بسم الله الرحمن الرحيم

Sudan University of Science and technology

College of Graduate

Faculty of Science

INVESTIGATING THE GEOLOGICAL ENGINEERING SITE OF THE PROPOSED SABALOKA DAM

تقصي الموقع الجيولوجي الهندسي لسد السبلوقة المقترح

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B.Sc. (Hons) Neelain University 2015

Dissertation submitted to Sudan University in Fulfillment of the Requirement for the

degree of M.Sc. in Geology

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December 2022

Dedication

Mother

She is precious in every way, the source of kindness.
The sunshine’s in my day.
The joy in my soul and the love of my life.

Father

He is a role model, a source of strength and inspiration. He's the most incredible man I've ever known, and I'm so proud of him
I ask the Most Merciful to grant him mercy and forgiveness

Brothers and sisters

They shared my childhood and stood beside me while no one was left aside.

My friends and classmates To whom I appreciate.
To whom I love and care.
To whom I won’t ever forget. To whom I do respect.

Dear teachers

You are caring, supporting, and kind words sharing.
I just want to say thank you for everything during this period.

Acknowledgments

My sincere gratitude and special thanks to Dr. Ibrahim Abdulgader Malik for his kind supervision, for his supervision, advice, continuous encouragement, guidance, and fruitful discussion throughout the research period. Also, I am indebted to Dr. Abdulatif Ahmed (May God have mercy on him) as co-supervisor.

Also thank the College of Science, Sudan University of Science and Technology, and the Department of Geology for their cooperation, and thanks are extended to Mr. Talha M. Youssef, Mr. Majid Elyas, and all employees of the College of Petroleum and Minerals at Al-Neelain University.

Thanks also to the Geology Research Authority of Sudan (GRAS) for their further helps.

I would like to thank (BRRI, University of Khartoum) and Road And Bridges Public Corporation (RBPC, Khartoum) for testing the rock samples in their labs.

Thank extend to my family and friends for their unlimited support.

Abstract

The proposed dam is located at the Sabaloka igneous complex on the sixth cataract of the Nile, where the Nile passes through the volcanic plateau of Sabaloka. The storage capacity of the proposed dam is about 4000 million cubic meters, its lake extends south to about 15 km, and the water level is expected to rise from 6 to 10 meters.

The Sabaloka dam is proposed for multi-purposes, mainly for hydropower generation and irrigation in addition to helping minimize the siltation for the Merwe dam to the north. Moreover, it will represent an excellent habitant for fisheries in the lake behind the dam.

The study relied on field tests, well data, and analysis, in addition to the structural analysis of fractures in the examined site.

Observing the results of drilling, the three boreholes are usually identical in lithology, where silt sands and conglomerates appear, but there is some difference in the depth of aggregation, in addition to the difference in the designation of rock quality (RQD), which decreases in borehole 403 in the left channel, due to the existence of Two sets of joints across the dextral fault

The proposed dam axis is located in the relatively less fractured Agglomeratic rocks. The main fracture trends are NW and NE directions and cut, respectively, the western and eastern flanks of the dam axis. Geotechnical tests on the area's rocks also proved the efficiency of the Trachybasalt and Suleik granite located in the Sabaloka area for use as concrete aggregate in construction according to the standard specifications.

الخلاصة

يقع السد المقترح في مجمع السبلوقة الناري على الشلال السادس لنهر النيل ، حيث يمر النيل عبر هضبة سابالوكا البركانية. وتبلغ الطاقة التخزينية للسد المقترح حوالي 0444 مليون متر مكعب ، وتمتد بحيرته جنوباً إلى حوالي 51 كم ومن المتوقع أن يرتفع منسوب المياه من 6 إلى 54 أمتار.

تم اقتراح سد السبلوقة لأغراض متعددة ، خاصة لتوليد الطاقة المائية والري بالإضافة إلى المساعدة في تقليل ترسب الطمي في سد مروي في الشمال. علاوة على ذلك ، سوف يمثل موطناً ممتازًا لمصايد الأسماك في البحيرة خلف السد.

