Geological and Geotechnical Setup of Dam Projects, African Rift Valley, Ethiopia

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Abstract

The project areas' forming a part of Ethiopia lies geologically between the African and Arabian plates, morphologically formed by the East African system. The area is marked by physiographic units, the Ethiopian plateau, Ogaden Plateau, and Rift Valley widening to the north into Afar Triangle material of sea floor spreading as a result of constant separation of Arabia and Africa plates during Tertiary times & Uplifted sea floors.

The Awash river form an important river system in the Central part of Ethiopia and has a long course after originating from the Highlands of Addis Ababa, the capital city of Ethiopia. The river flow has been utilized for development of irrigation systems and hydropower development by a number of foreign agencies including India since a long time.

The authors were associated with two major schemes in the Awash valley namely Tendaho and Kesem projects which are actively under construction.

Tendaho area exposes Volcanic (Paleocene-Miocene), younger silica rich volcanic (Miocene-Pleistocene) and Afar group volcanic (Pliocene- Holocene) of rocks are also well exposed. Tendaho dam site across river Awash is located within area known as the "Tendaho Graben" which forms the center of Afar Triangle. The dam envisaged is a composite of 55m high to facilitate sugarcane cultivation over an area of 60, 000 hectares. The Kesem Dam & Irrigation Project envisages construction of a 90m high dam across River Kesem a tributary to Awash River. The dam under construction is a central earth core rock fill dam. The scope of the project is to facilitate cultivation of sugarcane crop over an area of 20,000 hectares

The geological setups of these projects along with the tectonics and geotechnical problems at the dam sites are highlighted in the paper.

Introduction

The East African Rift system is one of the geological wonders, a place where the earth's tectonic forces are presently trying to create new plates by splitting apart the older ones. In simple terms, a rift can be thought of a fracture in the earths surface that widens overtime or more technically as an elongate basin bounded by opposed steeply dipping normal faults. There is still debate about this phenomenon and it is termed as a Nubian plate which includes Ethiopia, Kenya-Uganda and Tanzania while the smaller plate that is pulling away is the Somalia plate These two plates are pulling away from Arabian sea plate and junction of these three are in the Afar region of Ethiopia where it forms the triple junction. The oldest and best-defined rift occurs in the Afar region of Ethiopia and this rift is usually referred to as the Ethiopian Rift

The exact mechanism of rift formation is an on-going debate among geologists and geophysicists. One popular model for the EARS assumes that elevated heat flow from the mantle (strictly the asthenosphere) is causing a pair of thermal "bulges" in central Kenya and the Afar region of north-central Ethiopia. These bulges can be easily seen as elevated highlands on any topographic map of the area (Figure 1). As these bulges form, they stretch and fracture the outer brittle crust into a series of normal faults forming

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the classic horst and graben structure of rift valleys. Ideally the dominant fractures created occur in a pattern consisting of three fractures or fracture zones radiating from a point with an angular separation of 120 degrees. The point from which the three branches radiate is called a "triple junction" and is well illustrated in the Afar region of Ethiopia where two branches are occupied by the Red Sea and Gulf of Aden, and the third rift branch runs to the south through Ethiopia. (see Fig 1 a & b) Recently, basalt eruptions and active crevice formation have been observed in the Ethiopian Rift, which permits us to directly observe the initial formation of ocean basins on land. This is one of the reasons why the East African Rift System is so interesting to scientists. Most rifts in other parts of the world have progressed to the point that they are now either under water or have been filled in with sediments and are thus hard to study directly. The East African Rift System however, is an excellent field laboratory to study a modern, actively developing rift system. Just like the Grand Canyon, the East African Rift System should be high on any geologist's list of geologic marvels to visit.

In the following pages an account of two major irrigation projects namely Kesem project and Tendaho project both in Awash river basin developed for sugarcane cultivation with which the authors were actively associated are described for the benefit of the geological community. The projects are under active construction and the first author is still rendering advice on the foundation problems and treatment at the request of The Federal Democratic Republic of Ethiopia.

Geotopographical setup

The country of Ethiopia is marked by the main river system the NILE along with plateaus between the valley of the Upper Nile and Ethiopia's border with Eritrea is a region of elevated plateaus from which rise various mountain ranges. These tablelands and mountains constitute the Ethiopian Highlands. Nearly every side, the walls of the

plateaus rise abruptly from the plains, constituting outer mountain chains. The highlands are thus a clearly marked orographic division. The Awash River flows eastward. The main range at this point trends southwest, while south of the Awash Valley, which is some 3000 ft (1000 m) below the level of the mountains, another massif rises in a direct line south. This second range sends a chain (the Harar hills) eastward toward the Gulf of Aden

The physical aspect of the highlands is impressive. The northern portion, lying mainly between 10° and 15° N., consists of a huge mass of Archaean rocks with a mean height of 7000 to 7500 ft (2,200 m) above sea level, and is flooded in a deep central depression by the waters of Lake Tana.. Characteristic of the country are the enormous fissures, which divide it, formed over time by the erosive action of water. They are in fact the valleys of the rivers, rising on the uplands or mountainsides, have cut their way to the surrounding lowlands. Some of the valleys are of considerable width, in other cases the opposite walls of the gorges are two to three hundred meters apart, and fall almost vertically hundreds of meters, representing an erosion of many millions of cubic feet of hard rock.

