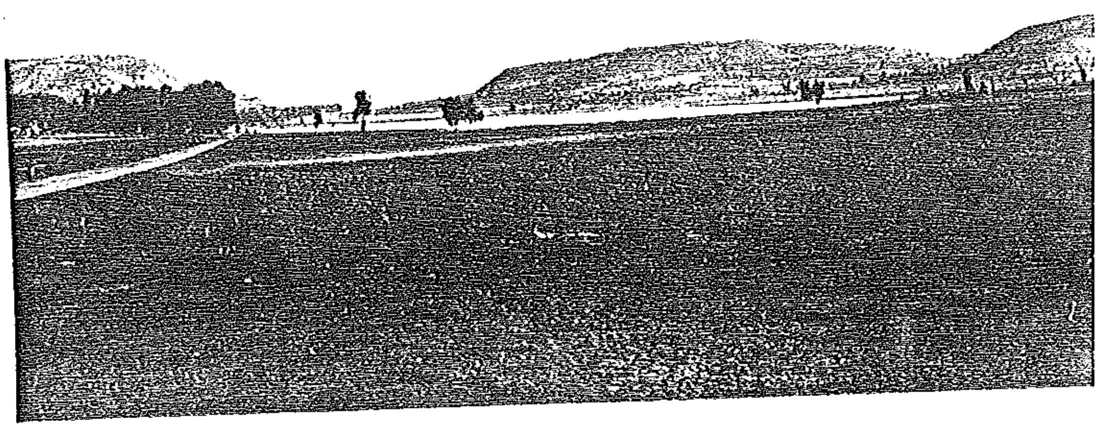


Plate 2A. Land forms of the Post - Trappean phase of Geomorphologic evolution

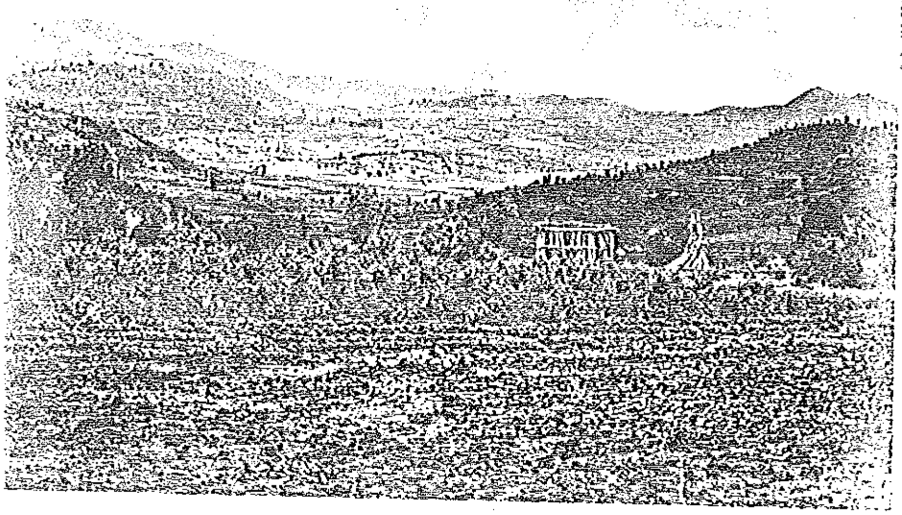
A. Lange plain

B. Adele plain. Note the ephemeral lakes in both cases.

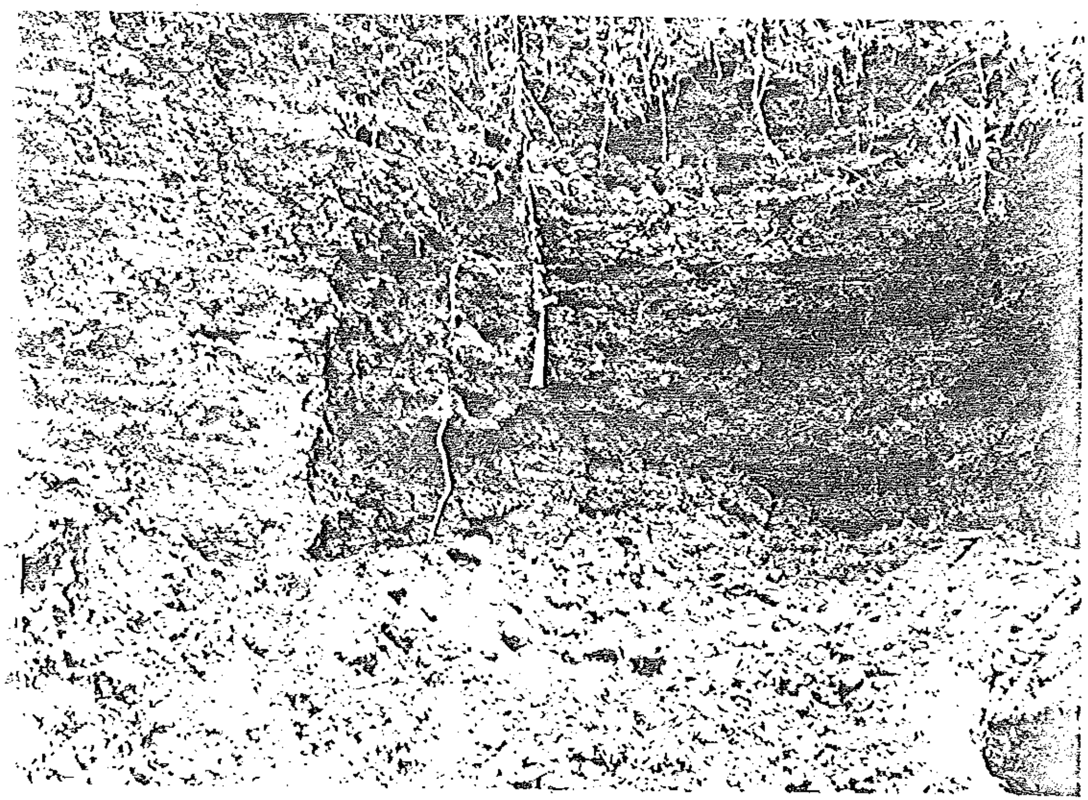
2B. The same as plate 2A, note the remnant Limestone hills shown in figure 3-1. The various stages in the geomorphological evolution are also depicted in figure 3-1.

The succession of the sediments found inthe superaggraded valley has a total thickness of about 13 m. A layer of basalt boulders, cobbles and pebbles with sands is found at the base. Upward, a series of alternating layers of dark gray to brownish colored sand 25-30 cm. thick, that show cross lamination., convolute and gradded bedding and large channel structures are found. In the latter, are found 5-10 cms. thick alternating layers of brown to red colored clay and light yellowish sand.

Coming to the age of the beginning of this recent phase of erosion it is necessary to consider various factors. The structures of the sediments described above indicates that they are of fluvio-lacustrine origin. The presence of fluviatile deposits of Quaternary age on the southeasternm plateau, associated with the Pleistocene pluvial periods determined for east Africa is reported by Mohr (1971). The well preserved nature of these E-W scarps, bounding these basins along with the age of 1.8 to 1.6 m.y given by Kazmin and Seife (1978) for this type of faulting suggest that this erosional phase may have started in the Pleistocene.



2C. Types of basin-plain structures occupied by fluvio-lacustrine sediments.



2D. A closer view of the fluvio-lacustrine sediments

Summary of the tectonic and geomorphologic evolution of the study area.

Stage	Age	Tectonics & Volcanism	Morphological events
VII	Quaternary	Development of E-W faults marking the early stages of the formation of the southern escarpment.	Suspension of previous base-levels, creation of valleys of tectonic origin, superaggradation in antecedent streams, and reversal of stream courses.
I VI	Tertiary	Development of initially narrow grabens bounded by NW-SE trending faults, outpouring of trappean volcanism.	End of preceeding peneplanation and beginning of formation of broad-alluviated plains, exhumation of Paleozoic erosional surfaces.
V	Late Cretaceous	Emergence of the land has completed, faulting occurs presumably along renoblized structures.	Late Mesozoic - Early Cenozoic peneplanation.
IV	Mid Cretaceous	Marks the beginning of the emergence of the land from the sea, deposition of the Upper Sandstone Unit along with outpouring of basalt flow along N-S fractures.	
III	Early Mesozoic	Beginning of land subsidence accompanied by compressional faulting.	
II	Paleozoic		Peneplanation
I	Precambrian	Development of N-S and E-W fractures, outpouring of trachyte flow along the latter.	

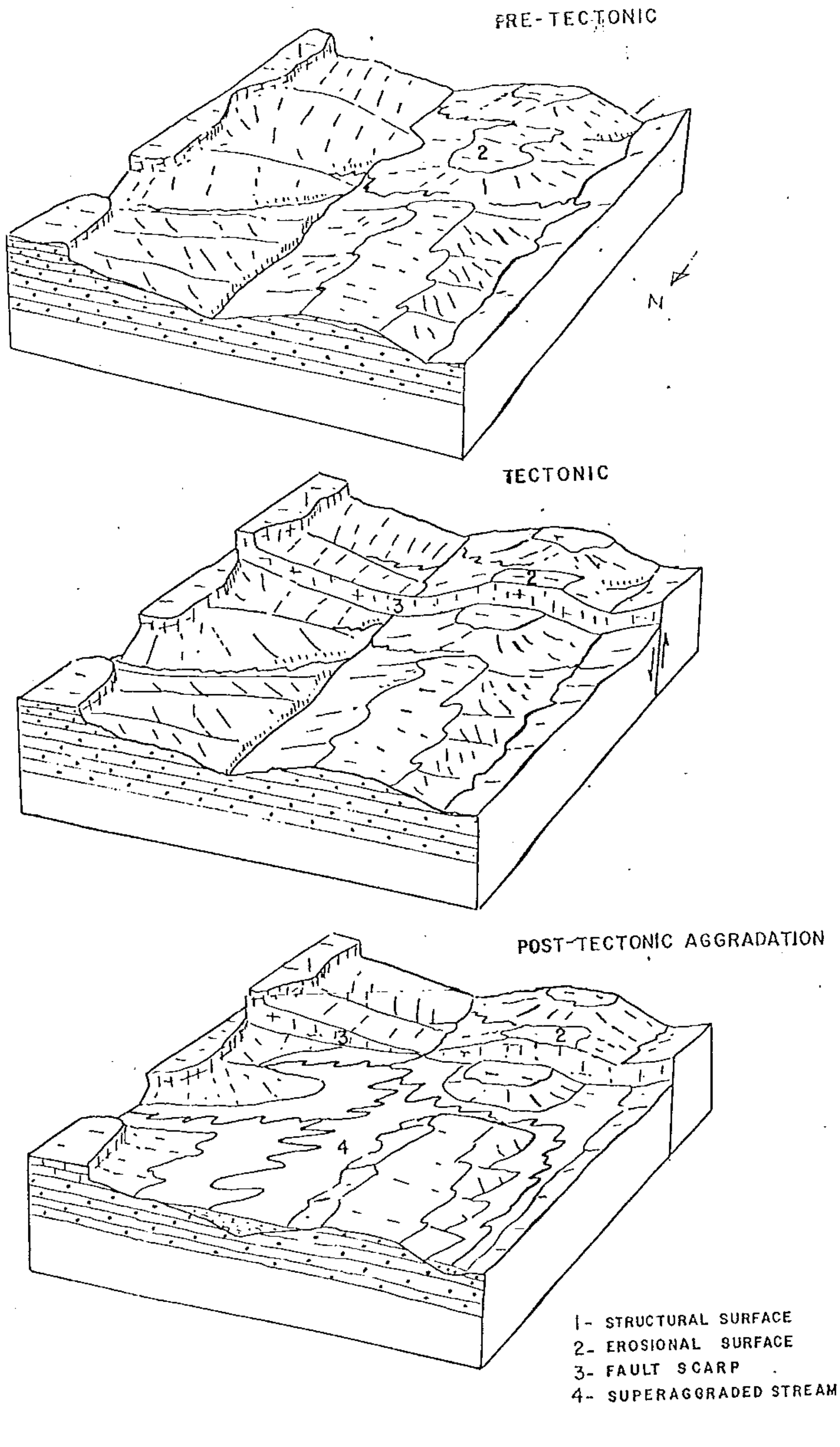


Fig. 3.1 Block diagrams showing successive stages of the geomorphologic evolution of the area

4. SOILS

4.1 Taxonomy of the soils

The classification system adopted in this thesis is that of the United states Department of Agriculture (USDA) (soil survey staff, 1975).

