UNIVERSITY OF NAIROBI

SCHOOL OF PHYSICAL SCIENCES

DEPARTMENT OF GEOLOGY

PROJECT IN GEOLOGY

TITLE

GEOMETRY AND LITHOLOGY OF THE SUBSURFACE RESPONSIBLE FOR COLLAPSING OF BOREHOLES IN OLOBANITA WELL-FIELD, KENYA-RIFT

BY

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Adissertation submitted to the department of geology in fulfillment for the requirement of SGL 413: Project in geology.

May, 2011

DECLARATION

I do hereby declare that this report is my original work and has never been presented in any institution for any award

Declaration by student

Ogeu Onyango Edwin

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Signature.......................

Date............................

Declaration by the project advisor

I declare that this report has been submitted for examination with my approval as an official University project advisor

Name Prof Barongo

Signature....................

Date..........................

Declaration by the project coordinators

I declare that this report has been submitted for examination with my approval as an official University project coordinator

1. Name: Dr. Gichaba

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   Date............................

2. Name: Dr. Olago
   Signature…………….
   Date………………….

DEDICATION

To my

Beloved family members

and friends

ABSTRACT

This project describes the analysis carried out in the Olobanita well-field, Nakuru county, Kenya, using geophysical surveys and geologic logs with an aim of investigating the geometry and lithology responsible for collapsing of boreholes in the Olobanita well field. This has been a major setback in an effort to provide water from the ground water rich basin.

In this case therefore, the project employ geophysical surveys and geologic logs to explicitly investigate and characterize the subsurface responsible for the drilling menace recently encountered by Zhonghao Overseas Construction Engineering Company Ltd.

Geophysical surveys used include, Vertical electrical sounding (VES), Electrical resistivity imaging (ERI) and ground magnetic measurements. The vertical electrical sounding was done using the SYSCAL R2 equipment in the Schlumberger electrode configuration, electrical resistivity imaging involved the SYSCAL R1 switch 72 resistivity equipment and magnetic measurements utilized the proton precession magnetometer.

Results obtained from the geophysical survey were then analysed and related to borehole log information of Olobanita well-field, this has revealed some correspondence between lithostratigraphic units and resistivity values.

From the results obtained it is true that the prominent fault systems within the basin alongside the heterogeneity of the ground coupled with the soft loose volcano-sediments are greatly responsible for the collapsing of freshly drilled boreholes in the area. Finally several recommendations are made to reduce or to completely avoid caving in of boreholes during and after drilling.

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ACRONYMS

BH………………….Borehole

2D…………………..Two dimensional distribution of resistivity in the ground

3D…………………..Three dimensional distribution of resistivity in the ground

dV…………………..Potential difference

ERI…………………Electrical resistivity imaging

Fig…………………..Figure

Ltd………………….Limited

Ohm-m……………..Ohm meter

R…………………….Resistance

VES………………....Vertical electrical sounding

1.0 CHAPTER ONE: INTRODUCTION

1.1 Geographic location

The Olobanita well-field is located in the Central Kenya Rift, Nakuru County. The area occurs within the Great Rift Valley system which is characterized by rhythmic successions of volcanic activities accompanied by major episodes of faulting Figure 1.1 and 1.2 shows geographic location and the localities of some of the boreholes in Olobanita well-field respectively.

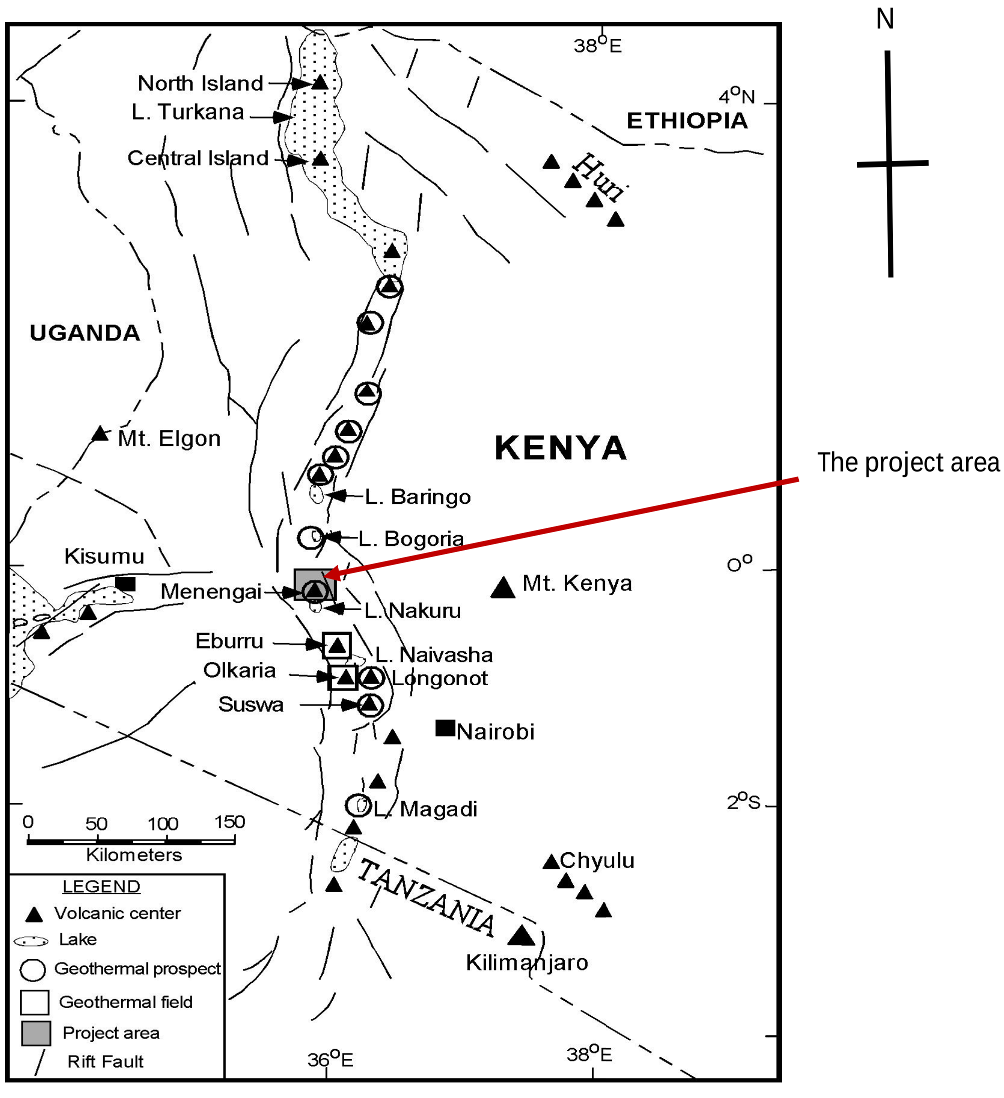

Figure 1. 1: Location of the project area. (Isaack, 2010)

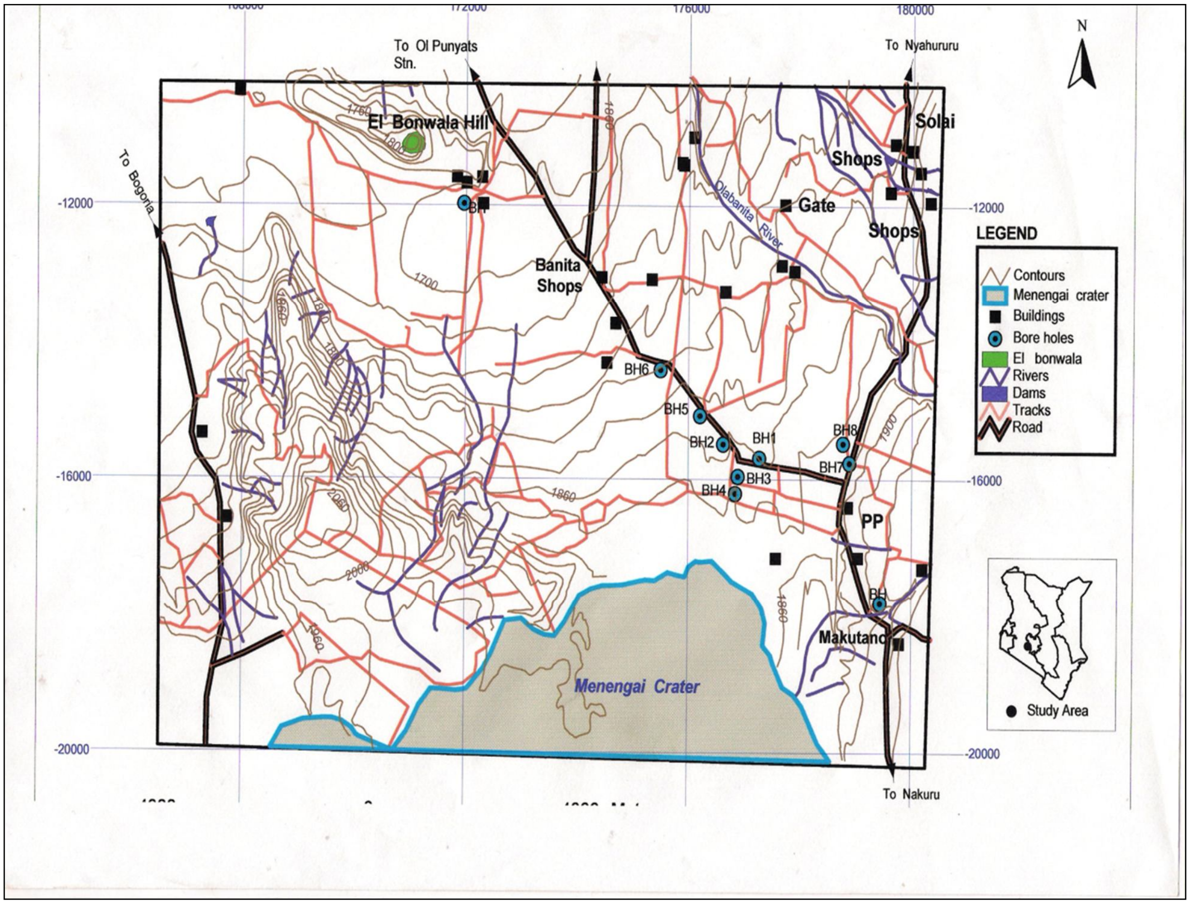

Figure 1. 2: Localities of different boreholes (BHs 1, 2, 5 & 6) in Olobanita area, insert is map of Kenya showing the area of study. (After Mathu, 2009. Department of Geology, University of Nairobi)

1.2 Geology of the Olobanita well-field

Geology predominantly consists of Tertiary to Quaternary volcanic suite, intercalated with thin successions of lake beds. Boreholes numbers 1 to 8 are dug in areas covered by superficial deposits and volcanic soils. Menengai crater which border the area of study to the South is dominated by Trachyte. The area is also bordered to the South Eastern by welded vitreous tuffs and to the North Western by Phonolitic trachyte. Figure 1.2.