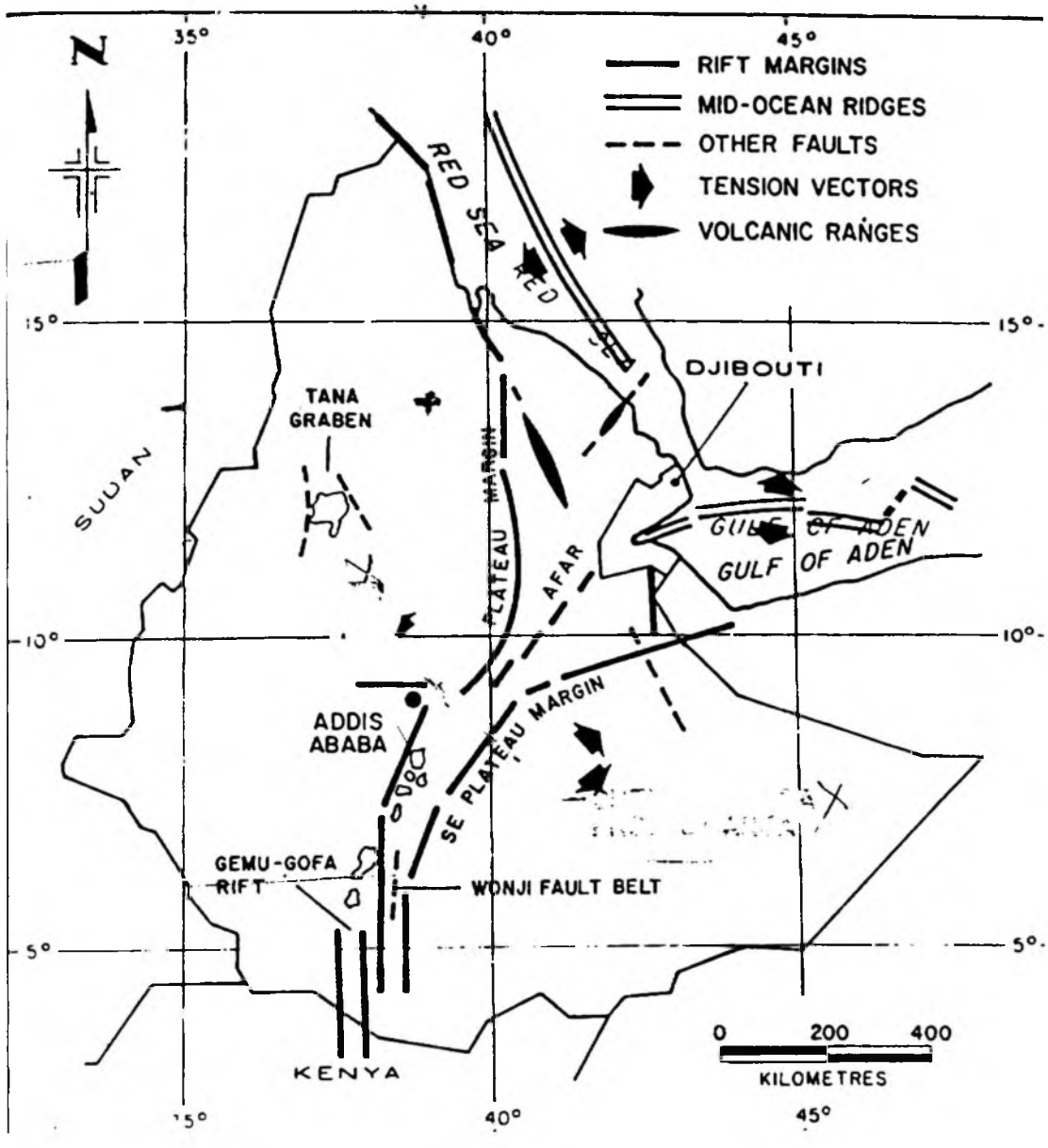

Fig. 2. Major Tectonic Features

Ethiopian uplands are sloping towards northwest, so that nearly all the large rivers find their way in that direction to the Nile. Such are the Tekezé River in the north, the Abay in the center, and the Sobat in the south, and about four-fifths of the entire drainage is discharged through these three arteries. The rest is carried off by the Awash, which runs out in the saline lacustrine district along the border with Djibouti; by the Webi Shebeli and the Jubba, which flow southeast through Somalia, though the Shebeli fails to reach the Indian Ocean; and by the Omo, the main feeder of the closed basin of Lake Turkana.