The soil units differentiated in this survey are at the great group and subgroup levels.

Three major soil orders have been recogized. These are Vertisols, Entisols and Mollisols.

The Vertisols in the area are represented by pedons 6, 12,17 and 21. The identification of these pedons under this order is made on the basis of the presence in these soils of well recognized properties of the Vertisols;

a) gilgai microrelief;
b) slickensides;
c) deep wide cracks;

In addition to the above, these pedons also meet the depth and textural requirements (Table 4.1). Because the cracks of these soils remain open for more than 90 cumulative days, for six months according to Ayele and Tamire (1974), these soils can further be classified into Usterts.

Further pedons 6, 12, and 17 have a moist chroma of less than 1.5 in the upper 30 cm, which puts them under the pellusterts. Pedon 21, on the other hand is a chromustert.

The properties of pedons 4,5,16 and 19 indicate their classification as Entisols. These properties include:-

(a) absence of distinct pedogenic horizons as expressed by preservation of original stratification;

(b) presence of a paralithic or lithic contact at depths shallower than 25 cm;

(c) dominance of non-resistant minerals like ferromagnesians and plagioclase feldspars.

Pedons 4,5, and 16 further meet the requirements of orthents with respect to depth, texture, organic carbon distribution and setting (Table 4.2). Pedon 19 is a Fluvent.

The rest of the soils studied in the present survey belong to the Mollisol order. All these soils have surface horizons that meet the definition of a mollic epipedon. Out of the number of factors that define this epipedon, the factors pertinent to the identification of the mollic epipedon in the present survey include color, depth, base-saturation and organic carbon content requirments (Table 4.3).

4.2 Description of the soil units

4.2.1 Vertisols

These soils occupy depressions in alluvial plains and scattered spots on the uplands, and are developed on alluvium and basalt parent materials respectively. Grass vegetation and gilgai microrelief are common characteristics of the places occupied by the Vertisols.

Morphologically the Vertisols are deep with low values and chromas (dark gray, dark brown, brownish black); they are clay with sand, silt and clay ranging from 19-39, 9-20, 42-65 per cent respectively. These data do not include the surface horizon of Pedon 6. This pedon has a surface mulch. The soils of this order developed on alluvial parent material have a higher content of clay (greater than 45%) than the same soils developed on basalt. Similar trends of clay content are shown by Vertisols in Alemaya region (Ayele & Tamirie, 1974). These soils have a firm moist consistence. The subsoils are characterized by abundance of lime concretions.

Chemical analysis shows that these soils are very slightly alkaline, except for pedon 6 which is medium to slightly acid, very low to medium in organic matter, low in total nitrogen, and very low to medium in phosphorous. In all but pedon 6 the distribution of organic matter and nitrogen show a decrease with depth while the pH increases. The cation exchange capacity of these soils is high. The CEC of the Vertisols also shows a similar trend of decreasing with depth but a very insignificant one especially when compared with the decrease in organic matter with depth which occurs approximately in halves from the surface soil to the next underlying subsoil. Available Pottasium was found to be significantly higher in the surface soils than in the subsoils.

Table 4-1 - VERTISOLS - PHYSICAL AND CHEMICAL ANALYSIS

Lab.No	Field No.	Depth cm	Texture, % (mm)			pH	+				Avail.(ppm)		Tot. N %	O.M. %
			Sand	Silt	Clsy		Na	Ca	Mg	C.E.C sum	K	P_2O_5		
429	6.1	0-23	59.4	8.6	32.0	6.55	--	23	6	38.0	758	0.9	0.084	1.10
430	6.2	23-120	39.4	18.6	42.0	5.75	0.87	24	1	46.0	875	---	0.210	3.90
405	12.1	0-23	21.4	20.6	58.0	7.40	0.44	28	7	44.6	875	---	0.070	1.45
406	12.2	23-80	26.4	21.6	52.0	7.45	0.87	43	2	43.0	625	0.9	0.042	0.69
391	17.1	0-45	19.3	15.0	65.7	7.20	3.48	67	3	46.0	750	10.8	0.056	0.90
392	17.2	45-105	21.3	15.0	63.7	7.60	1.74	40	10	45.6	250	---	0.042	0.55
397	21.1	0-30	37.3	17.0	45.0	7.15	9.57	40	10	49.0	1000	3.6	0.142	2.83
398	21.2	30-123	21.3	13.0	65.7	7.50	1.74	20	10	47.0	500	11.7	0.070	1.45

Table 4-2 - ENTISOLS - PHYSICAL AND CHEMICAL ANALYSIS

Lab.No	Field No.	Depth cm	Texture, % (mm)			pH	+				Avail.(ppm)		Tot.N %	O.M. %
			Sand	Silt	Clay		Na	Ca	Mg	C.E.C sum	K	P_2O_5		
393	4.1	0-9	48.0	33.4	18.4	6.00	3.48	42	13	21.6	500	---	0.084	2.07
394	4.2	9-20	48.2	39.4	12.4	6.15	1.74	39	11	17.4	250	16.2	0.070	0.97
395	4.3	20-30	50.2	27.4	22.4	6.10	1.74	43	22	25.8	500	19.8	0.112	2.55
396	4.4	30-37	40.2	31.4	28.4	6.35	6.96	34	14	33.4	375	7.2	0.656	0.90
404	5	0-18	57.4	10.6	32.0	6.15	0.44	26	9	31.0	1000	8.1	0.280	4.83
402	16.1	0-20	57.3	17.0	25.7	7.20	1.31	20	5	27.0	500	14.4	0.182	3.66
403	16.2	20-40	39.4	11.6	49.0	7.05	0.87	--	--	33.0	250	7.2	0.070	1.45
411	19.1	0-990	31.4	22.6	46.0	6.50	1.74	30	5	31.6	875	13.5	0.070	1.22
412	10.2	90-148	21.4	20.6	58.0	7.20	0.87	25	7	34.0	750	0.9	0.098	1.21
413	19.3	148-208	33.4	16.6	50.0	7.30	1.74	25	10	46.0	1125	2.7	0.042	0.38

+ = Exchangeables, Meq./100 gm Soil

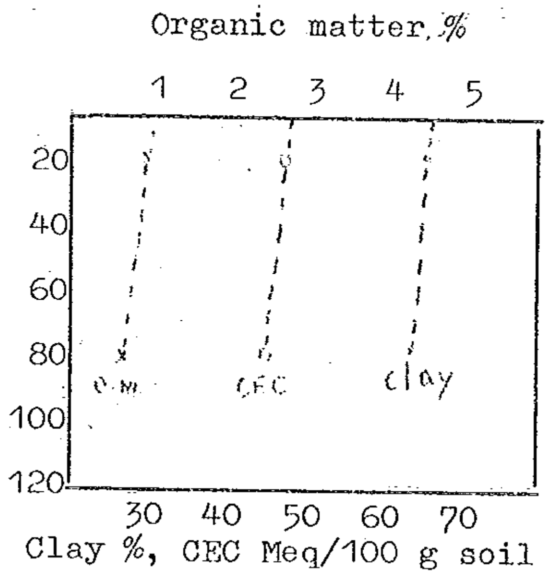


Fig 4-1 Distribution of clay, organic matter and CEC in surface and subsoil horizons of a representative Vertisol pedon (sample no. 391, 392).

4.2.2 Entisols

The Entisols in this area occupy landscapes that are actively eroding or flooding. Excepting Pedon 19 which is found on an alluvial plain, the rest of the Entisols occur on surfaces that are truncated by erosion. The soils of this order have developed from basalts, sandstones and gneisses. Vegetation, of shrubs and grass, is sparse.

The Entisols are shallow and are laterally discontinuous, being replaced by surfaces of bed-rocks. Thus these soils are characterized by abundant mineral grains at the surface. They are dark grayish and reddish brown, with loamy and finer texture. Pedon 19 which is developed on alluvium is clay throughout. The least content of clay

(12-28%) occurred in pedon 4 which is derived from basalt. The soils of this order are all characterized by a soft moist consistence.

Chemical analysis of representative pedons indicates that these soils are slightly acid to very slightly alkaline, generally low to meduium in organic matter and total nitrogen at depth but medium to high in both at the surface. Medium to very high amount of phosphorous were found in 70% of the samples analysed. The C.E.C. determined for these soils is distinctly lower than that of the Vertisols.

The variability of clay and organic matter with depth is a reflection of a stratified parent material; there is no evidence of translocation. The figure depicts the presence of a series of buried A horizons.

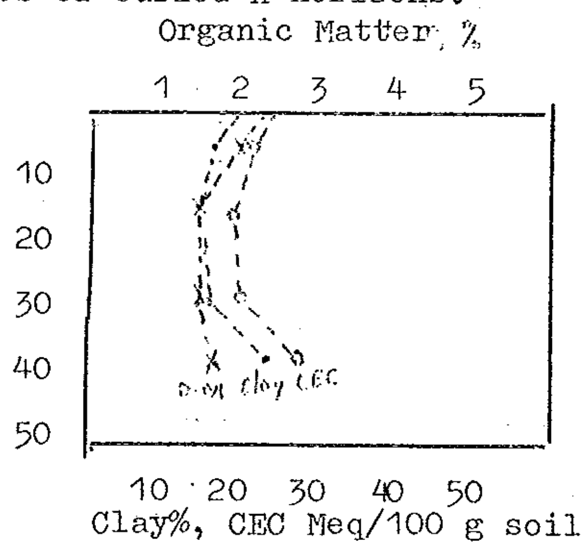


Figure 4-2 Distribution of clay, organic matter and CEC in surface and subsoils horizons of an Entisol developed from basalt (Sample nos. 391,392,393, 394).

4.2.3. Mollisols:-

The Mollisols occupy the largest portion of the studied area being developed on alluvial parent material and in situ on limestones, sandstones and gneisses. The Mollisols are found on gently to steeply sloping surfaces. Where they occur on steep slopes they are typically developed on limestpnes that have terrace like forms. The soils are discontinuous being separately developed on each bed. The bulk of the vegetation on these soils is Juniperous procera, podocarpus gracilior, and Euphorbia Sp.

The Mollisols in this area are shallow where they are developed on limestones and alluvium and deep on gentle slopes. They are brownish-black and reddish-brown in color. Where these soils are derived from transported earth material they are clay. Where developed in situ, they are sandy clay loam and clay loam. These soils have soft consistence. The subhorizons of some of these soils, in particular pedons 11 and 18, bear significant evidence for the presence of argillic horizons. In these horizons clay content increases more than 20 per cent at depth and clay bridges are clearly observable.

Taken as a whole the PH of these soils ranges from strongly acid to slightly alkaline. Only two samples from the subsurface horizons of pedon 1 fall in the strongly acid range so the greatest majority of these soils can be regarded as slightly acid to slightly alkaline. The organic matter contents deffer widely from 0.69 to 6.90 per cent for the surface soils and from 0.35 to 1.04 percent for the subsurface horizons.

In all pedons the organic matter content decreases with depth. A similar trend is observed for the low to medium amount of nitrogen present in these soils. The values determined for phosphouous content are highly erratic, and range from nil to high without any apparent trend of increase or decrease. However, most of the samples are very low in available potassium and calcium content of these soils are distinctly higher than for the Entisols (Table 4.3).