اعتمدت الدراسة على الاختبارات الميدانية وبيانات الآبار والتحليل بالإضافة إلى التحليل الإنشائي للكسور في الموقع الذي تم فحصه.

مراقبة نتائج حفر الآبار الثلاثة متطابقة في علم الصخور ، حيث تظهر رمال الطمي والتكتلات ولكن هناك بعض الاختلاف في عمق التكتل ، بالإضافة إلى الاختلاف في تعيين جودة الصخور (RQD) ، والتي تنخفض في البئر 044 في القناة اليسرى ، بسبب وجود مجموعتين من المفاصل تتقاطع مع الفالق الدكسترالي

يقع محور السد المقترح في صخور الاقلوميرات الأقل تكسرًا نسبياً. اتجاهات الكسور الرئيسية هي اتجاهات شمال غرب و شمال شرقي وقطع ، على التوالي ، الجانبين الغربي والشرقي لمحور السد. كما أثبتت الاختبارات الجيوتقنية على صخور المنطقة كفاءة التراكي بازلت و جرانيت منطقة السليك الموجود في منطقة السبلوقة لاستخدامهما كركام خرساني في البناء حسب المواصفات القياسية.

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AASHTO	American association of state High and transportation officials
A S T M	American Society for Testing and Materials.
AIV	Aggregate Impact Value.
ACV	Aggregate crushing value
BS	British Standards
D	Density
LAA	Los Angeles abrasion
SV	Soundness Value
SPT	Standard Penetration Test
UCS	Uniaxial compressive strength
BRRI	building and road research institute, University of Khartoum
GRAS	Geological research Authority of Sudan
RBPC	Road And Bridges Public Corporation
RQD	Rock quality designation

PL	Point Load Test
WA	Water absorption

LIST OF ABBREVIATIONS **VIII** **IX**

Chapter one

introduction

1.1 Location

The study area is located on the borders of two states, Khartoum state, and River Nile state. The study area is boarded by Latitude 16° 15` N, 32° 00` E Longitude 16° 30`N, 32° 30` E. (fig. 1.1)

