ENGINEERING GEOLOGICAL STUDY OF OMORATI AREA

A Thesis Submitted to the School of

Graduate Studies

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In Partial Fulfillment for the

Degree of the

Master of Science in Geology.

By: Germaye Mehari

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Engineering geological study of Omorati area

by

Germaye Mehari

Faculty of Science

Approved by: Board of Examiners

Prof. B. Grabowska-Olszewska
Advisor

Prof.Marcel Arnould
External examiner

Dr. A. Slioniaev
Internal examiner

Dr. Bekele Megerssa
Co-Examiner

Dr. Getaneh Assefa
Chairman -

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Abstract

Engineering geological study of an area amounting to $25km^2$ lying on the Western bank of Omo river at which a town is proposed to be located, was carried out. The study aims at evaluating the suitability of the area for its planned land use (urbanization) after considering the main existing and potential hazards which may severely endanger or preclude the various types of civil engineering works that may be associated with the urbanization.

The study revealed the presence of hazards, such as, the high seismicity of the area, probable flooding due to the fluctuating level of the Turkana lake lying 20 km South, the wide spread occurrence of sink holes and Cracks formed due to hydrocompaction and piping of soils in the study area, and the medium to high compressibility and low strength nature of the soils underlying the area which finally proved the unsuitability of the study area for its proposed land use (urbanization).

The local geology of the study area consists of clays, silty clays, clayey silts, sandy silts and silty sands, all of which are deposits of the flood plain of the Omo river and are characterized by thickness variation both vertically and laterally.

According to the laboratory analysis results, the cohesive soils of the area (represented by the clays, silty clays and clayey silts) are characterized by content of high organic matter and belong to OH, MH, OL or ML groups in the Unified Soil Classification System (USCS). Free swell values and clay mineral composition (by DTA) for few of the clay samples shows them to have medium to extreme expansiveness and as containing the clay mineral nontronite. The non cohesive soils (represented by the sandy silts and silty sands) are mainly composed of quartz, feldspars, micas, few heavy minerals and rock fragments. They belong to ML or SM groups in the USCS.

Based on the field and laboratory investigation results, engineering geological mapping at the scale of 1:10,000 was carried out on the basis of selecting the mapping units as recommended by the IAEG, commission for engineering geological mapping (1981).

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1. Introduction

1.1 Objectives

In conjunction with the Ethio-Korean Irrigation Project operating around the study area, the National Urban Planning Institute (NUPI) has been assigned to prepare plans for a future town to be established at Omorati on the right bank (or western side) of the Omo river.

From engineering geological point of view, the first step in selecting a site for a particular type of land use (urbanization, agriculture, etc.) is to study areas in a regional scale, and then promising sites are selected and evaluated for their hazards and opportunities. In the second step the site which presents the best opportunity and the least hazard for the planned land use is subjected to detailed engineering geological mapping. This mapping, describes the opportunities and hazards of the area, and accordingly sensible recommendations compatible to the best use of the site are made for its planned purpose.

This thesis, besides the preparation of the engineering geological map (1:10,000), aims at evaluating the suitability and presents the opportunities and hazards (existing and potential) of the study area for its planned purpose. Based on these, proper recommendation of necessary precautions to be observed and suitable construction methods are suggested.

1. Introduction

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1.2 Investigation Methods

The field investigation was mainly based on observation of profiles in dug pits. The density and depth of the pits was decided by compromising between the limited fund available and the practical detail which should be represented on the map corresponding to its final usage. Moreover, since the study area is flat (generally < 1% slope) and characterized by lensing and lateral variation of subsurface soils within short horizontal distance, a detail which shows the exact extent of such variation cannot be attained and is generally impractical trying to attain such detail on this mapping scale.

Considering the above conditions the number of observation pits was chosen to be 20 with an average depth of investigation of 3 meters, distributed, in a more or less grid pattern, through out the study area. This pattern is recommendable for such flat (< 1% slope) type of landscape.

Each horizon found in every pit was described engineering geologically following the guide line of IAEG. (Bulletin of the International Association of Engineering Geology, 1981) and Mathewson (1981). Samples from each horizon were taken for detailed laboratory classification tests as well as some chemical and physical property tests. The Classification of the soils is made in accordance to the Unified Soil Classification System to help assess their engineering geological properties.

Based on these, engineering geological map is prepared for an area amounting to 25 km^2. Aerial photographs of 1:20,000 scale together with 1:10,000 scale photo mosaic has been used to delineate the boundaries of each engineering geological soil units and other characteristics. Topographic base maps of the study area at the working scale (1:10,000) are not available. Hence the aerial photograph were also used as a base map.

1.3. Location

Omorati is located in the lower Omo basin situated in South western part of Ethiopia between 4° 30' to 6° 25'N latitude and 35° 13' to 36° 45' E longitude (Fig.1.1). The center of the Study area is particularly located at approximately 4° 50' N latitude and 36° 00' E longitude. Covering an area amounting to 25km^2 on the right bank of Omo river, and lies 20 km north of lake Turkana's shore line. The Omo river originates in the western highlands of the Shoa administrative region and ends in lake Turkana (formerly called lake Rudolf) after traversing a total distance of about 1000 km. The average width of Omo river near the study area is 150 m.The area can be reached through a road 880 km long, along the Addis Ababa - Arba Minch -Gidole - Turmi - Omorati road (fig1.1).

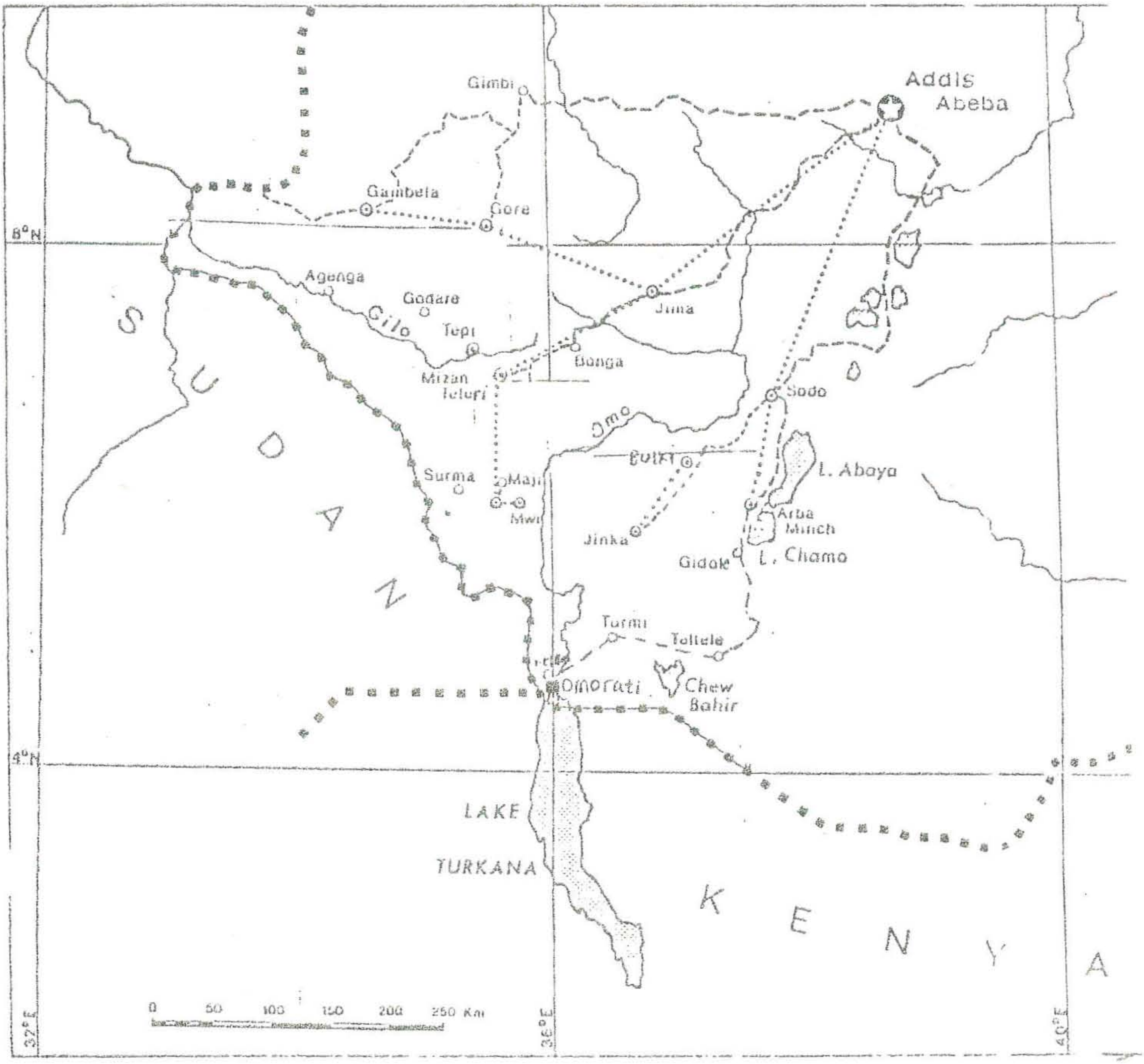

Fig. 1.1 Access routes to the study area
Dashed lines are roads, dotted lines are commercial air routes

2. Regional Geomorphology, Tectonic Setting, Geology and Seismicity

2.1 Previous Geological Works

A substantial amount of literature has been accumulated since the late 1960's, on the Plio-Pleistocene deposits of the lower Omo river basin in Ethiopia and around the Turkana in Kenya, related to researches on ancient fossil hominids proved to exist around the area (Coppens etal. 1976; Bishop. 1978: Butzer, 1970. 1971 a,b; etc). An excellent summary and compilation of previous publications has been made by Heinzelin. (1982) in the book called " The Omo group " which the following geological and stratigraphic description of formations in the area is mainly based on.

2.2 Regional Geomorphology and Tectonic Setting

The outstanding Geomorphic features of the region are the fault block mountains and highlands which generally trend N-S to NNE-SSW (Brown and Nash, 1976). These include the Labur hills (South west of the lower Omo basin), the Lorientom and Lokwanamoru ranges and Kacheriangorr hills (bordering the basin on the north west), and the Hamar highlands (which bound the basin on the east). These highland areas surround a topographically low area in which lake Turkana lies and which extends north ward from the lake nearly 100

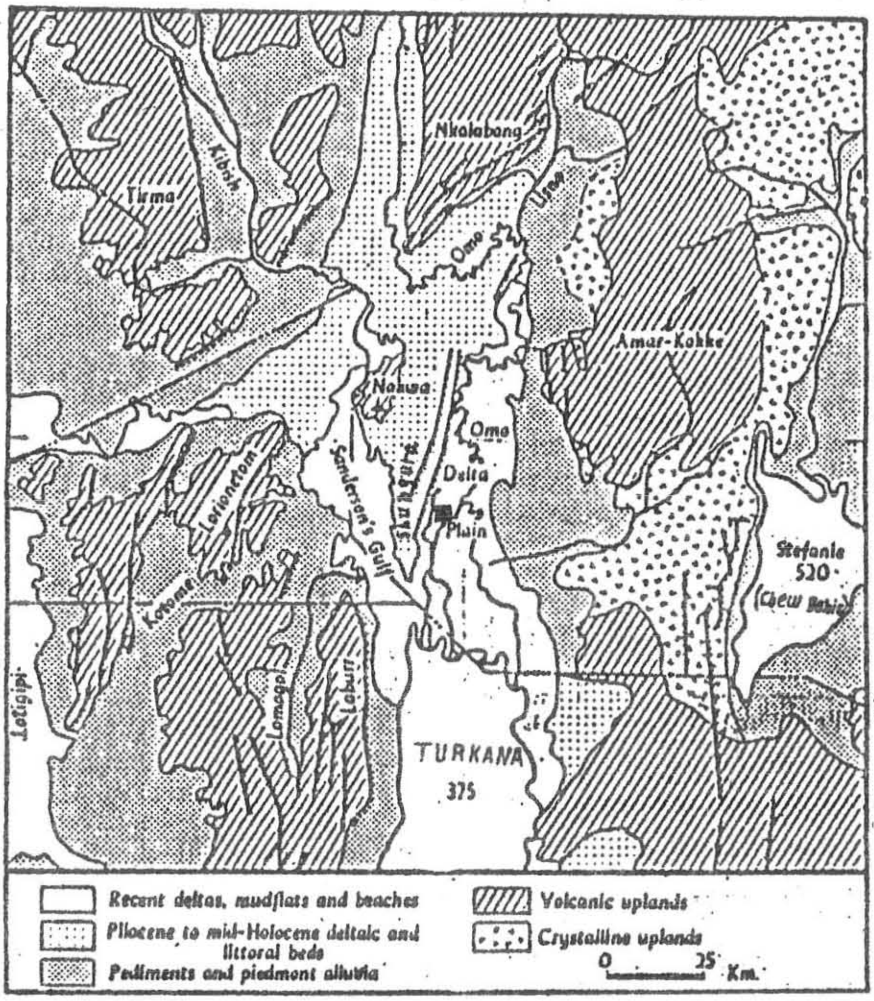

Fig.2.1 Simplified geological map of lower Omo basin (After , Butzer, 1971a)

beds are uncorrelated with the other four. All of these formations are tilted (usually to the west) and faulted Heinzelin (1982).

1A. Mursi formation

The Mursi formation is conveniently divided into two units (Davidson et al., 1983), the lower one sedimentary and the upper one flood basalt. The lower sedimentary unit, divided in to three members (Butzer, 1971 b), lies unconformably on west-titled rhyolites of probable Miocene age (Brown and Nash, 1976), and is composed of about 150m of clays, silts and sands with subordinate tuff and pebble beds (Davidson et al., 1983). These sediments are conformably overlain by flood basalts, dated 4.2 M.Y (Fitch and Miller, 1976) composed of a relatively few, thin, columnar flows of dark gray basalt locally carrying scattered plagioclase phenocrysts and chlorite filled amygdules (Davidson et al., 1983).

1D. Shungura formation

It includes at least 760m of brown, gray and buff clays, silts, sands, gravels, tuffs, marls and fresh water limestones (Davidson et al, 1983). These sediments are tilted gently to the west and are overlain with shallow unconformity by the Kibish formation (Davidson et al. 1983). Faulting both parallel and oblique to the northerly axis of tilting has offset bedding by several meters locally. The sedimentation record is one of fluctuating fluvial and lacustrine cycles, reflecting alternating changes in the level of ancestral lake Turkana (Heinzelin et al., 1982).Its age is estimated as spanning the time range from about 3.55 M.Y to 0.95 M.Y or perhaps 0.5 M.Y

1E. Loruth Kaado and Nayena Epul beds

These beds hardly deserve formational names. They occur in two limited areas of exposure at the north end of the Labur range west of Sanderson's Gulf. The Loruth Kaado sediments contain fossil wood, moluscs and sparse vertebrates. These beds haven't been correlated with the other formations in the lower Omo basin (Heinzelin, 1982).

2. The Turkana group (upper Pleistocene to Holocene deposits)

This name was suggested by Heinzelin (1982) for middle to upper Pleistocene and Holocene formations in the lower Omo basin. The following are formations included in the group.

2A. Bume formation

The Bume formation occurs in only two outcrops, between the exposures of the Shungura formation and the present course of the Omo river. It is made up of lacustrine deposits which differ in facies and shelly fauna (moluscs and astracods) from the deposits of the Shungura formation. It is bracketed in time between the upper most Shungura formation and the lower Kibish formation and is thus most likely of middle to upper Pleistocene age (Heinzelin et al., 1982).

2B. Kibish formation (upper Pleistocene to middle Holocene)

This formation composed of lacustrine and deltaic sediments of upper Pleistocene to middle Holocene age lies discordantly on the Omo group (Heinzelin, 1982). Near kibish it overlies the Nkalabong and Mursi formation. and farther south it occurs as a thin veneer of sediments overlving the Usno and Shungura formations (Butzer and Thurber, 1969).

At the type section, located at the south-west end of the Nkalabong range, resting with erosional unconformity on the Nkalabong formation, it comprises four members with a measured thickness of 120m (Butzer and Thurber, 1969; Davidson et al. 1983). The lowest unit (member I), is at least 31m thick, it has gravely sand at the base followed by alternating clay, silt and sand, in part laminated and ripple marked, and containing reworked tuffs close to the base. Its top is marked by a soil horizon. Member II, 22m thick, is composed predominantly of massive silts, deposited on a basal tuff that blanketed the dissected surface of member I. Member III, 46m thick, records two cycles of advance and retreat of lake Turkana, separated by a prominent subaqueous tuff bed 3m thick. Its sediments are clays, silts and sands with thin shell beds associated with the second cycle. Another erosional interval separates member III and IV, marked by a soil horizon and subsequent dissection. Member IV is divided into two units IVa comprises 13.5m of sand, silts and clays with a gravely base. IVb, 9m of sands, silts with minor tuff. The two submembers represent transgressions of lake Turkana, separated by a regression to close to present lake level

(Davidson et al., 1983). Tuff from member I has been dated at 0.13 M. Y. or middle Pleistocene. Member III is at least 30,000 years old or upper Pleistocene. IVa spans from 9500 to 7900. IVb from 6600 to 3250 years before present (Butzer, 1971 a, b).

2C. Errum formation

A group of lacustrine sediments, beach features, gravels, reddish sediments and a tuff lying discordantly on the Shungura formation in the Kelem area are defined as the Errum formation (Heinzelin, 1982). It may be lateral extension of the kibish formation although not yet demonstrated. The thickness of this formation is less than 10m and it is probably of upper Pleistocene age.

2D. Lobuni beds or Narok beds

These beds include young and modern features of the Omo delta, contemporary flood plains of the Omo river and beach of sanderson's Gulf and lake Turkana (Butzer and Thurber, 1969). Late cenozoic stratigraphy of the lower Omo basin is given in Table 2.1.

Table- 2.1 Late Cainozoic Stratigraphy of Lower Omo Basin

(After Butzer, 1971a) with some modification

Probable Geological Age	Isotopic Dates	Rock Units			Depositional Environments
Holocene		Contemporary deltaic, alluvial and littoral beds			
	C^{14} 3100-6200 yr		KIBISH FM. (115m)	Mb. IVb	Deltaic, littoral
	C^{14} 7500-9500 yr			Mb. IVa	Deltaic, littoral
Upper Pleistocene	K/Ar "O"			(Nakwa tuffs and basalt extrusions)	
	C^{14} 37,000 yr			Mb. III	Deltaic, littoral
				Mb. II	Deltaic
Middle Pleistocene	Th/U 130,000 yr			Mb. I	Deltaic
		(One or more episodes of faulting of Shungura Fm.) (Renewed sedimentation west of modern delta)			
Lower Pleistocene		(Faulting of Shungura Fm.)			
	K/Ar 1.81-3.75 mill. yr	OMO GROUP	SHUNGURA FM. ("Omo Beds") (80m)		Alluvial, deltaic, littoral, lacustrine USNO FM.
:	K/Ar 3.95 mill. yr	OMO GROUP	NKALABONG FM. (88m)		Alluvial, littoral-lacustrine eolian
to		OMO GROUP	(Faulting, local or general)		
	K/Ar 4.05-4.4 mill. yr	OMO GROUP	MURSI FM. (148m)	Mb. IV	Basalt
				Mbs. I-III	Deltaic, littoral alluvial
Upper Pliocene		(Downwarping and downfaulting of Omo Basin and Rudolf Rift, one or more major episodes)			
Lower Pliocene to Lower Miocene		(Repeated volcanic episodes with massive basalt and rhyolite extrusions over pre-existing erosional surfaces developed on the Basement Complex; followed by cutting of one or more planation surfaces)			

2.3.2 Major Structures

Brown and Nash (1976), noted that the East African Rift (Fig. 2.2) plays at best a subsidiary role in the structural evolution of the lower Omo basin. They also reasoned that the origin of the basin must lie in time between 12 M.Y (the youngest dates on the Turkana lavas) and about 4.5 M.Y (roughly the age of the basal sediments of the Mursi formation) which may be broadly coincident with the initial stages of formation of the Main Ethiopian Rift (Fig.2.2).

Based on different lithological and structural evidences (Heinzelin. 1982) postulated deposition in a subsiding basin. Altogether about 1km of sediments were accumulated in the lower Omo basin as it subsided. This filling continued with minor tectonic activity (except the subsidence) near the center of the basin until about 800,000 years ago.

In the Southern part of the lower Omo basin. the major structures parallel the major topographic features. and have an orientation which is more or less North-South (Brown and Nash, 1978). From East to West. these are the fault system forming the Western boundary of the lake stephanie (Chew Bahir) graben, the major fault bounding the Labur range on the East, the fault system which bounds the Lorientom and Kacheriangorr ranges on the East, and the fault which bounds the Lokwanamoru range on the East. All of

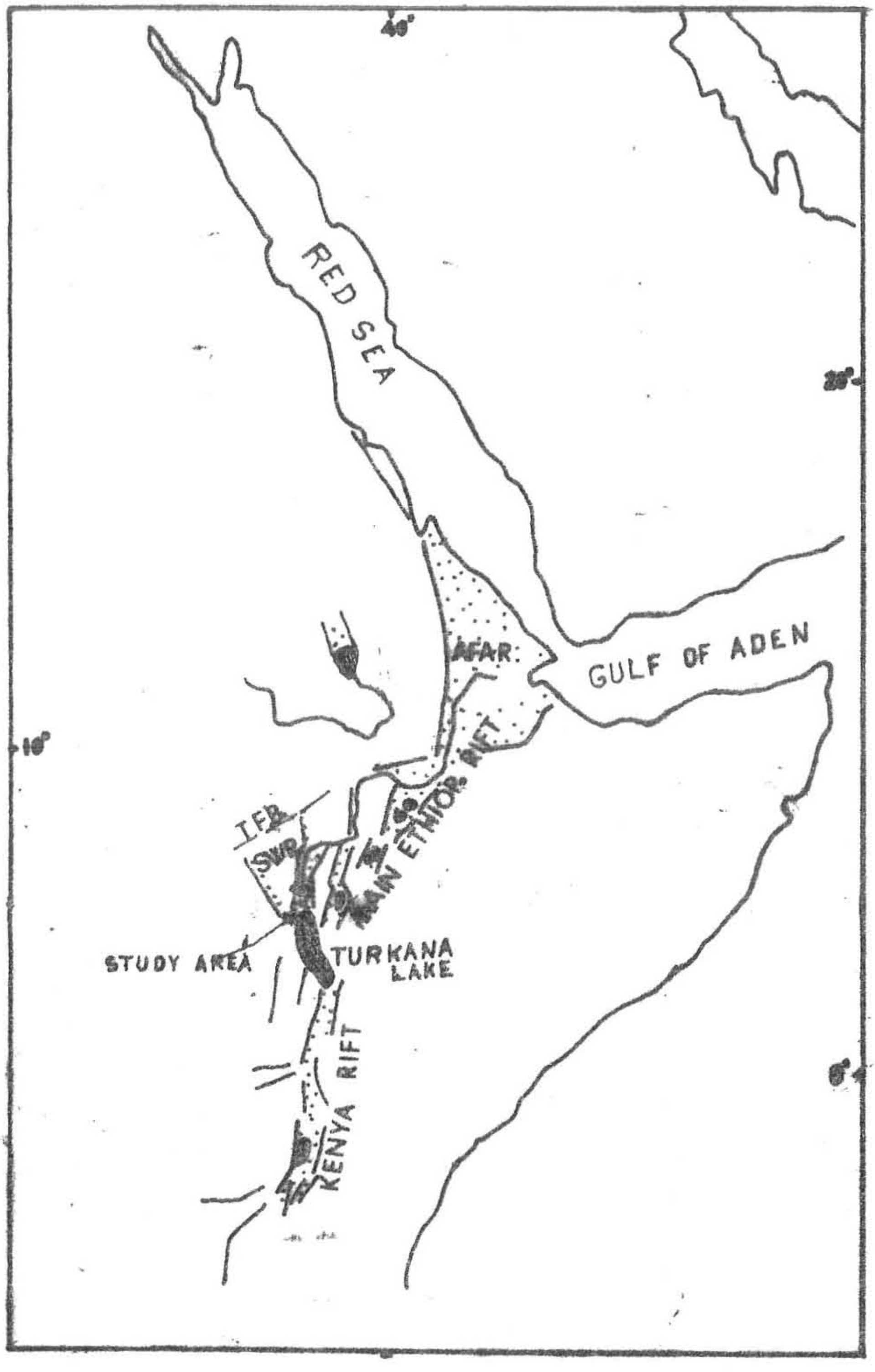

Fig. 2.2 The East African Rift System
TR, Turkana Rift ; SWR, South Western Rift
TFB, Tepi Fault Belt

these faults are normal and dip steeply to the East with the possible exception of the fault bounding the Labur range (Heinzelin, 1982).

The Eastern margin of the basin is formed by a tilted surface developed on metamorphic rocks, with major movements probably occurring along the faults which bound the Labur range and the Lorientom range (Heinzelin, 1982). These faults are arranged in enechelon fashion. The western margin of the basin is formed by the volcanic mass of Lorientom, which was probably a major volcanic center, a good portion of which is now down faulted and covered by younger alluvium, and which is presumed to have thinned to the East (Heinzelin and brown, 1969). The faults along the southern boundary of the Nkalabong probably had their major offsets at about this time, also resulting in a trapezoidal area in which sediments were deposited by the Omo and Usno river without evidence of tectonic disturbance for about 4 M.Y (Heinzelin, 1982).