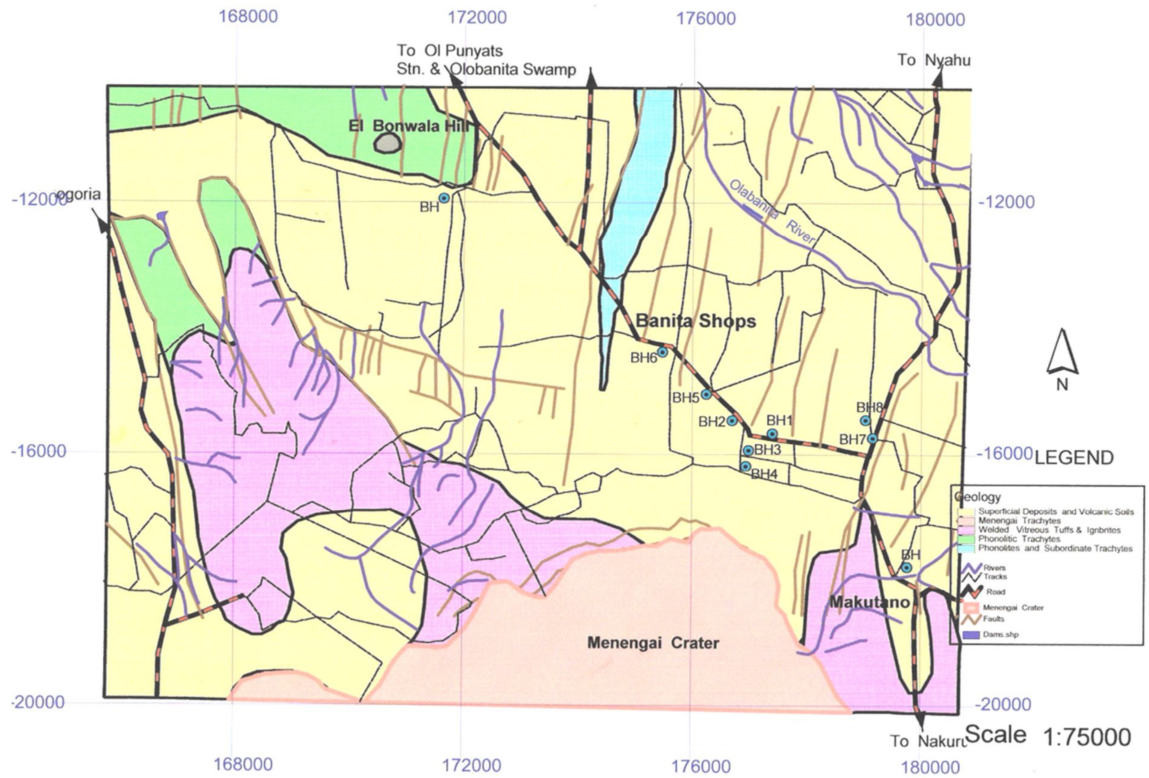

Figure 1. 3: Geological map of Olobanita well-field, (After Barongo, 2008)

1.3 Key objectives

- To use the magnetic and electrical resistivity methods to determine geometry and lithology of the subsurface rock materials at different areas of study.
- To use borehole logs to verify the results of the geophysical investigations.
- To recommend mitigation measures to reduce or to avoid future collapsing of boreholes.

1.4 Justification

No earlier research work has adequately addressed the present study subject, though geophysical exploration projects have been carried out recently by researchers and students with a view to assessing the groundwater potential of the area. The results of the present study would therefore try to shed light on the causes behind the caving in of freshly drilled boreholes for groundwater.

1.5 Literature review

In many parts of the world there is a heavy use of ground water as a primary drinking supply and as a supply of water for both agricultural and industrial use. The reliance on ground water is such that it is necessary to ensure that there are significant quantities of water and the water is of high quality.

The paper discusses use of geophysical methods to study geometry and lithology accountable for collapsing of drill holes during and after drilling operations for ground water exploration in the Olobanita well-field, Kenya rift.

McCall et al., (1965) investigated the general geology of the Nakuru basin-Kamasian. Their conclusion on groundwater resources agree with those drawn by Mooney and Wetzel, (1956). They went further and strongly recommended the sedimentary formations of the Nakuru basin to be of late Tertiary and Quaternary sediments. In addition, McCall, (1957) published a detailed survey of geology and groundwater conditions of the Nakuru area.

In his writing, Jakosky, (1950) describes the hydrogeology, quality and quantity of the groundwater in the south-east area of Kamasian. He made no attempt to carry out any geomerical or lithological investigation in Kamasian area. He, however, suggested that the real extent and thickness of the Kamasian area can be determined by electrical profiling and sounding, respectively.

Bristow, (1962) carried out geophysical surveys over part of the Kamasian area, involving magnetometric and resistivity surveys. He noted from the resistivity data that the top layer in sediments have generally high resistivities which rapidly decrease with depth perhaps due to groundwater salinity. Existing boreholes and wells within this area provided the controls. In the section dealing with groundwater it was noted that the faults acted as drains and caused a depression of the water table and that the fault zones are to be avoided when locating a suitable site for borehole.

Morris, (1964) and Keller and Frischknecht, (1970) are other reports which have a bearing on the present investigation. According to Barongo, (2008), the heterogeneity and the loose sedimentary materials are responsible for collapsing of boreholes during and after drilling operations and have undesirable outcome on drilling rods and bits.

The reports have little or no detailed geometrical or lithological investigation that cover the volcano-sedimentary formations found in this area. In these reports, the authors recommended further and detailed lithological investigation.

2.0 CHAPTER TWO: METHODOLOGY

2.1 Introduction

This work involves analysis of various Geophysical methods and geologic logs employed in the study of structures and lithology of the subsurface responsible for caving in of boreholes in Olobanita well-field. The field methods adopted include;

- Electrical resistivity (i.e. vertical electrical sounding and electrical resistivity imaging)
- Magnetic method
- Geologic logs

2.2 Electrical resistivity

The electrical resistivity is defined as the resistance offered by a given material to current flow. The resistivity of coarse-grained, well-consolidated sandstone saturated with fresh water is higher than that of unconsolidated silt of the same porosity, saturated with the same water. Also, the resistivity of identical porous rock samples vary considerably according to the salinity of the saturating water. The higher the salinity of the water, the lower the resistivity of the rock. (Mohamed, 1975)

According to Loke, (2000), electrical resistivity of any material is defined numerically as equal to the resistance in ohms offered between two opposite forces of a unit cube of the material. All resistivity methods employ an artificial source of current which is introduced into the ground through point electrodes. The procedure is to measure potentials of other electrodes in the vicinity of the current flow.

Parasnis, (1997) in his book described distribution of current in the earth surface using the Ohm's law as:

$$I = -dV/R$$

Where I is the electric current, dV is the potential difference and R is the resistance of the conductor.

2.2.1 Vertical electrical sounding

The method of vertical electrical sounding provide detailed information of the vertical succession of different conducting zones and their individual thickness and true resistivity. The measurements are made with a 4 electrode array, consisting of two current and two potential electrodes (Schlumberger array).

For purposes of measuring the apparent resistivity of the subsurface, professor Barongo in his study on the characteristics of the subsurface responsible for collapsing of boreholes in Olobanita well-field, used a SYSCAL R2 manufactured by Iris instruments of Orleans, France. The field measurement procedure for VES are made on some already predetermined sites within the project area.

A VES is typically carried out in Schlumberger array, where the potential electrodes are placed in a fixed position with a short separation and the current electrodes are placed symmetrically on the outer sides of the potential electrodes (Figure 2.1). After each resistivity measurement the current electrodes are moved further from the centre of the array.

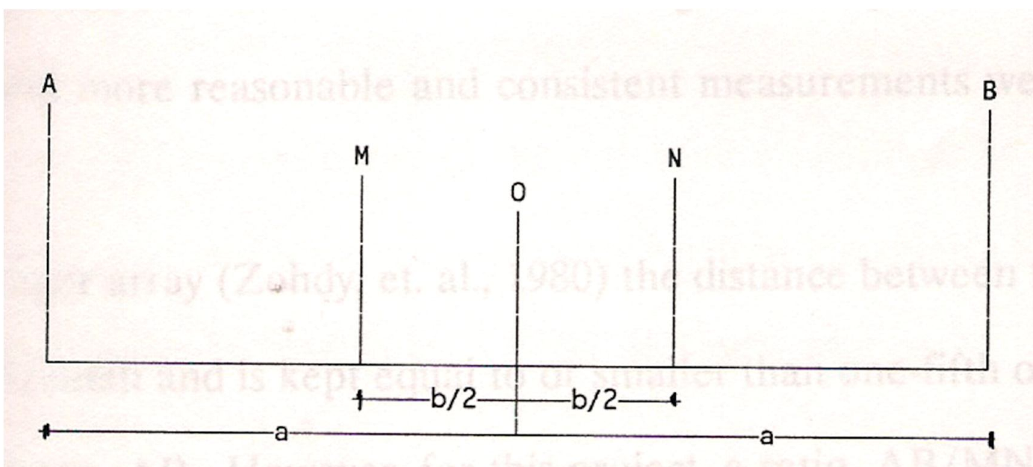

Figure 2. 1: Schlumberger electrode configuration, (After Das, 1995).