The chief river of Ethiopia flowing east is the Awash River (or Awasi), which rises in the Shoan uplands and makes a semicircular bend first southeast and then northeast. It

reaches the Afar Depression through a broad breach in the eastern escarpment of the plateau, beyond which it is joined on its left bank by its chief affluent, the Germama (Kasam), and then trends round in the direction of the Gulf of Tadjoura. Here the Awash is a copious stream nearly 200 ft (60 m) wide and 4 ft (1.2 m) deep, even in the dry season, and during the floods rising 50 or 60 ft (15 to 20 m) above low-water mark, thus inundating the plains for many miles along both its banks. Yet it fails to reach the coast, and after a winding course of about 500 miles (800 km), it passes (in its lower reaches) through a series of badds (lagoons) to Lake Abhe Bad (or Abhe Bid) on the border with Djibouti and some 60 or 70 miles (100 km) from the head of the Gulf of Tadjoura. In this lake the river is lost. This remarkable phenomenon is explained by the position of Abhe Bad in the centre of a saline lacustrine depression several hundred feet below sea level. While most of the other lagoons are highly saline, with thick incrustations of salt round their margins, Abhe Bad remains fresh throughout the year, owing to the great body of water discharged into it by the Awash.. There are numerous hot springs in Ethiopia (Sodere, for example).

Geology and regional setting:

Ethiopia can be divided into four major physiographic regions widely known as the western Plateau, southeastern plateau, the main Ethiopian rift and Afar depression. The Plateau is underlain at depth by Precambrian rocks of Afro-Arabian Shield .The Pre Cambrian basement is covered for the most part by glacial and marine sediments of Permian to paleogene period and tertiary volcanic rocks with related sediments .The Cenozoic volcanic succession is split apart by parts of the Great East African Rift System in Ethiopia .i.e the Afar Depression, Main Ethiopian Rift and related drifts.

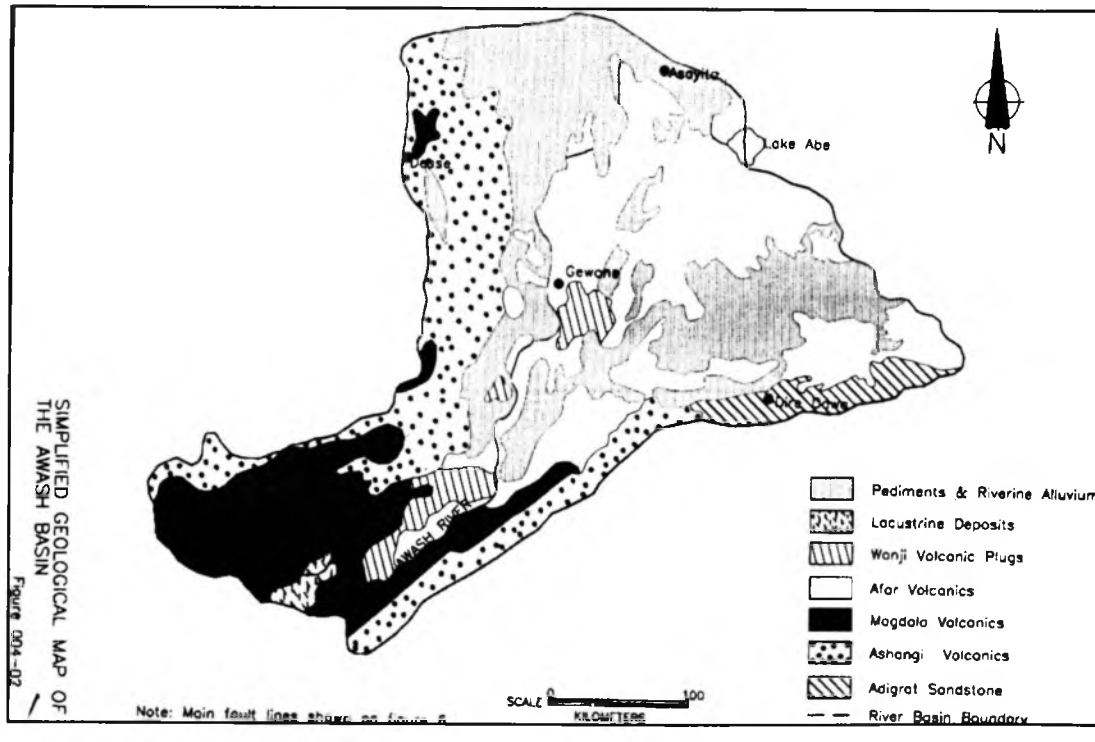

Fig. 3. Awash basin map with geology

Precambrian basement exposures are found in areas not affected by Cenozoic volcanism and rifting and where Phaneorozoic cover rocks have been eroded in to two major lithotectonic assemblages in the Precambrian basement in Ethiopia similar to these recognized in the neighboring countries of northeast Africa and Arabian peninsula.