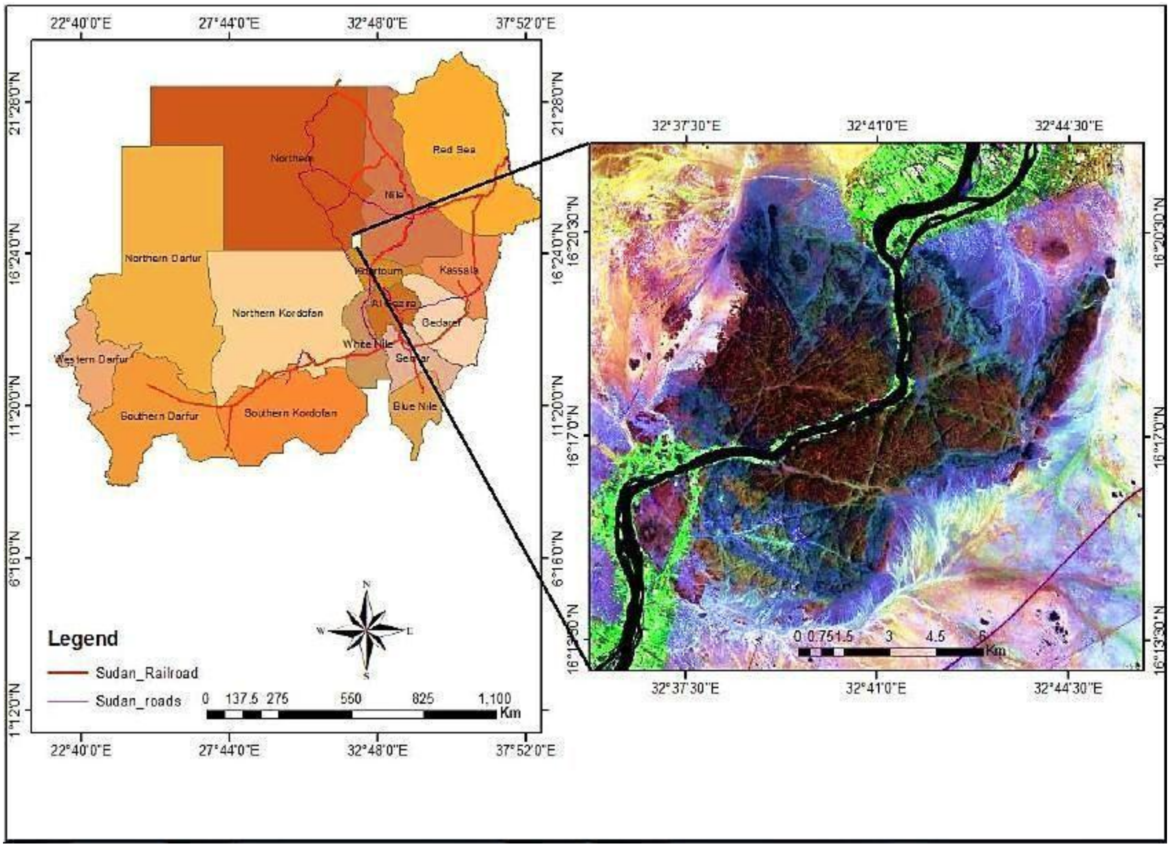

Fig. 1.1 Location map of the study area

1.2 Topography

Jebel Sabaloka (the Sabaloka Mountains) emerges like a rocky island out of the dusty plains of central Sudan about 80 km downstream Blue and White Niles confluence at Khartoum. It constitutes an area of great potential for landscape and geoarchaeological investigation for two reasons. First, the relatively small massif and its vicinity feature a comparatively high number of diverse landscape types and microenvironments with varying conditions for occupation and exploitation. Second, the area hosts rich resources of hard rocks, in particular rhyolites, gneisses, basalt, granite, and silicified sandstone, known to have been used as raw materials for stone tools in the entire Khartoum province since prehistoric times

The most prominent feature of the dome of crystalline rocks occurs at the Sabaloka gorge, 80km. North of Khartoum is a flat-topped mass of red

hills. After flowing over the clay plain of Central Sudan, the Nile enters a steep gorge carved through the Sabaloka hills, about 150 m. Below the level of the plateau. The gradient through the gorge is 1,015 cm/km (fig. 1.2). The hills are formed by a thick succession of Rhyolitic lavas, extruded in a flat cake over the gneiss. The lavas show a low degree of metamorphism, intense folding is mainly due to original flow banding, but the beds show a centripetal dip southerly. The dip is observed in the bedded tuffs and ash on the northern slopes of the hills and a northerly dip in the south.
North of Khartoum, is a flat flat-topped mass of red hills. After flowing over the clay plain of the Central Sudan, the Nile enters a precipitous gorge carved through the Sabaloka hills, about 150 m. Below the level of the plateau. The gradient through the gorge is 1,015 cm/km, (fig. 1.2) The hills are formed by a thick succession of Rhyolitic lavas which were extruded in a flat cake over the gneiss. The lavas show a low degree of metamorphism; strong folding is mainly due to original flow banding, but the beds show a centripetal dip southerly, dip is observed in the bedded tuffs and ash on the northern slopes of the hills and a northerly dip in the south. The most prominent feature of the dome of crystalline rocks which occuroccurs at the Sabaloka gorge, 80 km.