The SYSCAL R2 is placed at the centre O in Figure 2.1 of the sounding spread. The separation distance AB is the current electrode spacing and MN is potential electrode spacing. Point O is the reading station.

According to Barker, (1990), the distance between the potential electrodes is small and is kept equal to or smaller than one-fifth of the current electrodes spacing. In VES the depth of sounding increases with the distance between A and B electrodes.

The VES data obtained from the field in the schlumberger configuration were interpreted using the Auxiliary point method (Zhohdy, 1965) and the automated inversion programs SCHINV (Barongo, 1989 and Loke, 2001).

If VES is carried out during the dry weather, elaborate precautions should be taken to improve the surface contacts of the current electrodes (Parasnis, 1997). One way of doing this would be wetting the current electrodes, otherwise the dry nature of the surface soil would increase the contact resistance at the current electrodes, which makes current penetration a major hindrance.

2.2.2 Electrical resistivity imaging (Tomography)

Electrical resistivity imaging carries both the electrical resistivity sounding and profiling at the same time (Manzella, 1995). In this method either a two-dimensional (2-D) or a three-dimensional (3-D) distribution of resistivity in the ground can be obtained. SYSCAL R1 switch 72 system with72 electrodes and a total cable spread of 360 m capable of probing depth of up to 65 m was used with electrodes separation of 5 m.

Topographic corrections and 2D inversion model measurements were made using the inversion logarithm proposed by Loke and Dahlin, (2002). The extensive data resulting from measurements taken between the electrode arrays are processed to produce electrical resistivity tomographs (images).However, the resolution of the tomographic images created from the electrical resistivity data collected is controlled by the configuration and spacing of electrode arrays (Daily and Ramirez, 1999). For uniformity in the interpretation of different true resistivity sections along various profiles, a common colour code has been evolved and adjusted for presentation of the results (Tsourles, 1995).

2.3 Magnetic method

According to Parasnis (1997), magnetic method as applied in geophysics depends upon measuring accurately the anomalies of the local geomagnetic field produced by the magnetization in rock formations or other objects of search. The magnetization is partly due to induction by the magnetizing force associated with the Earth’s field and remanent magnetization. The induced intensity depends primarily upon the magnetic susceptibility as well as the magnetizing force.

Each magnetic mineral has a curie temperature, above which it loses its magnetic properties (Ward and Hohmann, 1991). Magnetic measurement of the Earth's magnetic field and local magnetic gradients are usually made with the proton precession magnetometers.

The method utilizes proton rich fluids surrounded by an electric coil. A current is applied through the coil, which generates a magnetic field that temporarily polarizes the protons. When the current is withdrawn, the protons realign or press along the line of the Earth's magnetic field intensity. Data acquisition for magnetic surveys involves taking a series of point readings at regular intervals on a survey grid. Various interpretation techniques are applied to the corrected data using specialist interactive software to identify the targeted anomalies.

Euler deconvolution (Thompson, 1982 and Reid et al., 1990) has come into wide use as an aid to interpreting profile or gridded magnetic survey data. It provides automatic estimates of source location and depth.

2.4 Geologic log

A geologic log is a record of various geological formations. It is constructed from sampling and examination of well cuttings at regular intervals during drilling of a well or test hole. A geologic log shows the geologic character and thickness of each stratum encountered as a function of depth (Todd, 1980)

Geologic logs are generally the most prolific form of existing data, however, the distribution of these data is usually restricted to areas of hydrocarbon exploration or existing subsurface storage operations and little data may be available for many areas of interest for underground storage. It is critical that a suitable log suite be properly acquired for every well drilled during the course of a storage operation. Most logs of geologic interest are open hole logs that can only be acquired before a well is cased and put into operation (Kurt, 2001).

According to Asquith and Gibson, (1982), borehole data are basically used in two different ways. First, the well logs give information specific to the borehole. Most borehole techniques only provide information in the immediate vicinity of the borehole. Depth of investigation is usually limited to a couple of feet. This information is crucial for determining reservoir characteristics, rock properties and engineering design criteria. The integration of core and log data is an important aspect of this type of geologic investigation. Running a core gamma-ray log will allow direct correlation of core data with the gamma-ray log run in the borehole allowing correction for cable stretch and variance between log depth and driller's depth (which is usually marked on the core). Correlation of a gamma-ray log with a core gamma also allows for locating lost core zones in relation to the borehole log data.

3.0 CHAPTER THREE: RESULTS AND INTERPRETATION

3.1 Vertical electrical sounding

Vertical succession of different conducting zones and their individual thicknesses and true resistivity was determined using the Schlumberger electrode configuration at few meters from each of boreholes BH 2 and BH 6. The electrodes spread direction in each case was nearly East-West at both borehole sites. The maximum AB/2 spread was 450m, which is capable of probing up to depth of about 300m.

3.1.1 VES results at BH 6

Figure 3.1 shows the results for this sounding, a KHKHK type curve with twelve geoelectric layers having distinct resistivities and thicknesses. From the figure, the first three layers have resistivities in the range 35 Ohm-m to 61 Ohm-m. These layers occupy a depth from the surface up to about 4m. The fourth layer with relatively very high resistivity in the range of about 190 Ohm-m to 1030 Ohm-m occupies a depth from about 4m to about 18m. It is the most resistive geoelectric layer in the sequence. The fifth, sixth and seventh layers have lower resistivities relative to layer four. Their resistivities range from about 5 Ohm-m to about 146 Ohm-m. The results further show that some of these layers consist of thinner layers as shown in the resistivity depth profile, (one of the layers was so thin that it could not be indicated on the VES graph).

The geologic log results confer with layer four and show that this particular zone is occupied by loose volcanics and loose gravels, tuffs and pumice. These rock materials are dry and vesicular since there is no indication of water, hence the high resistivity. All layers from a depth of about 18m to 165m are also resistive. Geologic log results confirm this. From the depth of 146 m onwards, the resistivity goes down denoting that the ground is soggy and approaching groundwater level at depth. Further evidence of the above observation is adduced from sounding curve shown in Figure 3.1.

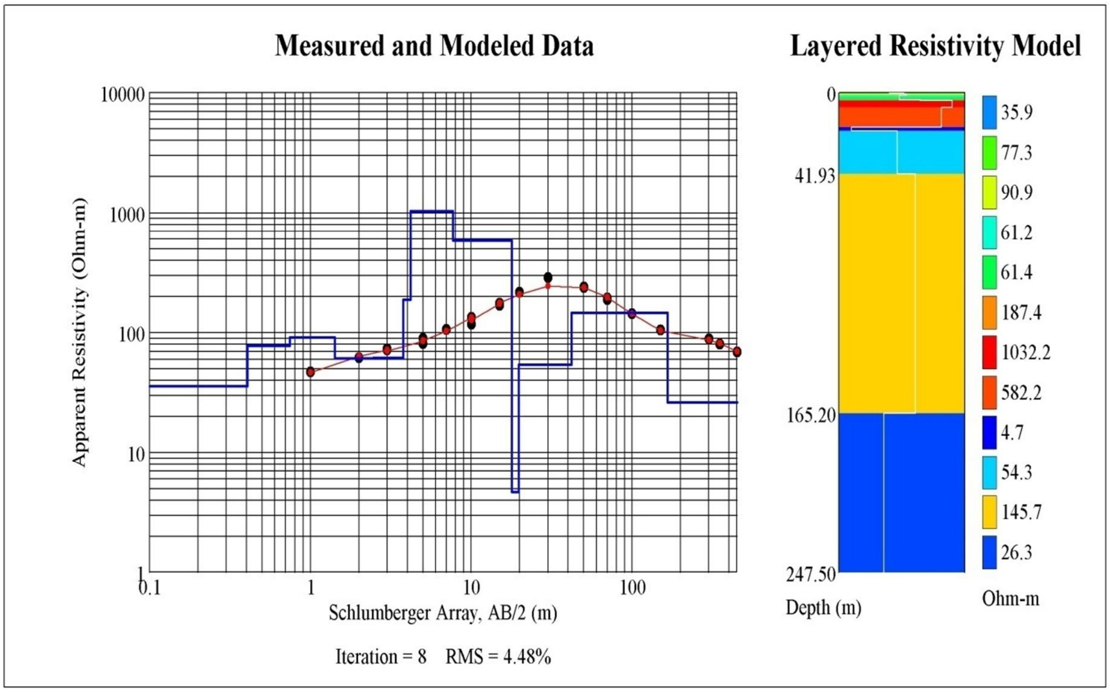

Figure 3. 1: Interpreted sounding results at borehole 6. (After Barongo, 2008).

3.1.2 VES results at BH 2

The results for this sounding are shown in figure 3.2. Here the sounding curve is also a KHKHK type curve consisting of 12 geoelectric layers. It has exactly the same characteristics as that of sounding at BH 6. The layer thicknesses and resistivities are quite similar except that the ground becomes wet from a depth of about 124 m. The drilling results by Zhongao Overseas Construction Engineering Company Ltd. Shows that this is the point where ground water level was struck. The borehole loggings discussed later in this project concur with the geophysical results.