From about 4.5 M.Y ago to about 0.8 M.Y ago, the sediments of the Mursi, Usno, and Shungura formations were deposited in the vast depression formed by the preceding tectonic activity. These formations consist of fluvial and lacustrine sediments.

The Mursi formation is capped by a lava flow (basalt) dated at about 4.2 M.Y.

In the lower Omo basin the only Volcanic feature which postdates the older Plio-Pleistocene formations is the Korath range on the divide between Sanderson's Gulf and the modern course of the Omo river. The lavas of the Korath range are basanites and tephrites of upper Pleistocene age.

After considering presence of many faults (mainly trending N-S) and folds in the Shungura formation, Brown et al.(1976) postulated their relation with a major fracture supposed to involve basement rocks of greater competence than the overlaying sediments. This major fracture is assumed to lie near the western margin of the flood plain of the Omo river. The faults which break up the Shungura formation are viewed as synthetic faults along the eastern bounding fault of a horst developed just west of the present flood plain of the Omo river. Another fault on the eastern margin of the flood plain, is also thought to be present. A displacement of 250m is necessary on this supposed fault (Brown and Nash, 1976). Evidence for such a fault is provided by the large metamorphic block found along the escarpment at the eastern margin of the usno formation, and by the fact that a large area of hot springs and geyser pools occurs at this boundary as well- (Brown and Nash, 1976).

As a brief summary, sometimes between 800,000 and 100,000 years ago, the deposits of the Mursi. Usno, Shungura and Bume formations were deformed by faulting with the creation of a horst or titled block along the axis of the basin (N-S). The strata of the Shungura formation were eroded following the event, and later deposits of the kibish formation were laid down on the eroded topography of the Shungura formation and also further north on the Usno and Mursi formation. These deposits too are faulted. Though not very extensively.

2.4 Seismicity

Due to its location in the vicinity of recognized seismically active tectonic feature, namely the Main Ethiopian Rift system (fig. 2.2), this area has experienced the effect of severe earth quakes throughout its history. Fig 2.3 attests to this fact. This map classifies the epicenters by order of magnitudes equal to or above the level of potential damaging force. Gouin (1976), in his report considered magnitude 5 (on Reichter's scale) as the threshold of damage for Ethiopia. This Figure also shows which regions of Ethiopia have experienced the strongest earthquakes, which means it singles out the areas where the seismic hazards are at their highest.

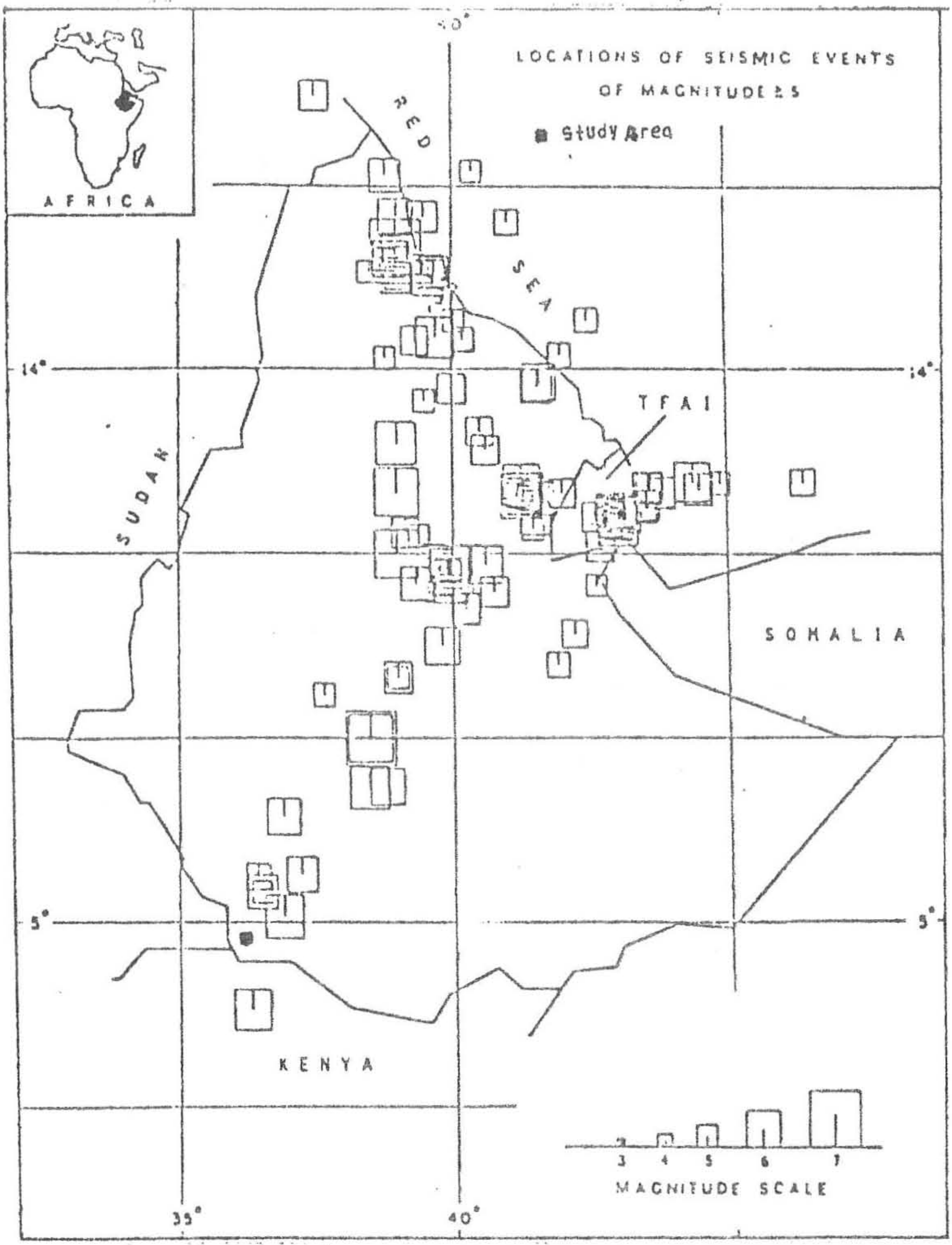

Fig. 2.3 Epicentral locations of earthquakes with magnitudes ≥ 5 in Ethiopia and surrounding areas. All sites of reported felt-intensities are eliminated. (After Gouin, 1976)

In his report Gouin also gave seismic hazards map of Ethiopia, which shows the distribution of predicted intensities based on a 100 years recurrence period and on a 1% annual probability that the maximum values will be exceeded (Fig. 2.4), computed by considering (assuming) solid ground condition only. However, it is a common opinion that rocky and semi-rocky unweathered soils are the least affected by earth tremors while hazards are much higher on unconsolidated soils and on major fault belts than on solid rock (see Fig.2.5). Based on this opinion, Gouin (1976) recommended that the predicted intensity values on his map (Fig 2.4) be upgraded by one unit in the case of average soil conditions (not too well consolidated formations) and by two units in the case of water saturated, sandy or loamy soils. Thus interpretation of this map for the study area yields grade IX or X instead of grade VIII shown on his map. It can be easily looked up on the Mercalli Modified Intensity Scale (MMIS) (Table 2.2) what amount of damage is attached to this intensity grade hence in accordance with the Table 2.2 which also shows a correlation of the Modified Mercalli Intensity scale with those proposed for ground acceleration by Cancani-Sieberg and Richter. it is considered that the seismic design for grade "IX " would be the maximum possible for engineering purposes since grade "X" is considered catastrophic (Zeevaert, 1983). The ground wouldn't support construction in a satisfactory way, even if the construction could be designed for an earth quake of such

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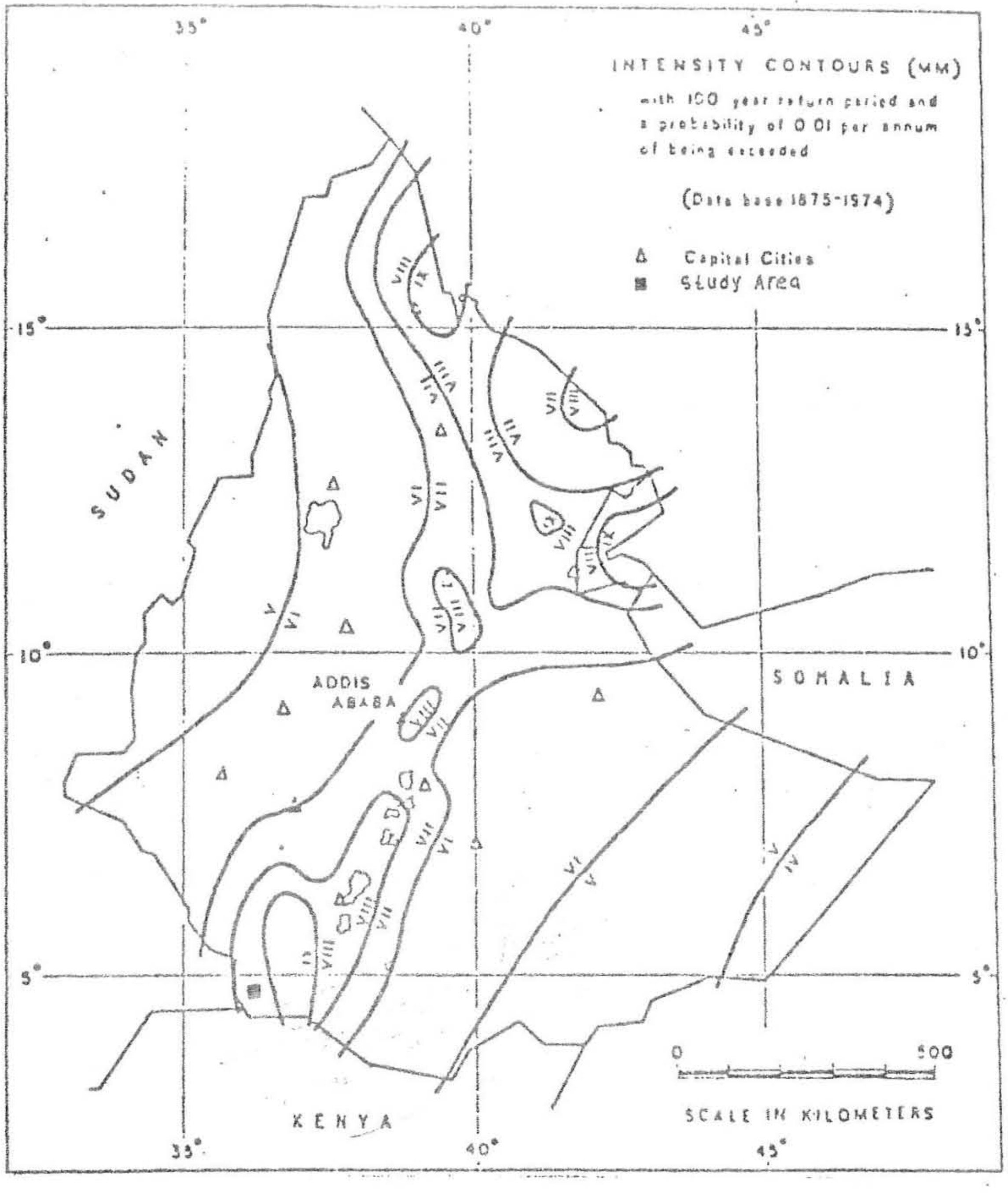

Fig- 2.4 Predicted Intensity map of Ethiopia based on a 100-year recurrence period and on a 1% annual probability that the maximum values will be exceeded.
(After, Gouin, 1976)

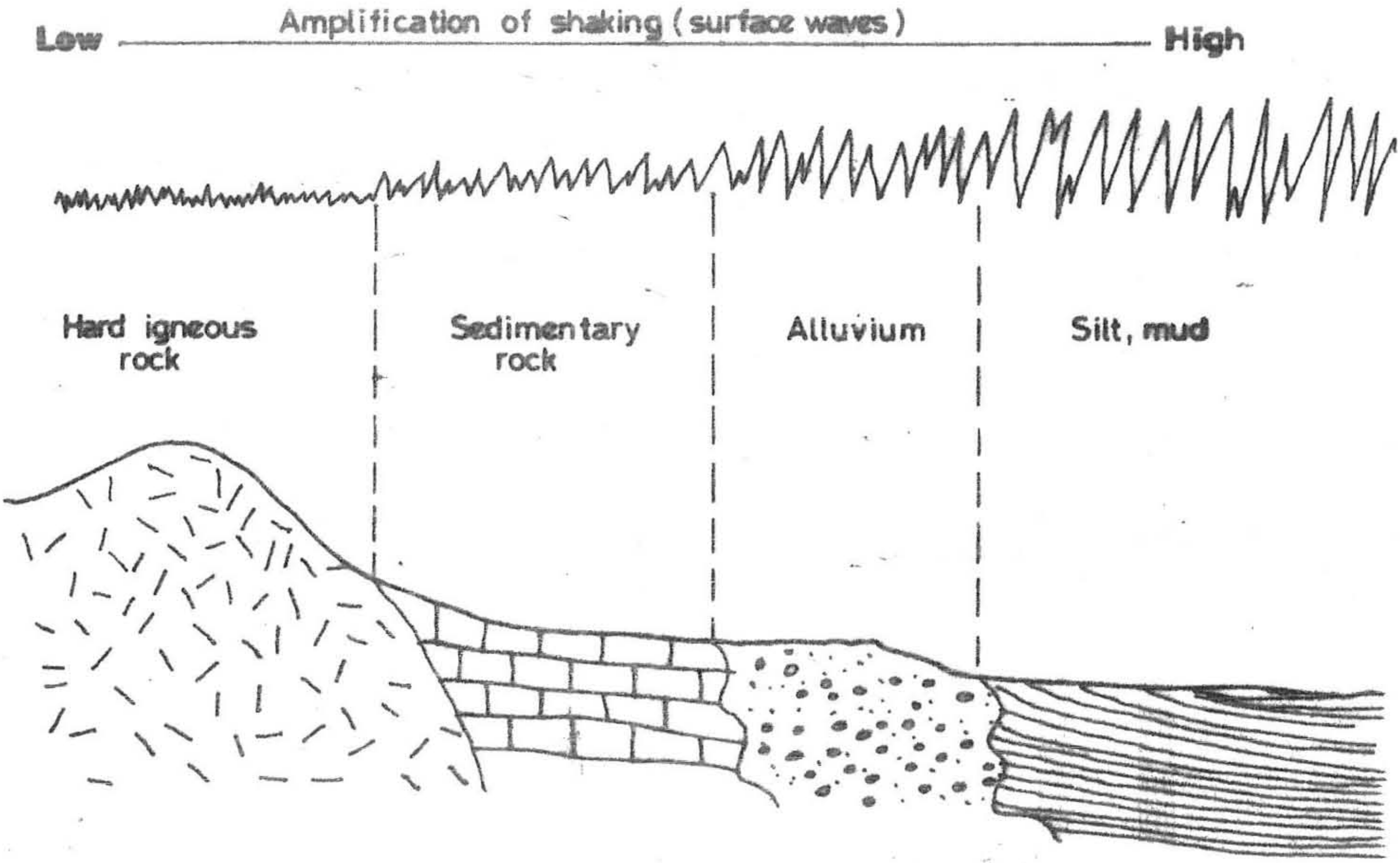

Fig. 2.5 Generalized relationship between near surface earth material and amplification of shaking during a seismic event.
(After, Keller, 1985)

Table 2.2 Mercalli Modified Intensity scale

Intensity	Effects	Acceleration in mm/sec²	
		Cancani-Sieberg	Richter
I	Not felt except by a very few under especially favorable circumstances.	5	7
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	10	13
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.	25	30
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.	50	70
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.	100	150
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	100 - 250	300
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.	500	700
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.	500-1000	1500
IX	Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	1,000	3,200
X	Some well-built wooden structures destroyed; most masonry and frame structures with foundations destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.	2,500	6,750
XI	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	5,000	15,000
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.	10,000	32,000

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XI	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	5,000	15,000
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.	10,000	32,000

magnitude. since there will be subsoils that will fail because of the shear forces induced in them before reaching these high accelerations.

3. Local Geomorphology, and Geology

3.1 Local Geomorphology

The main geomorphic features of the study area are the meandering channel of Omo river with its natural levee, point bars, scarp and a flood out let channel (locally called Kolum) in the west of the study Area. With its generally less than 1% slope. the area is crisscrossed by many dry river channels some of them having subdued natural levee while some are filled with silty material to be barely distinguishable from their surroundings. In addition to the network of channels, sinkholes with diameters of 1 to 3 meter and depths reaching 4 meter (see Plate 1 and 3) and cracks of 10 to 100 meters long and 1 to 2 meter deep (see Plate 2) abound in the area. Characteristic only to the southern part of the study area are some patches of small round dunes (having 2 meter diameter and about 1 meter height) naturally stabilized by vegetation.

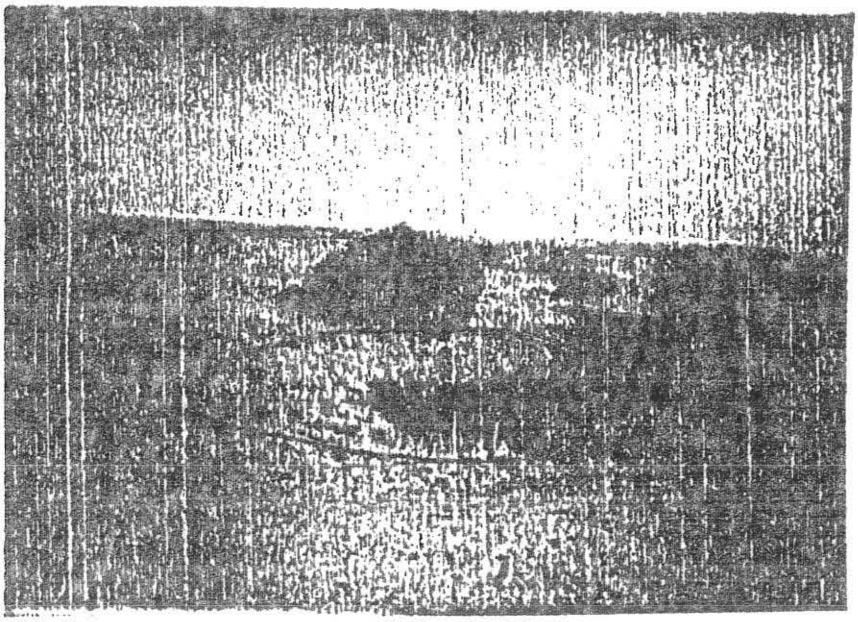


Plate - 1 An example of a sinkhole in Omorati area

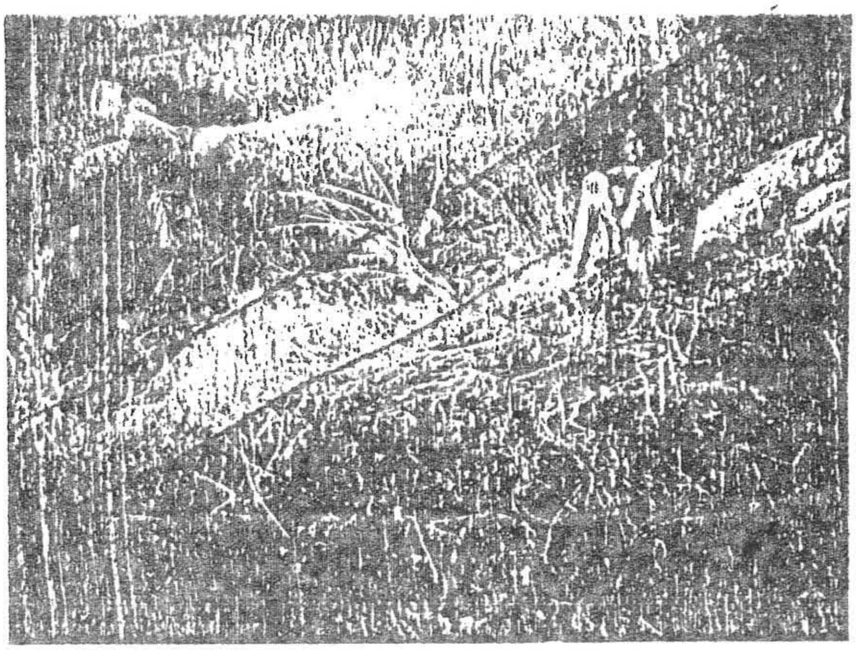


Plate - 2 An example of a cracked ground in Omorati area

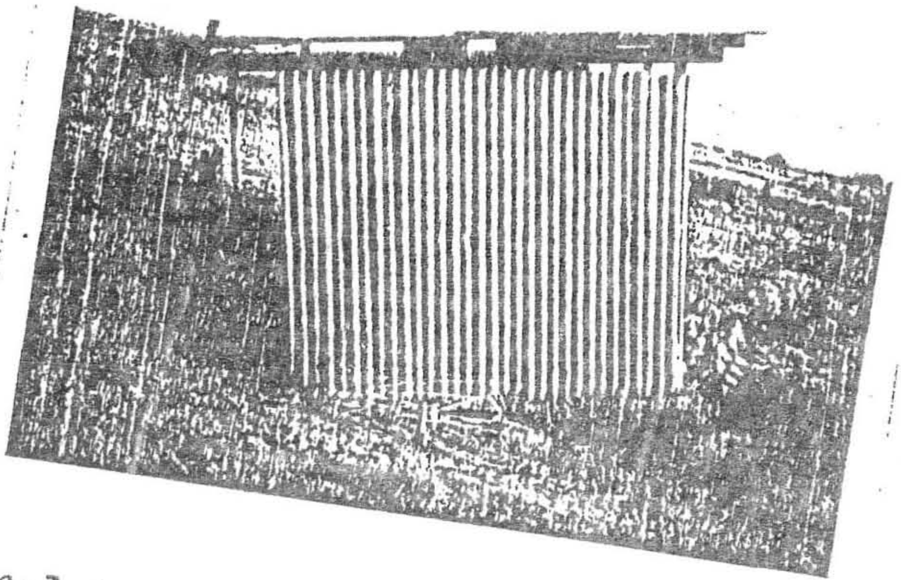


Plate- 3 An example of a toilet tilted due to ground collapse under it in Omorati

3.2 Local Geology

The study area totally lies in the subrecent flood plain of the Omo river and the characteristics of the soils of the area is typical of this depositional environment to at least the depth of investigation (3m). Associated with flood plain environment of deposition are found meander belts, natural levee, point bars, flood basins (back swamps) with gathering streams and numerous abandoned channels. Some of these, such as meander belts and natural levees can be distinguished by their geomorphic feature and others such as backswamps (although they are completely drained now) are inferred from characteristics of soils typical to this environment. Evidently the fluctuation of the Turkana lake level has had a great influence on the depositional history, disposition and characteristics of the subsurface sediments of the study area in particular and lower Omo basin in general. According to Butzer (1970) the deposits around the study area are described as a young (Holocene) and modern features of the Omo delta and contemporary flood plain of the Omo river. Thus, although not exposed at the surface, presence of the deltaic deposits can be inferred at deeper levels in the Study Area.

The following main lithological types have been distinguished in the study area, during the field investigation based on observation of profiles in 20 pits dug to 3 meter depth.

I. Clays of dark brown to dark grayish brown with reddish mottling and sometimes dark bluish tints, highly cracked, columnar to prismatic and sometimes subangular blocky and usually contain semi-decomposed rootlets. These soil types are typical of a formerly backswamp environment of a flood plain.

II. Silty Clays and Clayey Silts: at the surface this unit is mainly found along dry channels as a channel fill material. Based on the field lithological description, it has been subdivided in to the following sub types.

IIa. Silty clays: yellowish brown to dark yellowish brown with reddish yellow and black mottling. usually granular to columnar structure but sometimes subangular blocky, contains some vertical root holes and sometimes charcoal like inclusions are present.

IIb. Clayey Silt: Yellowish brown to dark yellowish brown usually platy structure but sometimes may be subangular blocky, numerous vertical root holes are present, and is highly porous. It has many features similar to loess like soils and is considered to be collapsing soil.

III. Sandy Silts and Silty Sands: The surface distribution of this lithological type is limited to the southern and south western parts of the study area not very far away from the western bank of the Omo river. This unit has also been subdivided into two subtypes based on the field description as follows.

IIIa. Sandy silts: dark yellowish brown, homogenous, loose to slightly cemented, with lot of micas, quartz and feldspars.

IIIb. Silty sands: dark yellowish brown, interstratified with small scale cross beds at some places, loose, angular, well sorted (poorly graded) containing lot of micas, quartz, feldspars and some heavy minerals.

The above described lithological types (see also Table 3.1) are found in different stratigraphic order from place to place and are characterized by lensing and thickness variation both laterally and in the vertical direction (Fig 3.1). Observation of two geologic borehole log data near the eastern bank of the Omo river (drilled by Ethiopian Water Wells Construction Authority, EWWCA) reveals that the above lithological types may prevail to at least 20 meter depth in the study area. The layout of the 20 observation pits and 2 boreholes and profiles in each are given in Appendix 1.