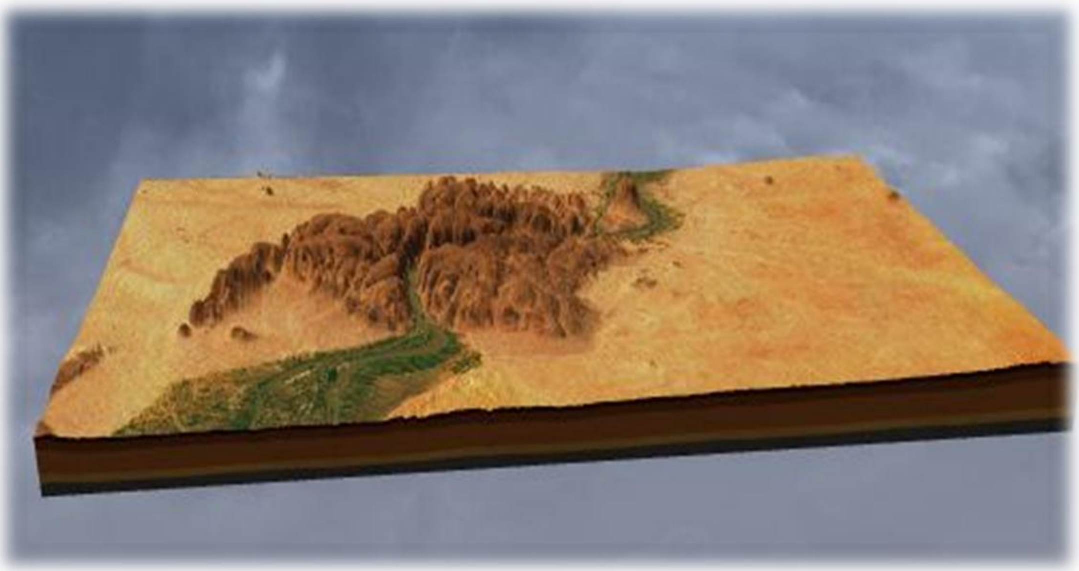

Fig. 1.2 3D view of the study area showing the topography of the region, a perspective from the north (https://3d-mapper.com)

1.3 Problem Statement

To what extent is the Sabaloka area suitable for constructing a dam by studying the structures and geology therein, With a geotechnical study of the rocks in the region to test its usability as a concrete aggregate?

1.4 Objective of the Study

This study aims to clarify the structural, lithological, geophysical, and geotechnical features of the proposed dam area

1.5 Climate

The Sabaloka area's climate is semi-arid, meaning its dry and cold, with temperatures varying to 12 °C in winter and hot to above 45°C in summer. The amount of rain range from 170mm (July to September) (Sudan Meteorological department)

Table 1-1 climatological information (https://worldweather.wmo.int/en/city.html?cityId=249)

month	Mean Daily Minimum Temperature (°C)	Mean Daily Maximum Temperature (°C)	Mean Total Precipitation (mm)	Mean Number of Precipitation Days
Jan	15.6	30.7	0.0	0.0
Feb	16.8	32.6	0.0	0.0
Mar	20.3	36.5	0.1	0.1
Apr	24.1	40.4	0.0	0.0
May	27.3	41.9	3.9	0.9
Jun	27.6	41.3	4.2	0.9
Jul	26.2	38.5	29.6	4.0
Aug	25.6	37.6	48.3	4.2
Sep	26.3	38.7	26.7	3.4
Oct	25.9	39.3	7.8	1.2
Nov	21.0	35.2	0.7	0.0
Dec	17.0	31.7	0.0	0.0

1.6 Population

The concentration of people is distributed into small villages along the trench of the Nile. They had different activities, such as agriculture and fishing; some people lived far from the Nile, such as Elban Jaded area.

1.7 Vegetation Cover

Sabaloka area has poor scattered ,lee bushes of acacia spices, and along or near to river Nile strip is rich in the palm and other fruit trees around this area Algili – Alkabashi and with some other trees Neem, Mango.

1.8 Drainage System

The primary drainage system in the region of Sabaloka inlier is the river Nile. It bisects the volcanic plateau approximately. A dendritic drainage pattern generally characterizes the others drainage system in the study area. It is straightforward, all water courses (Wadies) cut into the peneplain of the basement complex and appear to be structurally controlled, where the convergent of the canyons with their branches is an angular shape, running towards the River Nile. These Wadies supply a significant amount of water during the rainy season.