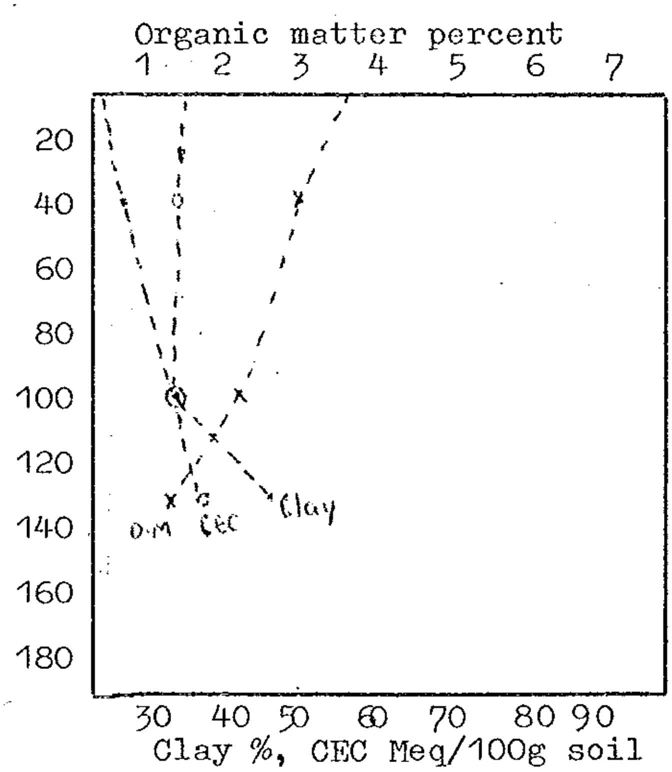


Figure 4-3 Distribution of clay, organic matter and CEC, in a Mollisol developed from sandstone (Sample nos. 399,400,& 401).

[illegible]e 4-3 - MOLLISOL - PHYSICAL AND CHEMICAL ANALYSIS

[illegible].No	Field No.	Depth cm.	Texture, % (mm)			pH	Exchangeables, Meq./100 gm soil				Available (ppm)		Tot. N. %	O.M. %
			Sand	Silt	Clay		Na	Ca	Mg	C.E.C sum	K	P2O5		
[illegible]9	1.1	0-80	59.3	15.0	25.7	6.50	0.87	20	3	33.0	750	0.9	0.14	3.04
[illegible]0	1.2	80-120	59.3	7.0	33.7	5.10	0.87	12	8	25.6	750	14.4	0.056	1.04
[illegible]1	1.2	120-147	47.3	5.0	47.7	5.00	0.87	20	5	48.0	875	15.3	0.028	0.35
[illegible]7	2.0	0.38	39.4	32.6	28.0	7.30	0.44	18	2	26.4	750	9.0	0.350	6.90
[illegible]1	3.1	0-33	53.4	14.6	32.0	7.25	---	30	3	34.0	1000	2.7	0.042	0.69
[illegible]2	3.2	33-75	31.4	28.6	40.0	7.50	0.87	23	1	33.6	1250	1.8	0.162	2.31
[illegible]5	15.0	0-45	29.4	22.6	48.0	7.65	---	52	13	41.2	500	2.7	0.140	2.90
[illegible]9	18.1	0-28	51.4	18.6	30.0	6.75	0.87	20	5	34.4	750	---	0.070	1.41
[illegible]0	18.2	28-80	45.4	10.6	44.0	6.35	0.44	20	4	30.0	875	---	0.042	0.45
[illegible]7	20.1	0-25	35.4	18.6	46.0	7.00	---	23	7	37.6	250	---	0.112	2.04
[illegible]8	20.2	25-300	31.4	18.6	50.0	7.60	0.87	60	10	31.2	625	---	0.056	0.48
[illegible]7	7.1	0-44	57.4	12.6	30.0	7.20	0.87	--	--	31.0	1000	---	0.084	1.73
[illegible]8	7.2	44-92	59.4	14.6	26.0	7.25	---	--	--	29.0	875	---	0.070	1.55
[illegible]4	8.0	0-28	51.4	20.6	28.0	7.10	3.48	23	7	30.8	875	5.4	0.098	1.86
[illegible]8	9.1	0-37	41.4	20.6	38.0	6.10	---	19	8	30.0	750	3.6	0.098	2.28
[illegible]9	9.2	37-85	25.4	20.6	54.0	6.05	0.44	30	5	42.2	625	1.8	0.042	0.47
[illegible]0	10.0	0-25	57.4	16.6	26.0	7.10	0.44	20	10	34.4	1000	3.6	0.112	2.07
[illegible]5	11.1	0-43	38.2	25.4	36.4	6.25	1.74	27	2	27.0	875	---	0.126	3.17
[illegible]6	11.2	43-70	29.4	10.6	60.0	6.45	1.75	27	3	44.0	1000	---	0.070	0.86
[illegible]3	13.1	0-88	15.4	24.6	60.0	7.60	1.74	55	13	43.2	750	2.7	0.070	1.62
[illegible]4	13.2	88-197	17.4	24.6	58.0	7.90	0.87	64	6	37.6	875	4.5	0.014	2.07
[illegible]6	14.0	0-40	35.4	26.6	38.0	7.55	----	32	6	----	1000	---	0.280	4.93

4.3. Soil Mineralogy

4.3.1. Sand Fraction

The total minerlogical analysis data of these soils indicates (Table 4.5) that the mineralogical composition of these soils is remarkably uniform. consisting of quartz, feldspar, amphiboles and clinopyroxenes decreasing in abundance in the order of listing. Magnetite and hematite are the most dominant opaque minerals. Hematite was always observed to occur in association with ferromagnesian minerals most probably as an alteration product.

Quartz was found to be absent in the upper two horizons of the Entisols developed from basalt. Except for the exclusive occurrence of plagioclase feldspars and abundance over quartz attained in this latter mentioned pedon, quartz was found in all the rest of the pedons, and the feldspars present were both alkali and plagioclase feldspars. The ratio of quartz to feldspars was highest in soils derived from alluvial parent material and decreased in abundance in the order sandstones and limestones, and gneisses, excluding the soils from basalt.

The amphiboles present include green and brown hornblende, cummingtonite, actinolite and riebeckite.

Green and brown hornblende are more common in the sandstones and alluvium. Cummingtonite is exclusive to the basalts and alluvium while the rest of the fibrous amphiboles occur as minor constituents in the alluvium and sandstone derived soils. The clinopyroxenes which are augitic in com composition are, with minor exception, exclusive to basalt and alluvium derived soils.

The Mineralogical composition of this fraction of the soils is of widely recognized importance in;

(1) The classification of parent material

(2) Furnishing useful criteria for the checking of the uniformity of parent material.

(3) Better evaluating soil fertility

(4) Understanding profile development (Van Baren 1971).

The various procedures and criteria for both qualitative and quantitative applications of soil mineralogical data to determine the type of information listed above have been further elaborated by Barshad (1976).

Both the total and heavy mineral analysis data (table 4.6) serve to classify the parent material and to check its uniformity, but the total mineralogical data is not as accurate as the heavy mineral suite. Careful examination of table 4-6 brings out the uniformity of the sandstone parent material signified by the occurrence of closely comparable amounts of green hornblende and occurrence of zircon and rutile that are predominantly comparable in amount. The amount of hornblende and the presence of garnet are unique to the alluvium. The soils developed on basalt are characterized by high conten of ferromagnesian minerals and absence of hornblende. The

Table 4-5 Total Mineralogical Analysis Data
(Per cent composition of grains)

Sample Number	Parent material	Soil order	Q	F	Am	Cp	Ap	R	Zr	Mg	H
391	Alluvium	Vertisol	77	5.7	2.8					1.5	13.0
392	"	"	50.5	10.5	2.1	27.4					9.5
397	"	"	67	14.7		8					10.3
398	"	"	62.52	10.4	1.06	23.9		1.06			1.06
405	"	"	88.8	4.5	2.2	4.5					
406	"	"	87	6	4.5						2.5
411	" →	Entisol	20.6	55	3.8						20.6
412	"	"	36	39	3	12					10
413	"	"	60	33							7
393	Basalt	"		30.9	7.2		1.2			30.9	29.8
394	"	"		43.2	13.6						43.2
396	"	"	19.3	5.8	32.6					34.6	7.7
402	Gneiss	"	26.6	60						6.7	6.7
403	"	"	8.7	36.9	13						41.4
407	Limestone	Mollisol	84.8	6.1	3	6.1					
414	Sandstone	"	26	47.8	13					4.3	8.9
416	"	"	83.8	6.5						4.2	6.5
417	"	"	73	17		2.7					7.3
420	"	"	81.8	6.2							12
421	"	"	80	8	4	4					4
422	"	"	82.2	8.8						4.2	4.2
428	"	"	68.8	25		6.2					
408	Alluvium	"	57.7	15.3		7.7			4		15.3
423	"	"	58.5	15.0	5.7	13.0					7.8
424	"	"	46.5	9.3		44.2					
425	"	"	48.8	14.6	7.4	14.6					14.6

Q= Quartz
F = Feldspar
Am = Amphibole
Cp = Clinopyroxene
Ap = Apatite
R = Rutile
Zr = Zircon
Mg = Magnetite
H = Hematite

Table 4-6 Heavy mineral Analysis Data
(Per cent grain Composition)

Parent material	Sample number	Apatite	Olivine	Clinopyrorene	Green Hornblende	Brown Hornblende	Fibrous Amphibolos	Garnet	Sphene	Tourmaline	Hematite	Ilmenite	Magnetite	Epidote Group	Zircon	Rutile
Basalt	395	3.7	1.8	47					1.8		37.7		8			
"	396		6.25	50			6.25				12.5		25			
Greiss	402	23.5		10		16.6	6.6						30		13.3	
Sandstone	414				28.C						17.0		22		11.0	22
"	417				10.3					6.8	20.6		41.3		7.0	14
"	428				8.2	5.2				5.2	23.6		34.2	2.6	18.4	2.6
Alluvium	405				26.6		13.3	26.6			13.3		6.9		13.3	
"	408			22.2	11.1	11.1		x					38.8	11.1		5.7
"	410			31.0	12.5						31.0	4.5	21.8			
	423			27.7	22.3			x			27.7		22.3			

x Could not be counted on account of [illegible] ness soils derived from gneisses contain apatite and brown hornblende.

4.3.2 Clay Fraction

Most of the samples gave similar spectra with absorption bands in the region of 1000 cm^{-1} and 700 800 cm^{-1} which are due to silica-oxygen and cation-oxygen bonds respectively. Such spectra are typical of kaolinite.

In samples obtained from Mollisols and Vertisols, absorption bands in the region of 3600 cm^{-1} and 3450 cm^{-1} were present, which are respectively due to the hydrogen-oxygen bond and water of hydration, clearly indicating the presence of halloystie.

The other most common constituent of the clay fraction of these soils are carbonates, indicated by absorption bands in the region of 950 cm^{-1}, and 1600 cm^{-1}.

Typical montmorillonite spectra were not obtained even in samples taken from Vertisols. This is likely the result of the low resolution power of the instrument. The absence of Montmorillonite clay spectra and the appearance of kaolin spectra may be due to the fact that the Vertisols, in which montmorillonite definitely occurs (Soil Survey Staff, 1975) are found in depressions to which abundant earth material is frequently added to from the surrounding uplands.