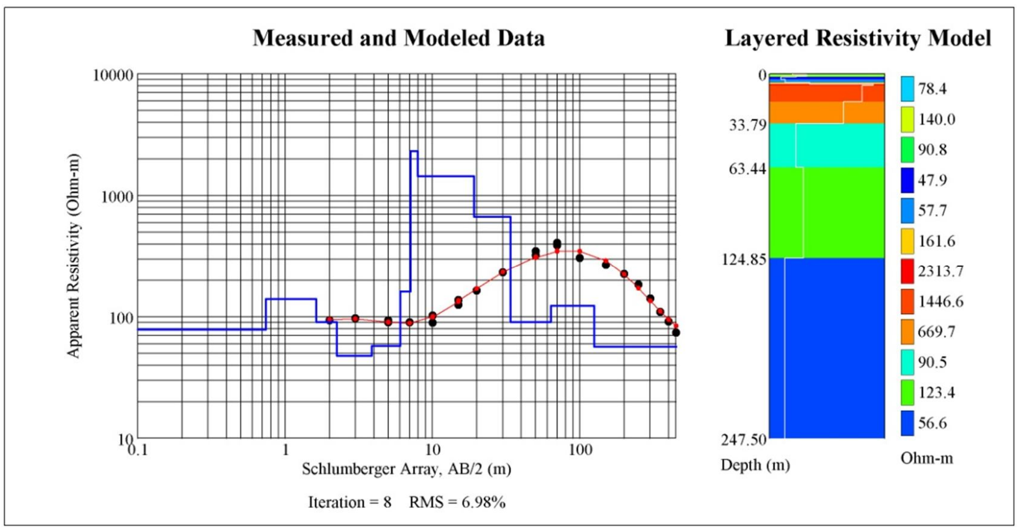

Figure 3. 2: Interpreted sounding results for borehole 2. (After Barongo, 2008).

3.2 Electrical resistivity imaging

Due to the detailed information obtained from this method, it was possible to get clear and detailed information from the surface up to a depth of 65 m and compare it with that obtained from vertical electrical sounding method, at least up to that depth. The following are some of the analysed results of electrical tomography method:

3.2.1 BH 2 results-Profile 1

Vertical section of this slice demonstrates three prominent geoelectric layers from the surface to the bottom of the slice. From top, there is a low resistivity layer that runs from the ground surface to a depth of about 20 m as shown by the blue colouration. From this depth to about 50 m is a very high resistivity layer ranging from 1870 Ohm-m to 7686 Ohm-m. The depth and high resistivity ranges compare fairly well with the corresponding VES at the same borehole location. Just as in the VES results, these imaging results concur with the geologic log results, which include dry volcano-sediments with masses of vesicles that tend to increase the resistivity. A fault zone appears at the eastern end of this profile. The mid-point of the profile marks the location of BH 2 drilled by the Zhonghao Overseas Construction Engineering Company Ltd. Figure 3.3 is a tomographs at BH2-Profile 1.

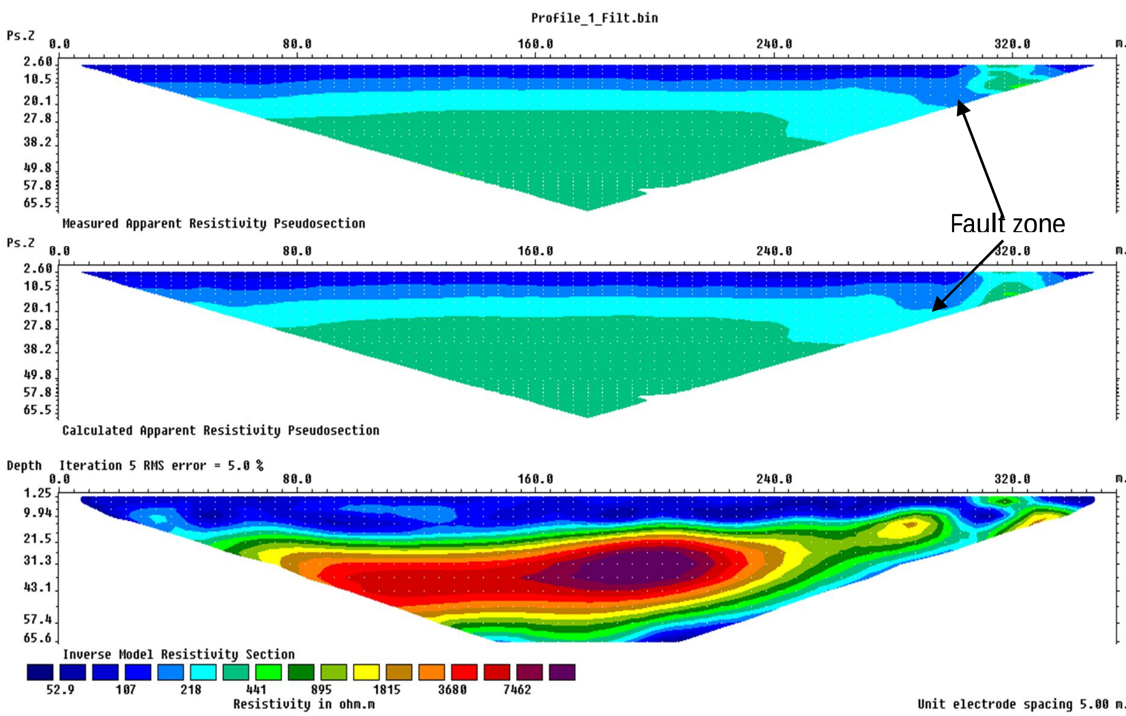

Figure 3. 3**:** Vertical slice acquired from BH 2-Profile 1. (After Barongo, 2008).

3.2.2 BH 2 results- Profile 2

Profile 2 is another slice obtained along a traverse about 500 m to the North of BH 2. The 20 m low resistivity layer observed along profile 1 is missing here. This could be due to tectonic uplift and subsequent erosion that removed the low resistivity deposits from near the surface. The ground at this point is quite heterogeneous. There is a very clearly displayed system of faulting and mixing up of ground rock material. A prominent high resistivity zone which contains very resistive rock material appears to occupy a fault system, such like are the conditions making boreholes vulnerable to collapsing during and after drilling. (Fig. 3.4)

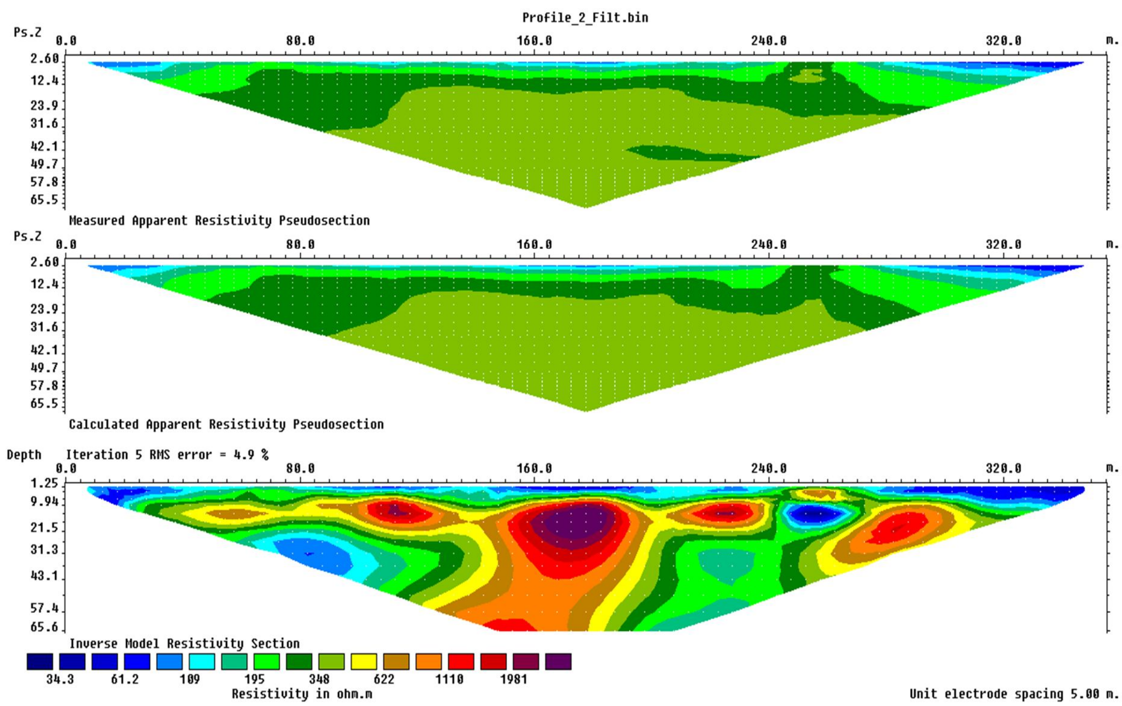

Figure 3. 4: Vertical slice obtained from BH 2-Profile 2. (After Barongo, 2008).

3.2.3 BH 1 results- Profile 1

As shown in figure 3.5, the situation along this profile is similar to that along BH 2-profile 1. There exists an outstanding low resistivity layer from the surface to a depth of about 20 m. From the depth of about 20 m to 50 m, is a high resistivity layer. This is attributable to a similar layer of dry, loose volcano-sedimentary rocks confirmed by the geologic log results.