Table 3.1 Lithological Description of the Identified Lithological types

General lithological description of the lithological types	Lithological type	Decription of the lithological sub-types	Lithological sub-types
CLAYS: Dark brown to dark greyish brown with reddish mottling and sometimes dark bluish tints, highly cracked, columnar to prismatic and sometimes subangular blocky structure. Semidecomposed rootlets are common. These are typical of formerly back swamp deposits.	I	-	
SILTY CLAYS and CLAYEY SILTS: Yellowish brown to dark yellowish brown sometimes with reddish yellow and black mottling, with columnar, subangular blocky, granular or platy structure, vertical root holes are present and sometimes they contain charcoal like inclusions. It has many features similar to loess like soils and is considered to be collapsing soil.	II	SILTY CLAYS: Yellowish brown to dark yellowish brown, with yellowish red and black mottling, usually granular to columnar structure but sometimes subangular blocky, some vertical rootholes are present, they also contain some times charcoal like inclusions	II a
		CLAYEY SILTS Yellowish brown to dark yellowish brown, usually platy structure showing fissility but sometimes subangular blocky, numerous vertical root holes are present and is highly porous.	II b
SANDY SILTS and SILTY SANDS: Dark yellowish brown homogeneous to interstratified sometimes with smalll scale cross beds, mainly composed of angular and well sorted grains of quartz, feldspars, micas and some rockfragments and heavy minerals	III	SANDY SILTS Dark yellowish brown, homogeneous, loose to slightly cemented, containing lot of quartz, feldspars and micas	III a
		SILTY SANDS Dark yellowish brown, interstratified with small scale cross beds at some places. loose, contains angular well sorted grains of lot of quartz, feldspars, micas and some heavy minerals.	III b

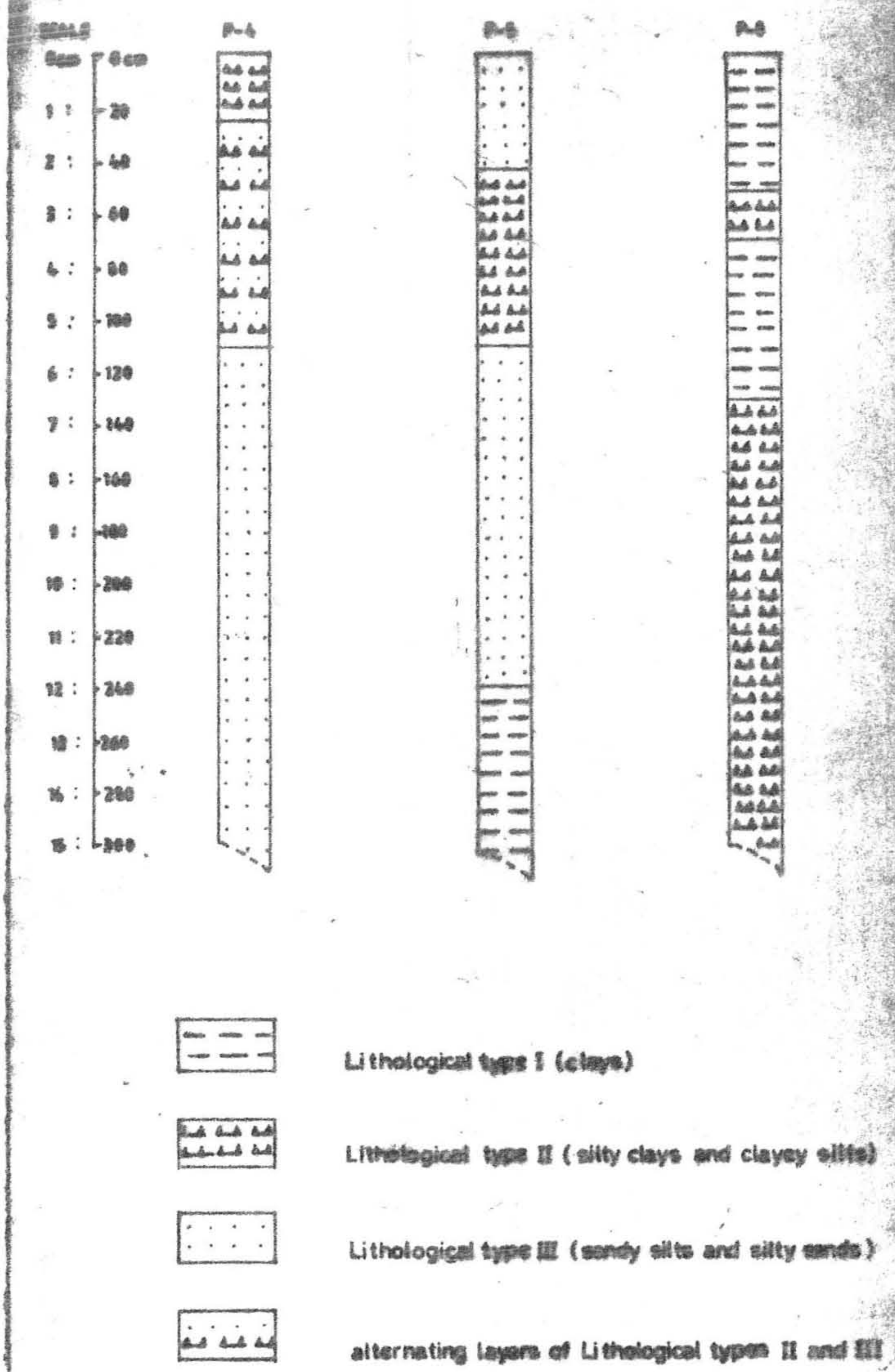


Fig. 5-1 Representative lithological profiles

4. Climate, Hydrology and Hydrogeology

4.1 Temperature, Precipitation, Evaporation and Run-Off

The lower Omo basin, including the study area has a semi-arid tropical climate (Butzer, 1970). In the absence of any climatic data for Omorati, an extrapolation of climatic observations made in 1975-77 at Kelem area (an area 7km far to the west of the study area, formerly police post but now abandoned) gives a mean monthly temperature range of 22°C to 25.5°C. (Table 4.1) Maximum daily temperature could reach up to 38°C. The coolest months are September and October. From the Isohevtal map of the area (Fig 4.1), a mean annual precipitation of less than 300 m.m can be inferred. Rainfall comes primarily in the form of thunder showers at intervals between late March and early June, supplemented by further but unreliable rains in July- August and October- December (Butzer, 1970). Incomplete records of monthly distribution of evaporation at Kelem for the years 1975-1977 (table 4.2) also shows an evaporation range of 189 to 350 m.m. The mean monthly run-off of the Omo river from this observation is 18908.27 million m^3. The discharge of Omo river starts gaining in June reaches its peak in August and starts to subside again. The high discharge months are coincident to the rainy seasons of the highland areas from which the Omo river originates and flows through.

Table 4.1 Monthly Distribution of Temperature at Kelem. o4 38' Lat. and 36 05'Lon
(Source - Water Resources Development Authority, WRDA)

	1975 Temperature (oC)			1976 Temperature			1977 Temperature			Average 1975 - 77 Temperature		
Month	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
Jan.	-	-	-	-	-	-	36.2	23.3	29.8	36.2	23.3	29.8
Feb.	-	-	-	-	-	-	37.6	22.9	30.3	37.6	22.9	30.3
Mar.	-	-	-	36.0	24.7	30.4	37.6	24.5	31.1	36.8	24.6	30.8
Apr.	-	-	-	35.9	22.3	30.4	34.9	23.8	29.4	35.4	23.1	29.3
May	-	-	-	35.9	23.7	29.1	34.4	23.1	28.8	35.2	23.4	29.3
June	38.6	23.8	31.2	35.5	21.5	29.8	35.4	23.6	29.5	36.5	23.0	29.7
July	37.7	23.3	30.0	34.2	22.7	28.5	-	-	-	35.5	23.0	29.3
Aug.	36.3	25.0	30.6	23.5	29.3	28.5	-	-	-	35.7	24.3	30.0
Sept.	35.6	24.4	30.2	23.2	29.0	-	-	-	-	35.2	23.8	29.6
Oct.	34.6	22.7	28.6	23.9	30.0	-	-	-	-	35.3	23.3	29.3
Nov.	-	-	-	23.3	29.6	-	-	-	-	35.9	23.3	29.6
Dec.	36.9	22.9	22.9	24.6	30.6	-				36.8	23.8	30.3

Table 4.1 Monthly Distribution of Temperature at Kelem. o4 38' Lat. and 36 05'Lon
(Source - Water Resources Development Authority, WRDA)

	1975 Temperature (oC)			1976 Temperature			1977 Temperature			Average 1975 - 77 Temperature		
Month	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
Jan.	-	-	-	-	-	-	36.2	23.3	29.8	36.2	23.3	29.8
Feb.	-	-	-	-	-	-	37.6	22.9	30.3	37.6	22.9	30.3
Mar.	-	-	-	36.0	24.7	30.4	37.6	24.5	31.1	36.8	24.6	30.8
Apr.	-	-	-	35.9	22.3	30.4	34.9	23.8	29.4	35.4	23.1	29.3
May	-	-	-	35.9	23.7	29.1	34.4	23.1	28.8	35.2	23.4	29.3
June	38.6	23.8	31.2	35.5	21.5	29.8	35.4	23.6	29.5	36.5	23.0	29.7
July	37.7	23.3	30.0	34.2	22.7	28.5	-	-	-	35.5	23.0	29.3
Aug.	36.3	25.0	30.6	23.5	29.3	28.5	-	-	-	35.7	24.3	30.0
Sept.	35.6	24.4	30.2	23.2	29.0	-	-	-	-	35.2	23.8	29.6
Oct.	34.6	22.7	28.6	23.9	30.0	-	-	-	-	35.3	23.3	29.3
Nov.	-	-	-	23.3	29.6	-	-	-	-	35.9	23.3	29.6
Dec.	36.9	22.9	22.9	24.6	30.6	-				36.8	23.8	30.3

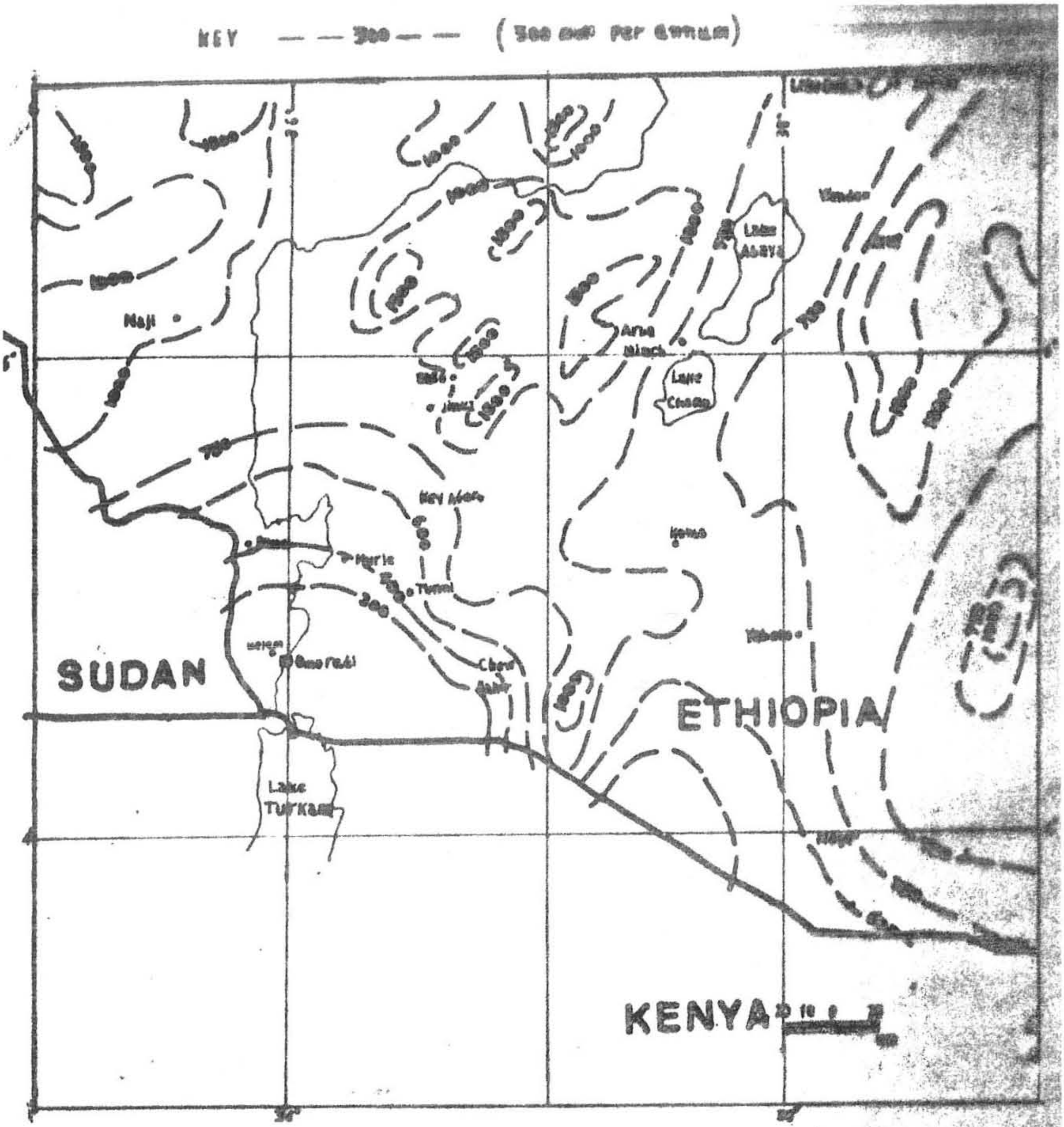


FIG 6.1 *ISOHYTALS* of South-Western Ethiopia

Table: 4.2 Monthly Distribution of Evaporation at Kelem (mm)
(Source - W.R.D.A)

Lat.04. 38
Lon. 36 05

Year	Jan.	Feb.	Mar.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1975	-	-	-	-	-	-	-	255.52	232.41	-	-
1976	-	-	240.79	142.12	214.12	209.30	268.99	250.50	284.48	183.72	329.95
1977	262.64	289.05	216.66	194.06	189.23	-	-	-	-	-	-

4.2 Ground Water Occurrence and Quality

Very few studies available, aimed at exploitation of ground water in Omorati area, indicate the existence of stratification of water salinities. where fresh and saline waters are sandwiched on top of each other (Redo Barna, 1982). Although no borehole data is available for the area west of the Omo river, from the few boreholes dug by Ethiopian Water Wells Construction Authority (EWWCA) on the eastern side it can be inferred that the ground water level in this area is deep (greater than 15 meter) and the ground water is most of the time salty (non potable) especially from deeper levels. However one VES (Vertical Electrical Sounding) data made by EWWCA at approximately 30 meter east of the eastern bank of Omo river gives an indication of fresh water aquifer at 5.5 - 15m depth. May be recharge from Omo river could be the reason for this.

4.3 History of Turkana Lake Level Fluctuation

At its highest level, about 80m above the present level (Davidson et al., 1983) ancestral lake Turkana was able to overflow through a low divide south west of Kibish settlement to the Nile drainage system (Fig 4.2). According to Butzer (1970), over flow level was last reached toward the end of the time of deposition of member IV of the Kibish Formation, about 3250 years ago. At some stage between this time and the present. the lake retreated and then

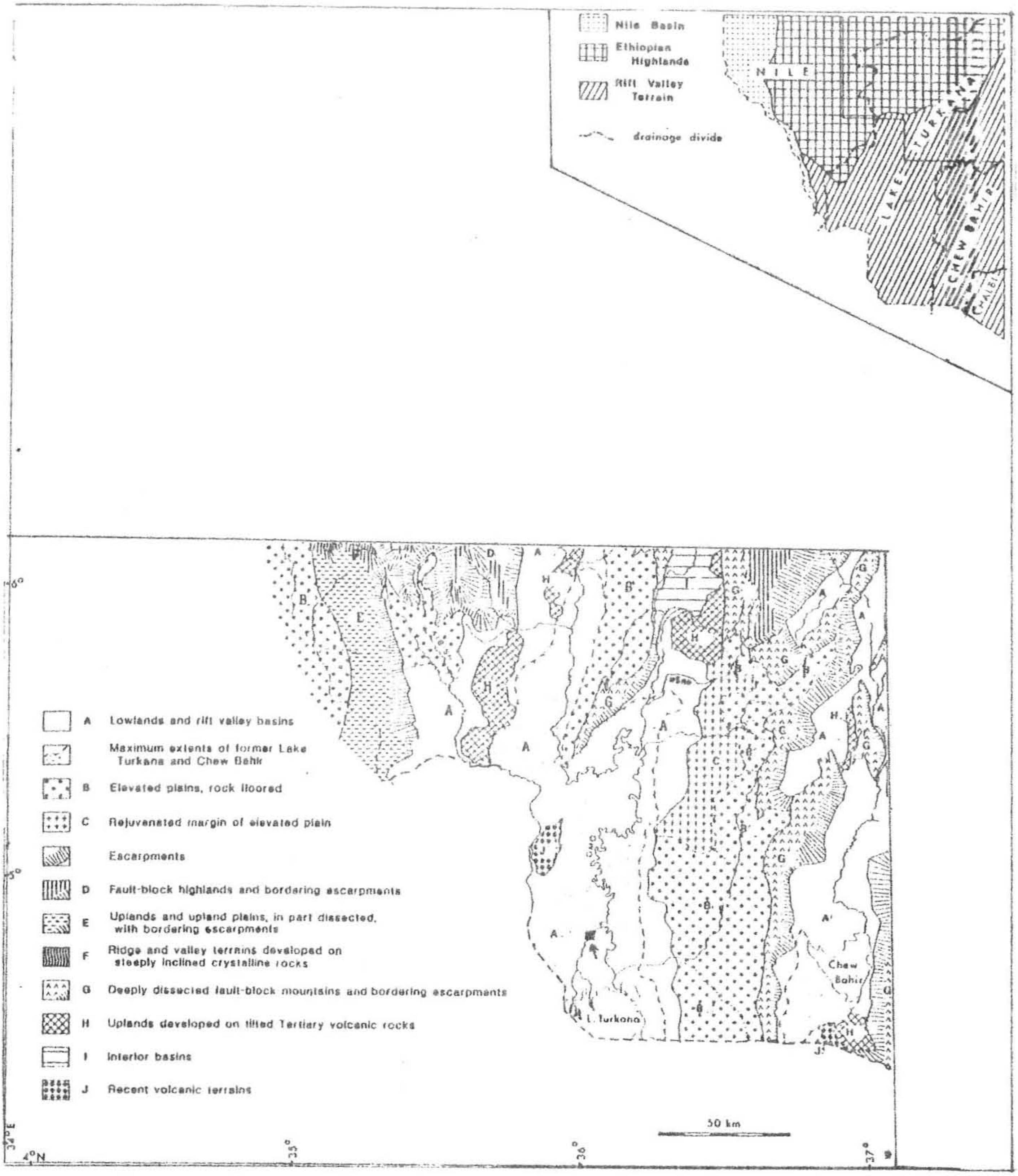


Fig. 4.2. Maximum extents of former lake Turkana and physiographic divisions in the Lower Omo basin and surrounding areas (After, Davidson, 1983. With some modification).

rose again, perhaps by as much as 40m enough to flood north ward along the east side of the Turkana depression in to the Usno plain (Fig. 4.2). Lacustrine sediments of this stage, named the Murle lake stage by Butzer (1971a), are now exposed in the banks of the Omo river south of the Usno river confluence.

Different source (Tamre Hawando, 1988) indicated that Turkana lake level in 1888 was 9 or 10m higher than the lake level in 1970. In 20 years time (starting 1888 up to 1908), the lake level went down and was only 2.5m higher than its level in 1970. Although from 1917-1918 (two years) the lake level rose a limited height but up to 1961 it decreased and was 4.5m below its level in the 1970 from 1961-1970. it rose up again and reached the lake level of 1970.

From 1898 up to 1955 (57 years) due to the retreat of Turkana lake Shore all in all 800km² land formerly under the lake emerged. However from this 800 km² land the 350km² was again submerged in the years 1961 up to 1965 (Redo Barna, 1982).

According to an interview with local people, it was noted that places high up from Omorati down to the present Turkana lake was covered by a shallow water around 1960's and remained covered for about 3 months and communication to the area was interrupted. Hence supplies to the police guards posted at Kelem area (now left out in 1972) were distributed by helicopters.

After distinguishing, upper, middle and lower delta plains on the basis of recent submergence (Fig. 4.3). Butzer (1970) noted that, upper and middle plains of the Omo delta as being repeatedly submerged during the nineteenth century, after which they were reduced to a marsh and finally drained after about 1908. While the lower delta plain emerged only as late as 1921. (Note that the study area lies near the border line between middle and lower delta plains).

Based on different observations of shifting of Omo river course through out its history (Davidson et al., 1983) believe that variation in rate and place of tectonic activity through time, in addition to climatic factors has played a definite part in the changing position of lake Turkana shore line with in this rift basin.

Today the study area is at 380m above sea level, which is only about 5m above lake Turkanas' ever changing shore (375m above sea level) lying only 20km far to the south of the study area. With this gradient 25 cm/km infact very little north ward tilt is enough to bring about inundation of this area by lake Turkana. Coppens etal. (1976) estimated that an increase of 10m in the lake level will extend the present Turkana as much as 40 km further

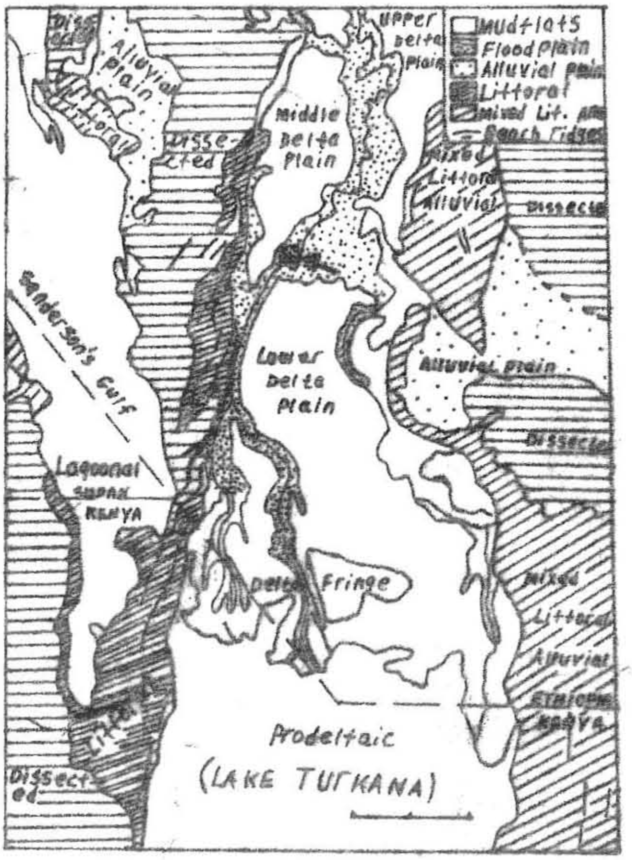


Fig. 4.3 Recent depositional environments of the Omo delta (After, Butzer, 1970)

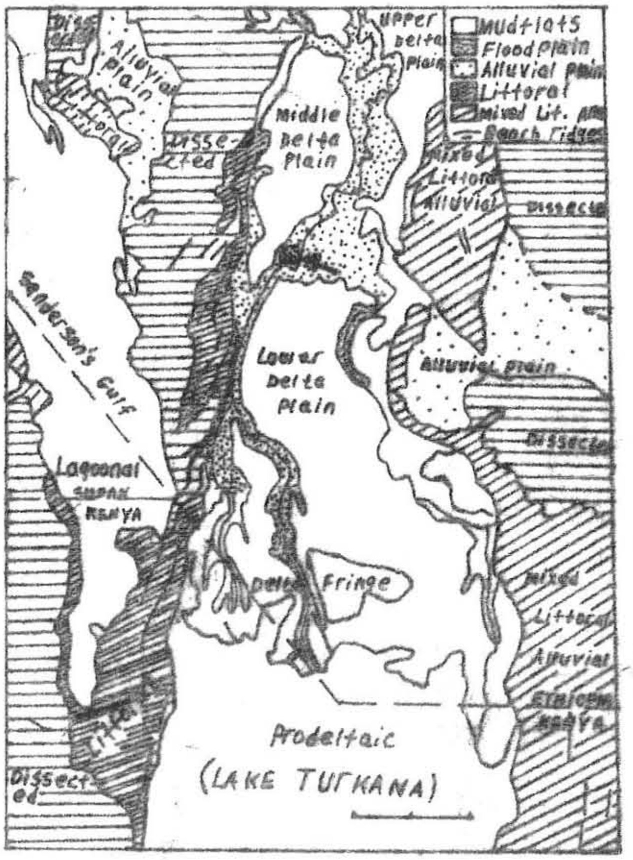


Fig. 4.3 Recent depositional environments of the Omo delta (After, Butzer, 1970)

north. Hence the study area being only 20 km far from the lake shore. it is highly probable that it may be inundated during such events of rising lake levels.