The predominance of kaolin group clays in the soils of this region is in good agreement with knowledge of clay genesis so far acquired. According to Keller (1964) kaolinization is favoured under conditions of:

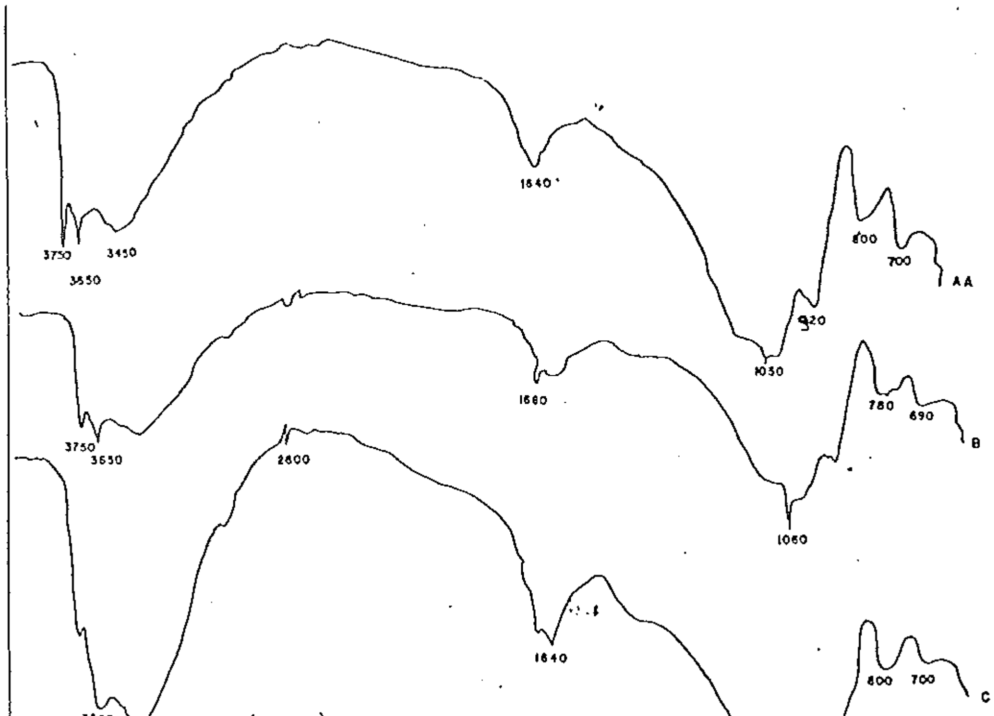


Fig 4-5 Infra-red spectra of mollisols (A B) and a vertisol (C)

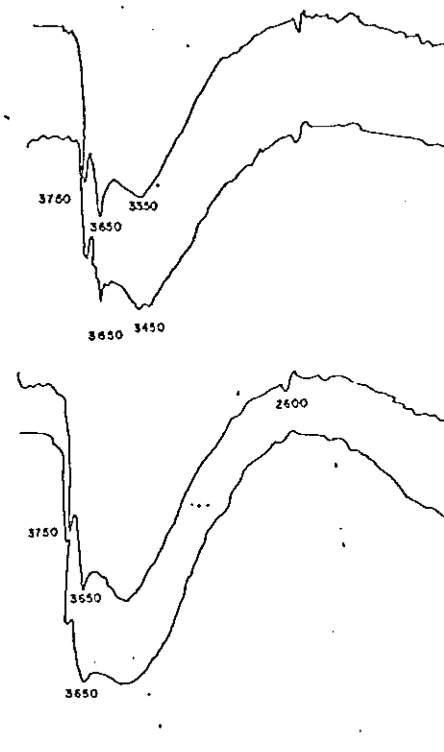


Fig 4-4 Infra-red spectra of selected [illegible] from

a) effluent drainage which removes Fe from the system;

b) acidic parent material which gives a high Al to Si ratio (1:1) present in the kaolin group of clay minerals. Silica should be lost in the absence of sources supplying Al.

c) removal of metallic ions either by substitution of these by H ions in acidic environments or by other mechanisms in environments of higher pH.

The reverse of these conditions favours the formation of montmorillonite clays. Similar ideas to those of Keller (1964) have been reported by Aba-Husayn et al (1980), Nash (1979) and Ojangua (1979).

4.4 Comparative Characterization of the Soils

The variability of the soils occurring in the study area is brought forth in more detail here than has been implied by the classification of these soils. Explanations are sought to account for the indicated variability. This approach is necessary to gain insight into those factors of soil formation whose effects are more pronounced than the rest.

4.4.1 Texture

The comparison of the sand and clay content of the different soils listed in table 4-4 demonstrates the existing relationship between soil texture and the various parent materials. Each figure quoted in the table represents the average content of sand and clay for a single profile .

Table 4-.. Relationship between texture and parent material.

Soils	Alluvium		Basalt		Limestone		Sandstone		Gneiss	
	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay
Entisol	28.4	51.3	46.7	20.4			57.4	32.0	48.5	32.35
Mollisol	16.4	59.0			39.4	28.0	55.3	35.7		
Vertisol	20.3	64.7	49.4	37.0						

Both within each soil order and among the different orders the clay content is highest for soils developed from alluvium, while the sand fraction is highest for soils developed from the sand-stones. A distinct trend of an increase in clay content is observable among the different soil orders derived from the same parent material as one goes from the Entisols to the Vertisols.

Leaving aside the pedons derived from alluvial parent material, it immediately becomes apparent that the clay con-tent of the various soils is comparable, with a notable occu-rrence of greater than 30% silt only in the case of the Entisol derived from basalt and the Mollisol developed from limestone.

The distribution of the clay content with depth in selected pedons of each soil order is shown in figure 4-4 below. It can't be noted that the distribution of clay with depth is highly erratic without any visible trend for the Entisols, while a net increase with depth is noted for the Mollisols. The Vertisols on the other hand, do not show

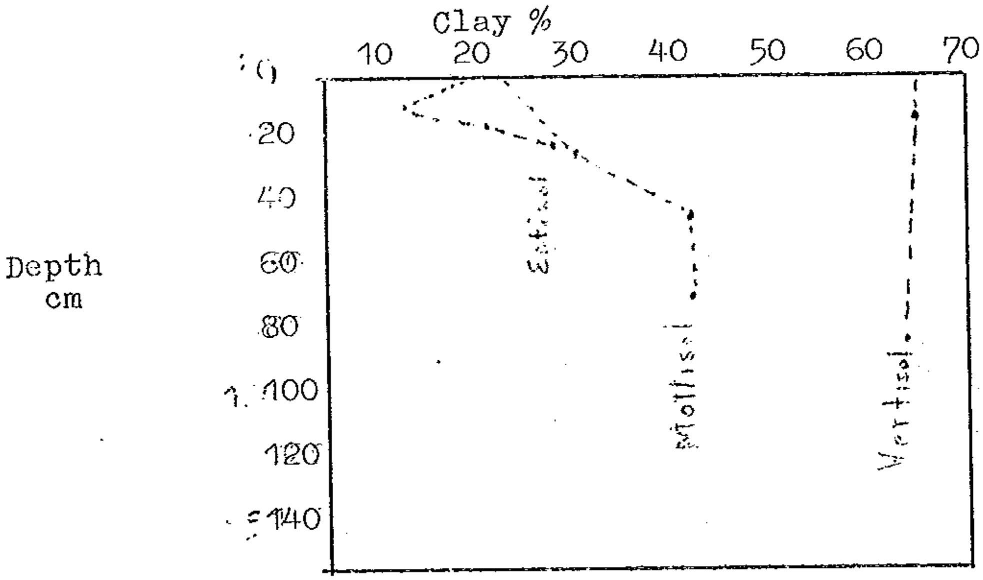


Figure 4-6 Distribution of clay in surface and subsurface horizons of pedons of Entisols, Mollisols and Vertisols (Pedons 4, 18, & 17).

significant difference in clay content from the top to the bottom. It is also interesting to note the general trend of variation in depth among the different soils from figure 4-6.

The foregoing discussion is significant in that it has shown that leaving apart the soils developed from transported parent material, the texture of each soil order is directly related to the mineralogy of the parent material and possibly to the moisture content of the soils. The first view is supported by the prevalence of the sand fraction in the sandstones in which relatively abundant resistant minerals occur. Despite this latter fact, the clay content of the various soils coming from different parent materials is comparable. This is clearly understood when one considers the amount of feldspars reported for the various lithological units in the chapter dealing with the geology of the study area. As would be remembered the highest feldspar percentage was reported for the gneisses and one may ask the reason why a corresponding amount of clay does not occur in the soils derived from these rocks. The reason is that the gneisses form part of the continuosly erosionally truncated surface. It is believed, also from the coarseness of the abundant weathered feldspars noted in the alluvium-derived soils and mentioned in the soil mineralogy part, that most of the feldspar supplies for the alluvium come from the gneisses. The relatively high content of silt in soils with basalt as a parent material is a reflection of the abundance of ferromagnesian minerals in this rock which do not either directly alter into clays or clay-sized particles under the circumstances of no transportation. The other significant occurence of silt observed in soils derived from limestones could probably be related to the impurities in the parent material.

Since all these soils occur in a region of the same amount of rainfall the moisture content of the various soil orders is expected to vary along with the topography which controls the runoff and the ground water table. Regarding the relationship between topography and ground water table the following two cases have been outlined by Jenny (1941). In humid climates the water table is the higher the greater the distance from a drainage channel while under conditions of rolling topography the depth to the water table increases as the distance from the draws becomes greater. With this in mind we note that in the Vertisols that occupy depressions in flat uplands and lowlands the clay content is always higher than the other soil orders that occur on slopes with steeper gradient. This occurrence clearly serves to draw the conclusion that the texture of these soils is somehow related to the topography. Next the exact nature of this relationship is examined. In regard to the abundance of clay in the different soils developed from alluvium, it may be said that this abundance is related to the continuous addition of earth-material to the local basins from surrounding uplands by runoff. But considering, as an example, the Entisol and the Vertisol derived from basalt and occurring on uplands without any significant addition of debris from other sources, the relative abundance of clay in the latter clearly shades light on the relationship between soil moisture has related to water table and clay content. It becomes apparent that chemical weathering of minerals is more pronounced in locally humid associates of the soils with the same parent material.

A number of factors and processes control the distribution of clay in the profiles of the different soil orders. In the Entisols it is the reflection of an originally stratified parent materil. In the Mollisols developed on sandstones the increase in clay at depth could be effected by illuviation and slow down-slope movement of soil material. In the Vertisols, the uniform clay distribution throughout their profiles owes its origin to poor drainage conditions and their vertic properties.

Concerning the depth of the various soil orders, it has been noted by Jenny (1941), soils on flat topography are generally deeper than soils on rolling topography, although the reason has not been stated. An obvious explanation for this would be the different rate of soil-erosion associated with the slopes on which the different soils occur.

4.4.2 pH

Measurement of the reaction classes of the various soil orders gave values ranging within narrow limits (5.00-7.90) as compared to the variations in parent materials, topographic sites, and current vegetal association of these soils. However subtle, certain trends of variation in the pH of these soils are observed.

The most notable of all the variations is the acidic tendency of the upland soils as compared to the lowland soils. Table 4-7 depicts this tendency of the former soils for representative frofiles of the various soil orders and corresponding parent material. On the contrary the lowland soils are generally very slightly alkaline to slightly alkaline (7.0 - 7.9) as shown in Fig. 4-7. Only five samples

Table 4-7 Reaction classes of upland soils

Parent Material	Soil Order	pH	Descriptive Term
Basalt	Entisol	6.00 6.15 6.10 6.35	Slightly acid
	Vertisol	6.55 5.75	Medium acid
	Entisol	6.15	Slightly acid
Sandstone	Mollisol	6.50 5.10 5.00	Strongly acid

fall in the slightly acid range and only two were found to be very slightly acidic out of a total of thirty samples obtained from lowlands.

Smaller variations of this nature are found within the lowland soils themselves. These trends of variation consist of an increase in the pH of these soils with depth, lowland Entisols having a lower pH than the rest, and a more significant pH increase with depth observed for the Mollisols and Vertisols than for the Entisols. Some of these situations are depicted in figure 4-8.

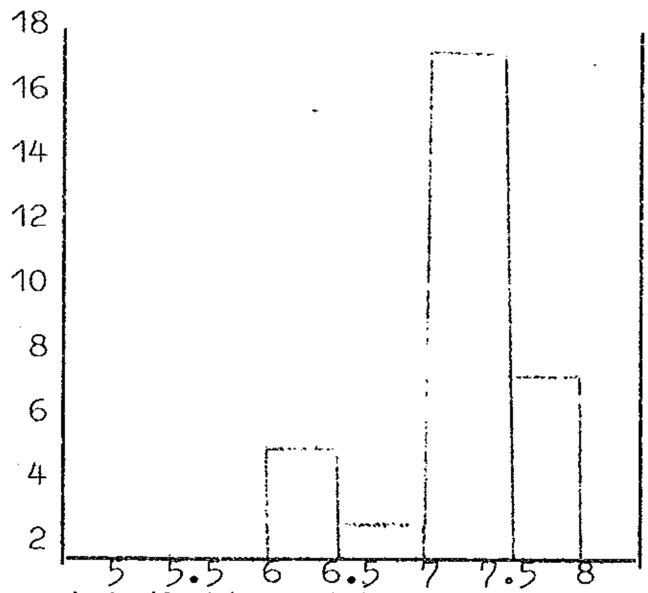


Figure 4-7 Distribution of lowland soils in the various reaction classes.