Following the Proterozoic to Early Paleozoic tectonic and magmatic activity peneplanation of the metamorphic basement took place until Carboniferous and Permian (Kazmin 1972) Late Paleozoic to early Mesozoic sediments accumulated in shallow basins and narrow channels cut in the Precambrian basement .Two major transgression-regression cycles took place during Mesozoic era(Kazmoin 1972). A third and more extensive transgressive event took place in late Cretaceous until Middle to late Eocene .Following the Late Mesozoic-Early Tertiary transgression of the sea from Southeast an epieorgenic uplift of Afro-Arabi(East Africa together with Arabian penisula and intervening regions now occupied by the Red sea and Gulf of Aden) occurred on an immense scale .According to Mohr(1962) the magnitude of the uplift was such that nowhere in the World uplift of such an a magnitude took place .The first volcanic activity occurred in the Late Mesozoic along the margins of the Proto-Afar These early flood basalts now cover extensive areas of western and southeastern plateaus. Several pulses of volcanic activity were always related to or preceded by major tectonic movements were identified. Then became focus of Quaternary and volcanic activity. Deep exploration drilling has proved the existence of geothermal reservoir related to Quaternary volcanic that can economically supply steam for power generation

Seismicity of the area

Ethiopia lies geologically between the two major tectonic plates namely the African and Arabian plates morphologically formed by the east African System .The rift valley is famed for its seismic and volcanic activity .Earthquake record both historical and instrumental exist and crustal dynamics is reported the be better know than in the rest of the African system .The monumental work

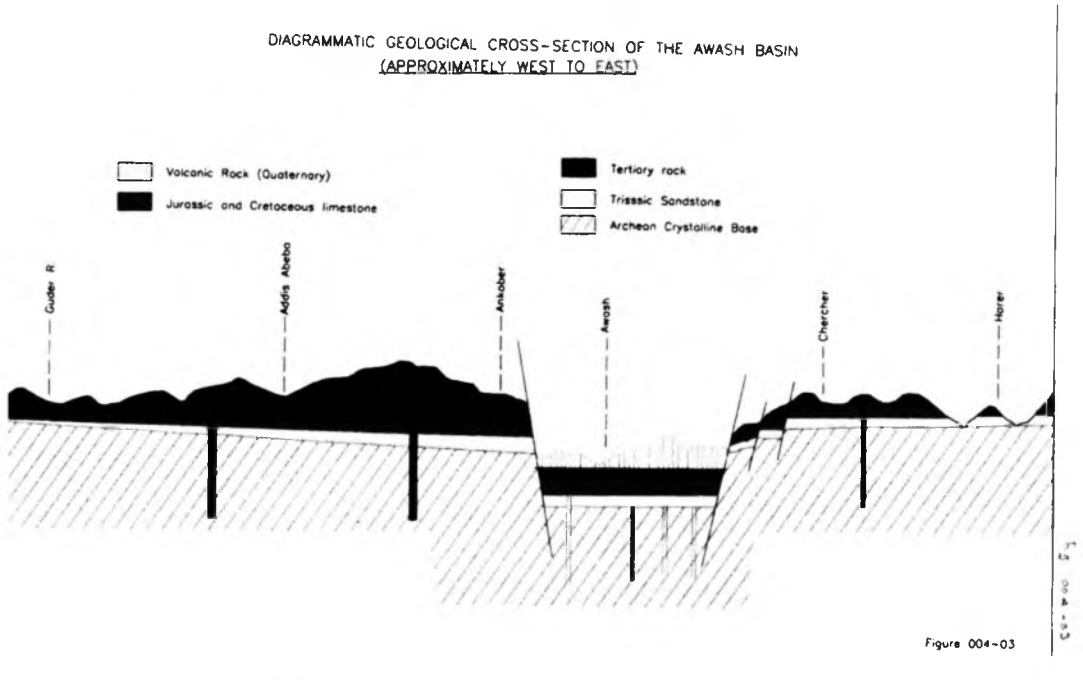

Fig. 4. Geological cross section of the awash basin

is regarding Seismicity is the Seismic Zoning map of Ethiopia (Gouin).The geophysical laboratory Addis Ababa University has prepared a catalogue of earthquakes .A perusal of regional Seismicity indicates that EQ events are all concentrated to the north and NE of capital city of Addis Ababa Earthquake occurrences ,younger faults and volcanoes along with plate tectonics considerations have been used to delineate different seismogenic source areas by a number of workers in Ethiopia. It is said that east African rift is capable of generation of Earthquakes of Magnitude 7 and above. The major event which has occurred is in Sedo area about 25km away of Tendaho dam site which had a magnitude of 6.3 and caused extensive damage.

Kesem dam and irrigation project

The Kesem Dam & Irrigation Project envisages construction of a 90m high dam across River Kesem a tributary to Awash river. The dam under construction is a central earth core rock fill dam. The scope of the project is to facilitate cultivation of sugarcane crop over an area of 20,000 hectares

Geology, Structure: and Evaluation:

The dam site area forming a gorge in the Kesem River a triburay of R.Awash exposes the older rift formation, paleo channel fluvial deposit and volcanic and recent alluvial deposits..