5. Settlement and Subsidence Problem In The Study Area

5.1 The Occurrence of Sinkholes and Cracks

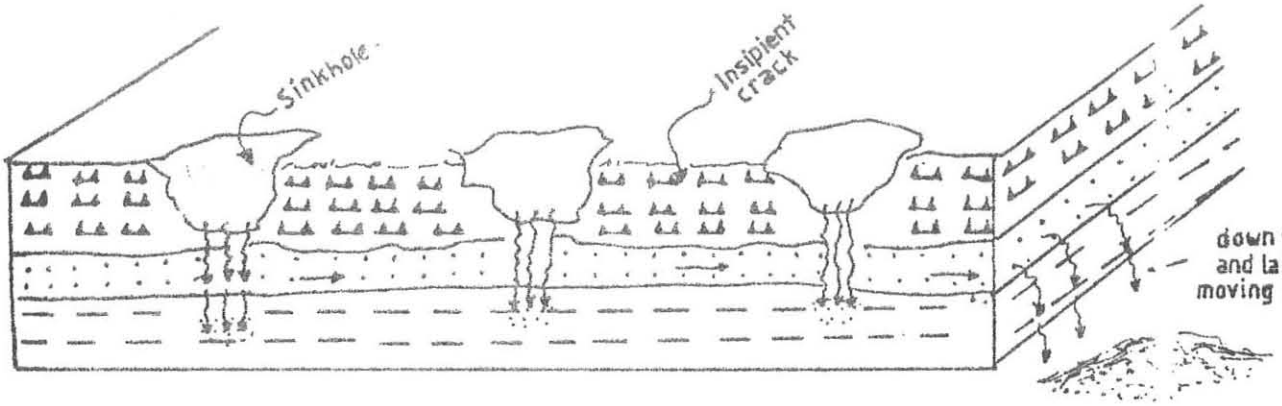
In the lower Omo basin in general and the study area in particular, a wide spread occurrence of ground cracks of (10-100 meter long and 1-2m deep) and sinkholes and sags with diameters of 1-3 meters and depth reaching 4 meter has been observed during the field investigation in the area (Plate 1 & 2). The presence of these cracks and sinkholes is also evident on the aerial photographs of the area. Comparison of two aerial photographs flown in different years, that is one in 1980 and the other in 1988, shows that some of the cracks are of very recent origin in that they haven't been observed in the 1980 aerial photograph while their presence is indicated on the later one. Occurrence of these geodynamic phenomena in the study area seems a very common one. Infact, the probability of a ground in the area to crack or collapse may be greater than not to crack, as can be observed from their density and their occurrence invariably in all types of soils found in the area. The density of occurrence of these cracks sinkholes is estimated to be 6 to 10 per square kilometer.

Interview with local people indicates that, especially after heavy rain, cracks and sinkholes are formed and sometimes it even caused a damage to cattle due to sudden ground collapse under their feet.

Close observation of sinkholes and cracks in the area shows that, at the bottom of the sinkholes and cracks, a loose, fine sand layer is present and usually sinkholes have hollows on their side wall, which sometimes extends up to other sinkholes nearby, (could be the effect of piping) such clear observation was made at one locality where sinkholes of one 4 meter deep and the other 3 meter deep and approximately 3 meter apart from each other, are connected by underground hollow opening. Another observation is that along some incipient cracks on the surface, there is an alignment of shallow sinkhole occurrences. Hence it can generally be said that, prior to occurrence of huge cracks, sinkholes are formed at different sites (due to collapsible nature of the silty soils by hydrocompaction) then underground piping through loose fine sand layers connects sinkholes at different places leading to collapse of ground in between, which forms the cracks (Fig. 5.1).

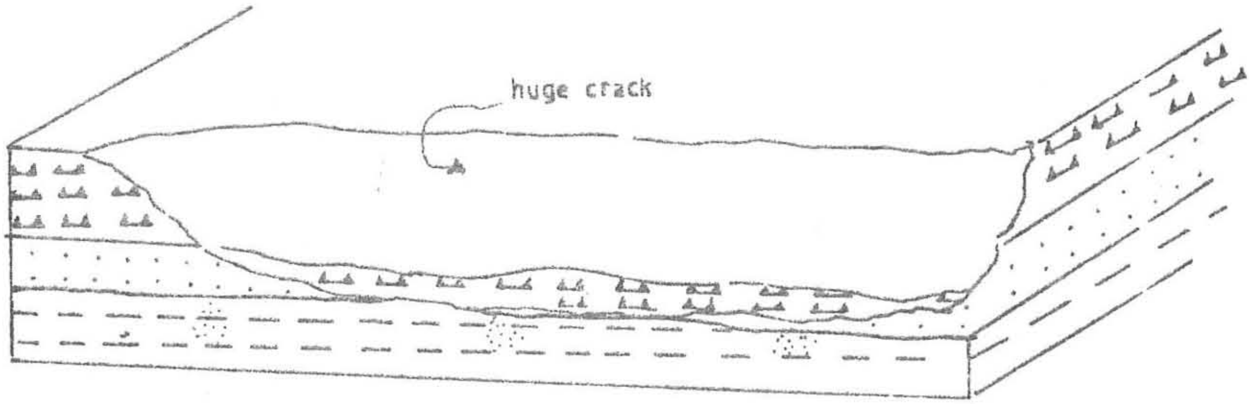
At the site of Ethio-Korean irrigation project, on the left bank of the Omo river, when water is allowed to pass through the canals, on site observation of formation of sinkholes, underground pipings and cracks within fraction of a minute has been reported (Tamre Hawando, 1988).

1)



First stage :- Formation of sinkholes due to hydro compaction of the collapssing soils and piping of the loose fine silty sand layer by down ward and laterally moving water.

2)



Second stage:- Collapse of the ground between the sinkholes due to formation of hollow (pipes) under it creates huge cracks.

clayey silts and silty clays (collapsing soils)

loose, fine, sandy silt and silty sands

highly fractured clays.

Fig. 5.1 Block diagram illustrating the mechanism of formation of sinkholes and cracks in Omorati area.

At some places in the area small dunes (circular, 1 meter high and having a diameter of 2-3 meters), which are stabilized naturally by vegetation are also present . Their presence is limited to areas covered by fine sandy silt and silty sand soil types mapped .

5.2 Probable Causes of Occurrence of Sinkholes and Cracks

In general, lowering of the ground surface can be accomplished by settlement or subsidence (Howard et al., 1978). Settlement results from compaction of the ground by loads naturally or artificially imposed upon them; subsidence is collapse of the ground due to development of subsurface voids or reduction in volume of subsurface materials either naturally or artificially.

5.2.1 Settlement, Nature, Causes

Compressible soils of low strength are most susceptible to settlement during and after the placing of loads upon them, such soils include peat and other organic materials, clays, silts and some other coarser grained sediments and artificial fill materials that were insufficiently compacted when emplaced. Thus settlement has been most common in depositional environments that include deltas, flood plains, tidal flats, old lake bottoms, and other areas of loose sediments.

Settlement also may result from compaction of water saturated sediments as additional sediments accumulate above them , and it may continue long after such deposition ceases. The included water is forced else where, and the sediment becomes more tightly packed, such changes can be initiated or hastened if fill or heavy structures are placed on the surface.

5.2.2 <u>Subsidence, Nature Causes</u>

Ground subsidence results from volume changes without benefit of a superposed load. Its surface expression may be similar to that of settlement. Subsidence can occur over periods of seconds or centuries and can range from millimeters to tens of meters. Some of the causes of subsidence which may have relevance to our study area are:-

a. <u>Withdrawal of ground water</u>: The most wide spread cause of extensive subsidence is the pumping of ground water. Such fluid withdrawal from clay bearing sediments, and other loose fine grained materials leads to volume reductions. Subsidence also results

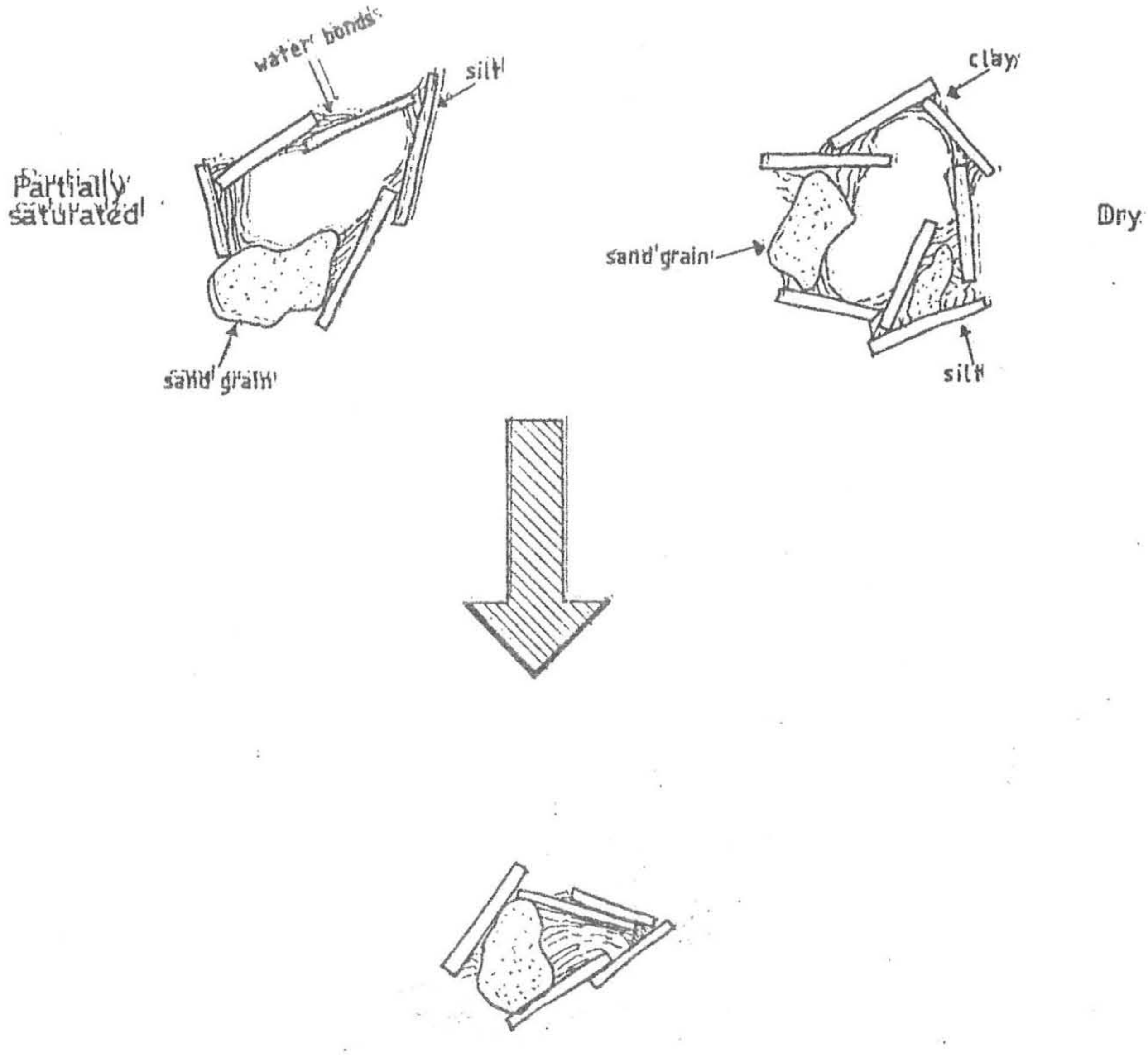


Fig. 5.2 Mechanism of collapse in a soil. The metastable fabric is maintained by water bonds or clay bonds that are broken when the soil is saturated. (After Mathewson, 1981)

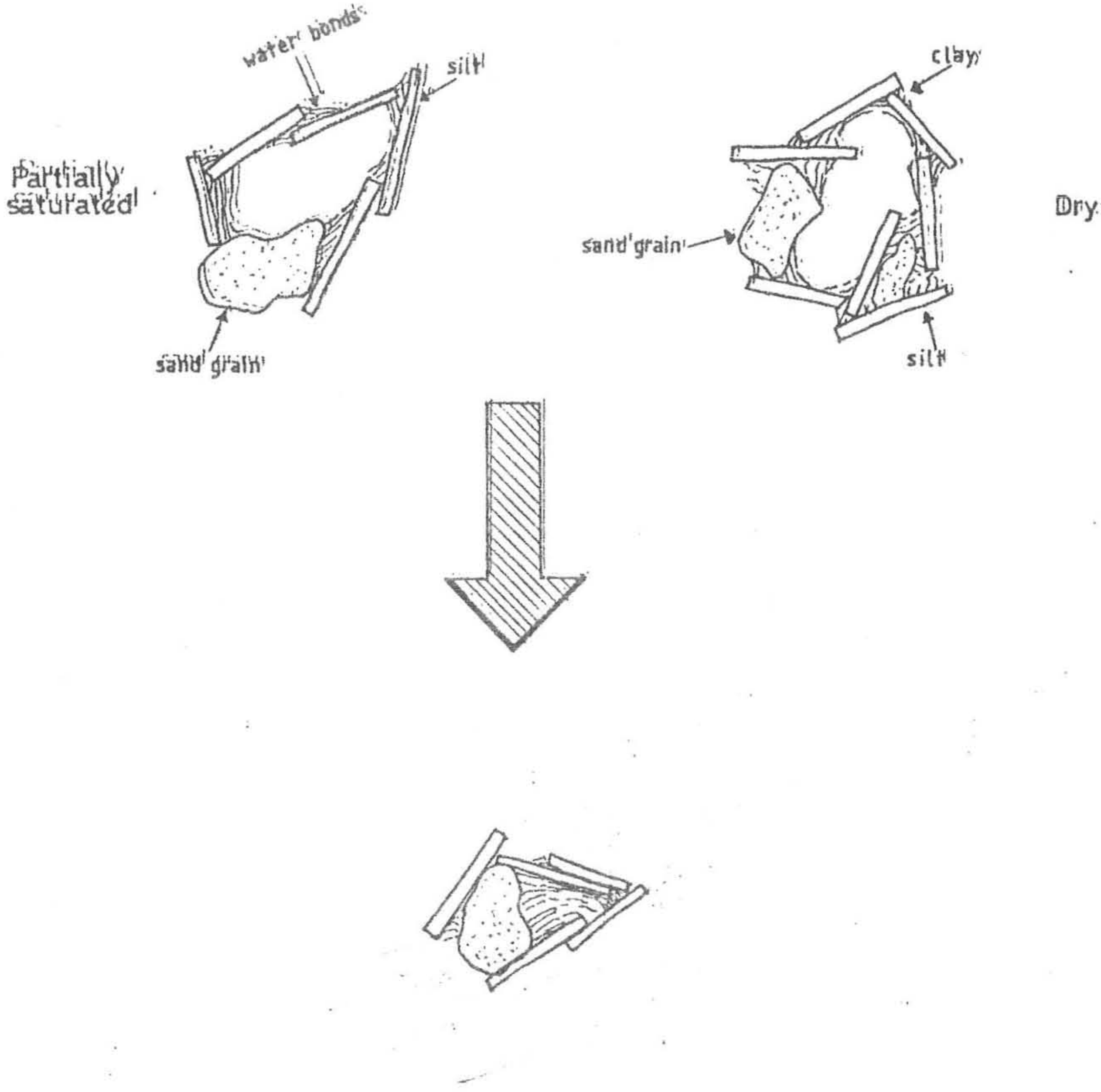


Fig. 5.2 Mechanism of collapse in a soil. The metastable fabric is maintained by water bonds or clay bonds that are broken when the soil is saturated. (After Mathewson, 1981)

example, can remove fine particles from loose subsurface passages which may be enlarged to widths of meters. The roofs of such cavities sometimes collapse to yield steep sided depression (sinkholes) or cracks at the surface.

d. Tectonic Subsidence

Earth quakes or high vibration caused by machineries.by Jostling sediments that vary laterally in porosity, may cause uneven ground subsidence. They also impart fluid like qualities (liquifaction) to water saturated silts or sands.

5.2.3 Treatment

Where ground materials are subject to volume change(collapsing soils) through hydroconsolidation or removal of fine sediments by under ground water piping care must be taken to avoid excess wetting by uncontrolled run-off or by leakage from wells, canals or faulty pipes etc. Alternatively, the ground can be thoroughly wetted and then compacted before structures are placed up on it, or other elaborate methods of soil treatment used for loesses can be employed for the collapsing soils of the study area (Table 5.1). The question here is whether it is economical to apply such treatments for every house, road allignment, ditch or other structures that are units of cities or towns. It is also known that run-off increases with urbanization mainly due to covering of ground surface by buildings and concentrated flows from roofings which could aggravate the subsidence problem. Hence run-off from house roofs should by no means be left to enter the foundation area.

Subsidence due to withdrawal of subsurface fluids can be reduced or arrested by reduction of pumping or recharging the ground with imported water. Even though this is not a problem at present in Omorati area, it can be marked as a potential hazard since in the future a trend may come that will induce people to use ground water as can be evidenced by the efforts being made, even at such very small level of urbanization in the area, to search for ground water, though it seems sufficient supply could be met from Omo river alone for every type of water consumption at present. Subsidence due to tectonic movement is usually beyond human control.

the classification tests lies in that the size range given for the three soil size grade (clay, silt, sand) by BS differs from that given by ASTM. Thus, the standard procedures available to the writer being only those of BS, while the available sieve size in the laboratory are only those compatible to the ASTM standard, it was necessary to make the following modifications on the BS procedures so as to be able to perform the classification tests as given in the Unified Soil Classification System.

1. To calculate the percent of fines the soil specimen is passed through the 0.075 mm (No 200) sieve instead of the BS of 0.063 mm. This is because the Unified Soil Classification System is based on calculation of percent of fines as the fraction passing the 0.075 mm sieve.

2. For the sedimentation analysis (hydrometer) too the materials that passed through the 0.075mm sieve was used instead of the 0.063 mm recommended by the BS. 1377: 1975, Test (7D).

Wet sieving of soils containing high amount of fraction of fines is made according to BS 1377: 1975, Test 7 (A), with the above modifications.

Determination of the plastic limit is according to BS 1377:1975, Test (3). Liquid limit by cone penetrometer method (BS 1377:1975 Test 2(A) and by one point cone penetrometer method as suggested by Clayton and Jukes (1978, fide, Head, 1984), see Appendix 2. Organic matter content is by the ignition loss method as given in Carver, (1971) based on measuring the weight loss of oven dried soil after heating it in a furnace to about 550°, expressed as percentage of the original weight. Free swell test is done according to proposition by Gibbs and Holtz (1956) fide, Head 1984 (see Appendix 3), and finally the particular instrument used for the Differential Thermal Analysis (DTA) was NETZSCH, DTA-Apparatus 404 EP/1/416/1L made in West Germany.

6.3 Laboratory Analysis and Results

6.3.1 Mineralogical and Chemical Composition

6.3.1.1 Mineralogical Composition

a. Non Clay Minerals

Determination of non clay mineral types was done only on silt and sand fractions of few samples using a binocular microscope with 63 times magnification and the analysis showed that the soils of the study area mainly consist of quartz, feldspar, micas, rock fragments and some heavy minerals such as garnet. The diagram in Fig 6.1 shows the relation between granulation and mineral composition of loesses (Rybicka and Rataiczak, 1978, fide. Grabowska-Olszewska, 1988). From this diagram it can be visualized that the share of quartz increases with increasing grain sizes and the share of feldspars is optimum in the rage of grain size 0.002 - 0.06mm. Comparison of this figure for loess soils with the soils of the study area may be justified since soils which have properties similar to loess are widespread in the study area. Particularly the soils of the lithological type II (see Chapter 3, section 3.2)

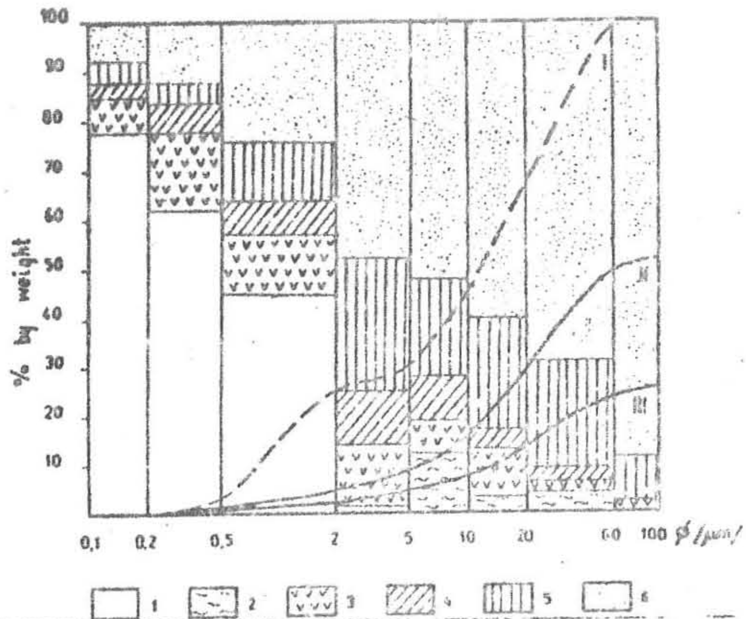


Fig - 6.1 The diagram of mineral composition

I) the curve of grain sizes

II) the curve of quartz distribution

III) the curve of feildspars distribution

1) smectite/illite, 2) chlorite, 3) illite, 4) kaol
5) feildspars, 6) quartz

(Rybicka and Ratajczak, 1978; fide Grabowska-

b. Clay Minerals

Determination of the types of clay minerals has been attempted by the method of Differential Thermal Analysis (DTA) after obtaining DTA curves for three selected clay samples. Although it can not be expected to accurately determine the clay mineral present by this method alone. never the less, the interpretation of the curves for the three samples after comparing them with standard curves given in literature (Grim 1968, Mitchell, 1976) and in the Manual of the apparatus used for the DTA analysis, indicated the presence of Nontronite in all the tested samples. In Fig 6.2 the curves are given adjacent to each other for comparison, and Table 6.1 gives the peak reaction temperatures, for each sample. obtained by the DTA.

6.3.1.2 Carbonate Content

The presence or absence of calcium carbonates on all samples was tested by dropping 10 % HCl on them. If a soil contains carbonate. it normally shows an effervescence to a drop of HCl due to a reaction taking place between the HCl. and carbonate. The strength of the effervescence can usually be an indication to the abundance of the carbonate in the soil (strong effervescence is associated with high amount of carbonates). Thus. except for the clay sample No P-20-7

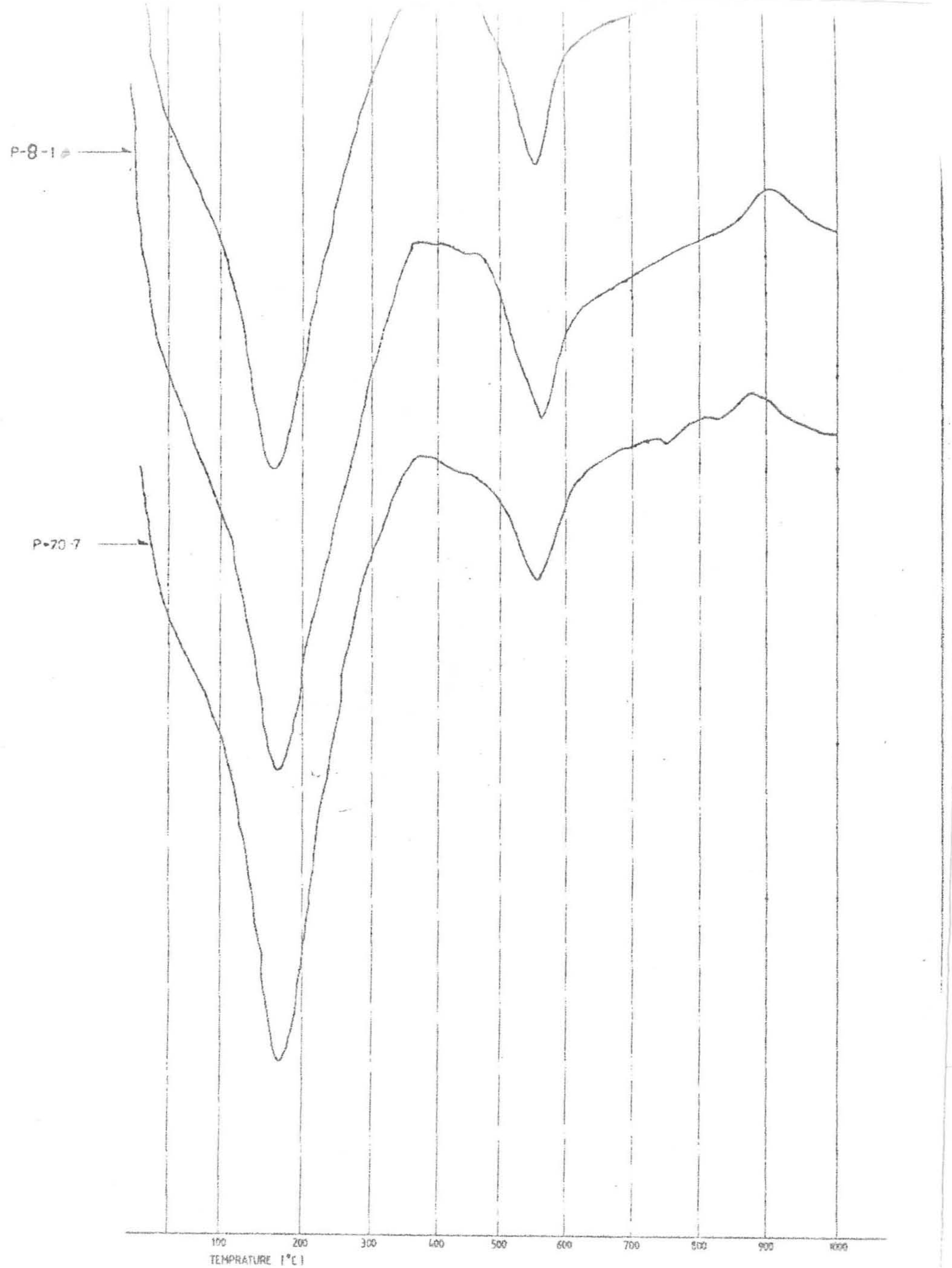


Fig. 6.2 DTA CURVES OF CLAY SAMPLES FROM OMORATI AREA

Table 6.4 Peak Tempratures of Exothermic and Endothermic Reactions of Differential Thermal Analysis of the Tested Samples

Sample No and location	Depth of sampling (cm)	Lithological description	Peak exothermic effect at (°c)	Peak endothermic effect at (°c)
P-20-7	200-300	Dark brown, fresh, intact, hard, clay moderate effervecence in HCl	172 555 750	375 875
P-[illegible]-1	0-50	Dark greyish brown, highly weathered, granular, hard clay, with many grass roots	172 565	375 900
P-16-1	0-180	Dark brown, moderately weathered granular to columnar, hard, clay with black and dark bluish mottling	172 555	458 900

collected from North Western part of the study area, at the depth of 200-300cm(see location of pit 20 in Appendix 1) which shows a slight effervescence to HCl, all the rest samples do not do so, indicating absence of carbonates in them.