The question now arises as to what controls these variations. All the trends of variation shown to exist in these soils point to a single important controlling factor of the pH of these soils. The topographic factor is responsible for these variations through its modification of the microclimates of the soils through its control of runoff. It is fact that much runoff water from uplands reaches the lowland soils. This runoff water that eventually reaches the low-land soils becomes rich in bases that are leached off from the upland soils during its passage downwards. This situation is indicated in equation 1.

Before proceeding to examine the nature of the chemical reactions involved in the observed distribution of the pH of the soils it is necessary to note that this distribution

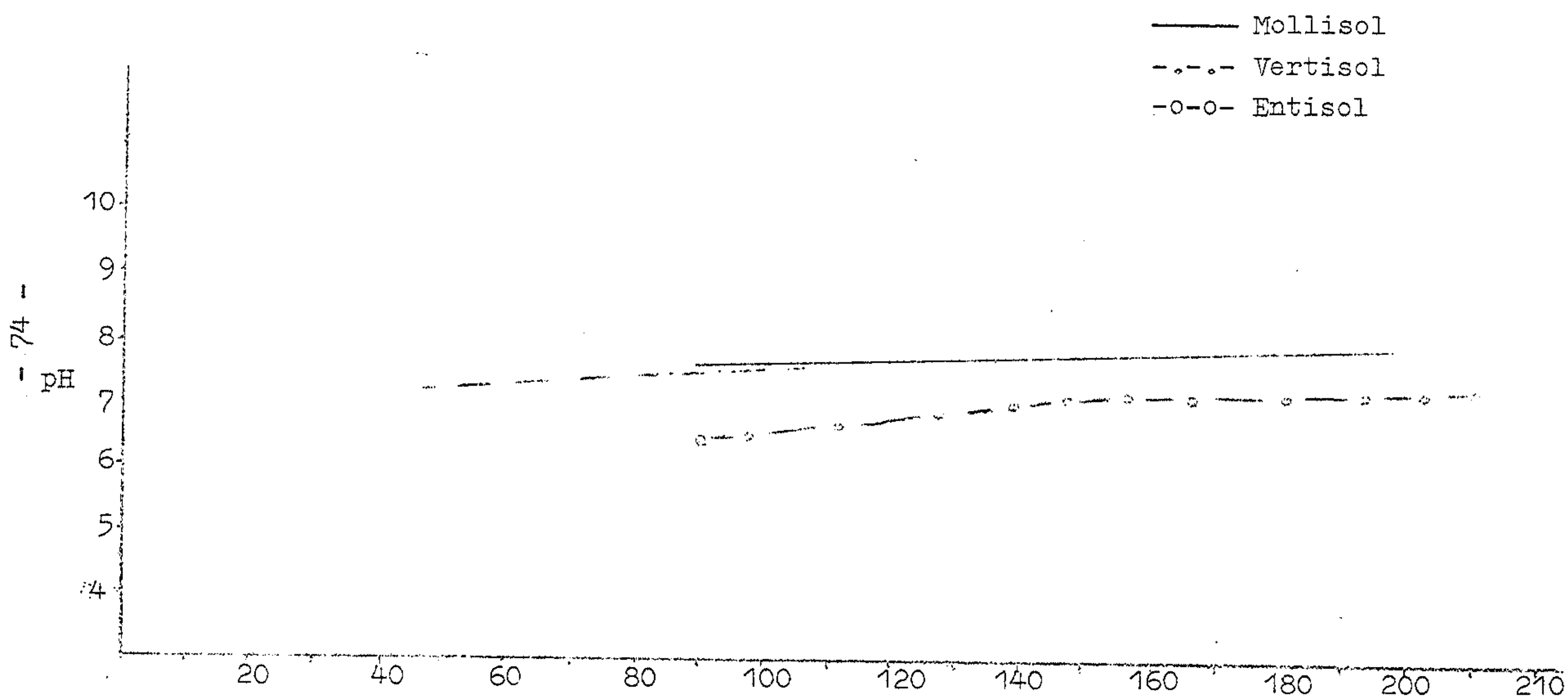
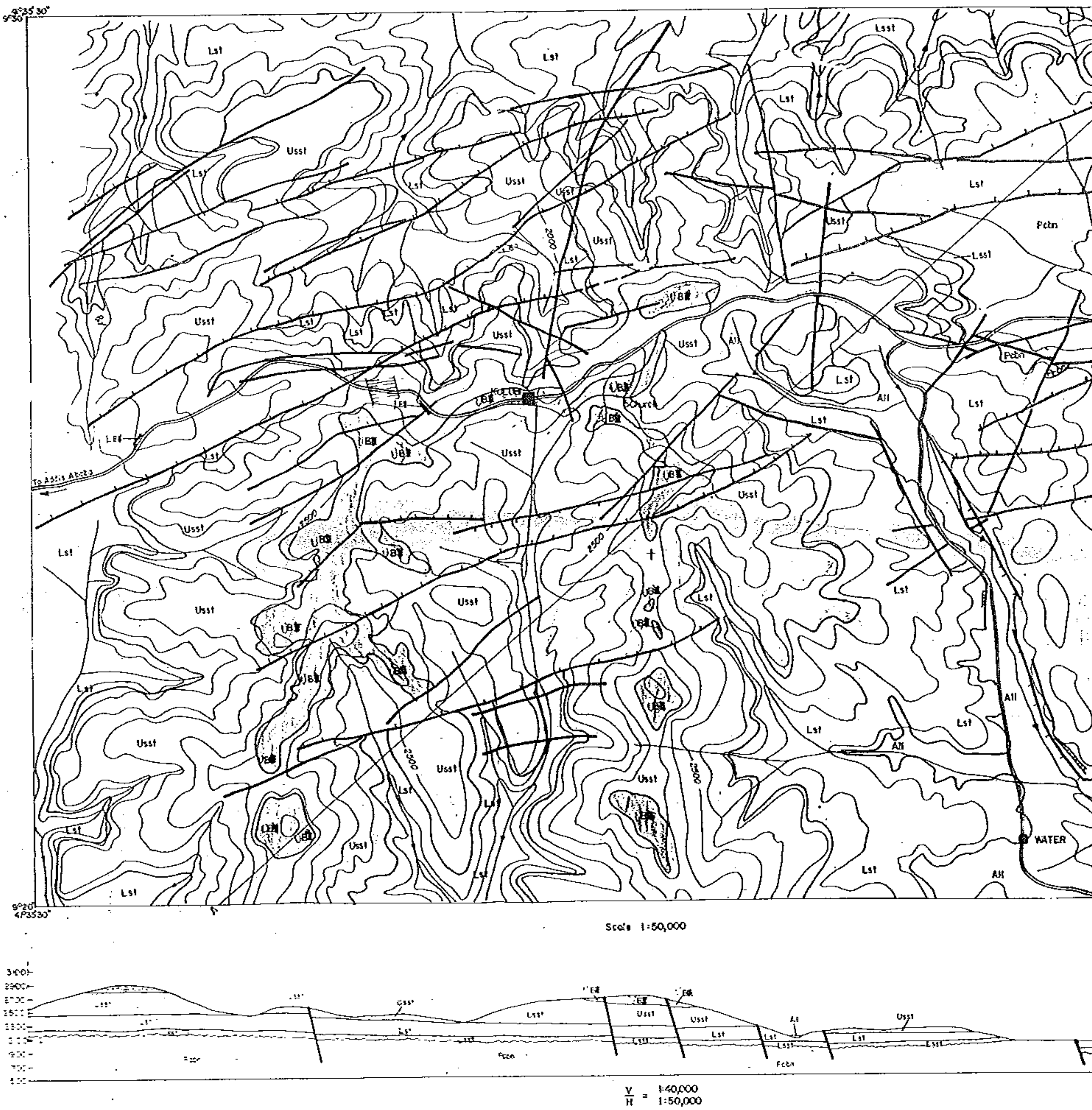


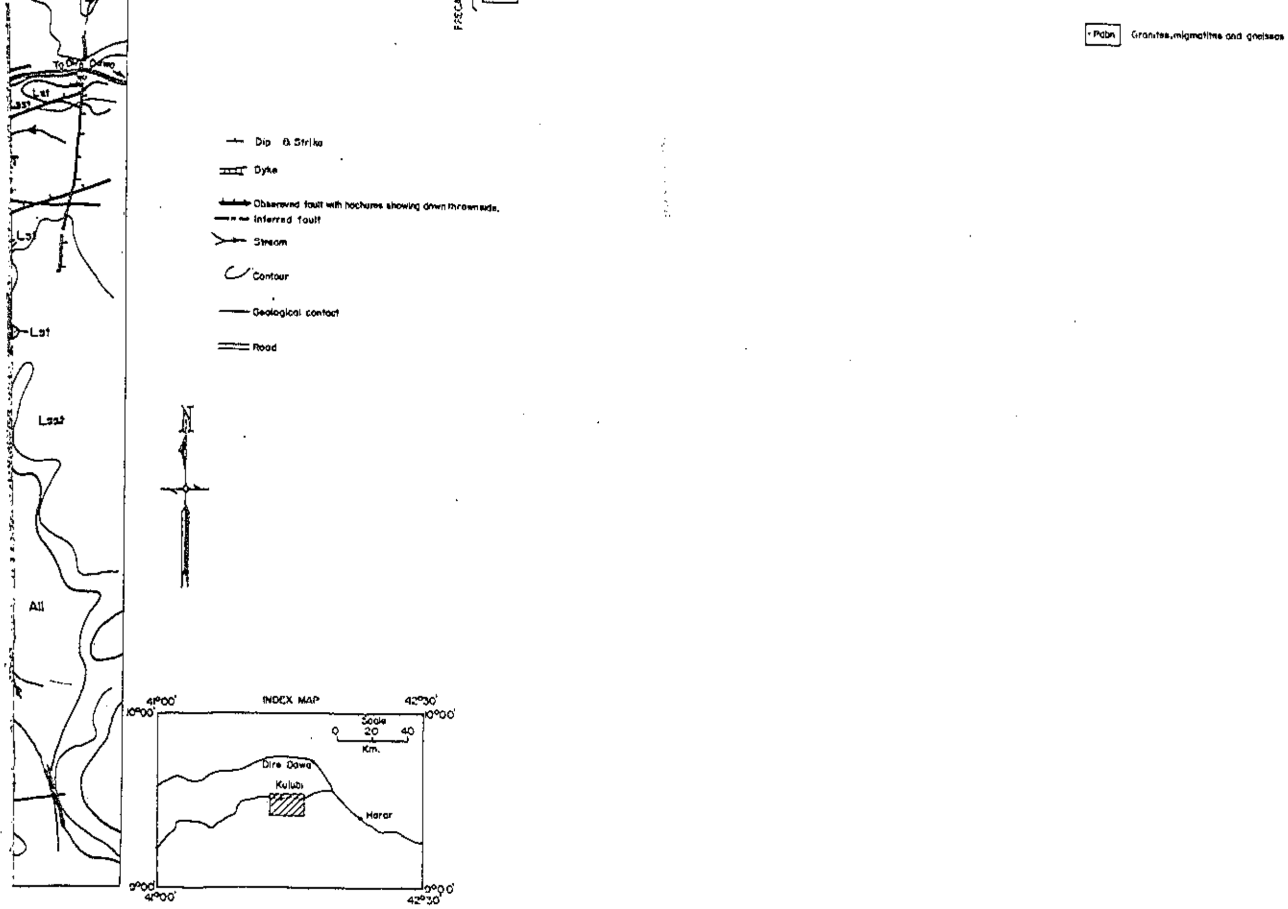
Figure 4-8 pH - depth relationship of lowland soils