The Kesem River flows in a general easterly direction and the axis of the dam is aligned in a NNE-SSW direction. Two major pyroclastic Ignimbrite layers have been recognized on the abutments with Basaltic layers in the mid section. The Ignimbrite layers vary in thickness from 6-25 m and three basaltic lavas vary from 3 - 4.5 m in thickness. The Tuff/'red bole layers have a

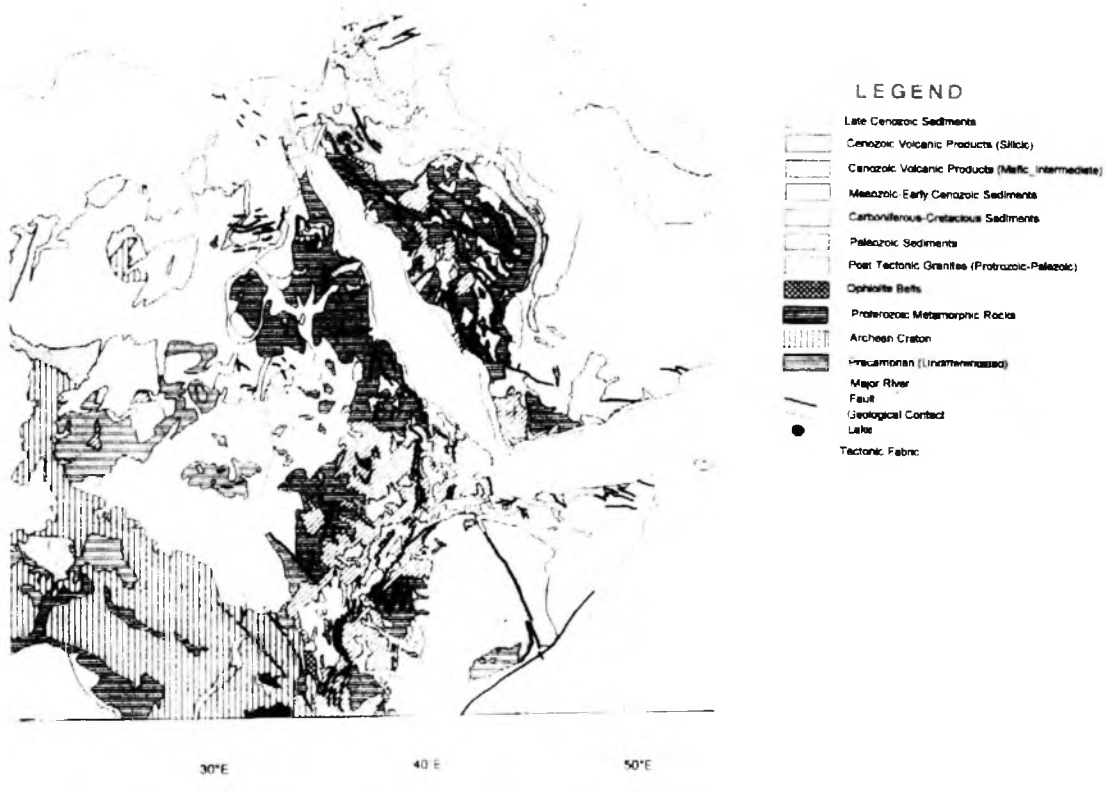

Fig. 5. Geological sketch map of North Africa and Arabian Peninsula.

mapped variable thickness of 1.5 to 5 m but in addition thinner zones have been also demarcated on the left abutment excavation Both springs and seepages are commonly found at the lowest levels on both banks of the river and the spring hot waters are with temperatures of 35 to 53 degrees and artesian hot springs show a pressure of 1.55 to 2.5m head.

The volcanic rocks have a uniform upstream dip with an average dip of 4 to 5 degrees towards N60 W and they strike N30E-S30W. The rock types are jointed and the prominent sets are as follows.

i) Strike NNE-SSW with dip of 4 to 8 degrees towards north.

ii) StrikeN30E-S30W with sub vertical to vertical dip.

iii) Strike N10W-S10E with 80-85 degrees dip to S80W.

The dam site is dissected by faults, which are reported to be mainly normal. A geological map of the dam site is enclosed as Fig-6 A fault has been interpreted along the course of the river and this is based on the highly fractured Ignimbrite bedrock and hot springs in the boreholes. The dam site has bee explored as many as eight boreholes along with insitu tests in the boreholes located on left abutment. The permeability values vary from 24 to54 lugeons at higher levels but in the lower level of Ignimbrites and basalts it is the range of 8 to 12 lugeons. Tuffs have a K vale of 2-4 lug eons. In the river channel bed rock indicate including tuff show high value of 20 to 50 lug eons and only at lower elevations it is 0-4 lugeons. On the right abutment the permeabilty values show 10-39 lugeons at higher levels and lower levels it is 8-10 lugeons.

The compressive strength of the Ignimbrites vary from 10-14 for weak varieties to 41 Mn/m2 and basalts have a high range from34-58Mn/M2.The tuff has a low value of 4-6Mn/m2.