6.3.1.3 Organic Matter Content

The organic matter content by the ignition loss method was determined for a number of selected samples. The results are shown in Table 6.2. The highest ignition loss value was obtained for the lithological type I soils and it is from 5.8 to 8.0%, the maximum value being 8.0.% For lithological type II soils the range is from 3.4 to 6.6% Usually, soils containing organic matter > 2% are considered as organic soils. Therefore the soils in the study area can be considered as organic soils.

6.3.2 Physical Properties

For the disturbed soil samples collected from the field, determination of the following physical properties was carried out on selected representative samples.

Table 6.2 Organic Matter Content of the Soils of Omorati Area

Sample No and location	Depth of sampling (cm)	Organic matter in %	Litholog-ical type	Litholog-ical sub-type
P-6-4	240-250	7.6		
P-7-2	100-130	**N.D		
P-8-1	0-50	8.0	I	
P-12-1	0-40	N.D		
P-14-1	0-65	7.7		
P-15-1	0-108	5.8		
P-4-1	0-25	5.3		
P-4-2	25-110	N.D		
P-7-4	205-220	4.8		
P-9-1	0-18	6.0		II a
P-11-2	30-80	6.6		
P-13-1	0-60	6.4		
P-3-5	89-139	3.4	II	
P-3-7	169-191	N.D		
P-5-2	42-107	4.1		
P-8-4	128-300	6.3		II b
P-12-2	40-62	4.6		
P-12-7	300-305	4.0		
P-16-2	180-230	3.8		

Contd.

Sample No and location	Depth of sampling (cm)	Organic matter in %	Litholog-ical type	Litholog-ical sub-type
P-19-1	0-8	5.1		
P-20-1	0-20	6.6		
P-5-1	0-42	N.D		
P-6-1	0-45	N.D		III a
P-18-3	67-76	N.D		
P-3-8	191-206	N.D		
P-11-1	0-30	N.D		
P-12-5	152-202	2.8	III	III b

Example
* P-6-4: Fourth layer down from the surface of the ground
Pit Number 6
** N.D = Not determined

6.3.2.1 Specific Gravity

Specific gravity values for representative samples from lithological types II and III are presented in Table 6.3. The range of values is 2.42 to 2.71 for all the sample, and sample from lithological type III shows the highest value while the lowest value is for samples from lithological type II. The lower value of specific gravity for these samples 2.42-2.52) could probably be accounted to their high organic matter content (see Table 6.2).

6.3.2.2 Grain Size Analysis

Grain size analysis results for all the samples tested is shown in Table 6.4 and Fig 6.3. The range of percentages of the three size fractions (clay, silt and sand) for the soils of the study area are as follows:

Lithological Type I (Clays)

Based on simple field and laboratory identification procedures such as dry strength and toughness. The soils of the lithological type I has been estimated to contain:

Table 6.3 Specific Gravity of Soils of Omorati Area

Sample No.	Depth of sampling (cm)	Specfic gravity	Lithological type
P-4-1	0-25	2.52	I
P-8-4	128-300	2.42	II
P-15-2	108-130	2.44	II
P-12-5	152-202	2.71	III

Table 6.4 Granulometric Composition of the Soils of Omorati Area

Sample No and location	Depth of sampling	Clay <0.02 m.m	Silt 0.002-0.06 m.m	Sand 0.06-2.0 m.m	Classification according to Triangular Classification Chart (by PRA)	Lithological Type	Lithological sub-type
P-6-4	240-250						
P-7-2	100-300						
P-8-1	0-50						
P-12-1	0-40						
P-14-1	0-65	80-90%	10-20%	—	Clays	I	
P-15-1	0-108						
P-16-1	0-180						
P-17-6	210-260						
P-20-7	200-300						
P-4-1	0-25	46	54	-	Clay		
P-4-2	25-110	36	64	-	Silt Clay		
P-7-4	205-200	49	51	-	Clay		
P-10-4	155-300	36	64	-	Silt Clay		II a
P-11-2	30-80	46	54	-	Clay		
P-13-1	0-30	54	46	-	Clay	II	
P-3-7	169-191	39	61	-	Silty Clay		
P-6-2	45-170	40	60	-	Silty Clay		
P-7-1	0-100	20	80	-	Silty Clay Loam		

Contd.

Sample No and location	Depth of sampling	Clay <0.02 m.m	Silt 0.002-0.06 m.m	Sand 0.06-2.0 m.m	Classification according to Triangular Classification Chart (by PRA)	Lithological Type	L thologic s b-type
P-7-5	220-280	64	36	-	Clay	II	II b
P-7-6	128-300	41	59	-	Silty Clay		
P-8-4	40-62	45	55	-	Silty Clay		
P-12-2	55-145	41	59	-	Silty Clay		
P-14-2	108-130	40	60	-	Silty Clay		
P-15-2	130-140	39	61	-	Silty Clay		
P-15-3	180-230	37	63	-	Silty Clay		
P-16-2	0-8	43	57	-	Silty Clay		
P-19-1	0-20	52	48	-	Clay		
P-20-1	42-107	53	47	-	Clay		
P-5-2	0-15	13	69	18	Silty Loam		
P-10-1	0-42	13	69	18	Silty Loam		
P-5-1	0-45	15	48	37	Loam		
P-6-1	67-76	16	44	40	Loam	II or III	II b or III a
P-18-3	191-206	14	49	37	Loam	III	III a
P-3-8	0-30	5	11	83	Sand		
P-11-1	0-30	11	20	69	Sandy Loam		III b
P-12-5	152-202	9	13	78	Sandy Loam		

* PRA Public Road Adminstration, US

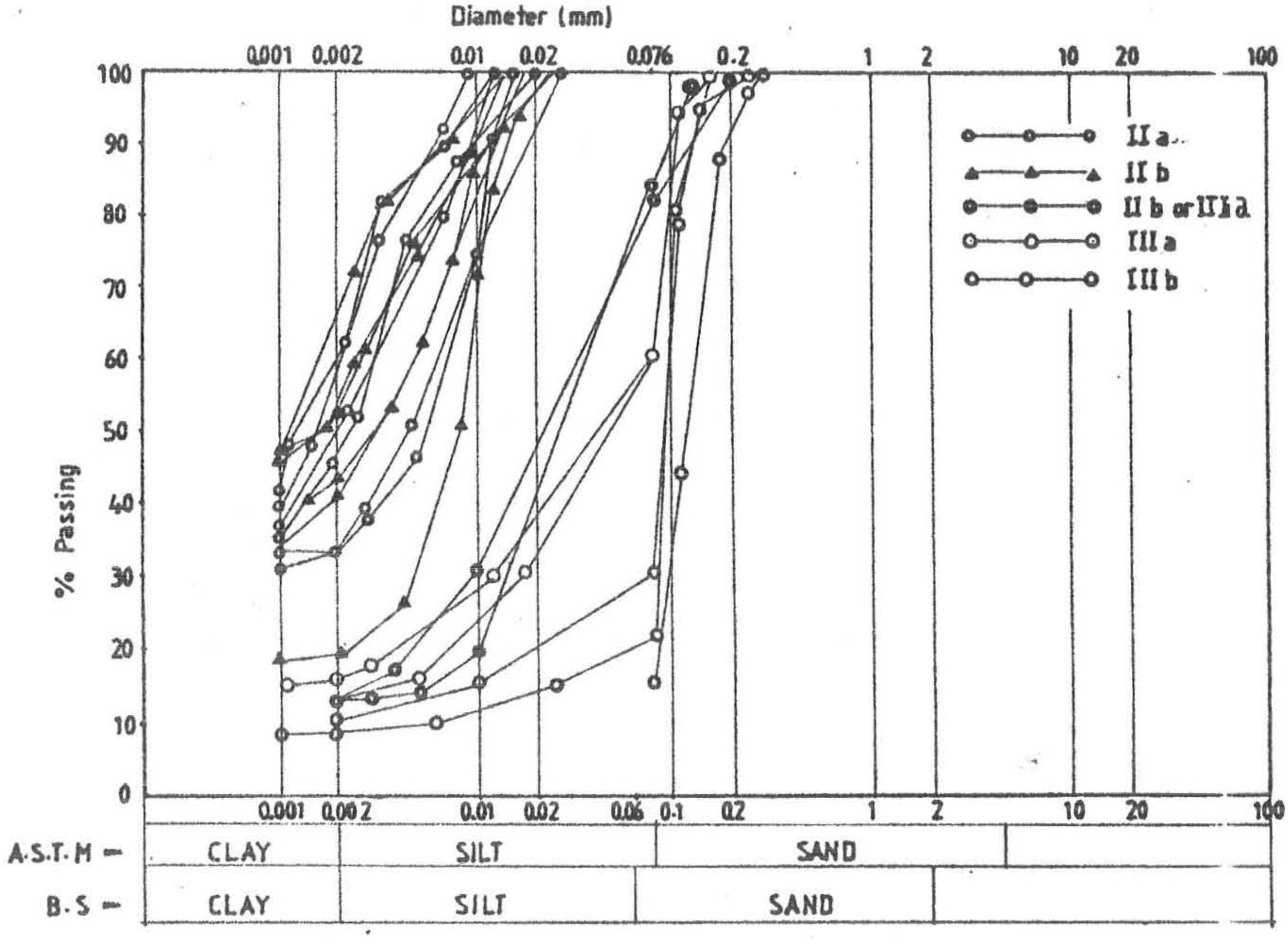


Fig. 6.3 Grain Size Analysis Curves of the Soils of Omorati Area.

Clay 80 to 90 %

Silt 10 to 20%

Sand -

Lithological Type II (Silty Clays and Clayey silts)

IIa) Silty Clays	IIb) Clayey Silts
Clay 36% to 54%	Clay 13 to 64%
Silt 44 to 61 %	Silt 36 to 80 %
Sand negligible	Sand 0 to 18 %

Lithological Type III (Sandy Silts and Silty Sands)

IIIa) Sandy Silts	IIIb) Silty Sands
Clay 14 to 16%	Clay 5 to 11%
Silt 44 to 49 %	Silt 11 to 20 %
Sand 37 to 40%	Sand 37 to 83 %

The shape of curves in Fig 6.3 show that the soils of the lithological type III are poorly graded. From this data it is also evident that unlike the lithological type III soils. the distinction which has been made on the lithologic type II in to the subtypes IIa (silty clay) and IIb (clayey silt) based on the field description alone. is not confirmed by the laboratory grain size analysis, which in this case shows that a soil identified as silty clay in the field may become a clay silt and vice versa, based on the laboratory grain size analysis. This is to be expected because of the different levels of accuracy involved between these two methods.

The plot on US. Public Road Administration's Triangular Classification Chart for the tested samples is shown in Fig. 6.4. In this chart samples from lithological type II fall mainly in the region for silty clays and some in a region for clays and samples from lithological type III mainly in the regions of loam, sandy loam or sand. Silty loam varieties are also found which could belong either to the lithological type II or III.

6.3.2.1 Atterberg Limits

The results of the Atterberg limit tests are shown in Table 6.5. The values can be classified in 3 groups. The first one with the highest values of liquid limit from 60 to 78% and plasticity index 18 to 35 is for lithological type I soils. The second group with liquid limit from 35 to 58% and plasticity index 7 to 22% is for lithological type II, The third group from lithological type III soils is with out any plasticity, hence non plastic. All values determined for all samples of the three lithological types

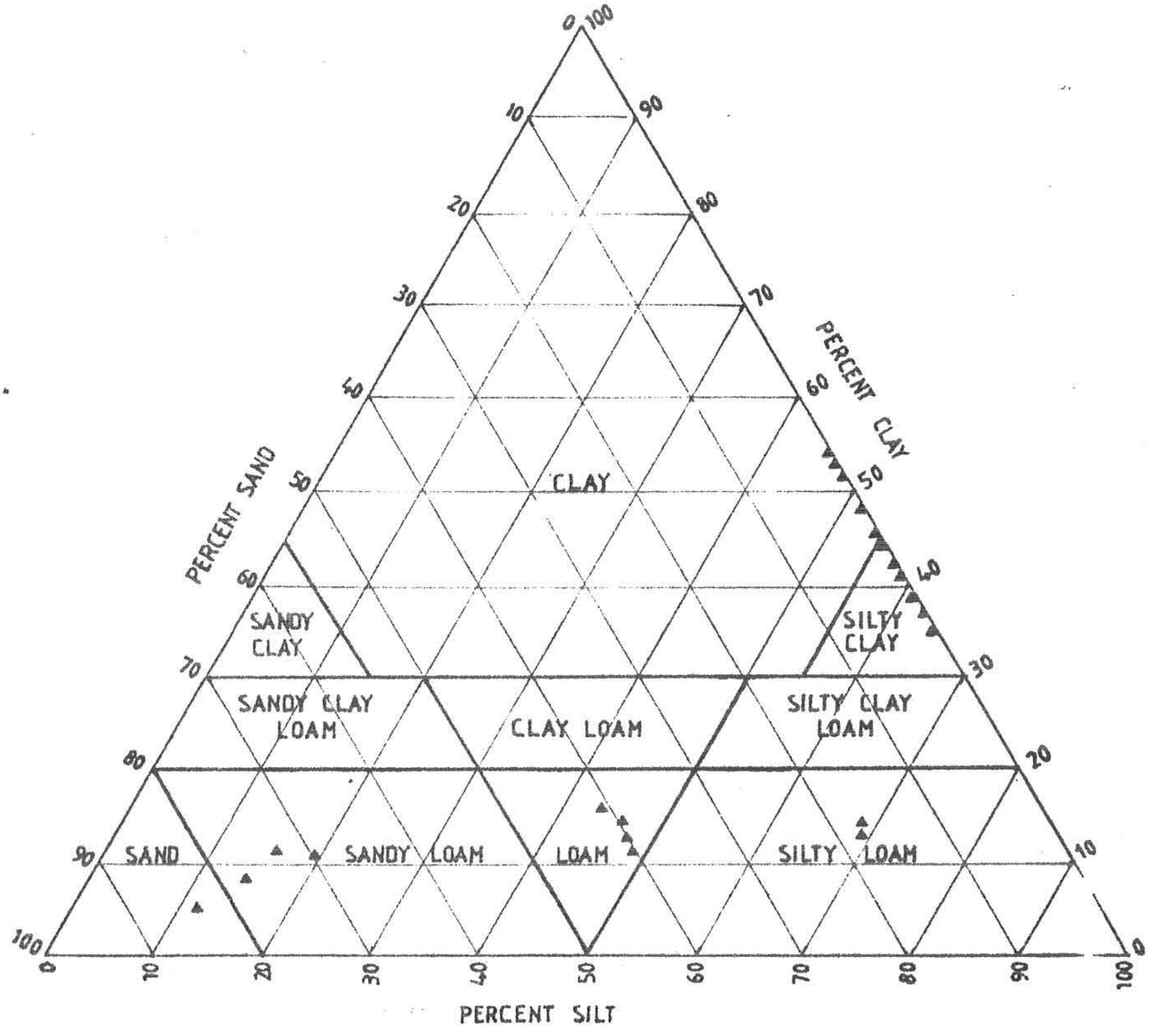


Fig. 6.4 Plot on Triangular Clasification Chart of the Soils of Omorati area.

(US, Public Road Administration, Triangular Clasification Chart)

Table 6.5 Atterberg Limits of the Soils of Omorati Area
Soils of (Source - W.R.D.A)

Sample No and location	Depth of sampling (cm)	Liquid limit (LL) (in %)	Plastic limit (PL) (in %)	Plasticity index (PI) (in %)	Classification *(U.S.C.S	Lithological Type	Lithological Sub-type
P-6-4	240-250	75	41	34	OH		
P-7-2	100-130	78	45	33	OH		
P-8-1	0-50	64	40	24	OH		
P-12-1	0-40	63	44	19	OH		
P-14-1	0-65	60	42	18	OH	I	-
P-15-1	0-108	70	44	26	OH		
P-16-1	0-180	68	44	24	OH		
P-17-6	210-360	77	46	31	OH		
P-20-7	200-300	71	36	35	OH		
P-4-1	0-25	56	36	20	OH		
P-4-2	25-110	52	34	18	OH		
P-7-4	205-220	56	36	20	OH		
P-10-4	155-300	**N.D	34				IIa
P-11-2	30-80	53	36	16	OH		
P-13-1	0-60	54	ND	21	OH		
P-3-7	169-191	49	37	15	OL(ML)		
P-6-2	45-180	58	33	21	OH		
P-7-1	0-100	N.D	34			II	
P-7-5	220-280	57	37	22	OH(MH)		

Table 6.5 Atterberg Limits of the Soils of Omorati Area Soils of (Source - W.R.D.A)

Sample No and location	Depth of sampling (cm)	Liquid limit (LL) (in %)	Plastic limit (PL) (in %)	Plasticity index (PI) (in %)	Classiff-ication *(U.S.C.S	Lithological Type	Lithological Sub-type
P-6-4	240-250	75	41	34	OH		
P-7-2	100-130	78	45	33	OH		
P-8-1	0-50	64	40	24	OH		
P-12-1	0-40	63	44	19	OH		
P-14-1	0-65	60	42	18	OH	I	-
P-15-1	0-108	70	44	26	OH		
P-16-1	0-180	68	44	24	OH		
P-17-6	210-360	77	46	31	OH		
P-20-7	200-300	71	36	35	OH		
P-4-1	0-25	56	36	20	OH		
P-4-2	25-110	52	34	18	OH		
P-7-4	205-220	56	36	20	OH		
P-10-4	155-300	**N.D	34				IIa
P-11-2	30-80	53	36	16	OH		
P-13-1	0-60	54	ND	21	OH		
P-3-7	169-191	49	37	15	OL(ML)		
P-6-2	45-180	58	33	21	OH		
P-7-1	0-100	N.D	34			II	
P-7-5	220-280	57	37	22	OH(MH)		

Contd.

Sample No and location	Depth of sampling (cm)	Liquid limit (LL) (in %)	Plastic limit (PL) (in %)	Plasticity index (PI) (in %)	Classiff-ication *(U.S.C.S	Lithological Type	Lithological Sub type
P-7-6	280-300	50	32	18	OH(MH)		IIb
P-8-4	128-300	53	35		OH		
P-12-2	40-62	47	32	13	OL		
P-14-2	55-145	50	52	17	OH(MH)		
P-15-2	180-130	49	34	15	OL(ML)		
P-15-3	130-240	N.D	33				
P-16-2	180-230	49	34	16	OL		
P-19-1	0-8	41	N.D	11	OL		
P-20-1	0-20	50	33	18	OH		
P-5-2	42-07	46	32	14	OL(ML)	II or III	IIb or III a
P-10-1	0-15	35	28	7	OL(ML)		
P-5-1	0-42	***N.P	N.P	-	OL(ML)	III	III a
P-6-1	0-45	N.P	N.P	-	OL(ML)		
P-18-3	67-76	N.P	N.P	-	OL(ML)		
P-3-8	191-206	-	-	-	SM		III b
P-11-1	0-30	-	-	-	SM		
P-12-5	150-202	-	-	-	SM		

* U.S.C.S = Unified Soil Clasffication System (see table 8.8)
** N.D = not determined
*** N.P = non plastic

would plot below A-line on the Cassagrande's plasticity Chart. One clear observation that can be made from this data is that in the lithological type II, the Atterberg limit values for the samples containing higher silt fractions, are as high as for those containing higher clay fraction. Two probable reasons can be stated to explain this phenomenon.

One reason may be that the silt fraction of the Silt dominated soils could be predominantly represented by the very fine silt fraction near the boundary to the clay size fractions (0.002 mm). The second reason could be that the clay fraction of the clay size dominated soils may be predominantly represented by fractions near this arbitrary boundary between clays and silts.

6.3.2.4 Free Swell

Free swell test, a simple test which was proposed by Gibbs and Holtz (1956), fide. Head (1984) is defined as the increase of the soils volume from a loose dry powder form when it is poured into water expressed as the percentage of the original volume. Table 6.6 shows free swell values for selected clay samples. According the above cited authors soils with free swell values less than 50% are not likely to

Table 6.6 Free Swell Value of Clay Soils of Omorati Area

Sample No. and location	Depth of sampling	Free swell value in %	Lithological type
P-6-4	240-250	60	
P-7-2	100-130	40	
P-8-1	0-50	60	I
P-16-1	0-180	50	
P-20-7	200-300	110	

Table 6.7 Table of Estimation of Expansiveness Based on Free Swell value (After, Mathewson, 1981)

Free swell value (%)	Expansiveness
Less than 50	Low
50-75	Medium
75-100	High
Greater than 100	Extreme

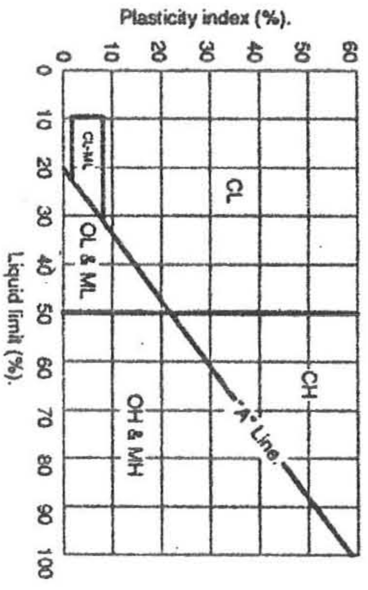
show expansive properties values of 100% or more are associated with clays which could swell considerably when wetted, especially under light loading. Making use of Table 6.7 which classifies soils to their degree of expansiveness based on their free swell value; the clay samples P-8-1, P-16-1 and P-20-7 have medium to extreme expansiveness. This high expansiveness could be due to the presence of nontronite detected in them by the DTA (See, section 6.3.1.1), which belongs to the clay minerals of the Smectite group known for their highly expansive lattice.

6.4 Engineering Geological Classification of the Soils of the Study Area

Soil classifications is the placing of a soil into a group of soils, all of which exhibit similar behavior (Lambe and Whitman, 1969). The correlation of behaviors with a group in a soil classification system is usually an empirical one developed through considerable experience. Most soil classifications employ very simple index- type tests to obtain the characteristics of the soil needed to place it in a given group. The most commonly used characteristics are particle size and plasticity. In 1952 the Bureau of Reclamation and the Corps of Engineers in US developed a Unified Soil Classification System (USCS) intended for use in all engineering problems involving soils. This classification is presented in Table 6.8, and to which classes the soils of the study area may belong is indicated below:

Fig. 6.5 shows plot on Cassagrande's Plasticity Chart of all the soil samples tested in the laboratory. Accordingly all the values fall below A- line on the Plasticity Chart. Hence most of the soils of the area belong to OH (organic clays of medium to high plasticity),or MH (inorganic silts, micaceous fine sandy or silty soils). OL (organic silts and organic silty clays of low plasticity) or ML (Inorganic silts and very fine sands, silty, or clayey, fine sands with slight plasticity). The coarser grained fractions are mainly classified as SM (silty sands, poorly graded silt, sand mixtures)

Table-6.8 Unified Soil Classification System (After Wagner 1957)

Major divisions.			Group symbols.	Typical names.	Laboratory classification criteria.		
Coarse-grained soils. (More than half of material is larger than No. 200 sieve size)	GRAVELS. (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels. (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures.	Determine percentages of sand and gravel from gradation curve. Depending on percentage of fines, coarse-grained soils are classified as below: - Less than 5 %: GW, GP, SW, SP. - From 5 to 12 %: *Borderline* cases requiring use of dual symbols. - More than 12 %: GM, GC, SM, SC.	$4 \le Cu$ and $1 \le Cc \le 3$.	$CU = \frac{D_{60}}{D_{10}}$ $CC = \frac{(D_{30})^2}{D_{60} \times D_{10}}$
			GP	Poorly graded gravels, gravel-sand mixtures.		Not meeting all gradation requirements for GW.	
		Gravels with fines. (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.		Atterberg limits below "A" line or $Ip \le 4$.	Above "A" line and $4 \le Ip \le 7$ are *borderline* cases requiring use of dual symbols.
			GC	Clayey gravels, gravel-sand-clay mixtures.		Atterberg limits above "A" line and $7 \le Ip$.	
	SANDS. (More than half of coarse fraction is larger than No. 4 sieve size)	Clean sands. (Little or no fines)	SW	Well-graded sands, gravelly sands.		$6 \le Cu$ and $1 \le Cc \le 3$.	
			SP	Poorly graded sands, gravelly sands.		Not meeting all gradation requirements for SW.	
		Sands with fines. (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.		Atterberg limits below "A" line or $Ip \le 4$.	Above "A" line and $4 \le Ip \le 7$ are *borderline* cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures.		Atterberg limits above "A" line and $7 \le Ip$.	
Fine-grained soils. (More than half of material is smaller than No. 200 sieve size)	SILTS and CLAYS. (Liquid limit less than 50)		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands, clayey silts with slight plasticity.	Casagrande plasticity chart. Fig. 1.e 		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.			
			OL	Organic silts, organic silty clays of low plasticity.			
	SILTS and CLAYS. (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays.			
			OH	Organic clays of medium to high plasticity, organic silts.			
	HIGHLY ORGANIC SOILS.		Pt	Peat, highly organic soils.			

Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For instance: GW-GC means well-graded gravel-sand mixture with clay binder.

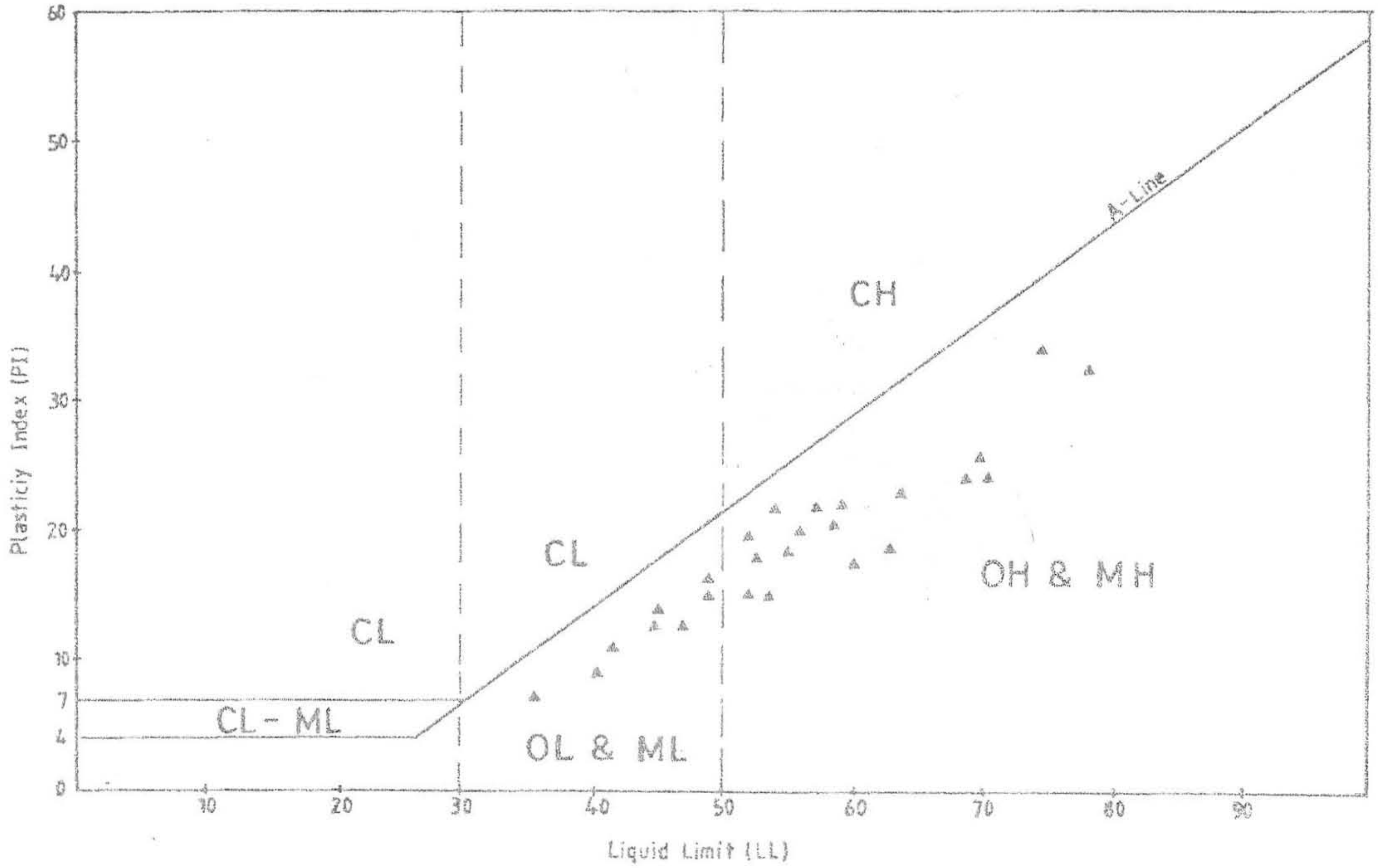


Fig. 6.5 Plot on Casagrandés Plasticity Chart of the Soils of Omorati area.

Silt is inherently unstable, particularly when moisture is increased, with a tendency to become quick when saturated. It is relatively impervious, difficult to compact, easily erodible and subject to piping and boiling. As a result of the platy morphology of micas: sand and silts containing only a few percent mica may exhibit both high compressibility and large swelling during unloading as may be seen in Fig 6.6

Organic matter present even in moderate amounts increases the compressibility and reduces the stability of the fine grained components. It may decay causing voids or by chemical alteration change the properties of a soil. Hence organic soils are not desirable for engineering uses. Since most of the soils in the study area are consisted of high silt fraction containing micas and appreciable amount of organic matter (Table 6.2), they may not be desirable for engineering uses.

In Table 6.9 a general indication of the permeability, strength and compressibility of the various soil groups along with an indication of the relative desirability of each group in earth dams, canal sections, foundations and runways is given. From this table it can be seen that the soils of the study area which mostly belong to OH, MH, ML, OL or SM groups in the Unified Soil Classification System (USCS) are unsuitable for most civil engineering works.

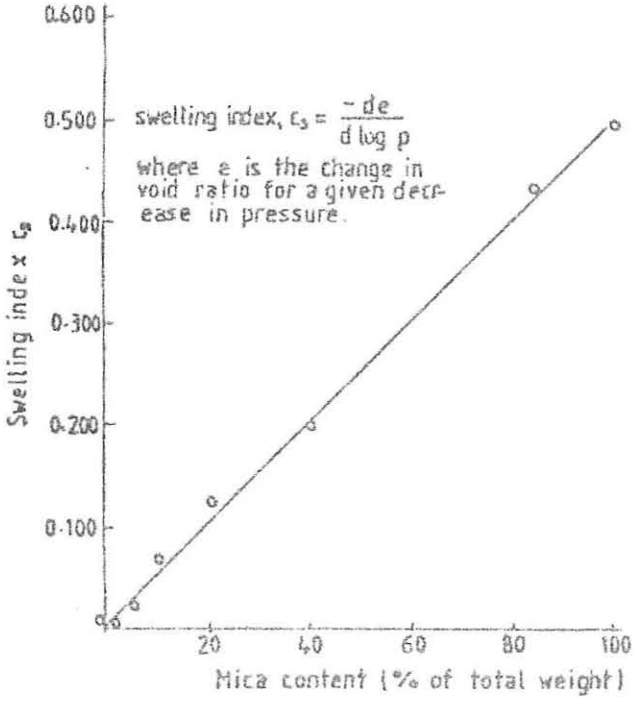


Fig. 6.6 Swelling index as a function of mica content for coarse grained mixtures. (After Terzaghi, 1931; fide, Mitchell, 1976)

Table- 6.9 Engineering Use Chart (After Wagner 1957)

Typical Names of Soil Groups	Group Symbols	Important Properties				Relative Desirability for Various Uses									
						Rolled Earth Dams			Canal Sections		Foundations		Roadways		
													Fills		
		Permeability when Compacted	Shearing Strength when Compacted and Saturated	Compressibility when Compacted and Saturated	Workability as a Construction Material	Homogeneous Embankment	Core	Shell	Erosion Resistance	Compacted Earth Lining	Seepage Important	Seepage not Important	Frost Heave not Possible	Frost Heave Possible	Surfacing
Well-graded gravels, gravel-sand mixtures, little or no fines	GW	pervious	excellent	negligible	excellent	—	—	1	1	—	—	1	1	1	3
Poorly graded gravels, gravel-sand mixtures, little or no fines	GP	very pervious	good	negligible	good	—	—	2	2	—	—	3	3	3	—
Silty gravels, poorly graded gravel-sand-silt mixtures	GM	semipervious to impervious	good	negligible	good	2	4	—	4	4	1	4	4	9	5
Clayey gravels, poorly graded gravel-sand-clay mixtures	GC	impervious	good to fair	very low	good	1	1	—	3	1	2	6	5	5	1
Well-graded sands, gravelly sands, little or no fines	SW	pervious	excellent	negligible	excellent	—	—	3 if gravelly	6	—	—	2	2	2	4
Poorly graded sands, gravelly sands, little or no fines	SP	pervious	good	very low	fair	—	—	4 if gravelly	7 if gravelly	—	—	5	6	4	—
Silty sands, poorly graded sand-silt mixtures	SM	semipervious to impervious	good	low	fair	4	5	—	8 if gravelly	5 erosion critical	3	7	8	10	6
Clayey sands, poorly graded sand-clay mixtures	SC	impervious	good to fair	low	good	3	2	—	5	2	4	8	7	6	2
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	semipervious to impervious	fair	medium	fair	6	6	—	—	6 erosion critical	6	9	10	11	—
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	CL	impervious	fair	medium	good to fair	5	3	—	9	3	5	10	9	7	7
Organic silts and organic silt-clays of low plasticity	OL	semipervious to impervious	poor	medium	fair	8	8	—	—	7 erosion critical	7	11	11	12	—
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH	semipervious to impervious	fair to poor	high	poor	9	9	—	—	—	8	12	12	13	—
Inorganic clays of high plasticity, fat clays	CH	impervious	poor	high	poor	7	7	—	10	8 volume change critical	9	13	13	8	—
Organic clays of medium to high plasticity	OH	impervious	poor	high	poor	10	10	—	—	—	10	14	14	14	—
Peat and other highly organic soils	Pt	—	—	—	—	—	—	—	—	—	—	—	—	—	—

7. Engineering Geological Mapping of the Study Area

7.1 Selection of Mapping Units

Engineering geological mapping is based, not on the lithostratigraphic units in conventional geological mapping, but on the recognition of homogeneous lithological units that in any one area may have a range of geological ages (Bulletin of IAEG, No. 24, P.251, 1981). The degree of homogeneity is related to the scale of the map and an internationally acknowledged set of taxonomic units (UNESCO/IAEG, 1976; fide Bulletin of IAEG, No. 24, 1981) based on lithology has been established. The lithological engineering geological units and their definition as given in this Bulletin is as follows.

1. Engineering geological type (ET)

The engineering geological type has the highest degree of physical homogeneity. It should be uniform in lithological character and physical state. These units can be characterized by statistically derived values from individual determinations of physical and mechanical properties and are generally shown only on large scale maps (larger than 1:5000)

2. Lithological type (LT)

A lithological type is homogenous throughout in composition, texture and structure, but usually is not uniform in physical state. Reliable values of average mechanical properties cannot be given for the entire unit; usually only a general idea of engineering properties, with a range of values can be presented. These units are shown on large-scale, and where possible, on medium scale maps(1:5000-1:10,000).

3. Lithological complex (LC)

A lithological complex comprises a set of genetically related lithological types developed under specific paleogeographical and geotectonic conditions. within a lithological complex the spatial arrangement of lithological types is uniform and distinctive for that complex, but a lithological complex is not necessarily uniform in either lithological character or physical state. In consequence, it is not possible to define the physical and mechanical properties of the whole lithological complex, but only to give data on the individual lithological types comprising the complex and to indicate the general behaviors of the whole lithological complex. The lithological complex is used as a mapping unit on medium scale and some small-scale maps(1:10,000 - 200,000)

4. Lithological suite(LS)

The lithological suite comprises many lithological complexes that developed under generally similar paleogeographical and tectonic conditions. It has certain common lithological characteristics throughout which impart a general unity to the suite and serve to distinguish it from other suites. Only very general engineering geological properties of a lithological suite can be defined. This units are used only on small scale maps.

7.2 Delineation and Engineering Geological Characteristics of the Mapping Units

Based on the above definition of the taxonomic units, the surface engineering geological mapping of Omorati area at a scale of 1:10,000 has been carried out on the basis of identifying the main "lithological complexes" as mapping units, characterized by information acquired by field observation and sampling followed by systematic laboratory tests such as index properties and grain size analysis. Although, the analysis of laboratory test results confirmed the three lithological distinction of chapter 3, section 3.2, in engineering geological terms, but it did not provide any result that may enable to make further clear sub-divisions which may be used to characterize the "lithological types in to sub-types. Accordingly, it was found possible to identify three "lithological units" for the mapping purpose all of them which coincide with the three lithological types of Chapter 5. These lithological units and their engineering geological characteristics are as follows:

Lithological Unit A

Clays:- dark brown to dark grayish brown, with reddish mottling and some times dark bluish tints, highly cracked, columnar, to prismatic or sometimes subangular blocky structure. Usually contain semi-decomposed rootlets. They are hard, moderately weathered to highly weathered. The liquid limit for this type ranges from 60-78%, plastic limit 40-44% and plasticity index is generally from 18-35%, while the organic matter ranges from 5.8-8.0%. All the laboratory tested samples fall below A-line on Cassagrande's Plasticity Chart and are classified as OH (high plasticity organic clays) according to the Unified Soil Classification System (USCS).

Lithological Unit B

Silty Clays and Clayey Silts:- of mainly dark yellowish brown, sometimes with reddish yellow and dark mottling, it may usually have granular to columnar, subangular blocky sometimes platy structure. Some varieties are very porous with numerous vertical rootholes which in most cases are similar to loess like soils in their property including collapsing. The liquid limit ranges from 35-56%, plastic limit 28-37% and plasticity index 7-21%, organic matter is 3.8-6.6%. All samples fall below A-line on the Cassagrande's Plasticity Chart and are classified as OH, MH or OL (low plasticity organic silts or clays). Mineralogically they are composed of lot of angular grains of. quartz feldspars and mica plates.

Lithological Unit C

Sandy Silts and Silty Sands:- mainly dark yellowish brown color, may be homogenous or interstratified with small scale cross beds at some places.loose, fine grained angular sands, all passing (No. 60 sieve, i.e. 0.30 mm), poorly graded, they contain lot of micas (mainly muscovite). They are classified as ML (inorganic silts and very fine sands, silty or clayey fine sands with slight plasticity) to SM (Silty sands, poorly graded sand, silt mixtures). Determination of the sand, silt, clay % for this lithological unit gives sand% = 37-83 silt % = 11-50 and clay %

5-16%. Examination under binocular microscope shows presence of angular grains of quartz, feldspars, mica plates, some heavy minerals and rock fragments.

Delineation of the approximate boundaries between the three mapping units was done from an aerial photographic mosaic of the area with the same scale as the mapping scale (1:10,000), mainly based on their relative tonal differences. In addition to the above major mapping units, two other subordinate mapping units of an undifferentiated lithological units A and B; and lithological units B and C, are included because of the difficulty of putting the boundaries between them at this mapping scale.

Cross and long profiles along selected lines with their location are given in Appendix-4, to show a generalized picture of the distribution of and relationship between the various lithological units identified in the study area. These profiles make it clear that the various lithological units are characterized by lensing and thickness variation both in the vertical and horizontal direction.

8. Conclusions and Recommendations

8.1 Conclusions

The lower Omo basin whose formation is believed to be as one of the branching rift system (Turkana Rift) of the East African Rift is underlain by a very thick (about 1 km) of deltaic, lacustrine and fluvial sediments, with some horizons of tuff and basaltic flows, which were deposited in a subsiding basin starting approximately 4.5 M.Y ago. The deposits of the lower Omo basin are all faulted and fractured extensively and some in minor extent. The fluctuation of the lake level of the ancestral lake Turkana, whose fluctuation is known to exist still to the present time, has had a great influence on the character and distribution of the subsurface sediments of the whole basin. The study area totally lies in the subrecent flood plain of the Omo river, the deposits of which are composed of clays, silty clays, clayey Silts, sandy silts and silty sands. All are characterized by lensing, thickness variation both horizontally and vertically, and are found in different stratigraphic order from place to place. There is a wide spread occurrence of sinkholes and cracks in this area which is believed to be due to hydrocompaction of collapsing soils and piping through fine silty layers.

Due to its location in the vicinity of recognized seismically active tectonic feature (the Main Ethiopian Rift) has experienced the effect of severe earth quakes throughout its history (Gouin, 1976). The Seismic intensity grade of the area corresponds to "IX" or "X" on the MMIS.

The results of the laboratory analysis performed on selected representative disturbed samples show that the clay soils of the area contain nontronite. The Free swell values for these clay samples is 60 to 110 which corresponds to medium to high expansiveness. The dominant non clay minerals in the coarser grained soils (Sandy silts and silty sands) are quartz, feldspars, micas, some heavy minerals and rock fragments. All the tested samples contain appreciable amount of organic matter (2.6-8%) and carbonates are absent except in one sample. Specific gravity ranges from 2.42-2.71, the highest value being for sample from the silty sands. The grain size analysis results show that the coarser grained soils as being poorly graded and all are pass through the 0.3mm sieve. The plot on the Triangular Classification Chart (US. Public Road Administration) of the tested samples show them as falling in the regions of clay, silty clay, silty loam, sandy loam and sand. And the plot on the Cassagrande's plasticity Chart based on the Atterberg limits shows them all to fall below the A-line. and they are classified mainly as OH, MH, OL, ML or SM in the Unified Soil Classification System.

Engineering geological mapping at the scale of 1:10,000 was carried out. The basic taxonomic unit chosen for the mapping purpose is the "Lithological Type (LT)". Accordingly three lithological units are identified, which are:

Lithological unit A: Clays

Lithological unit B: Silty Clays and Clayey Silts

Lithological unit C: Sandy Silts and Silty Sands

The Engineering geological study carried out in Omorati area whose main purpose is to evaluate and map the area for the purpose of urbanization has revealed the following hazardous conditions, with out whose considerations may not be possible any undertaking of Civil engineering work in the area.

1. Although not yet well established some geological evidences indicate the presence of major fault on the western margin of the flood plain of the Omo river which lies some kilometer away from the western boundary of the study area. Therefore, the possibility of a future displacement along this fault which could be accompanied with earth quakes of appreciable magnitude may be disastrous, as it is known that several destruction of cities in the world had been associated with major fault displacements along near by faults.

2. The area lies in one of the most seismically active zone of Ethiopia. Study of Figure 2.4 (Map of seismic Intensity) and applying the recommendation by Gouin (1976), to upgrade the corresponding intensity grade on this map, in the case of not too well consolidated and saturated soil conditions, gives an intensity grade of 'IX' and 'X' for the study area. It is considered that the seismic design for grade 'IX' would be the maximum possible for engineering purposes since grade 'X' is considered catastrophic (Zeevaert, 1983). Therefore, the ground would not support construction in a satisfactory way, even if the construction could be designed for an earth quake of such magnitude, since there will be subsoils that will fail because of the shear forces induced in them.

3. Study of the history of Turkana lake level fluctuation indicates that this area is prone to flooding by the Turkana lake whose ever changing shore lies only 20 km south of the study area. It has been estimated that an increase of 10 m in the Turkana lake level can extend this lake as much as 40 km further north (Coppens, 1976). With the gradient of approximately 25 cm/km between the Turkana lake shore line (375 m a.s.l.) and the study area (380 m a.s.l.), the inundation of this area by the lake, in the future, is highly probable.

4. Presence of active geodynamic phenomena, such as, widespread occurrence of sinkholes and cracks, whose occurrence is mainly attributed to piping and presence of collapsing soils*[1] is by it self a red sign, warning against any civil engineering use of the area, with out careful consideration of this phenomena.

5. In general, the study area is characterized by difficult subsoil conditions*[2]. With the existence of the above hazardous

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*1 Soils that are susceptible to large decreases in bulk volume when they become saturated are termed collapsing soils (Mitchell, 1976). Collapse may be triggered by water alone or by saturating and loading acting together.

*2 According to Zeevaert (1983), difficult subsoil condition may be defined as those encountered in soil sediments of medium to very high compressibility and medium to very low strength extending to great depth, and in those where the hydraulic conditions play an important role, as well as when the soil deposits are found in areas subjected to strong ground motions induced by earth quakes.

conditions in the study area, in addition to the highly compressible and low strength soils characteristic to the area it can be definitely concluded that the study area is characterized by difficult subsoil condition. Thus, presence of difficult subsoil condition in an area may incur extra costs for remedial majors on every kind of civil engineering works in the area which may be uneconomical in many cases, or it may even preclude construction of others, such as heavy buildings.

Hence, considering the presence of the aforementioned hazards; the area is totally unsuitable for urbanization. Thus it should either be avoided or the type of land use (such as agricultural, tourism or residential) should be regulated which keeps the number of occupancy per acre to a minimum in keeping with the degree of hazard. However, which ever is the land use type, the following precautionary measures should be observed.

8.2 Recommendations

1. The susceptibility of some of the soils of the area to collapse settlement should be elucidated by scientific criteria available. One such criteria of Gibbs and Bara (1962) is a probability of collapse graph through which the collapse potential of soils can be assessed plotting them based on their natural dry density verses liquid limits. Accordingly proper stabilization methods such as compaction after wetting to the optimum moisture content

or other elaborate methods of soils stabilization used for loesses listed in Table 5.1 can be employed before placing any structure on them.

2. Concentrated run-off from building roofs or other sources should not by any means be allowed to enter the foundation area on the collapsible soils.

3. Even with the provision of enough structural safety for the seismic hazard, buildings with more than 1-storey are not recommended considering the high degree of seismic hazard ("IX" or "X" on the M.M.I.S) involved in the area.

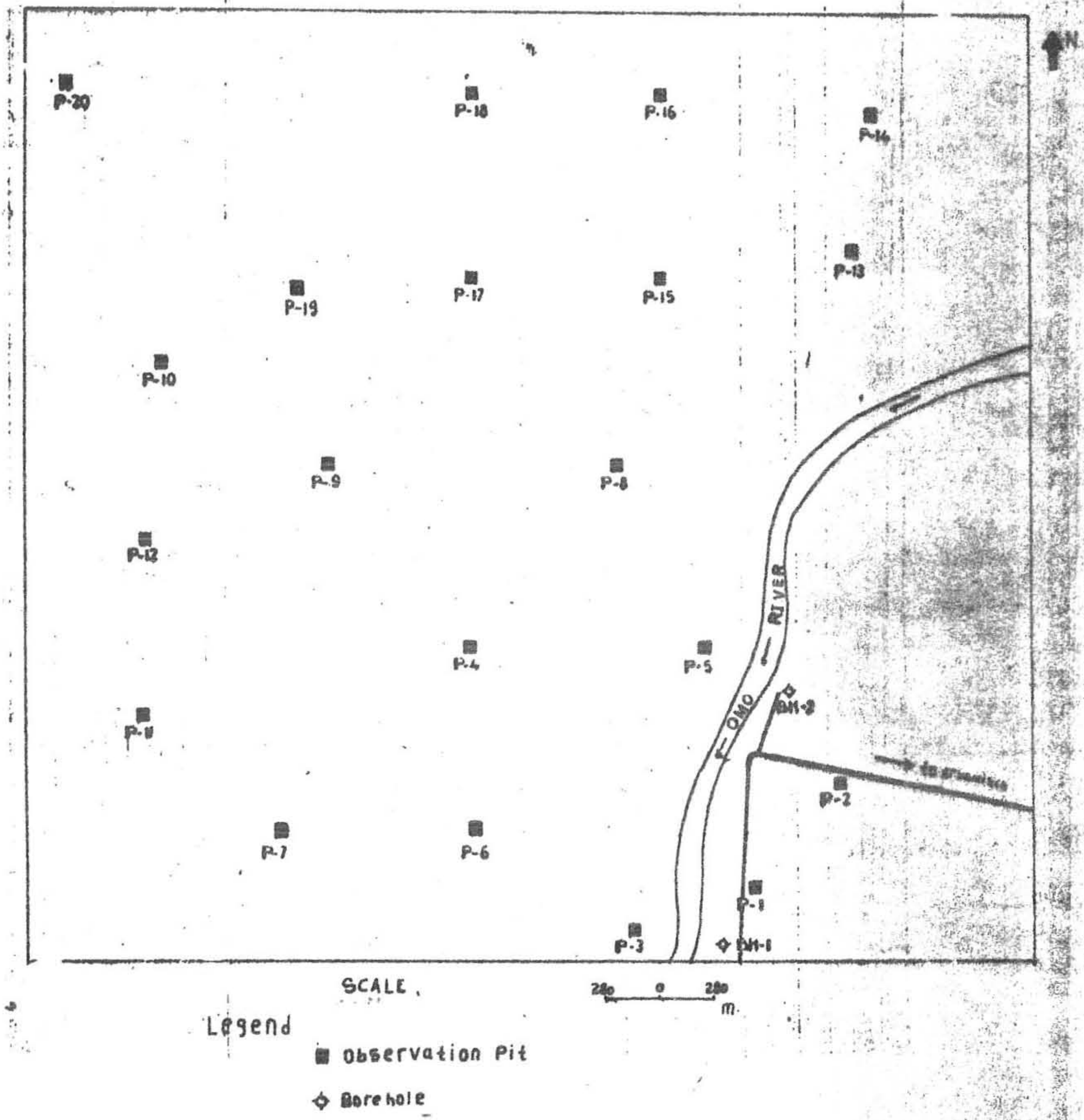
4. Designs of buildings and other constructions should take in to account the excessive compressibility of the soils (which mainly belong to OH, MH, OL, ML, or SM groups in the USCS) underlying the area.