GEOLOGICAL MAP OF KULUBI AREA

By Begashaw Wolde

July 1981





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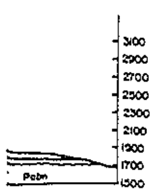

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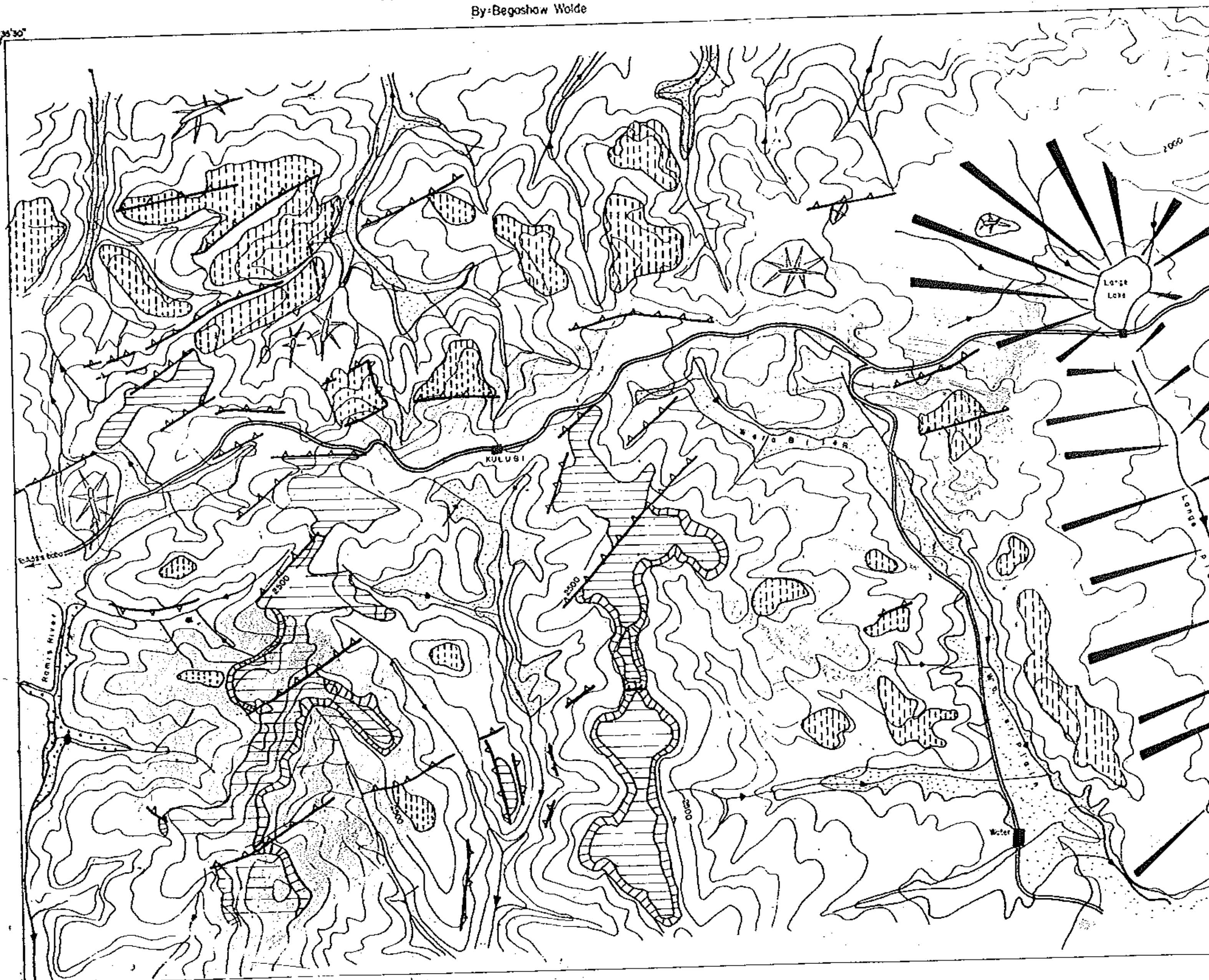
MAP-2

GEOMORPHOLOGICAL MAP OF KULUBI AREA

By:Begoshow Wolde



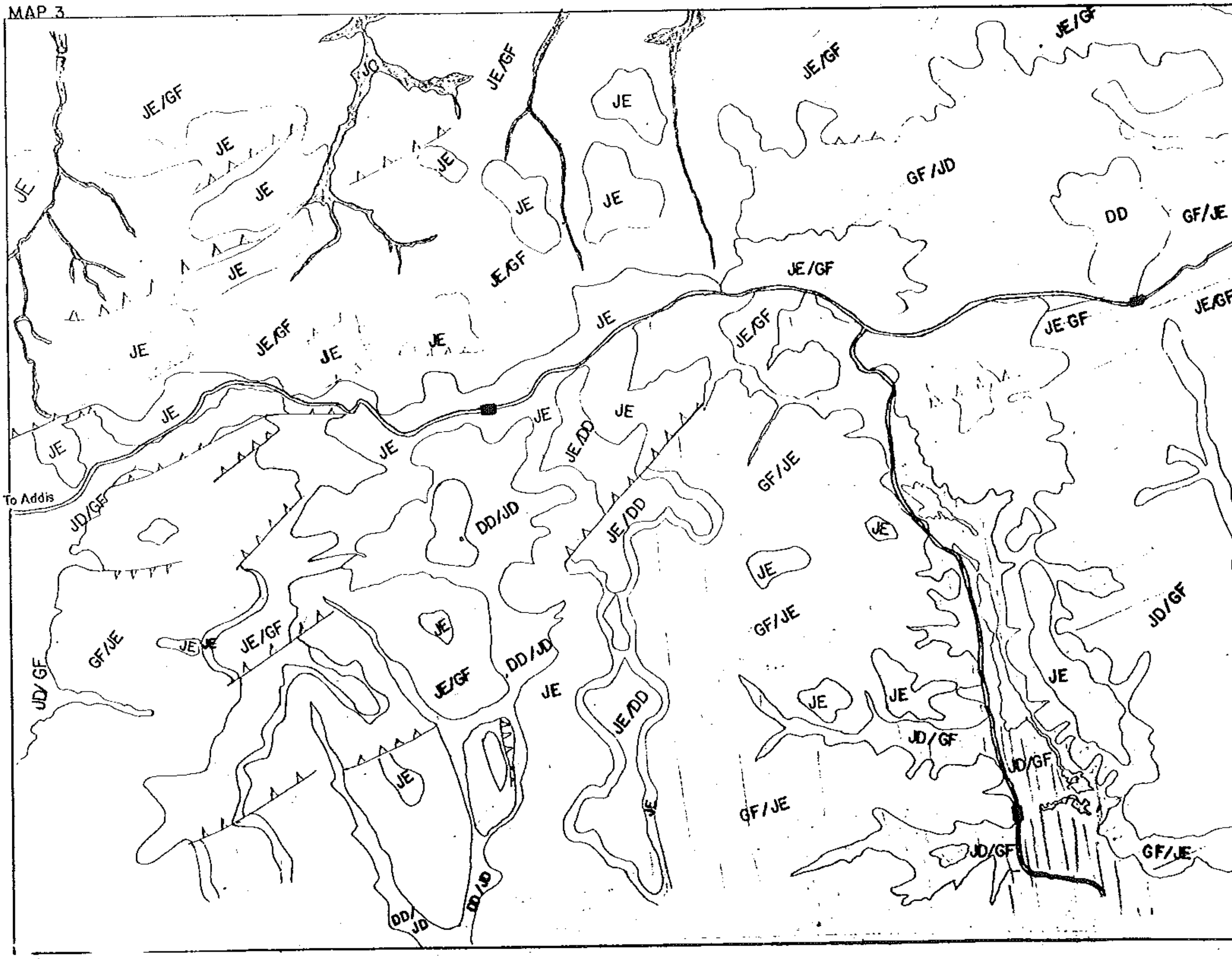
Scale 1:50,000

SOIL ASSOCIATION MAP OF KULUBI AREA

By Begashaw Wolde

July 1981

MAP 3



is not conclusive, since the sampling of the soils was not a random one.

According to Jenny (1941), soil acidity increases with both increasing amount of rainfall and under poor drainage conditions, i.e. the higher the ground-water table, the more acid the soil profile becomes. Other workers of interest include that of Johnson and Siccama (1979) who have demonstrated that pH varies with vegetation in their study of soils in connecticut and that of Perkins andHutchins (1980) who have shown that soils developed from calcareous parent material were usually nonacid whereas those from noncalcareous sediments were in acid families.

Thompson and Troeh (1978) discuss at length the dependence of pH on the base status or base saturation of the soils. The modification of soil base status and the formation of soil acidity under conditions of high precipitation has schematically been represented as follows by Jenny (1941)

Eqn. 1

$$\underset{\text{Neutral clay}}{\boxed{\text{Colloid}}\begin{matrix}Ca\\Mg\\K\end{matrix}} + \underset{\text{Water and carbonic acid}}{\begin{matrix}HOH\\HHCO_3\end{matrix}} \longrightarrow \underset{\text{Acid clay}}{\boxed{\text{Colloid}}\begin{matrix}H\\H\\H\\H\end{matrix}} + \underset{\text{Removed by leaching}}{\begin{matrix}KOH\\Ca(HCO_3)_2\\Mg(HCO_3)_2\end{matrix}}$$

The exchangeable bases of the neutral clays are replaced by hydrogen ions of water and carbonic acid. This interchange of ions converts the neutral clay into a hydrogen or acid clay. The hydroxides and bicarbonates formed as a result of the reaction are leached out by percolating rain water (Jenny, 1941). Leaching of hydroxides and bicarbonates of the type propounded above, from upland soils and their accumulation in the lowland soils, and within the lowland soils leaching of the hydroxides and bicarbonates from surface horizons to subsurface horizons may account for existing tendency of reaction classes of the upland and lowland soils of the study area.

4.4.3 Organic Matter and Nitrogen

The organic matter and nitrogen contents of these soils show similar trends of variation. The total nitrogen determined was also highest in the Mollisols and lowest in the Vertisols, as is the case for organic matter. Within each soil order, total nitrogen was found to be highest where organic matter was also high, and with a few discrepancies, the former decreased or increased with depth in a similar fashion to the latter but in varying proportions. For the Vertisols the distribution is such that they both decrease with depth. For the Mollisols there is not a single significant trend of variation with depth as illuvial horizons rich in organic matter are found. In the Entisols descrepancies to this and other relationships found in the other soil orders are common.

Table 4-8 Organic matter - nitrogen relationships in Vertisols

Sample number	Organic matter %	Total nitrogen %
405	1.45	.070
406	0.69	.042
391	0.90	.056
392	0.55	.042
397	2.83	.142
398	1.45	.070

Available literature was surveyed to discover nitrogen-organic matter relationships and the relationship of these to various soil forming factors. Based mainly on the works of Jenny (1941), and Thompson and Troeh (1978), these relationships are:

1) Soil nitrogen is closely related to the total organic matter content, to the extent that nitrogen analyses may be taken as an index of organic matter;
2) Both soil nitrogen and organic matter increase with time;
3) Parent material thickness, texture and mineral content indirectly influence organic matter. Thin soils resulting from hard rocks and coarse - textured soils produce less plant growth and contain less organic matter than deeper and finer-textured soils. Soils derived from clacareous sediments are richer in

organic matter than soils from noncalcareous sediments.

4) Vegetation influences the amount and pattern of distribution of organic matter with depth. Forest soils are richer in organic matter than grassland soils, but in the latter the organic matter content regularly decreases with depth while in the former it is highly irregular.

5) Topography modifies the microclimate and influences the vegetation, thereby producing a strong effect on the amount of organic matter in the soil. Soils on steep slopes have more runoff and make less water available to plants. Not only the organic-matter content is less but also some of the organic matter produced is lost by erosion from the steep slopes.