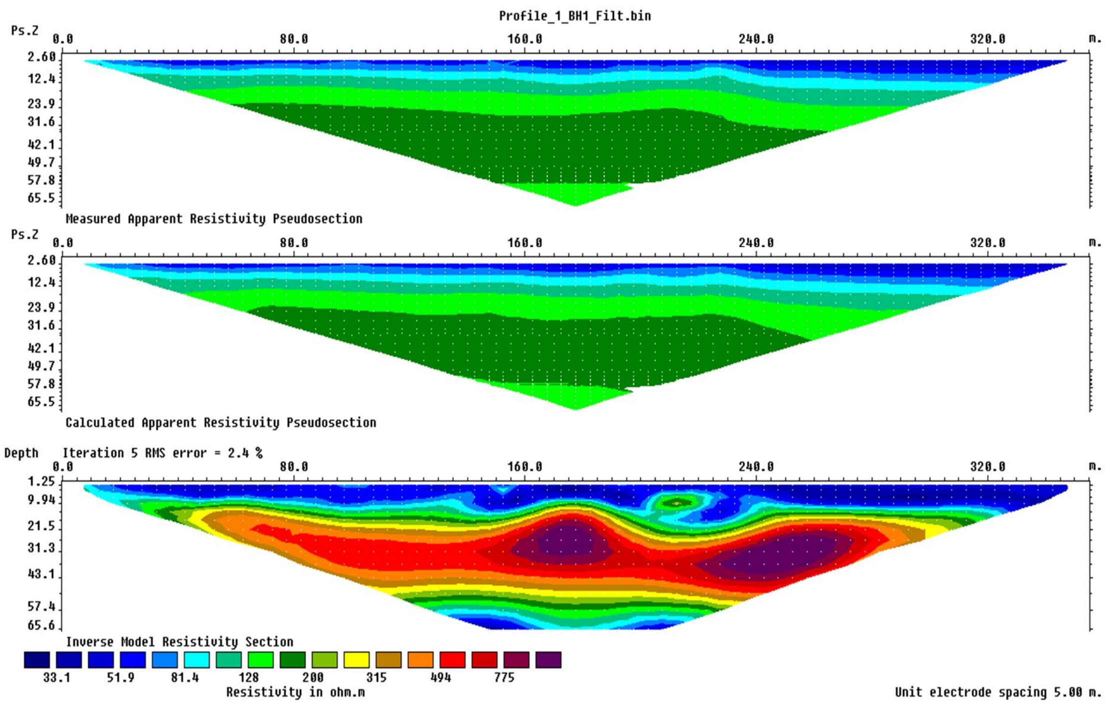

Figure 3. 5: Profile 1 showing the vertical slice obtained from borehole 1. (After Barongo, 2008).

3.2.4 BH 5 results-Profile 1

The vertical slice along this profile depicts a heterogeneous ground. A nearly related fault system witnessed along BH 2-profile 2 is also captured at the mid-point of this profile where borehole 5 is also located. This profile is within the vicinity of BH 2- profile 2. This heterogeneity together with the loose sedimentary materials are not good for drilling operation since they are prone to the caving in of boreholes during drilling operations and have undesirable outcome on drilling rod and bits (Fig.3.6).

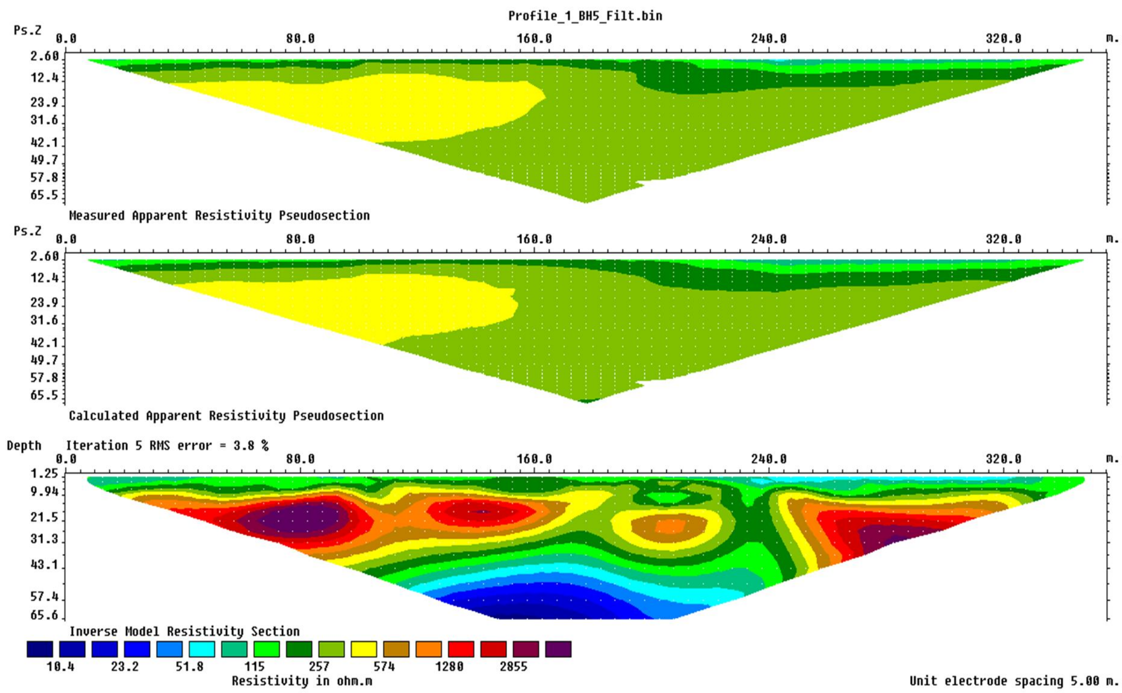

Figure 3. 6: Profile 1 showing the vertical slice obtained from borehole 5. (After Barongo, 2008).

3.3 Magnetic method results

From all the magnetic results shown below, it is outstanding that some of the borehole crop up on the fault system, near the fault system and off the fault system. Magnetic signatures due to rock materials containing magnetic inducing minerals occur within the sediments between depths of about 5 m to 50 m on average. These are a result of the segregated mafic volcaniclastic materials within the sedimentary sequence.

3.3.1 Magnetic Profile result at BH 1

The profile in figure 3.7 shows magnetic material between depths of about 5 m to 20 m. These materials do not occupy the entire profile but about the Western half of the profile. The materials may be problematic to the drilling bits.

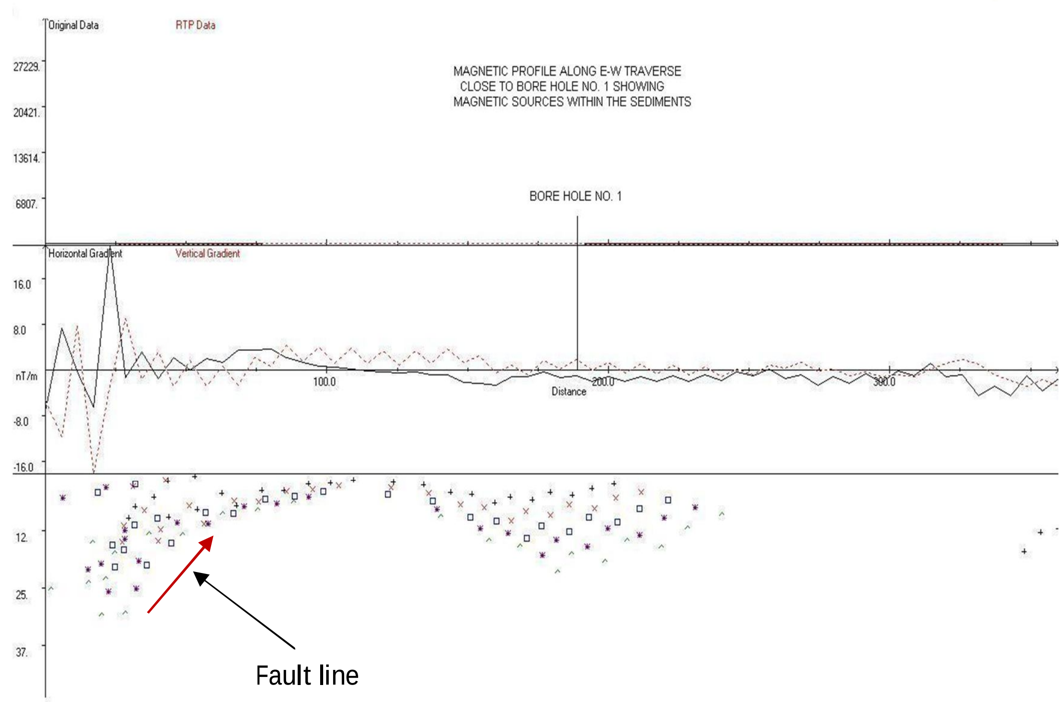

Figure 3. 7: Magnetic profile result along borehole 1.(After Barongo, 2008)

3.3.2 Magnetic profile results at BH 2

The profile in Figure 3.8 demonstrates magnetic materials occupying depth of about 5 m to 50 m. The thickness of the materials beneath BH 2 is about 20 m. The borehole occurs near a very extensive fault zone perceptible on the eastern side of the profile. A further relatively narrow fault zone occurs on the western side of the profile. The bottom sediment layer is not detectable due to the small spacing of the reading stations.