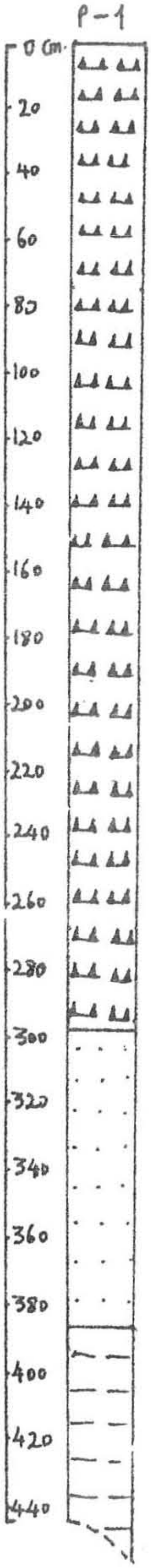
Appendix - 1

- The lay out of the 20 observation pits (P) and 2 boreholes (BH)

- Description of the profiles in each pit and borehole

The lay out of the 20 observation pits and 2 bore holes in the study area

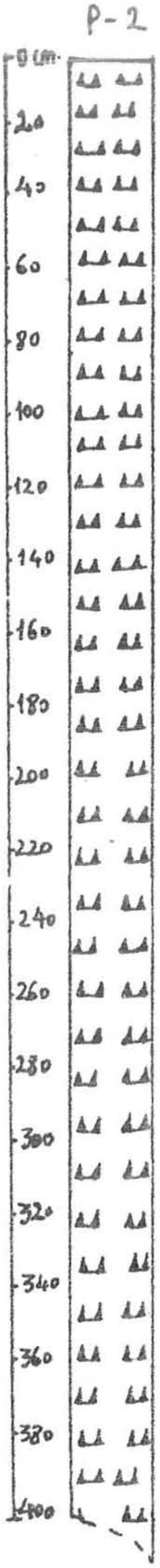




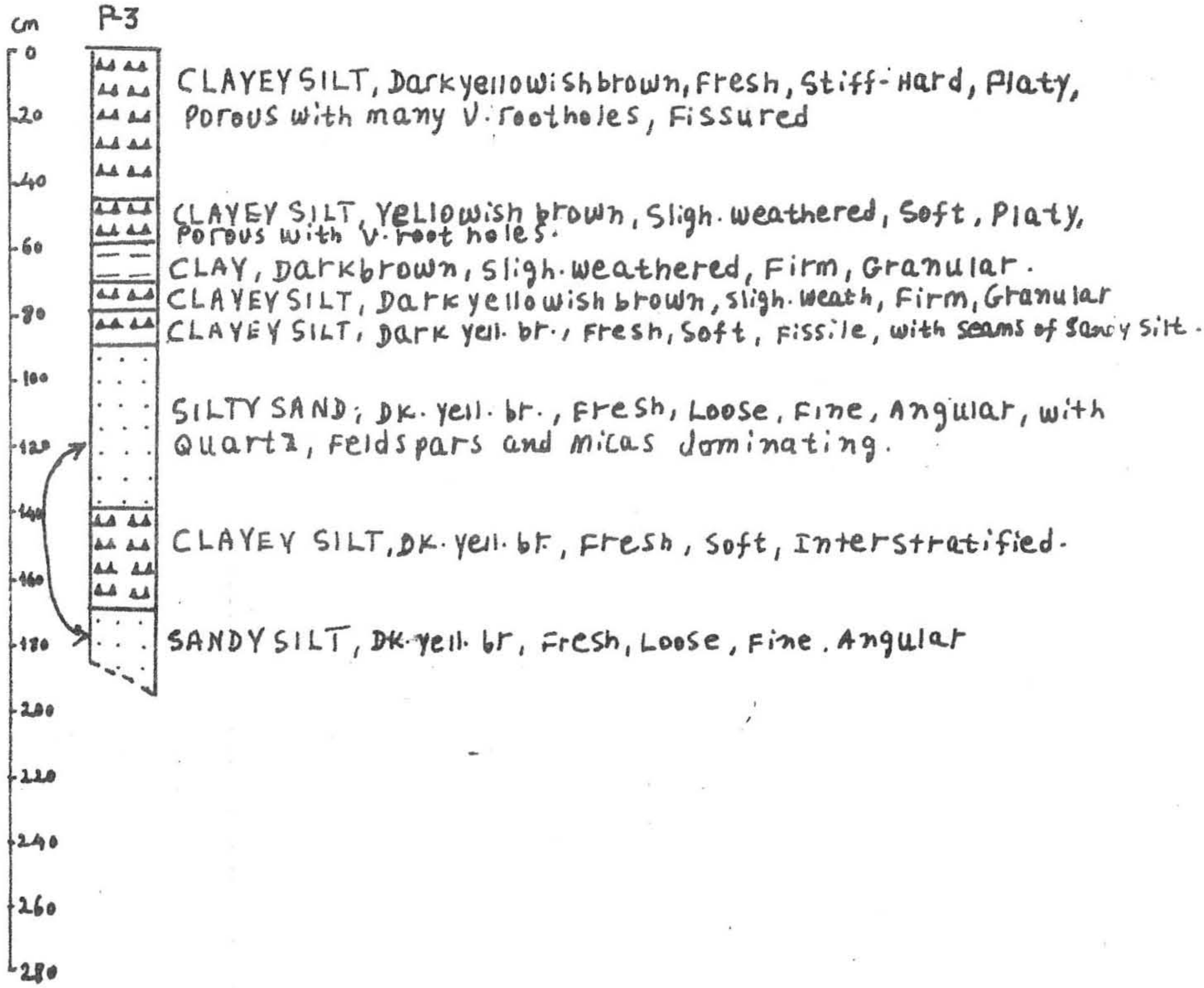
SILTY ClAY, Light brown, Fresh, Stiff, Interstratified with fine Silty sand at various levels
Light brown

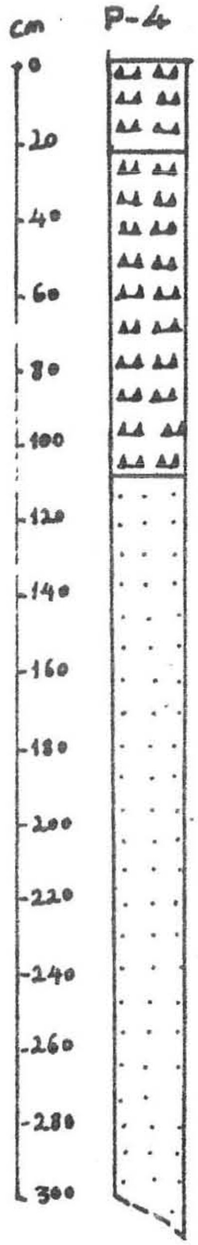
SILTY SAND, Dark yellowish brown with reddish tinting, Loose, Interstratified with slightly coarser silty san
Small scale cross bedding is present.

CLAY, Light brown, Hard, Interstratified with fine silty sand.



SILTY CLAY, Light brown, Stiff, Interstratified with fine silty sand at various levels, small scale cross bedding common at 2 meter depth in the slightly reddish, fine silty sand.

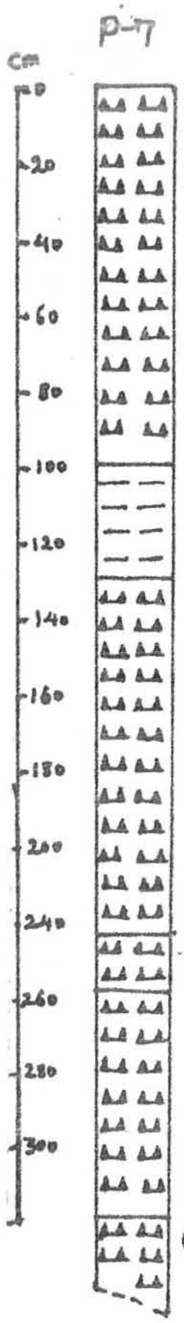

cm
P-3
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
CLAYEY SILT, Dark yellowish brown, Fresh, Stiff-Hard, Platy, Porous with many V. rootholes, Fissured
CLAYEY SILT, Yellowish brown, Sligh. weathered, Soft, Platy, Porous with V. root holes.
CLAY, Darkbrown, Sligh. weathered, Firm, Granular.
CLAYEY SILT, Dark yellowish brown, sligh. weath, Firm, Granular
CLAYEY SILT, Dark yell. br., Fresh, Soft, Fissile, with seams of Sandy Silt.
SILTY SAND; DK. yell. br., Fresh, Loose, Fine, Angular, with Quartz, Feldspars and Micas dominating.
CLAYEY SILT, DK. yell. br, Fresh, Soft, Interstratified.
SANDY SILT, DK. yell. br, Fresh, Loose, Fine. Angular



SILTY CLAY, DK. yell. br., Sligh. weathered, Hard, Granular

SILTY CLAY, Light br., Sligh. weathered, Hard, wt. reddish-tints, Interstratified with, Loose, Fine, silty sand.

SILTY SAND, DK. yell. br., Loose, fine, Angular, Quartz, Feldspars and Micas dominating, small Scale Cross beds are present at Some levels.



CLAYEY SILT, Dark yellowish brown, Fresh, Soft, Interstratified, with intercalation of loose, fine Sandy Silt.

CLAY, Darkbrown, Slightly weathered, Hard, Columnar, Grass roots and semidecomposed vegetation present.

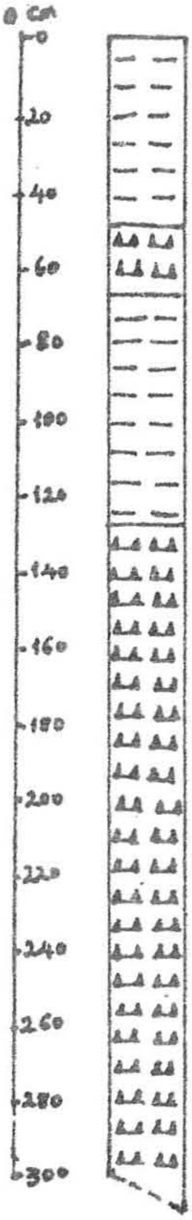
CLAYEY SILT, Yellowish brown, Fresh, Firm-Stiff, Platy.

SILTY CLAY, Yellowish brown, Slightly weathered, Hard, Angular blocky,

CLAYEY SILT, Yellowish brown, Fresh, Firm-Stiff, Platy.

CLAYEY SILT, Dark yellowish brown, Fresh, Soft, Homogeneous.

P-8

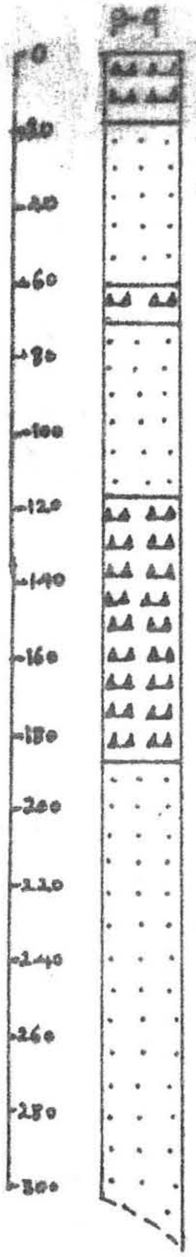


CLAY, Dark brown, Mod. weathered, Hard, Granular.

SILTY CLAY, Yellowish brown, Fresh, Hard, Columnar, Porous, with numerous vertical root holes.

CLAY, Dark yellowish brown, Mod. weathered, Hard, Columnar-Granular.

CLAYEY SILT, Yellowish brown, Slightly weathered, Hard, Angular blocky, Porous with numerous vertical root holes.



SILTY CLAY, Moderately weathered, Light brown, with reedish yellow mottling, Hard, Grass roots and vertical root holes are present.

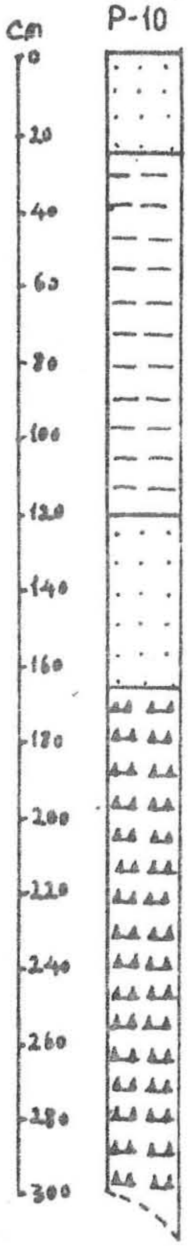
SILTY SAND, Dark yellowish brown, Fresh, loose, Fine, Quartz, feldspars and micas are the dominant minerals.

SILTY CLAY, Light brown, Mod. weathered, Firm-Hard, Granular, with grass roots and vertical rootholes.

SILTY SAND, Dark brown, Fresh, Loose - Slightly cemented, Homogeneous with quartz, feldspars and micas dominating.

SILTY CLAY, Brown, Mod. weathered, Hard, Granular - Columnar, with reddish and black mottling.

SILTY SAND, Dark yellowish brown, Fresh, loose, Homogereous, quartz, feldspars and micas dominating.



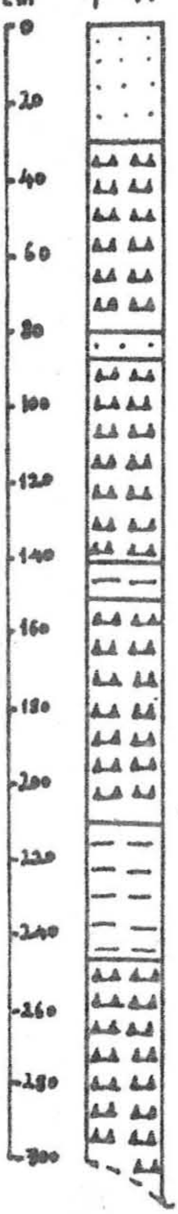
SANDY SILT, Dark yellowish brown, Loose, Fine

CLAY, Dk. greyish br., Mod. weathered, Hard, Granular, with lot of grass roots.

SILTY SAND, Dk. yell. br., Fresh, Sligh. cemented, Fissured (~60cm apart), with lot of grass roots.

SILTY CLAY, Dk. br., Fresh, Hard, Granular - columnar, with bluish tints at some levels.

P-11



SILTY SAND, Dk. yell. br., Fresh, Loose, Fine, Homogeneous, with Quartz, Feldspars and Micas dominating.

SILTY CLAY, Dk. yell. br., Mod. Weathered, Soft-Firm, Columnar-Granular, Semidecomposed Vegetation and nodular Cavities present.

SILTY SAND, Dk. br., Fresh, Loose

SILTY CLAY, Dk. yell. br., Mod. weathered, Soft-Firm, Columnar-Granular

CLAY, Dk. br., Sligh. weathered, Hard, Columnar, with reddish tints.

SILTY CLAY, Dk. yell. br., Mod. Weath., Soft-Firm, Columnar-Granular

CLAY, Dk. br., Highly weathered, Firm-Hard, Columnar-Granular, with reddish and dark mottling.

SILTY CLAY, Dk. yell. br., Mod. weath., Soft-Firm, Columnar-Granular

P-12

CLAY, Dk. greyish br.; Highly weath., Hard, Granular, Grass roots are present.

CLAYEY SILT, Dk. yell. br., Sligh. Weath., Soft, platy, Porous with v. rootholes, (silty sand intercalation)

CLAY, Dk. greyish br., Highly weath., Hard, Granular.

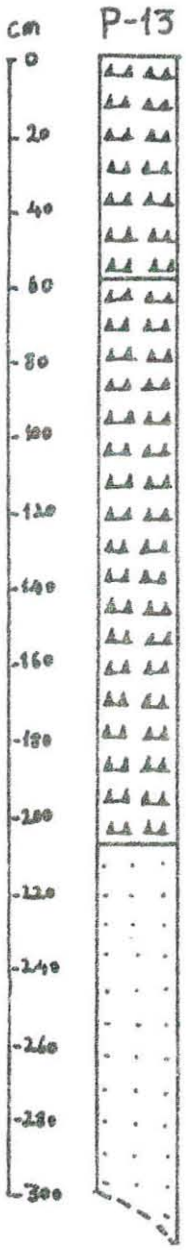
SILTY SAND, Dk. br., Fresh, Loose

CLAYEY SILT, Dk. br., Sligh. weath., Firm

CLAY, Dk. br., Mod. weathered, Hard, Columnar-Granular, with reddish and dark mottling.

CLAYEY SILT, Dk. yell. br., Sligh. weath., Firm, with intercalations of Hard Silty Clay and loose silty sand.

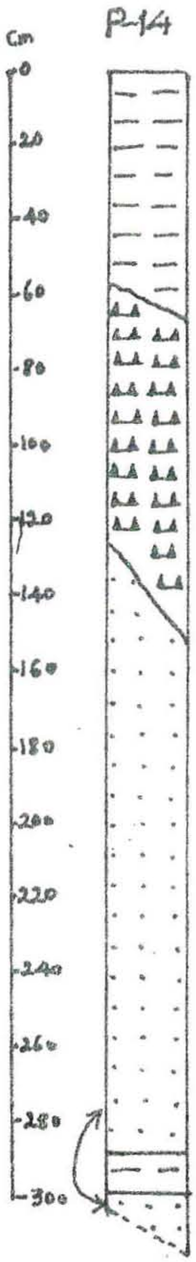
SILTY SAND, Dk. br., Fresh, Loose, Fine, with yell. br., Fresh, Firm, Fissile (platy) Clayey Silt at the bottom.



SILTY CLAY, Dk. yell. br., Mod. weath., Stiff-Hard, Subangular-blocky - Granular, with lot of Grass roots and V. rootholes, Pocket of Silty sand, Fine, present and Laminae of Hard Clay.

CLAYEY SILT, Dk. yell. br., Mod. weath., Firm, Porous with numerous rootholes and grass roots,

SILTY Sand, Dk yell. br., Fresh, Sligh. Cemented



CLAY, Dark greyish brown, Highly weathered, Hard, Granular, Grass roots are present.

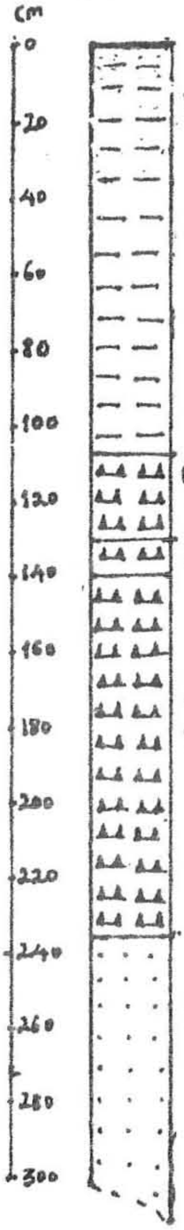
CLAYEY SILT, Dark yellowish brown, Sligh.-Mod. weathered, Stiff-Hard, Colunar-Subangular blocky, porous with numerous V. root holes,

SILTY SAND, Dark yellowish brown, Fresh-Sligh. weathered, loose, Some what fissile in the middle (Clayey-silt).

CLAY, Dark brown, Hard, Columnar-Granular

SILTY SAND, ---

P-15



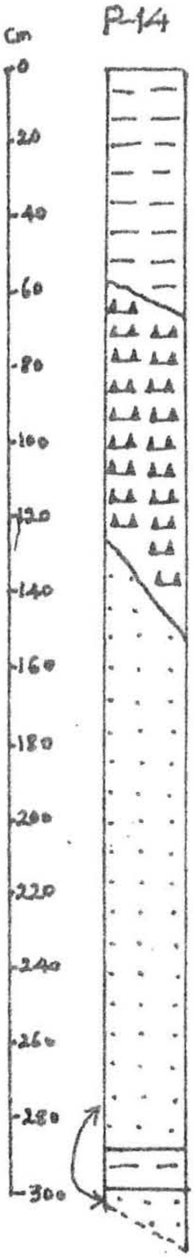
CLAY, Dark brown with reddish mottling, Highly weathered, Hard, Subangular blocky.

CLAYEY SILT, Dark yellowish brown, Slightly weathered, Stiff, Subangular blocky, Porous with numerous vertical rootholes

CLAYEY SILT, Dark yellowish brown, Fresh, Soft, Fissure; (10-20cm)

CLAYEY SILT, DARK yellowish brown, slightly weathered, stiff, Subangular blocky, Porous, with vertical rootholes.

SILTY SAND, Dark yellowish brown, Fresh, loose, Homogeneous



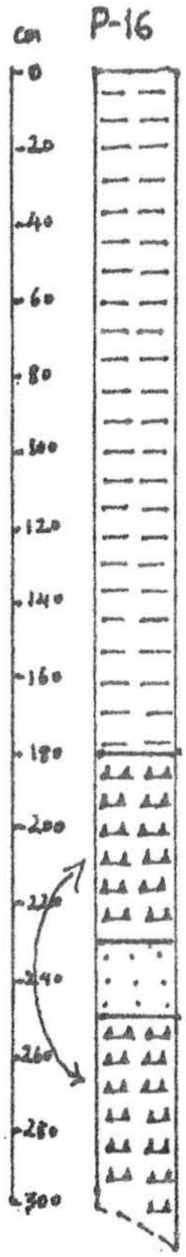
CLAY, Dark greyish brown, Highly weathered, Hard, Granular, Grass roots are present.

CLAYEY SILT, Dark yellowish brown, Sligh.-Mod. weathered, Stiff-Hard, Colunar-Subangular blocky, porous with numerous V. root holes, &

SILTY SAND, Dark yellowish brown, Fresh-Sligh. weathered, loose, Some what fissile in the middle (Clayey-silt).

CLAY, Dark brown, Hard, Columnar-Granular

SILTY SAND, ---

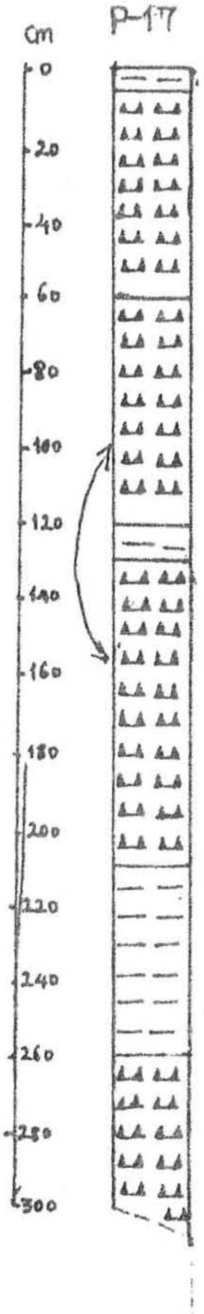


CLAY, Dark brown, with black and bluish mottling, med - highly weathered, Hard, Columnar - Granular.

CLAYEY SILT, Dark yellowish brown, Slightly weathered fissile, Firm - stiff, Porous with numerous v. rootholes, Quartz, feldspars and micas dominate.

SAND, Dark yellowish brown, Fresh, Loose, Fine, Homogeneous.

CLAYEY SILT, - - -



CLAY, Dark brown, Extremely weathered, Granular.

CLAYEY SILT, Yellowish brown, Sligh. weathered, Hard, Plcty, with reddish mottling, porous with numerous V. root holes. V. Fissures ~ 3 cm. apart.

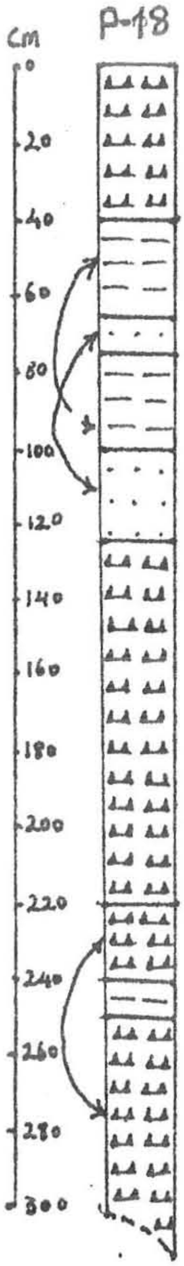
CLAYEY SILT, Yellowish brown, Sligh. weathered, Hard, Angular-blocky, Reddish and black mottling, porous wt. V. root holes. Similar to above except that fissures are ~ 7-10 cm. apart.

CLAY, Dark brown, Hard, Columnar - Granular.

CLAYEY SILT, - - -

CLAY, Dark brown, mod.-Highly weathered, Hard, Subangular blocky, with bluish tint at places.

CLAYEY SILT, Yellowish brown, sligh.-mod. weathered, Hard, Intact.



CLAYEY SILT, Dark yellowishbrown, Fresh, Soft, Homogeneous.

CLAY, Dark yellowish brown, highly weathered, Hard, subangular-blocky - Granular,

SILTY SAND, Dark yellowishbrown, Fresh, Loose, Fine, Homogeneous.

CLAY, - - -

SILTY SAND, - - -

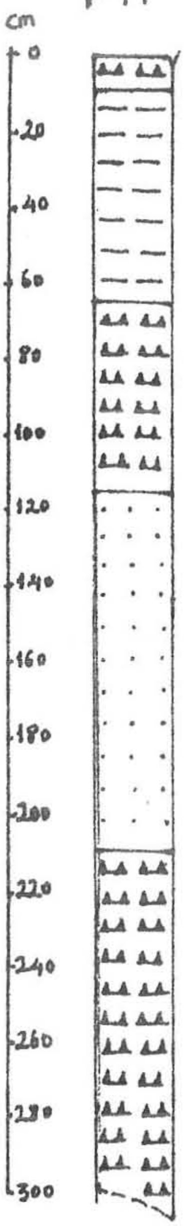
CLAYEY SILT, Dark yellowishbrown, Mod.-Highly weathered, Stiff-Hard, Angular blocky, Porous with v. rootholes reddish and dark mottling.