6) The effect of climate is well understood in that it controls the rate of decompositoon of organic matter. Under conditions of reasonably constant soil-forming factors, the nitrogen and organic-matter content of surface soils becomes higher as the moisture increases, and decreases as temperature increases.

Coming back to the relationship already indicated to exist in the presently studied soils, we find that the only factor-property relationship that approximates the present situation is that outlined in number four. As was mentioned in the description of these soil units the Vertisols are the only soils exclusively characterized by grass vegetation.

Corresponding to this situation we find the lowest amount of organic-matter and a regular decrease with depth of this organic-matter. It would therefore seem highly probable that vegetation is the single soil-forming factor controlling the distribution of nitrogen and organic-matter in the soils of the study area.

4.5 Soil fertility and productivity

The concepts of soil fertility and soil productivity have been defined by Jenny (1941). Soil fertility pertains to the quantities of nutrient elements present in the soil. The definition of soil productivity requires the definition of the agricultural productivity of a tract of land. As shown in eqn. 2 below the yield obtained from a plot of land. is a function of climate, crops, parent material, management

Eqn. 2

$$\text{Yield} = f(\text{climate, plant, man, parent material, time})$$

practices and time. The term parent material, which is defined as the initial state of thesoil system, has been used in the above equation instead of soil, since the introduction of man's activity or alteration of any variable in the parentheses clicks in a new set of processes. The variables in parentheses are designated as productivity factors and the yield is taken as a numerical index of productivity.

Soil productivity is then described as the value of yield obtained for any given soil under conditions where all the other variables are identical (eqn. 3). As defined so, soil productivity and fertility are synonymous. Since

Eqn. 3

$$\text{Productivity} = \text{Yield} = f(s)\ cl,\ v,\ h,\ t$$

where cl climate, v the crop, h management and t time.

the area now studied offers this situation, soil fertility and productivity are used in the sense just defined.

Important contributions on the management practices and fertility status of the soils in this region are that of Murphy (1968) and Tamirie (1974 b).

Within this region indecated as Wòina Dega agro-ecological zone by Tamirie (1974b) maize, sorghum, barley, chat and sweet potato are predominantly grown. Sorghum is interplanted in maize, coffee, chat and sweet potato.

The management practices are marked by the lack of crop rotation and complete removal of crop residues from the farm. This has accelerated the removal of top soils by erosion. Frost is the recurring severe natural calamity that comes every other year and damages crops.

On Vertisols 400 Kgs of sorghum per hectar was obtained without any application of fertilizer. Maximum yield of sorghum and maize in this soil type will be obtained by applying 150 kg P_2O_5 and 128 kg N/ha (Tamirie 1974b).

These soils are very hard when dry and very sticky when wet thus presenting a hard working condition. The cracking characteristic of these soils has a two-fold adverse effect. Firstly, roots are broken off as a result of this cracking, thus reducing the absorption of nutrients (Tamirie, 1974). The second effect is that this cracking facilitates an easy removal, by evaporation, of subsurface water and these soils are very draughty. These soils in the study area do not produce any crop yield if rainfall is less than 600 mm. during the sorghum or maize growing season. Because of the above stated reasons, the soils comparative productive capacity for agricultural crops is minimum in most years.

For the Entisols, the recommend rate of fertilizer is 150 kh N/ha and 92 kg P_2O_5/ha. Yield of sorghum and maize with the above recommended fertilizer dosage is given in table 4-8 below.

Table 4-8 Yield of sorghum and maize on Entisols

Crop	No fertilizer	NP_2O_5	N	P_2O_5
	Grain Yield kg/ha			
Maize	1360	3644	2436	510
Sorghum	320	2800	2750	1041

The shallow nature of these soils does not provide optimum conditions for development of roots, nor does it provide strong support for the crops grown. Further, the topographic sites occupied by these soils are such that either they are open for erosion or are frequently flooded by rainwash. These conditions generally make these soils less porductive.

The recommended rate of fertilizer for the Mollisols is 128 kg N/ha and 92 kg P_2O_5/ha. On a farmer's plot, a yield of 2700 kg/ha and 5300 kg/ha of maize was obtained without any application of fertilizer and with the above recommended rate of fertilizer respectively. These soils provide a very good physical condition for the plant root to spread deeper and farther. Thus with proper fertilization and management the highest crop yields are obtained from these soils with lesser inputs than required for the other two soils.

The use of improved seeds, selection of optimum population of crops per hectare, introduction of crop rotation practice and application of fertilizers are highly recommended for a better production.

4.6 Conclusion

The effects of parent material on soils have been studied by Boul et al(1975), Jenny (1941), Perkins and Hutchiins (1980), Thompson and Troeh (1978), and many others. Frequently, direct relationships have been found to exist between the texture and mineralogy of the parent material and the texture, sand fraction mineralogy, and the base status of the soils. The clay mineralogy of the soils is controlled by parent material compostion, drainage, and pH of the chemical system (Aba-Husayn et al, 1980; Keller, 1964). Again, the mineralogy and permeability of the parent material are known to control the depth of soils that may develop on it. In some cases, the existence of specific relationships between a type of parent material and the organic-matter content and pH of the soils have been shown but these relationships in many instances are indirect. In all cases the properties of the parent material whose effects on soil morphlogical, physical and chemical properties are separately or combinedly considered are texture, mineralogy, thickness, and permeability. A detailed geological study thus appears to be important in a study primarily designed to determine soil variations and the factors controlling these variations.

The texture and mineralogy of the presently studied soils can in some cases be related to the parent material. Examples which represent these relationships include the abundance of clay in soils developed on alluvium, predominance of the sand fraction in soil pedons developed on sandstones (table 4-6), the occurrence of high amounts of resistant minerals in alluvium- and sandstone-derived soils and relatively high amount of easily weatherable minerals (ferromagnesians, and plagioclase feldspars) in soils developed on basalts (table 4-7). Considering the abundance of feldspars in basalts and the gneissic rocks in the region, a higher amount of clay could be expected to occur in the soils developed on these parent materials than on sandstones. Instead, the clay content of soils on all these parent materials are comparable in amount. This condition has already been explained by invoking topography which controls runoff. The clay fraction of the soils developed in situ are easily carried away by water leaving behind a residual concentration of sand and silt.

The deep profiles of pedons 1 and 18 may be specific examples showing parent material control. These pedons are developed on sandstone. Similarly, the high content of organic matter and the alkalinity of pedons 2 and 14 that are obtained from limestones, may indicate specific parent material control. The existence of such relationships has already been reported by Jenny (1941) and Perkins and Hutchins (1980).

The effect of topography on the texture of these soils has been described above. The effect of topography on the soil mineralogy is even more important than its effect on texture. This is best exemplified by the occurrence of

Vertisols in depressions with their well estabilshed montmorillonite mineralogy (Soil Survey Staff, 1975) developed from material derived from neighbouring uplands with a characteristic clay composition of kaolinite and halloysite. These are not transformed into montmorillonite, but the latter may have been formed in situ by neoformation. Smectite formation by precipitation of solutes in alkaline and semiarid soils has been proposed (Boul, 1965). If the soil drainage is poor enough to permit the solution to remain in the soil profile, the solutes such as silica, aluminium, magnesium and commonly iron would be concentrated by evaporation in alkaline environment (Millot, 1970).

The organic-matter content of the soils in this region has been shown to be controlled by vegetation in section 4.4.2. On the other hand, the acidic nature of upland soils in contrast to the alkaline tendency of the lowland soils points to the control of topography. The soils pH is directly related to the base status of the soils (Thompson and Troeh (1978). Thus when the pH is high thebase status of the soils is also high. This implies that the inorganic nutrient supply of the soils under consideration are not only related to parent material composition but also to the topography.

A reasonable estimate of the age of these soils may be made on the basis of the geomorphologic study. Thus, the soils on the structural surface, that are represented by pedons 1,4,5 and 6 can be considered as Miocene in age, while the soils in the superaggraded streams (pedons 9&10)

may be of Pleistocene age. In the broad-alluviated plains the age of the soils may range from Miocene to recent.

The various time-soil relationships are all contained in the concept of soil maturity. This refers to soils in equilibrium with the environment. In morphological terms, soil maturity refers to a soil whose profile features are well developed (Jenny, 1941). Of all pedons mentioned above, well developed profile features are observed only in pedon 1 and it immediately becomes apparent how the geomorphic processes, that have operated and are still operating in the region, obliterate the effect of time.

The control of topography on specific soil properties is evident from the above discussions. It cannot however be said that the distribuyion of the soils in the study area is controlled by topography only.

Considered as a whole the formation of Entisols is favoured by sparse vegetation which facilitates erosion, parent materials with abundant resistant minerals, and finally the landscape. The Mollisols form on gently sloping surfaces with thick forest vegetation, sometimes mixed with grass. These soils are more alkaline when developed on limestones than on other parent materials. This latter fact coupled with the observation that the formation of Vertisols is always favoured under conditions of poor drainage indicates that the distribution of the soils of the study area is controlled by type of vegetation, parent material (thickness, composition, and permeability), and topography.

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Appendix

Description of Representative Profiles of Soil Units

Vertisols

The soils classified under this order are deep, poorly to imperfectly drained, dominantly brown to brownish black, clay soils with wide cracks. They occur on flat and depressed surfaces on alluvium and basalt.

Profile 6:

Location......................300 m South of st. Gabriel church.

Elevation.....................2500 m.

Physiography..................Upland

Microrelief...................Gilgai

Parent Material...............Basalt

Drainage......................Imperfectly drained

Soil Moisture.................0-23 cm dry, 23-120 moist

Rockiness.....................Fairly rocky

0-23	Dark brown (10 YR 3/3) dry and brownish black (10 YR 3/1) moist; sandy clay loam; weak, coarse, subangular blocky and loose grains; slightly sticky, non-plastic, very friable, soft; many very fine vesicular pores; frequent gravels of weathered sandstone; common very fine roots; clear wavy boundary.
23-120	Brownish black (10 YR 3/2 dry; 10 YR 3/1 moist) clay; strong coarse prismatic, sticky, plastic friable, extremely hard; patchy

thin cutans of clay mineral with iron oxide mainly on vertical ped faces; many very fine vesicular pores; few angular gravels of quartz and weathered basalt fragments; very few fine roots.

Profile 12

Location .... Mid-way between Water-Lange road road junction and Water town.

Elevation .... 2080 m

Physiography .... alluvial plain

Slope .... Flat

Parent Material .... Alluvium

Drainage .... Poorly drained

Soil Moisture .... 0-23 moist, 23-80 wet

0-23 cm Brown (10 YR 4/3) dry and dark brown (10 YR 2/3) moist; clay; strong coarse prismatic, sticky, plastic friable, extremely hard; slickens and cracks; few very fine vesicular pores; few rounded gravels of quarta, few small hard irregular carbonate nodules; few very fine roots; clear irregular boundary.

23-80 cm Dark brown (10 YR 3/4) dry and brownish black (10 YR 2/3) moist; clay; structure similar to horizon above; patchy thin cutans of organic matters; very few fine roots.

Profile 17

Location .... North of Lange lake

Elevation .... 1990 m

Physiography .... alluvial plain

Slope .... gently sloping

Microrelief .... gilgai

Parent Matérial .... alluvium

Drainage .... poorly drained

Soil moisture .... moist throughout

0-45 cm	dark gray (19 YR 4/1) dry and very dark gray (10 YR 3/1) moist clay strong very coarse columnar; sticky, very plastic, very friable, extremely hard; slickensides, cracks; many very fine vesicular pores; very few small hard spherical calcuim carbonate nodules; common very fine roots; gradual irregular boundary.

Profile 21

Location .... Extreme south of Lange Plains.

Elevation .... 1980 m

Physiography .... alluvial plain

Slope .... flat

Microrelief .... gilgai

Parent Material .... alluvium

Drainage .... poorly drained

Soil Moisture .... 0-30 cm dry 30-123 moist

0-30	Dark grayish brown (10 YR 4/2) dry and very dark grayish brown (10 YR 3/2) moist; clay; strong very coarse subangular blocky that break into coarse granular, sticky, plastic, very friable, extreemly hard; patchy thin cutans of clay minerals with iron oxide on vertical ped faces, slickensides, cracks, many very fine tabular open pores; few fine roots; clear irregular boundaries.