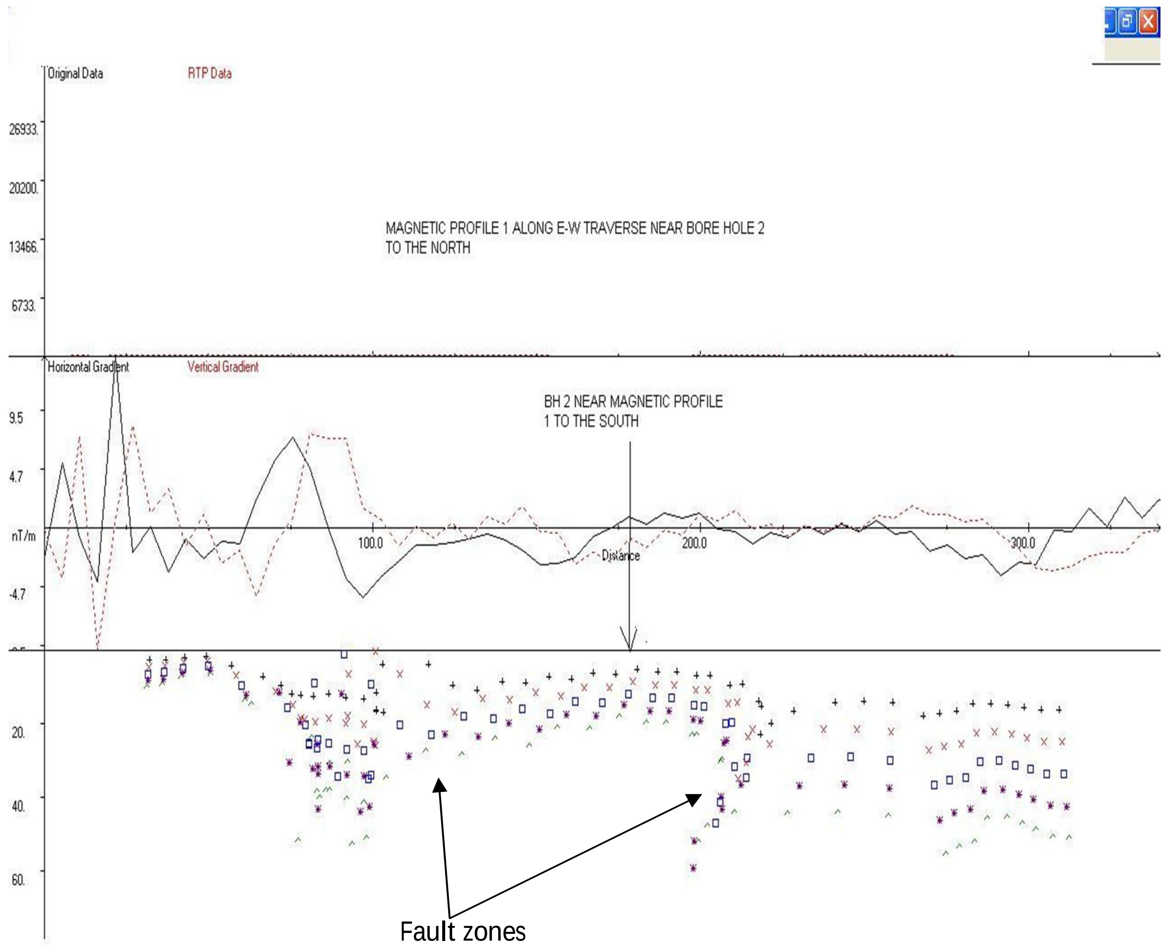

Figure 3. 8: Magnetic profile along BH 2. (After Barongo, 2008).

3.3.3 Magnetic profile results at BH 5

This magnetic profile displays two prominent mini-grabens as shown in figure 3.9. The fault systems marking these grabens are clearly singled out by the magnetic results and harmonize the heterogeneity depicted by the electrical resistivity imaging results. BH 5 occurs right in the middle of one mini-graben near the eastern side of the profile. The magnetic material occurs from a depth of about 7 m to 35 m. The system of faults which scuttle much deeper even in the rest of the profiles in the entire Olobanita area is a major impediment to the drilling operations given that it sets up heterogeneity.

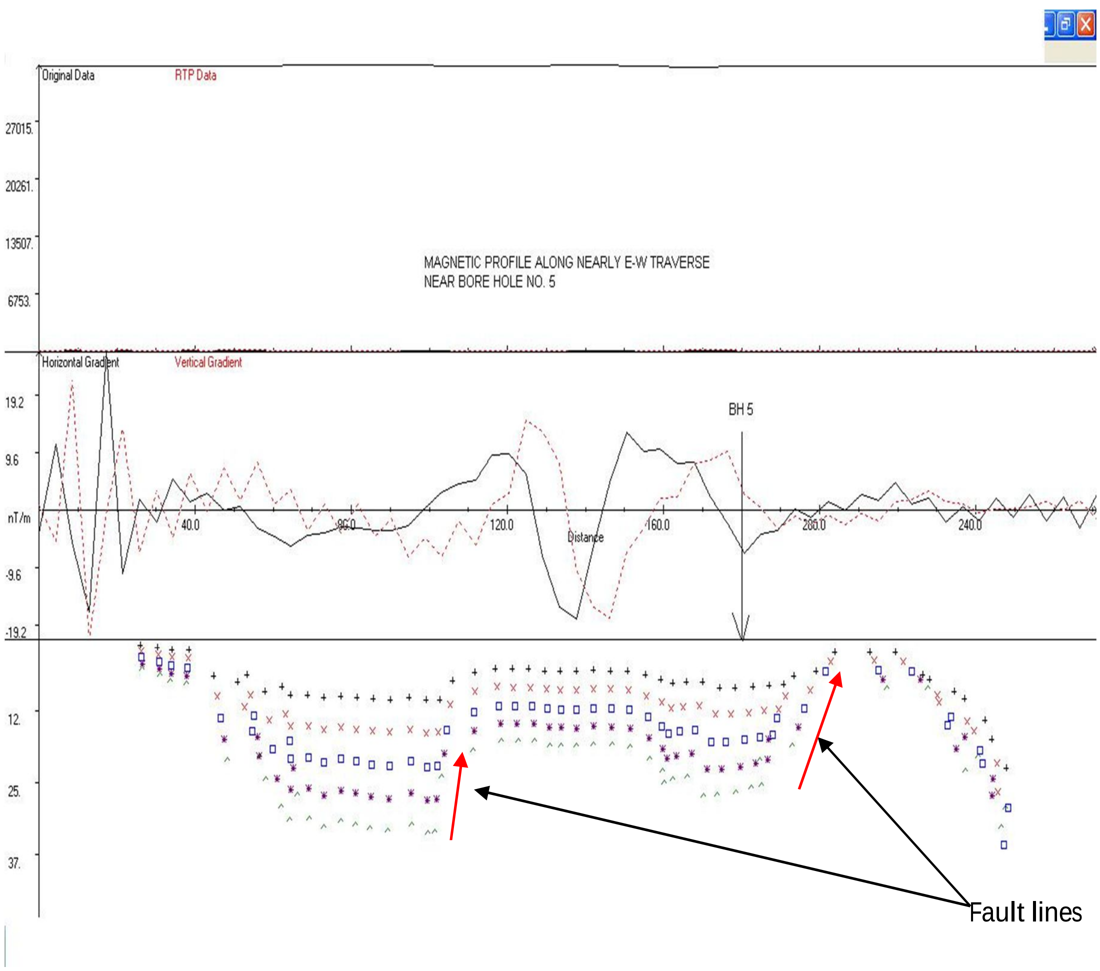

Figure 3. 9: Magnetic profile along BH 5. (After Barongo, 2008).

3.3.4 Magnetic profile results at BH 6

Borehole 6 profile shows three foremost fault zones (Figure 3.10). It was done between two of the fault systems. The magnetic materials in this case are sandwiched between a depth of about 5 m and 40 m. Heterogeneous subsurface and fault systems adjoining one another is not desirable for drilling.

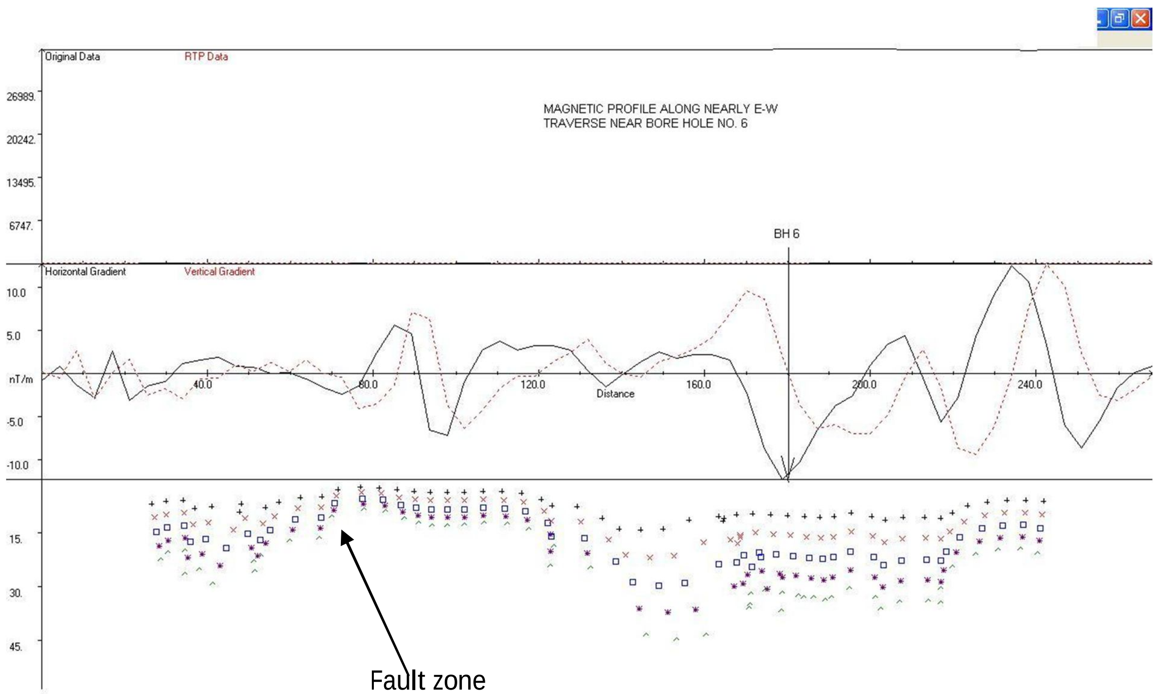

Figure 3. 10: Magnetic profile along BH 6. (After Barongo, 2008).