CLAYEY SILT, Dark yellowish brown, Fresh, Soft, Fissured (10 cm. apart

CLAY, Dark brown with bluish and reddish tints, Hard, Columnar-Granular.

CLAYEY SILT, - - -

P-19



CLAYEY SILT, Dark yellowish brown, Fresh, Soft, Homogeneous

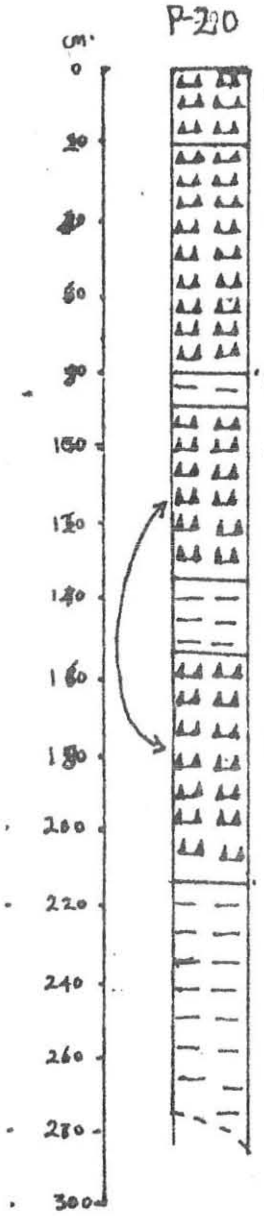
CLAY, Dark brown, Moderately-Highly weathered, Hard, Granular

CLAYEY SILT, Dark yellowish brown, Moderately weathered, Firm, Granular

SILTY SAND, Dark yellowish brown, Fresh, Loose, Fine, Angular, Quartz, Feldspar and micas present.

CLAYEY SILT, Dark yellowish brown, Slightly weathered, Firm, Fissile

P-220



CLAYEY SILT, Dark yellowish brown, Fresh, soft,

SILTY CLAY, Yellowish brown, Sligh.-Mod. weathered, Hard, Pl[illegible]ty, with reddish mottling.

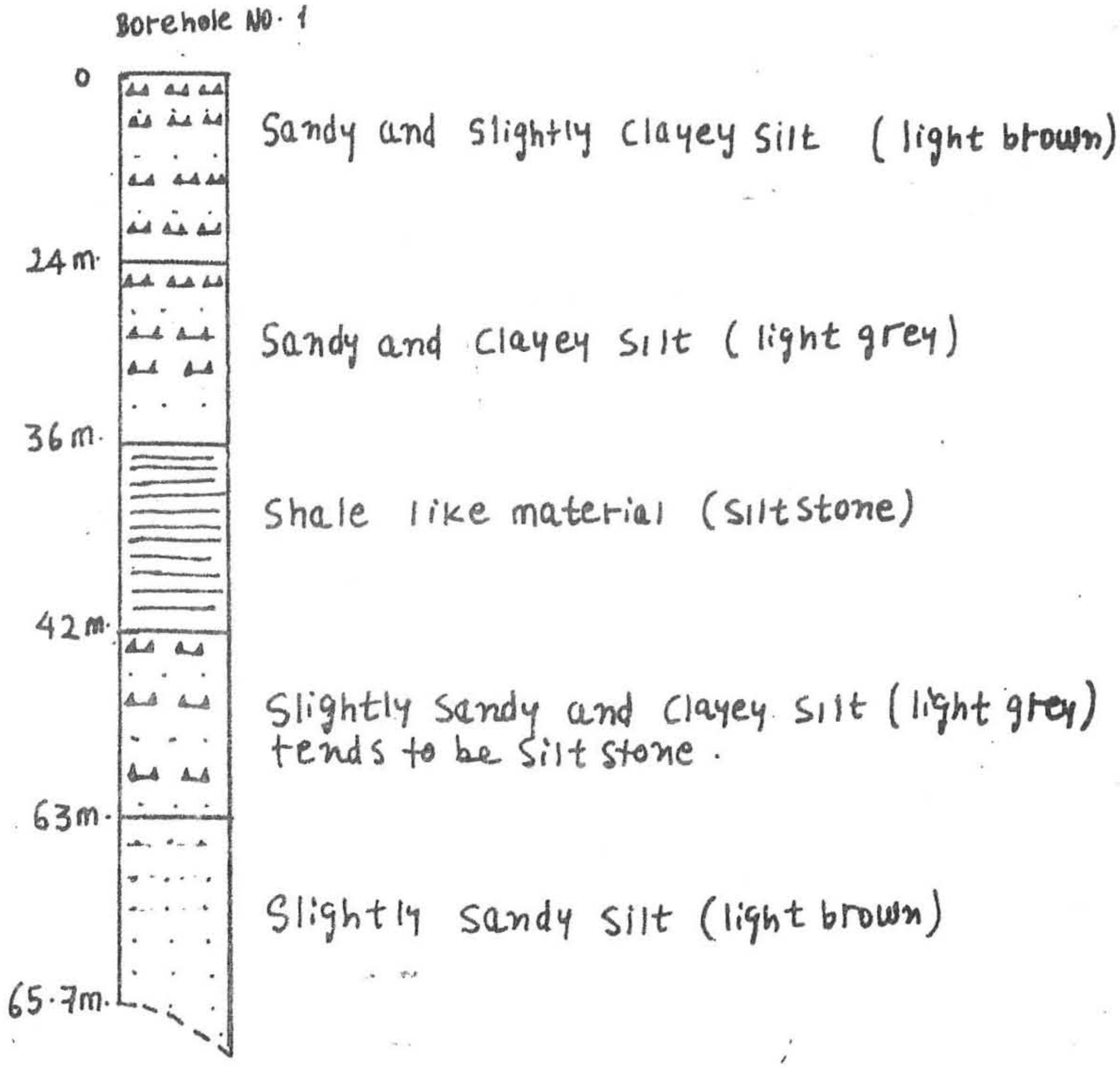
CLAY, Dark brown, Hard, Prismatic - Granular.

CLAYEY SILT, Dark yellowish brown, Mod. weathered, Firm - St[illegible]ff. Intact, reddish and dark mottling, porous with v. root holes.

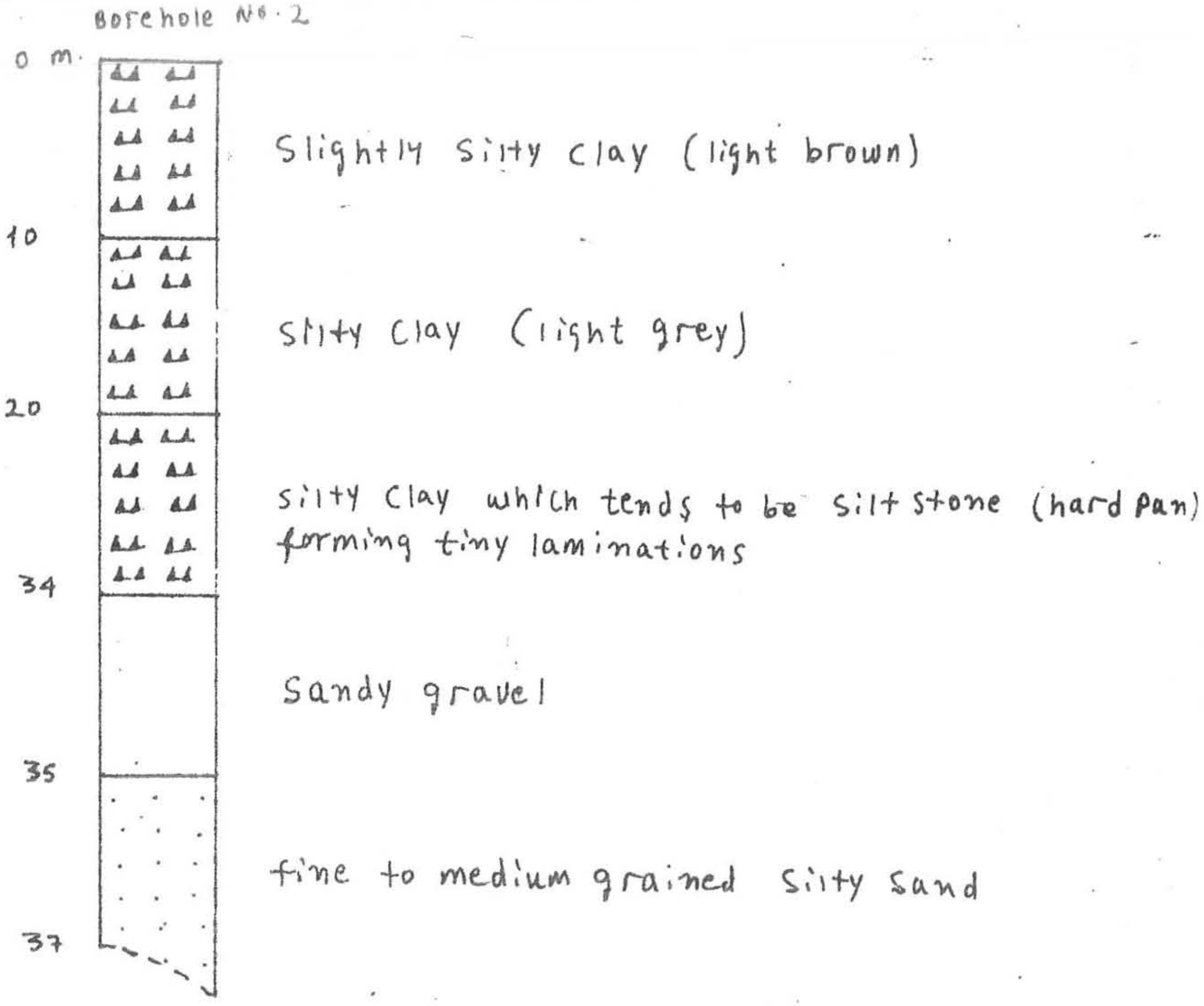
CLAY, Dark brown, Mod. weathered, Hard, Granular.

CLAYEY SILT, ---

CLAY, Dark brown, Fresh, Hard, Shows moderate effervcence to HCl Indicating presence of Carbonate.



Source : E.W.W.C.A. Southern region.



Source : E.W.W.C.A.

Not to scale

Appendix - 2

Free Swell Test (Gibbs and Holtz, 1956), Fide. Head (1984)

Free swell is defined as the increase of the soils volume from a loose dry power from when it is poured in to water, expressed as a percentage of the original volume. Its purpose is to indicate the possible expansive characteristics of a clay, whether in its natural state, in situ or as a fill after being compacted.

Soils with free swell values less than 50% are not likely to show expansive properties. Values of 100% or more are associated with clays which could swell considerably when wetted especially under light loading.

Preparation of Sample

- About 50 gram of sample is oven dried, and passed through a 0.425 mm sieve.
- Place the dried soil loosely in dry 25 ml. cylinder up to the 10 ml mark.
- The power shouldn't be compacted or shaken down.

Procedure

1. Place 50 ml. of distilled water in a 50 ml glass measuring cylinder.

2. Pour the dry soil powder slowly and steadily in to the water.

3. Allow the main part of the solid particles to come to rest; this will take from a few minutes to half an hour. The finest particles may remain in suspension for much longer but these can be ignored.

4. Read off and record the volume of settled solids s(v) in ml.

Calculation and Report

"Free Swell" is defined as the change in volume of the dry soil expressed as a percentage of its original volume. It is calculated from the equation.

Free swell $S_F = \frac{V-10}{10} \times 100\%$ if the original dry loose volume was 10 ml.

- The result is reported to the nearest whole number.

Appendix - 3

Liquid Limit, One - Point Cone Penetrometer Method

(Clayton and Jukes, 1978), fide. Head (1984)

This method was suggested by clayton and jukes (1978) as a possible less elaborate routine method of assessing the liquid limit of a soil than the four point cone penetrometer test described in the standard BS 1377:1975 Test 2 (A). it is based on a statistical analysis of their experimental data and on similar work carried out by soil mechanics limited. The principles is analogous to the one point Cassagrande test. The apparatus and all the procedures are identical as in the standard, except that a smaller quantity (about 100g) of soils is required and penetration and moisture content measurements are made only once, instead of four times. The moisture content of the soil should be adjusted so that the cone penetration of between 15mm. and 25 mm is obtained.

The moisture content obtained at the respective cone penetration, is expressed to the nearest 0.1% and is then multiplied by a factor obtained from Table-1 to obtain the liquid limit of the soil. The factor to be used for a given penetration depends up on whether the soil is of low, medium or high plasticity.

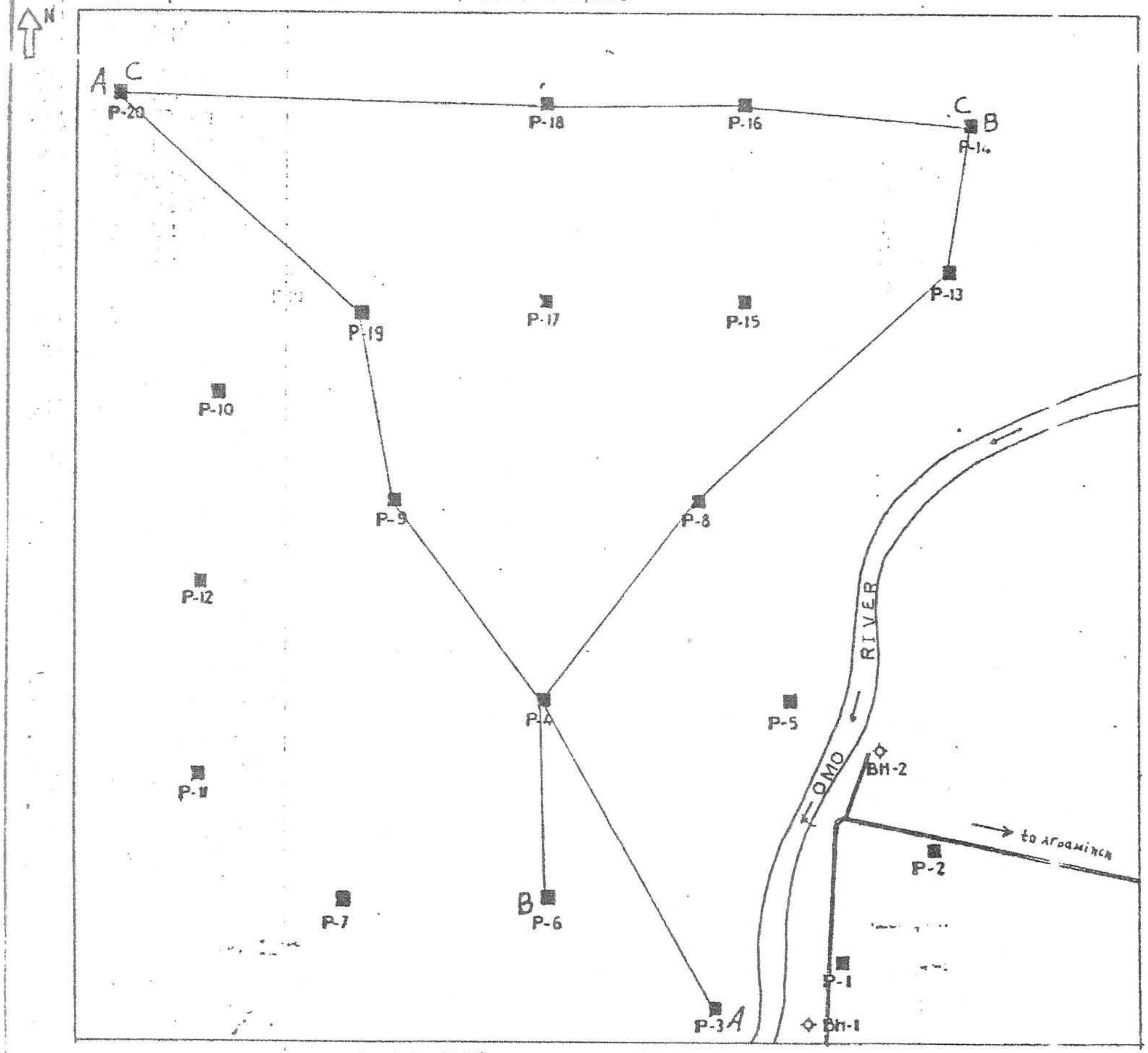
The measured moisture content indicates to which group the soil belongs as indicated at the bottom of Table-1. The factor to be used is read off from the appropriate column opposite the measured penetration. The liquid limit (LL) calculated in this way is reported to the nearest whole number, and the method is reported as the suggested one-point cone penetrometer test. The percentage passing the 0.425 mm sieve, and whether natural or air-dried soil was used, are also reported.

Appendix - 4

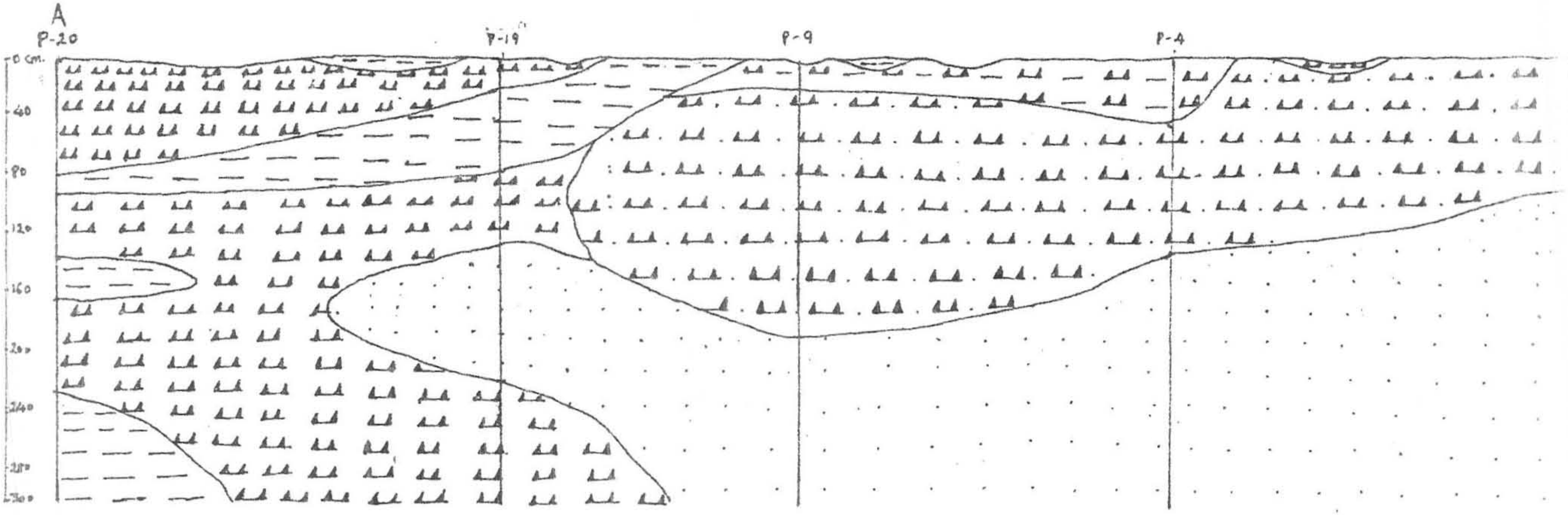
- The location of long and cross profiles

- Long and cross profiles along : A - A, B - B, C - C

Location of Long Profiles

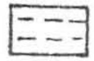


SCALE 1:28,000

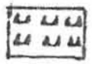


Horizontal scale 1:21,800
Vertical scale 1:40

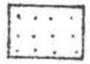
LEGEND



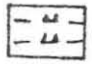
Lithological unit A (Clay)



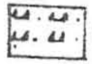
Lithological unit B (Silty Clay



Lithological unit C (Sandy Silt



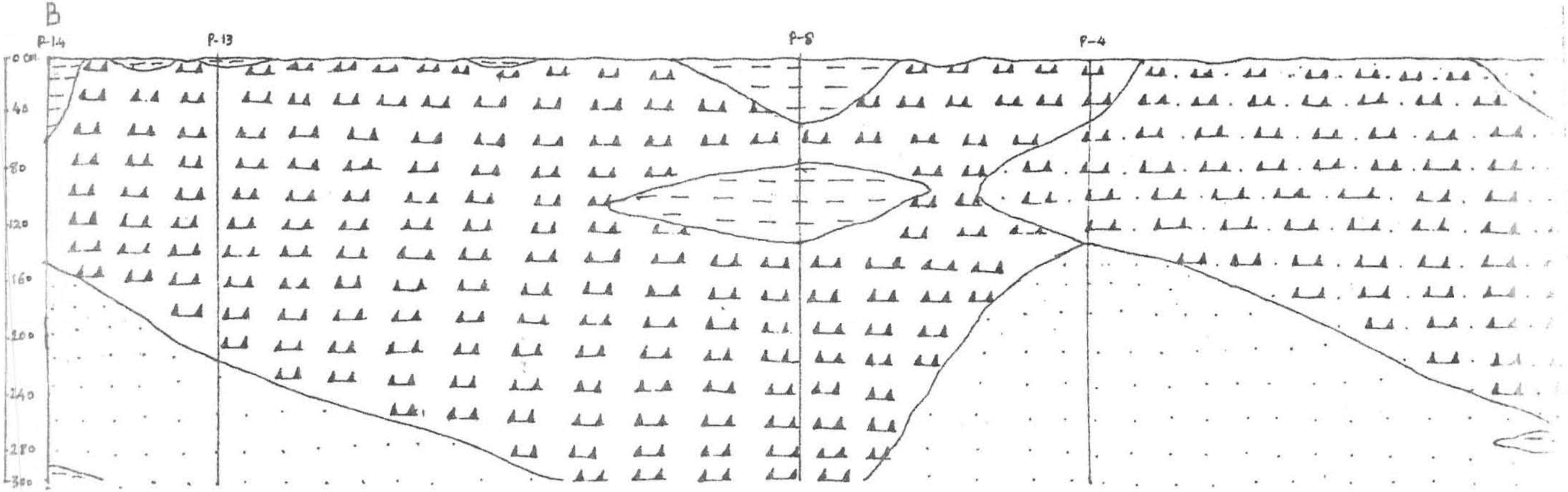
Lithological units A and B undiff



Lithological units B and C und

Long profile along A-A

All boundaries between different units are approximate.



Horizontal scale 1: 20,300
Vertical Scale 1: 40

LEGEND

Lithological Unit A (Clay)

Lithological unit B (Silty Clay and Cla

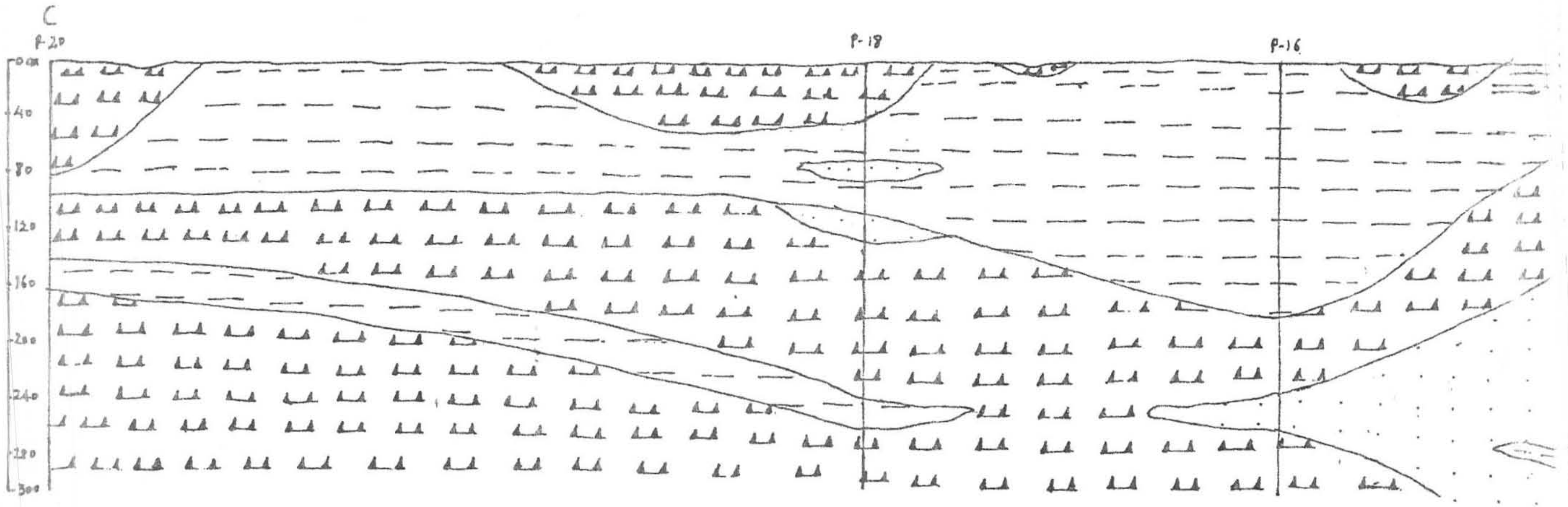
Lithological Unit C (Sandy Silt and Sil

Lithological units A and B undifferent

Lithological Units B and C Undiffere

Long profile along B-B

All boundaries between different units are approximate.



Horizontal scale 1:17,000
Vertical scale 1:40

Long profile along C-C

All boundaries between different units are approximate.

LEGEND

Lithological unit A (Clay)

Lithological unit B (silty clay and Cla

Lithological unit C (Sandy silt and S

Lithological units A and B undifferent

Lithological units B and C undifferen

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