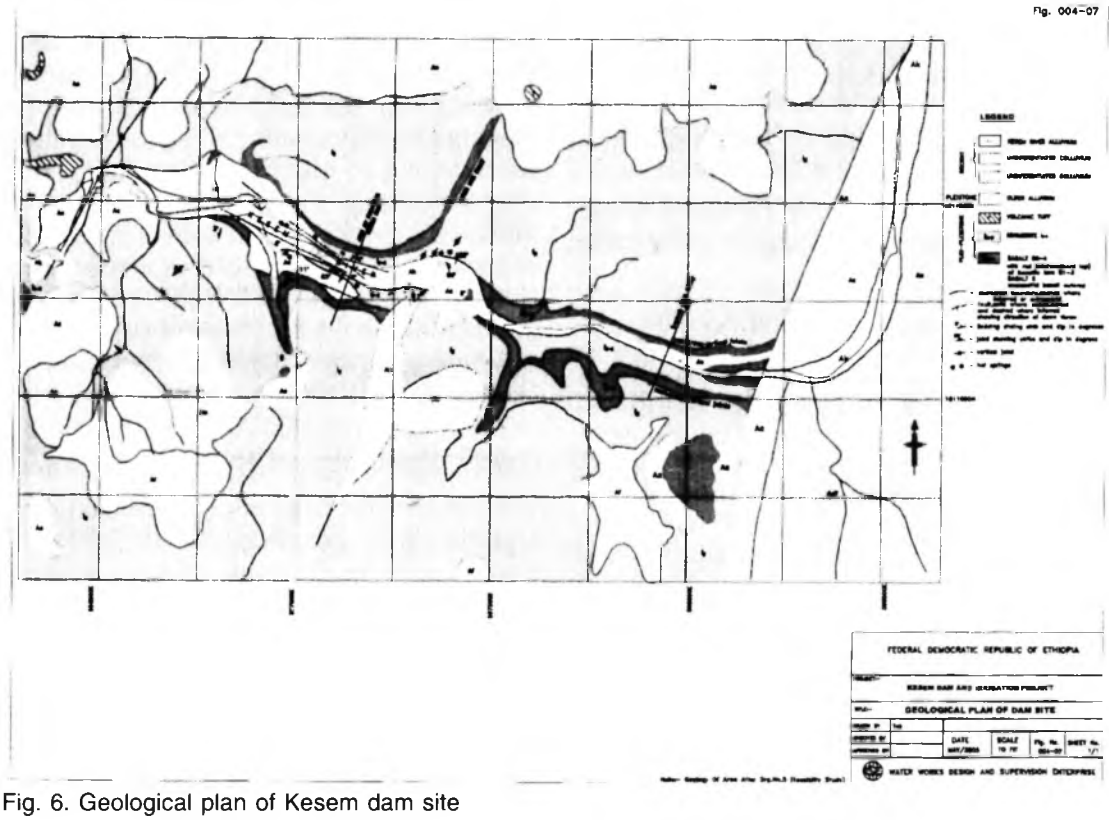

Fig. 6. Geological plan of Kesem dam site

Geotechnical studies have brought out the followings:

1. The gorge exposes the Ignimbrites and lavas of the layered ignimbrites of the Late Tertiary age.
2. The total thickness of the successions of the order of 90m in the dam axis consisting of thicker Ignimbrite layers with layers of hard basaltic lava,
3. Points of engineering interest are the prominent weathered tuff zones formed at intervals (Red bole layers) at some places and along the abutments. And four such layers varying from1.5 to 5m have been identified by surface mapping and drilling,
4. The presence of a thin white tuff bed at base of the ignimbrites unit 12 was considered weak rock,
5. The rocks dip upstream fairly uniformly with dip angles of 4 to 5 towards S60 W
6. Formations are cut by prominent faults trending across the gorge with shear and fractured zone 10-20cm wide,
7. The rock mass are prominently jointed by two sub vertical and one parallel to bedding
8. Superficial deposits in the dam and site area consist of sand, gravels and cobbles in the riverbed.
9. Hot springs are prominent and close to axis in the river channel portion,
10. A fault has been interpreted that should have existed and explorations have proved. Jointed Agglomerates with hot water springs above it are found.
11. The depth of stripping on the left abutment is of the order of 10-15m and on the right abutment it is of the order of 6m
12. In order to make the foundation rocks watertight, grouting has been provided for with holes normal to the face on the abutments and vertical in the riverbed.
13. The river diversion has been achieved by provision of a diversion tunnel on the right abutment and tunneling was done with out any major problems.
14. In view of the difficulties of providing a chute spillway on the left abutment a saddle on the left abutment far away from the dam axis have been utilized.

Tendaho dam and irrigation project

The Tendaho Dam & Irrigation Project envisages construction of a dam across River Awash with a diversion tunnel, irrigation inlet and a spillway on the left abutment ridge. The scope of the project is to facilitate cultivation of sugarcane crop over an area of 60,000 hectares

Geology, Structure: and Evaluation:

Physiographic units of the area include, the Ethiopian plateau, Ogaden Plateau, and Rift Valley widening to the north into Afar Triangle mark the area. Tendaho area exposes Volcanics (Paleocene-Miocene), younger silica rich volcanics (Miocene- Pleistocene) and Afar group volcanics (Pliocene- Holocene) of rocks are also well exposed. During Pleistocene pluvial period very large lakes were formed on the rift valley bottom. The plains of Wonji and Metehara and lower Awash contain thick succession of Lacustrine deposits. Ogaden plateau is separated from Ethiopian plateau by a fault and these plateaus are supposed to be moving apart. Tendaho area is within the Afar Triangle junction of three rifts: the Red Sea, the Gulf of Aden, and the East African rift, an area known for seismic and volcanic activity.