3.4 Geologic log method results

The figures below shows the geologic logs (Courtesy of Mathu, Department of Geology, University of Nairobi) of the various boreholes obtained from the Olobanita well-field.

3.4.1 Geologic Log Results at BH 1

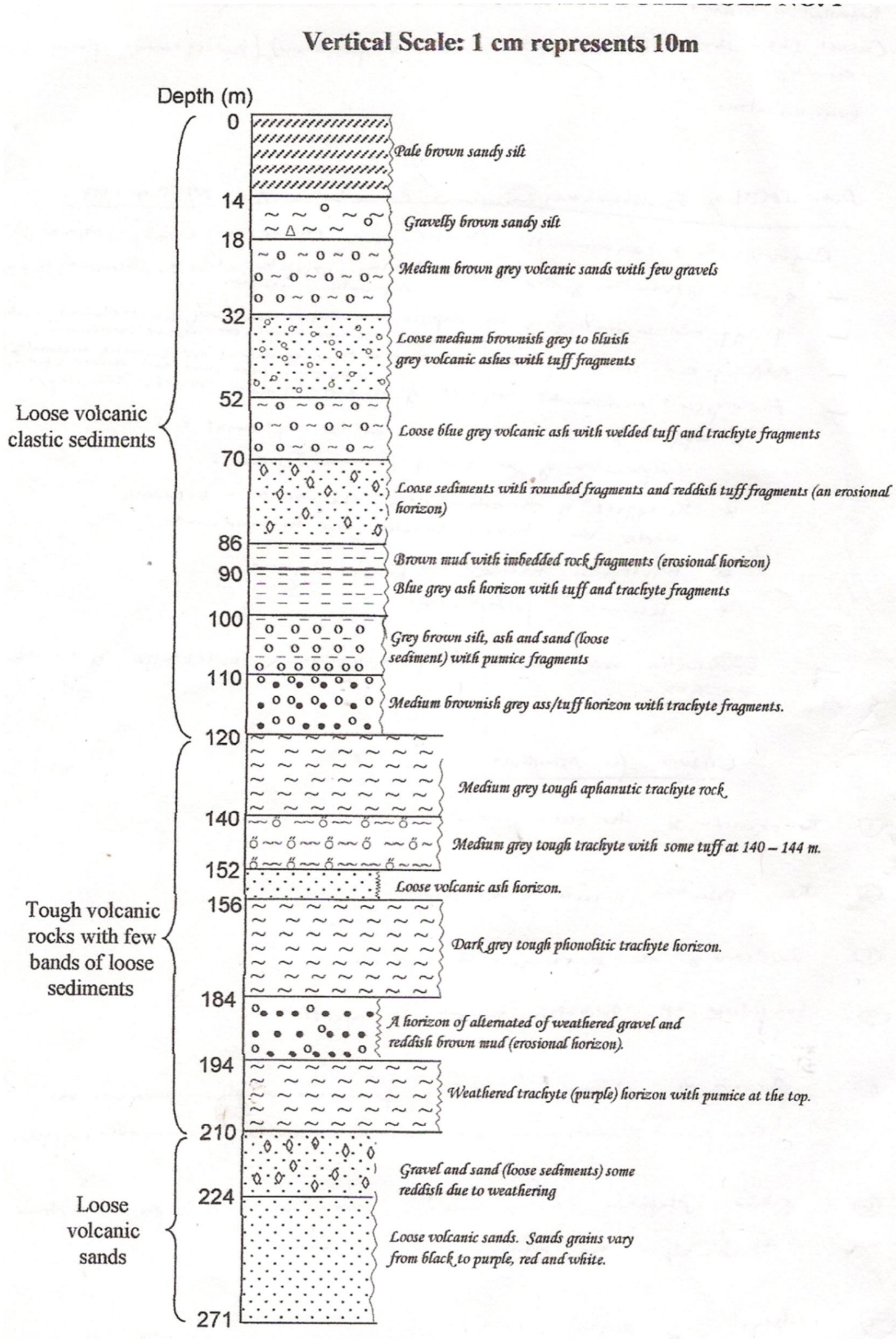

Figure 3. 11: Geological log of Olobanita at Borehole 1. (After Mathu, Department of Geology, University of Nairobi)

3.4.2 Geologic Log Results at BH 2

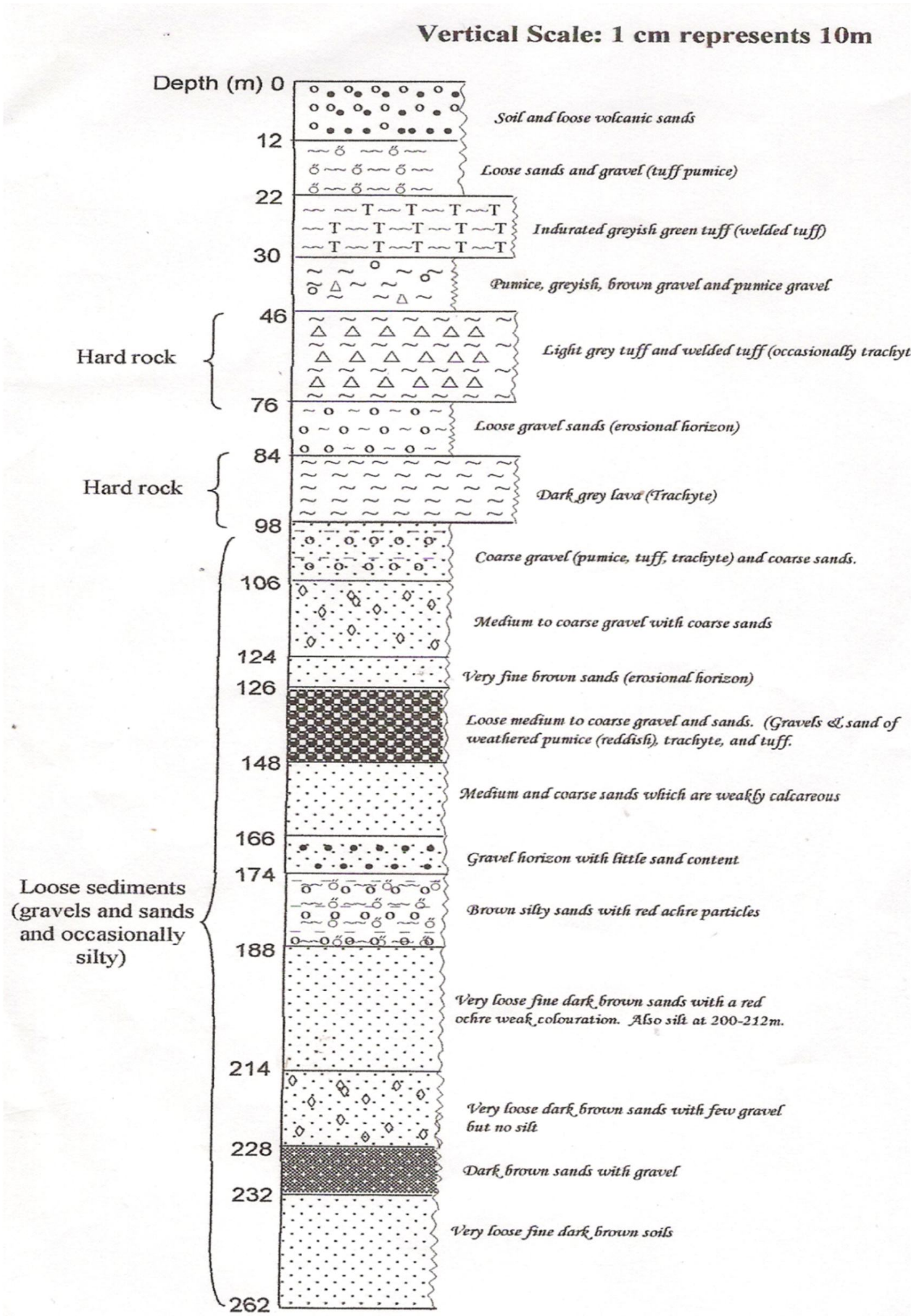

Figure 3. 12: Geological log of Olobanita at Borehole 2. (After Mathu, Department of Geology, University of Nairobi).