39-123 .... Similar to horizon above in color and structure. Few large soft irregular white calcium carbonate nodules.

Entisols

The soils of this roder are shallow, well drained, dark-grayish and reddish brown, loamy soils. They occur either on actively eroding surfaces on basalts, sandstones, and gneisses, or on flooding surfaces on alluvium.

Profile 4

Location .... 500 m west of microwave station

Elevation .... 2700 m

Physiography .... convex slope

Slope .... basalt

Drainage .... well drained

Soil Moisture .... dry throughout

0-9 cm — Brown (10 YR 4/3) dry and dark brown (10 YR 3/3) moist; loam; moderate very coarse granular, slightly sticky, slightly plastic, friable, slightly hard; many very fine vesicular pores; very fine common roots; abrupt smooth boundary.

9-20 cm — Similar to horizon above

20-30 cm — Color and texture similar to horizons above; strong coarse columnar structure that breaks into very coarse granular structure, slightly sticky, slightly plastic, friable, extremely hard; many very fine open tabular pores; few angular gravels of weathered basalt; very fine few roots; clear smooth boundary.

30-37 cm — Dark grayish boown (10 YR 4/2) dry and very dark grayish brown (10 YR 3/2) moist; loam; moderate very coarse granular, slightly sticky, slightly plastic, friable hard; many very fine vesicular pores; frequent angular gravels of strongly weathered basalt.

<u>Profile 5</u>

Location .... Near elementary school, Kulubi town.

Elevation .... 2400 m

Physiography .... convex slope

Slope .... gently sloping

Parent Material...................... sandstone

Drainage .... well drained

Rockiness .... fairly rocky

0-18 cm — Grayish brown (10 YR 4/2) dry and brownish black (10 YR 3/2) moist; sandy clay loam; weak medium subangular blocky and loose grains, slightly sticky, non-plastic, very friable, soft; common very fine to fine open tabular pores; very few angular gravels of weathered sandstone; very few very fine roots.

Profile 16

Location .... Western end of Lange town

Elevation .... 2000 m

Physiography .... pediment

Slope .... gently sloping

Parent Material .... gneiss

Drainage .... well drained

Rockiness .... fairly rocky

0-20 cm

Brown (7.5 YR 4/3) dry and brownish black (7.5 YR 3/2) moist; sandsy clay loam; strong coarse subangular boocky that breaks into medium grangular and very fine blocky structures, slightly sticky, slightly plastic, very fine open tabular pores; few prismatic gravels of feldspar and angular quartz; common very fine to medium roots; abrupt smooth boundary.

20-40 cm

Dark brown (7.5 YR 3/4 dry, 7/5 YR 3/3 moist); clay; moderate very coarse granular, slightly sticky slightly plastic, very friable, soft; very frequent angular gravels of quartz and platy weathered feldspars; many very fine closed interstitial pores; very few very fine to fine roots.

Profile 19

Location .... 2 km south of the hills found at 480 km milestone

Elevation .... 2020 m

Physiography .... broad valley

Slope .... gently sloping

Parent Material .... alluvium

Drainage ....welll drained

0-90 cm	Brown (7.5 YR 4/4) dry and dark brown (7.5 YR 3/3) moist; clay; strong very coarse sub-angular blocky, slightly sticky, slightly plastic, very friable soft common fine vesicular pores; common fine roots; clear smooth boundary.
90-148 cm	Grayish brown (7.5 YR 4/2) dry and dark brown (7.5 YR 3/3) moist clay; strong very coarse angular blocky, slightly sticky, slightly plastic, friable, slightly hard; common very fine and fine pores; common fine roots clear smooth boundary.
148-208 cm	Dark yellowish brown (10 YR 4/4 dry, 10 YR 3/4 moist); clay; strong very coarse prismatic, slightly sticky, slightly plastic firm slightly hard; few very fine vesicular pores; very few small grains of anguler quartz and flattened feldspar.

Mollisols

In the study area these soils are sha;;pw to deep, well-drained, brownish-black and reddish-brown, clay, clay loam, and sandy clay loam.

Profile 1

Location...................... Western flank of mapped area 1 km south of main road Addis Ababa - Dire Dawa

....

....

Elevation .... 2600 m

Physiography .... convex slope

Slope .... gently sloping

Parent Material .... sandstone

Drainage .... well drained

Soil Moisture .... 0-80 cm dry, 80-120 moist, 120-147 dry

0-80 cm — Very dark grayish bronn (10 YR 3/2) dry and very dark brown (10 YR 2/2 moist; sandy clay loam; strong very coarse granular, slightly sticky, non plastic, very friable, slightly hard; many very fine vesicular pores; few very fine roots, abrupt smooth boundary.

80-120 cm — Dark reddish brown (5 YR 3/4 dry, 5 YR 3/3 moist); sandy clay loam strong medium columnar; sticky, plastic, firm, hard; many very fine vesicular and coarse open tabular pores; very few very fine roots; abrupt smooth boundary.

120-147 cm — Dark red (2,5 YR 3/2) dry and dark reddish brown (2.5 YR 3/4) moist; clay; structure and pores similar to horizon above.

Profile 7

Location .... Along Addis Ababa - Dire Dawa road 1.5 km west of Kulubi town.

Elevation .... 2350 m.

Physiography .... footslope

Slope .... gently sloping

Parent Material .... sandstone and out washed basalt material from above.

Drainage .... well drained

0-44 — Dark brown (10 YR 3/4) dry and brownish black (10 YR 2/3) moist; sandy clay loam; strong coarse prismatic, slightly sticky, slightly plastic, friable, slightly hard; many very fine vesicular pores; frequent angular and rounded quartz and weathered basalt fragments; fine common roots; clear smooth boundary.

44-92 cm — Dark brown (10 YR 3/3) dry and brownish black (10 YR 2/3) moist; sandy clay loam; strong coarse prismatic, slightly sticky, slightly plastic, friable, extremely hard; many very fine open tabular pores; few rounded quartz gravels; few very fine to fine roots.

Profile 11

Location .... At Water - Addis Ababa road junction

Elevation .... 2180 m

Physiography .... foot slope

Slope .... gently sloping

Parent Material .... sandstone

Drainage .... well drained

Soil Moisture .... horizons dry throughout

o-43 cm — Dark brown (7.5 YR 3/4) dry and very dark brown (7.5 YR 2/3) moist clay loam; strong coarse subangular blocky, slightly sticky, slightly plastic friable, hard; many very fine vesicular pores; few very fine roots; clear smooth boundary.

42-70 cm — Dark reddish brown (5 YR 3/6 dry and moist); clay; strong coarse columnar, sticky, plastic, friable, extremely hard; many very fine open tabular pores; few very fine roots.

Profile 8

Location .... Mid-way between Lange and Kulubi towns.

Elevation .... 2340 m

Physiography .... hillside slope

Slope .... gently slopihg

Parent Material............... sandstone and down washed basalt material

Drainage .... well drained

Stoniness .... stony

Rockiness .... very rocky

0-28 Dark brown (10 YR 3/3) dry and brownish black (10 YR 2/3) moist sandy clay loam; strong, coarse subangular blocky, slightly sticky slightly plastic, very friable, soft; many very fine open tabular pores; frequent rounded and angular gravels of weathered basalt and sandstone, common very fine roots.

Profile 9

Location .... Gully in Werabelle river

Elevation .... 2200 m

Physiography .... valley-head

Slopes .... gently sloping

Parent Material .... alluvium

Drainage .... well drained

Soil Moisture .... 0-37 dry, 37-85 moist

0-37 cm	Brownish black (10 YR 2/3 dry, 10 YR 2/2 moist); clay loam; strong coarse prismatic,slightly sticky, slightly plastic, very friable soft; many very fine to medium vesicular pores; few angular gravels of quartz, common fine to medium roots, clear smooth boundary.
37-85	Brown (7.5 YR 4/4) dry and dark brown (10 YR 3/4) moist; clay strong medium prismatic, sticky plastic, firm, hard; patchy, thin cutans of clay minerals on vertical and horizontal ped faces; common very fine vesicular pores; few very fine roots.

Profile 10

Location	Oda river gully 3 km north of Kulubi town.
Elevation	1850 m
Physiography	valley
Slope	flat
Parent Material	alluvium
Drainage	well drained
0-25 cm	Dark brown (7.5 YR 3/3) dry and very dark brown (7.5 YR 2/3) moist sandy clay loam; moderate coarse granular and loose grains; sticky slightly plastic, friable, slightly dark; many very fine to medium vesicular and tabular pores, few very fine roots.

Profile 13

Location	Northwest of Water town

Elevation .... 2100 m

Physiography .... plain

Slope .... flat

Parent Material .... alluvium

Drainage .... well drained

0-88 cm

Brownish black (10 YR 3/2 dry, 10 YR 2/2 moist); clay; strong very coarse, angular blocky, slightly sticky, slightly plastic firm hard; few fine and medium pores; very few rounded gravels of quartz and weathered gravels of limestone; common very fine and medium roots, strongly calcareous, clear smooth boundary.

88-197

Brown (10 YR 4/3) dry and dark brown (10 YR 3/4) moist; clay; strong, medium subangular blocky slightly sticky, slightly plastic, friable soft; patchy thin cutans of possibly carbonate and clays filling cracks; few vesicular pores; strongly calcareous.

Profile 14

Location .... Northwest of Water town

Elevation .... 2200 m

Physiography .... gently convex slope

Slope .... sloping

Parent Material .... limestone

Rockiness .... extremely rocky

0-40 cm

Brownish black (10 YR 2/2 dry and moist); clay; medium coarse subangular blocky, slightly sticky, slightly plastic, friable hard, cracks common very fine roots frequent angular gravels of weathered limesone; very frequent very fine roots.

Profile 15

Location .... 3 km southwest of Water town

Elevation .... 2000 m

Physiography .... broad valley

Slope .... gently sloping

Parent Material .... alluvium

Drainage .... moderately well drained

0-45 cm

Bronish black (10 YR 2/3 dry, 10 YR 2/2 moist); clay; strong very coarse angular blocky; slightly sticky, slightly plastic, firm, hard croacks common fine and medium open tubular pores; few flattened gravels of limestone and rounded quartz, frewuent medium roots; clacareous.

Profile 16

Location...................... Western end of Lange town

Elevation .... 2000 m

Phsiography .... pediment

Slope .... gently sloping

Parent Material .... gneiss

Drainage .... well drained

Rockiness .... fairly rocky

0-20 cm

Brown (7.5 YR 4/3) dry and brownish black (7.5 YR 3/2)moist; sandy clay loam; strong coarse subangular blocky thet breaks into medium granular and very fine blacky structures, slightly stocky, slightly plastic, very fine friable, soft; common very fine ppen tubular pores; few prismatic gravels of feldspar and angular quartz; common very fine to medium roots; abrupt smooth boundary.

20-40 cm

Dark brown (7.5 YR 3/4 dry, 7.5 YR 3/3 moist); clay; moderate very coarse granular, slightly sticky slightly plastic, very friable, soft; very frequent angular gravels of quartz and platy weathered feldspars; many very fine closed interstitial pores; very few very fine to fine roots.

<u>Profile 20</u>

Location .... Same as profile 19

Elevation .... 2020 m

Physiography .... broad valley

Slope .... gently sloping

Parent Material .... sandstone

Drainage .... moderately well drained

0-25 cm

Brownish black (10 YR 2/3 dry, 10 YR 2/2 moist); clay; weak very coarse granular and loose grains; slightly sticky, slightly plastic friable loose; common fine vesicular pores; frequent fine roots clear smooth boundary.

25-300 cm

Reddish brown (5 YR 4/3 dry; 5 YR 3/6 moist); clay; strong very coarse angular blocky, slightly sticky slightly plastic, friable, soft; patchy thin cutans of clay; medium, tubular simple pores; frequent fine roots.