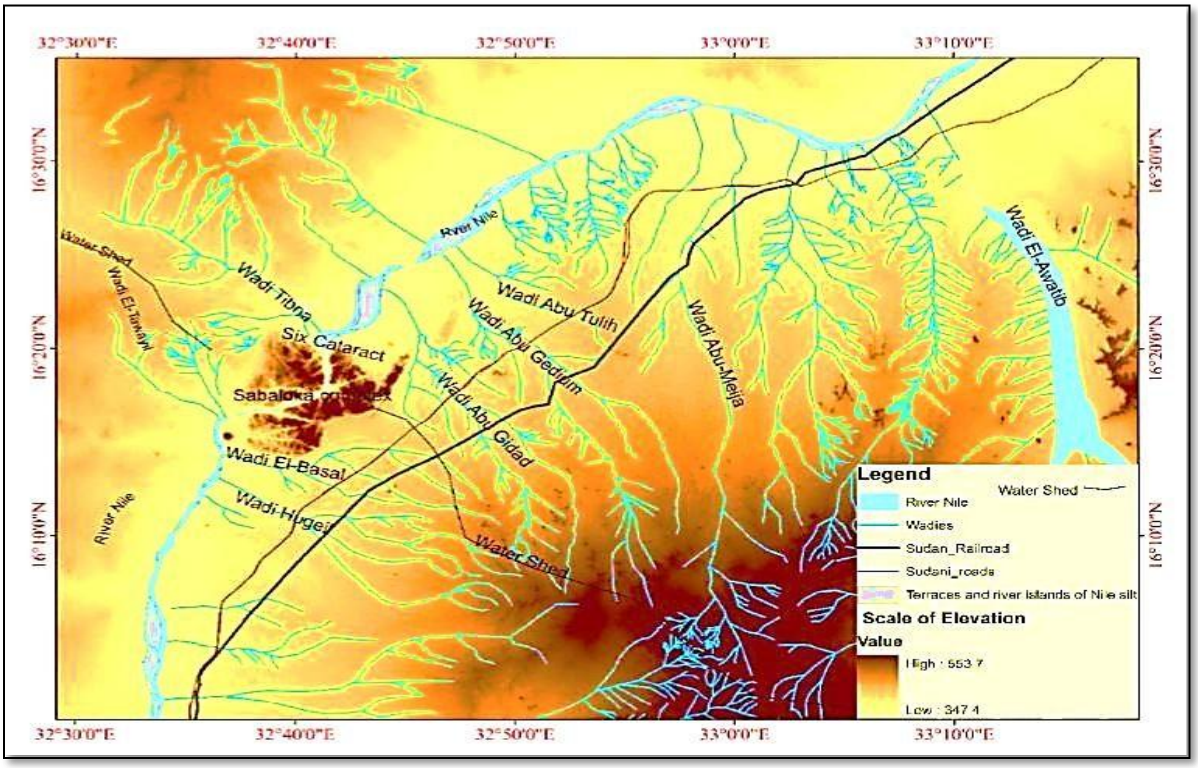

Fig. 1.3 drainage in the study area

1.9 Methodology

1.9.1 Office work (Data collection)

In this phase, Landsat images and geological maps are collected entire informative study area that previous studies can be collected (Fig. 1.4)

1.9.2 Field work

Geological field work is essential to understand rocks in their natural environment and their natural relationship to one another. It seeks to describe and explain the surface feature and underground geology

1.9.3 Laboratory work

At this stage, materials are tested, grain size is analyzed, space gravity data is processed, and geotechnical tests are conducted for photographic samples from the study area to test their suitability for use as concrete aggregates (Fig. 1.4)