The Tendaho dam site is located within area known as the "Tendaho Graben" which forms the center of Afar Triangle. It is considered that the volcanic rocks here are material of sea floor spreading as a result of constant separation of Arabia and Africa plates during Tertiary times & Uplifted sea floor forms now a part of Tendaho Graben.

The basalts generally trend NNW-SSE to

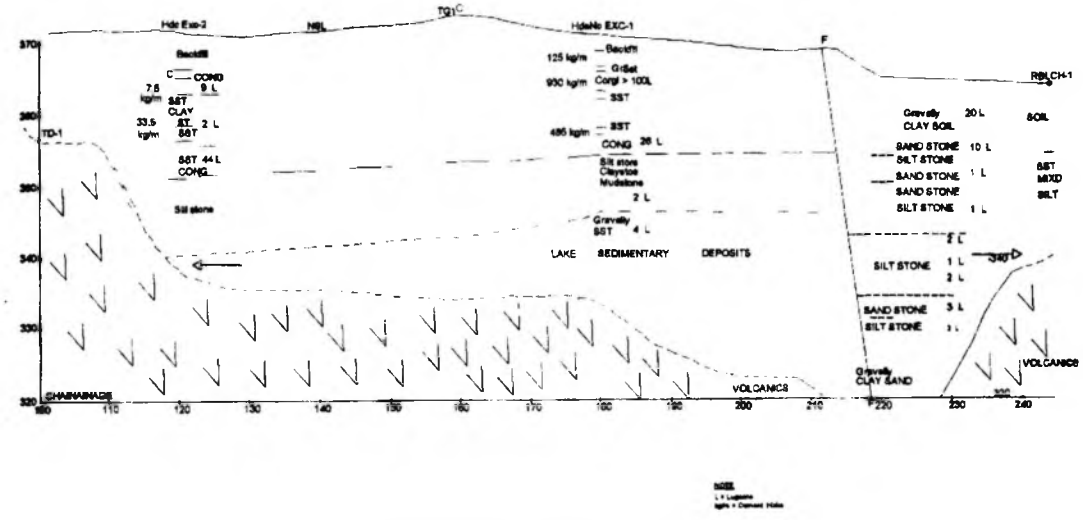

Fig. 7. Geological section along dam axis

NW-SE and dip at low angles of 3° to 5° towards right abutment. The rock types are jointed and the prominent sets are as follows.

iv) Strike NNE-SSW with dip vertical, prominent system and repeats at 20-50cm intervals, clean joint with no infilling.

v) Strike East –West with dip of 70° towards south prominent system. Repeats at 50 cm to one-meter intervals.

vi) Bedding joint strikes NNW-SSE with horizontal dips at 2° towards SSW.

vii) Three major faults NNW-SSE, NNE-SSW and East – West, have been recognized in the area. The river is along the NNE fault direction. Tendaho graben is a result of NNW Tensional faults. The East-West faults are reported in the saddle on right abutment

Land sat scenes show numerous linear parallel to 'graben' scarp traversing the lava plateau on both sides of the proposed reservoir

The geotechnical assessment of the dam site after geological mapping and evaluation of the explorations has led to the following conclusions:

1. The Tendaho project area is within the Afar Triangle Junction of three rifts the red sea the Gulf of Aden and the east African rift and this is an area known for seismicity and volcanic activity. The dam site is located within area known as Tendaho graben forming the center of Afar triangle.

2. The reservoir are forms a part of the down faulted block(Graben) refilled with alluvial flood and lacustrine deposits bounded by faulted basalts .Investigations indicated that reservoir alluvium is fairly impervious and there are three major fault systems paralleling the three rift directions.

3. The dam site exposes the volcanic sequence of rocks of basalts on the abutment hills whereas the river channel and banks consist of recent alluvial deposits of silt, sandy soil underlain by lake sedimentary deposits,

4. Basatls forming the main rock type is thought to be from the ocean floor spreading by fissure eruption. Characterized by their rubble nature and varying degree of weathering. Individual bottom blocky base with in between occupied by Aphanitic, Porphyritic ,Scoraceous,Volcanic Breccia and tuff varieties. These basalts are adjudged to be formed before the deposition of Lacustrine deposits.

5. The recent alluvium on the banks and river consist of silt, sandy silt clays of low to intermediate plasticity with an explored thickness of 5-8 meters.

6. The lake sedimentary deposits in the river bed, banks and tunnel outlet portion consist of an interlayer sequence of mudstones, siltstones, sandstones, conglomerates and these deposits are noted in addition to dam site at the outlet portal of the tunnel and lower reaches of the spillway.