3.4.3 Geologic Log Results at BH 5

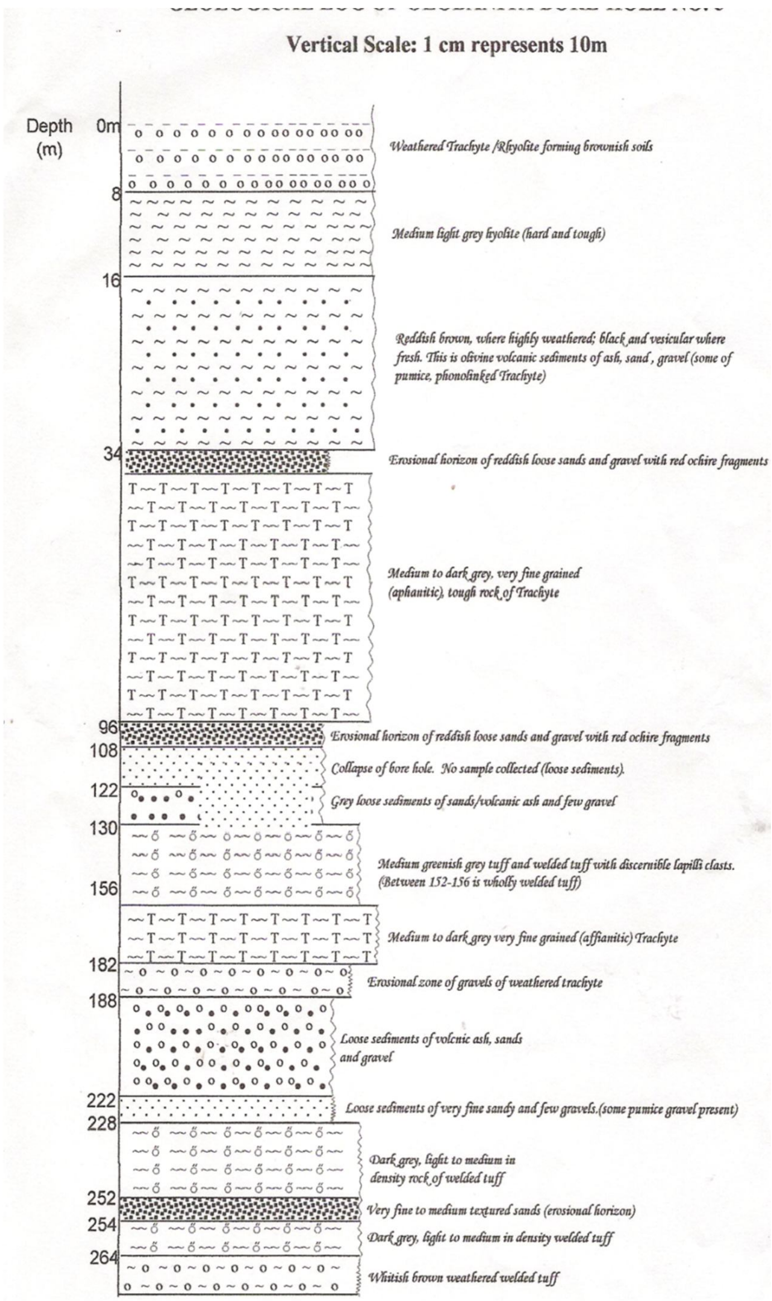

Figure 3.13: Geological log of Olobanita at Borehole 5. (After Mathu, Department of Geology, University of Nairobi).

3.4.4 Geologic Log Results at BH 6

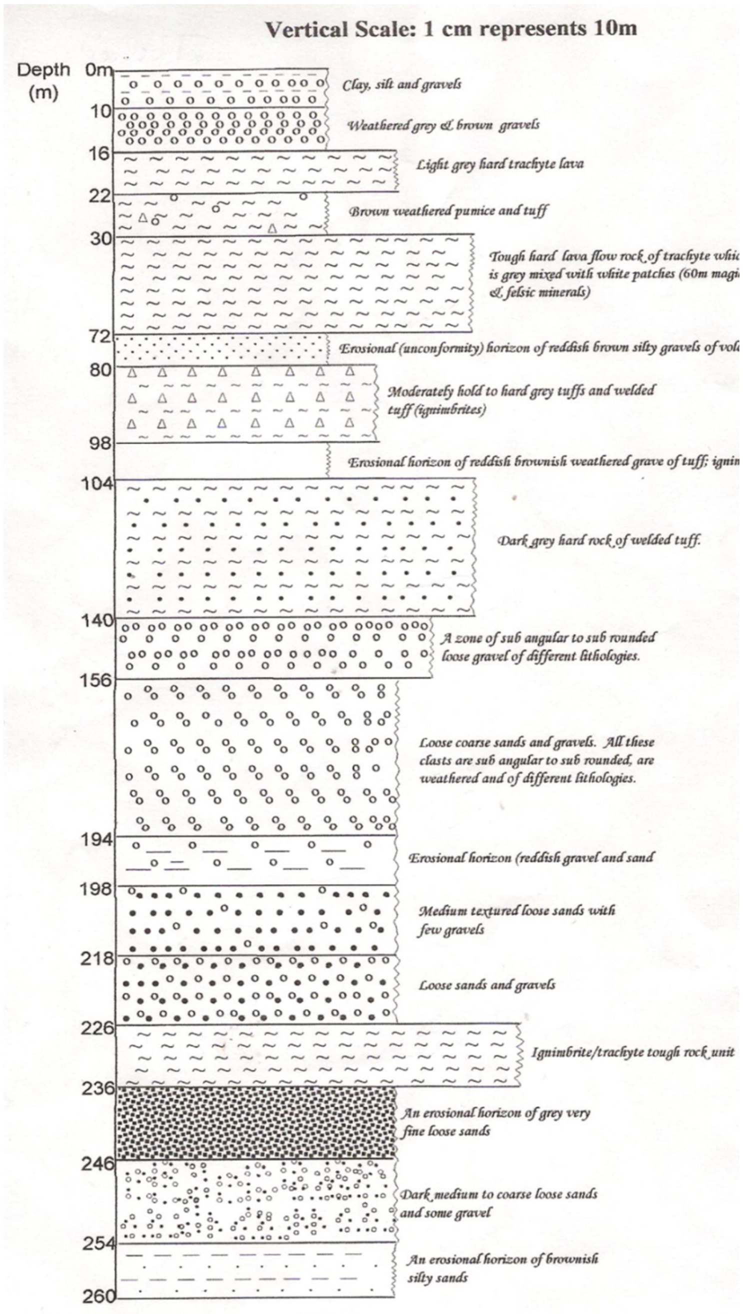

Figure 3. 14: Geological log of Olobanita at Borehole 6. (After Mathu, Department of Geology, University of Nairobi).

The use of geologic log allows a degree of predictability regarding future expansion, optimizing well placement, evaluating reservoir conditions, risk assessment, etc. If sufficient well control exists, the geologic framework is provided by analyzing and correlating the well data in the area. This method is highly dependent upon the distribution, density, quality and type of available log data.

The four geological logs data above taken at different boreholes showed more or less similar results, for example all of them depicted heterogeneous ground together with loose sedimentary materials-conditions which do not support drilling operations. The geologic log results however show more layers than the VES and ERI results, this is because some of the layers were so thin that they could not be detected by VES and ERI methods.

4.0 CHAPTER FOUR: CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The research has come up with very interesting discoveries pertaining to the geometry and lithology of the subsurface responsible for collapsing of boreholes in Olobanita well-field, the results were as follows:

- Highly heterogeneous subsurface, for example immediately to the northern side of BH2, the ground beneath is much more heterogeneous. The heterogeneity increases much more towards the western side of BH2, more especially at boreholes BH5 and BH6.
- There are several fault systems such as those detected at and in the vicinity of all boreholes drilled by Zhonghao Overseas Construction Engineering Co. Ltd. For example, Borehole BH 2 occurs next to a fault system. From the magnetic studies, the fault zone comes out prominently
- Loose and dry volcanosediments sometimes interbedded with hard mafic volcanic rock bodies resulted into collapsing of the freshly drilled boreholes and in destroying the drilling rods and bids, respectively.
- Boreholes drilled nearer to the fault systems are more prone to collapsing than those far away, for example Zhonghao Overseas Construction Engineering Co. Ltd experienced a greater challenge at BH 5 than at BH 2.

With the above discoveries, it is therefore not strange that Zhonghao Overseas Construction Engineering Co. Ltd encountered a lot of drilling problems during their drilling operations. It was unfortunate that none of these problems were mentioned in the report on "Groundwater Investigations for Nakuru Water Supply" given to Zhongho Overseas Construction Engineering Co. Ltd as a drilling guide by the Client. Most of the statements and recommendations cited in that report are contrary to the findings in this study.

4.2 Recommendations

Before any additional drilling operation to be carried out in Olobanita well-field or any other area with similar lithology and structures of their subsurface, the following five recommendations should be taken into consideration.

1. Boreholes should be located as far as possible from fault systems. Before any bore hole is dug, thorough geophysical studies need to be carried out and accurate interpretation made by qualified geophysicists. In this report it is well established that more problems were encountered by Zhongho Overseas Construction Engineering Co. Ltd. in areas near faults e.g. at BH 2. Rocks strength around faulted areas is weakened by the extensional forces during the deformation.
2. To reduce the effect of loose heterogeneous sediments in drilling of boreholes, grouting of the borehole walls should be done. This is done by injection of certain substances into the voids of the earth materials to consolidate or to increase their strength. Grouting can be done as the drilling continuous or by filling the annular space between the casing and the drilled holes with suitable slurry of cement or clay. Materials which are commonly used for grouting include cement, hydrated lime, bentonite, and synthetic materials such as polymers.
3. Casing of the boreholes should be done at the same time of borehole drilling, e.g. the use of Dual Tube Rotary as a drilling method. In this method the drill pipe and bit are joined and advanced simultaneously. The conventional top drive drills the open hole and the lower rotary drive is used to set casing without any requirement for casing hummers, under-reamers or drilling mud.

<u>Further Recommendations</u>

1. Minimum underground fluid pressure should be maintained. Increase of fluid pressure in such a heterogeneous area may destabilize subsurface materials and their adjustment to gain stability can result into caving in of freshly drilled boreholes. To reduce the induced fluid pressure, Direct Air Rotary Drilling technique or any other equivalent technique need to be employed. In this method air is circulated in through the system instead of water based drilling fluid to remove cuttings. To reduce infiltration of surface water on pervious ground surface, addition of impervious materials is necessary. Alternatively the surface around potential borehole site can be cemented.

2. Reduction of the subsurface pressure due to overloading of the earth surface by heavy tractors or large structures should be taken into consideration. According to Latynina and Vasiler, (2003), after creating a load on the earth surface, formation of underground tilts and cracks were observed. The reason behind this fact is that loading of the earth surface initiates seismic waves which if exceeds the rock strength can lead to movement of the earth surface and accelerates collapsing of boreholes. It is therefore recommended that boreholes should not be drilled near very large structures.

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