1.10 Previous Work

Delany (1955) and Ahmed (1968, 1977) mapped the complex of Jebel Sileitat Es Sufr, and they found that the complex consists of a pluton of riebeckite granite, volcanic and sub-volcanic rocks, including rhyolite lavas and breccia, micro diorite, pegmatitic syenite, and riebeckite quartz syenite. Delany (1960) considers the Basement complex in Sudan to be Precambrian. Kheiralla (1966) and Omer (1975) give general descriptions of the Cretaceous sediments (the old term Nubian) between Khartoum and Shendi NE of Sabaloka. Dawoud, (1970) and Almond (1977, 1980) showed that in the Sabaloka basement inlier, granulitic facies rocks occurred as lenses, bands, and irregular bodies. Almond (1977) mapped the Sabaloka igneous complex and found the complex has a volcanic phase that consists mainly of rhyolites, agglomerates, and ignimbrites forming a plateau and intruded by elliptical ring dyke of micro-granite. Almond (1980) analyzed the rocks of Sabaloka Cauldron and calculated that they are poorer in Na_2O and have lower Na_2O/K_2O ratios than Nigerian granites. Almond (1980) also found that the gneiss assemblage contains evidence that an early granulite facies metamorphism occurred, was followed by regression into the amphibolite facies. Berry and Whiteman (1968) considered the Sabaloka complex an inlier. The term exhumed monadnock or inselberg is more appropriate, as the Sabaloka complex is not directly surrounded anymore by Nubian sandstone. Also they are correct and supposing that the course of the Nile was superimposed above, and thus its position about Jebel Sabaloka is entirely accidental. Kroner et al, (1987) dated the granulite facies metamorphism in the Sabaloka area as occurring around 720 Ma, and this age is similar to the Mozambique Belt, which extends northward to include Sabaloka and forms a geographical and metamorphic bridge between the Pan-African arc accretion green schist assemblage of the Arabian Nubian Shield to the east and Pre-Pan-African higher grade metamorphic terrain to the west.

Elyas (2016) indicated that the region went through four phases of deformation, and there is a low k-shaped tholitic island like the remnants of the thickness of the oceanic crust of the granite surface in the region Dawoud and Sadig (1988) indicated thrusting by structural and gravity data as the major cause of uplift for the granulite rather than by erosion only. The geophysical measurements by Sadig and Ahmed (1989) across selected complexes of younger granite from Sudan indicate different gravity signatures, whereas the Sabaloka complex is characterized by low Bouguer gravity values. Dawoud and Dobrik (1993) discussed the P.T condition of PanAfrican granulite facies metamorphism in Sabaloka inlier. Abdalla Elsheikh and Khalid Elsayed (2010) used remote sensing and fracture analysis to investigate the proposed site for the Sabaloka hydropower dam project