7. The basalts generally trend NNW-SSE to NW-SE and dip at low angles of 3 to 5 degrees towards right abutment or upstream. The rock types are affected by three major systems of joints, two subvertcial to vertical across the ridges and one bedding low dipping joint. Landsat imagery show numerous linear parallel to graben scarp traversing the lava plateaus on both sides of the reservoir..

8. Geotechnical drilling investigations carried out consist nine boreholes at dam site, four along tunnel alignment and three along spillway totaling to about 740m. These boreholes have proved the presence of basalt varieties on abutment hills with good core recoveries and RQD. Mostly During drilling of the holes in the abutments portions, heavy water loss have been noted indicating the open nature of joints on the ridge and the two boreholes on either side of the axis on the left bank have proved the existence of recent alluvium and lake deposits to be of 12m thick and two boreholes in the river channel sections proved 28m underlain buy volcanic rocks. The three holes on the right bank proved a deep fossil valley going down to a depth of 78m. Exploration along tunnel alignment that tunnel will be through variety of volcanic rocks ad tuff and Paleosols

9. Insitu tests of permeability indicates low value (of 2-4 lugeons) of permeabilty but holes on abutment ridge have indicated a moderate K value.Gravelly sandy soil in the river channel and banks have indicated a moderate permeability at higher levels with improvement at lower levels.

10. Evaluation of drilling data and surface mapping at dam site has indicated the basalt varieties can be characterized as Amydaloidal / Porphyritic and aphanitic variety as Class II Good rock with fracture index of less than 10or 20. Scoraceous basalts as Class III to IV as Fair to poor rock with a fracture Index of more than 20 and Vesicular basalts as Class III as fair rock with a Fracture Index of 10-20.

11. Observations indicated that stripping for 5m on the right side and 2-3m on the left abutment for placing of the core beyond the weak rock zones.

12. In view of jointed nature of basaltic rock grouting was done as per the programme. In the design stage of the project the grouting pattern of holes has been decided stage wise .In the designs two patterns A and B had been suggested for the abutments and Pattern C for the banks and river channel part with holes spaced 3m apart. It had been also stated that primary holes be drilled and grouted first and then secondary holes shall be drilled and grouted if grout intake by primary holes has been appreciable and the permeability of foundation as determined by percolation tests in a check hole is found to be more than 3lugeons.

The grout holes on the abutments be inclined at 30 degree to the vertical and may be adjusted to the field condition. Grouting of the abutments of the dam exposing the basalts of different types have been carried out by vertical and inclined holes using Portland cement mostly and Pozzolona Portland Cement recently with addition of bentonite. The analysis of the grouting effort carried out brings one to the following conclusions.

On the right abutment it is noted that even with closer spacing of holes, increase of grout lines, inclination of grout holes, use of fine pozzolona cement and fine ground cement, higher pressures have not improved the lugeon value to the required standards calling for introspection and devising remedial measures. The grouting effort and testing have brought out tuff and volcanic layers between 392-399m and 374-382m have not been effectively grouted and may provide the pathways for leakage of reservoir water .The possible ways of tackling these reaches are;

- Pressure washing of the layers of tuff and making an opening for fine pozzolona cement and grouting of the same and verifying by check holes
- Use of fine chemical grouting media to seal the permeability layers.
- As an added precaution provision of downstream relief holes for monitoring of seepage along with piezometers. The relief holes should be shrouded with filters to prevent particle carriage.

On the left abutment the grouting effort has been checked by a number of vertical check holes The Check hole closer to Pattern- A group of holes has indicated higher permeability in the upper stages but in the lower stages it is quite less. The check holes in the middle of Pattern B have indicated K values of 0 to a maximum of 12 lugeons in the top stage but all the values are less than 5. The grout intake in the check holes is also quite less than 5kg generally as per one result available. In view of lower order of permeability the grout intake is also normal and no abnormality has been recorded and grout intake has not exceeded12kg/m in any stage

The check holes have shown positive efficacy in all the stages indicating the positive effects of grouting which might be also due to use of Bentonite

The relief hole top be provided on the downstream side should be shrouded with filter material and monitoring by piezometers should be made regularly. In the river channel and bank areas recent alluvial deposits of silt and gravel overlie the consolidated older sedimentary deposits thought to be lake bed deposits having a thickness of 50-75m.The grouting effort have been carried out after a provision of a 30cm thick concrete slab to avoid surface leakage. For effective treatment measures, Removals from the foundation grade of the highly permeable conglomerate layer and overburden to a depth of say 10m.

- Provision of adequate relief holes on the downstream side with filter material to prevent particle carriage.
- Instrumentation by piezometeres for monitoring the seepage.
- Identification of the fault zone in the river channel portion and based on its extent provision of a deep cutoff with concrete based on design requirements. This will prevent the fault zone acting as a specific channel for escape of reservoir water.

13) The canal alignment posed the problem of encountering hot water under pressure and it was not possible to align the canal alignment. In order to circumvent the problem pressure relief measures are being provided as in the other areas nearby.

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