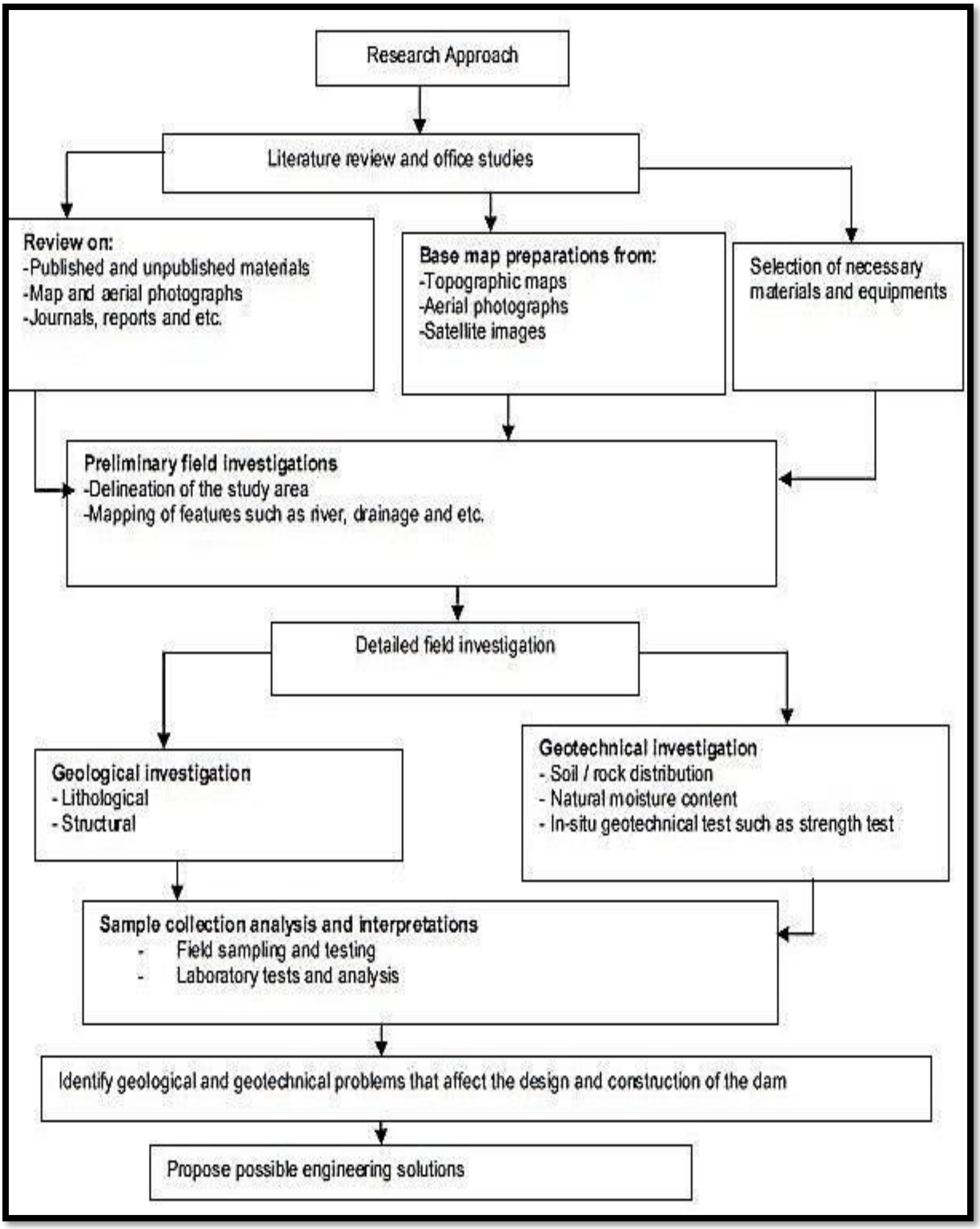

Fig. 1.4 : The Research Methodologies

Chapter Two

Geological Setting of Sabaloka Igneous Complex

2.1 Introduction Geological conditions are often so complicated that they don't permit investigations to be conducted as routine work. Various geotechnical works can never replace a detailed study by an expert engineering geologist. Geological processes may endanger the construction site. When investigating the area, the engineering geologist should assess its general geological structure and grasp the geological processes that have led to its development and morphological form.

The characteristics of soil and rock play essential roles in engineering evaluation and mineral composition, structure, grain size, and their arrangements, and some minor properties arrangement in accordance to the purpose of use.

Other factors used in rock mass evaluation are their origins, joint condition, joint orientation, roughness separation, spacing, frequency continuity, and joint hardness; all mentioned above are for engineering projects.

The area around the Sabaloka igneous complex has been the subject of much research work and previous workers have adopted a lithostratigraphic sequence. This has also been adopted in this work, with some modifications (Table 2.1).

Where new basement outcrops have been mapped for the first time. The different lithology units will be described below from older to younger according to the litho-stratigraphic sequence (Table 2.1).

The geology of the Sabaloka is described below. The enormous dusty plain of central Sudan is underlain by flatting continental sandstone of late Cretaceous early Tertiary age and Nubian facies, covered in many places by silt and clay of late Tertiary and Quaternary age, Almond et al, (1993). streams of the Sabaloka area stream from Khartoum the Precambrian gneisses from country rocks of the Sabaloka igneous complex.

Table.2.1 Summarize the sequence of the central rock units and compositional units in the region of Sablouka and also illustrates the absolute age and relationships between these rock units after Almond et al, (1993).

- **Superficial deposits** Nile silts, alluvial fans, Aeolian sands, lag gravels, wash-zone sands	**Cenozoic, largely Quaternary**
——— Unconformity ———	
-**Nubian sediments** Alluvial sand stone, grits stone, conglomerate, silt stone, locally feruginized	**Late Cretaceous Early Tertiary** (Fossil dated, e.g. Prasad et al., 1986)
——— Unconformity ———	
-**Sileitat Es-Sufur igneous complexes** Peralkaline granite, syenite, and rhyolite	**Middle Jurassic** (dated at 169± 2 Ma by Klemenic , 1987)
——— Disconformity ———	
- **Sabaloka cauldron complex** Trachybasaltic lava, agglomerate, and tuffs, (rhyolite and ignimbrite, ring dyke of porphyritic micro granite, and a range dyke-rocks - **Subvolcanic sediments** Conglomerate, sand stone, and shale (thermally metamorphosed)	**Lower Devonian** (dated at 383 ± 14 Ma by Harris et al., 1983)
——— Unconformity ———	
-**Tuleih igneous complex** Quartz syenite, microgranite, and range of dyke-rocks	**Lower Ordovician** (dated at 465± 14 Ma by Harris et al., 1983)
——— Disconformity ———	
- **Basement** • Granotiods - Late-tectonic granitiods batholiths-predominantly ademellitic and mostly porphyritic - Late tectonic-tholeiitic composition in small masses - Postassic granites related to migmatiazation and perhaps their ultimate product; locally garnetiferous • Migmatite, and grey gneisses: (biotite gneiss, and granitic gneiss). • Scattered relict granulite (including calc-silicate rocks, garnet cordierite gneiss, enderbite)	**Precambrian** the oldest sediments dated are at 870 Ma. The meta-morphic and igneous crys-llization dates are in the range 719 ±81 Ma~540Ma (Kröner et al., 1987)

2.2 Geological Setting

2.2.1 Granulite rocks

The oldest rock unit in the inlier, occurs as irregular patches and bands ranging in size from a few meters to more than 500 meters across between biotite gneisses and migmatite rocks (Almond, 1980). These rocks are two types of the origin: meta-sediments and meta-igneous. The meta-sediments (para-granulite) are divided into meta-semi pelitic rocks existing in the inlier as patchy outcrops located west Al Jebelaite Al humor, and Ban Gadeed area

2.2.2 Biotite and Migmatite Gneisses

Biotite and migmatite gneisses are the country rocks. They have patches of granulite rocks, batholithic older granites, and younger igneous complexes with their foliation. They a retreat from granulite facies to amphibolite facies. The origin of the retrograded rocks is para granulite gneiss rocks of semi-pelitic sediments, with garnet considered an indicator of the retrogressive metamorphism. Also, the retrogressive metamorphism is indicated by the gradual change from a two-pyroxene gneiss, through rocks containing both granulite and amphibolite facies assemblages to typical amphibolite facies assemblages in the same outcrop (Almond, 1980). Dawoud, (1970) noted no noticeable structural differences between the granulite and the enclosing gneisses and migmatites.

2.2.3 Lower Rhyolite

The rock type is concentrated in the southern and south eastern the volcanic plateau, it is usually pink to brown. In the places where the ring dyke is intruded, the color is changed into black with an appearance similar to basalt. Mineralogically the lower rhyolite comprises sanadine, quartz, biotite and opaque mineral. The alteration of sanadine gives rise to the cloudy appearance of the rock under the microscope in most case.

2.2.4 Agglomerate

It is widely distributed in the form of massive boulders made up of a large fragments of lower rhyolite surrounded by tuffaceous material at the western part of the volcanic plateau.

2.2.5 Upper Rhyolite

Upper rhyolite is distinguished by flow banding two major sets of NE and NW random joints of different size, irregular block shapes, and moderately weathered.

2.2.6 Ignimbrite

Almond (1977) (1980) recognized three types of ignimbrite: scarp ignimbrite, plateau ignimbrite, and graben formation. The light ignimbrite is pink or brownish when fresh and pale grey when altered. The dark one is mainly dark to black. The varieties are essentially composed of sanadine, quartz, and rock fragments mainly of basalt; the basalt fragment seems to be more abundant in the light one, and dark ignimbrite is relatively massive and hard enough to resist alteration compared to light ignimbrite.

2.2.7 Sabaloka Ring Complex

This is a post-organic, Subvolcanic magmatic ring complex comprising a volcanic portion consisting of rhyolite, agglomerate, ignimbrite, and minor traces of the early phase of Trackybasalt these form of plateau cycled elliptical ring dyke micro granite. The volcanic beds are gently dipping to words center of the plateau.

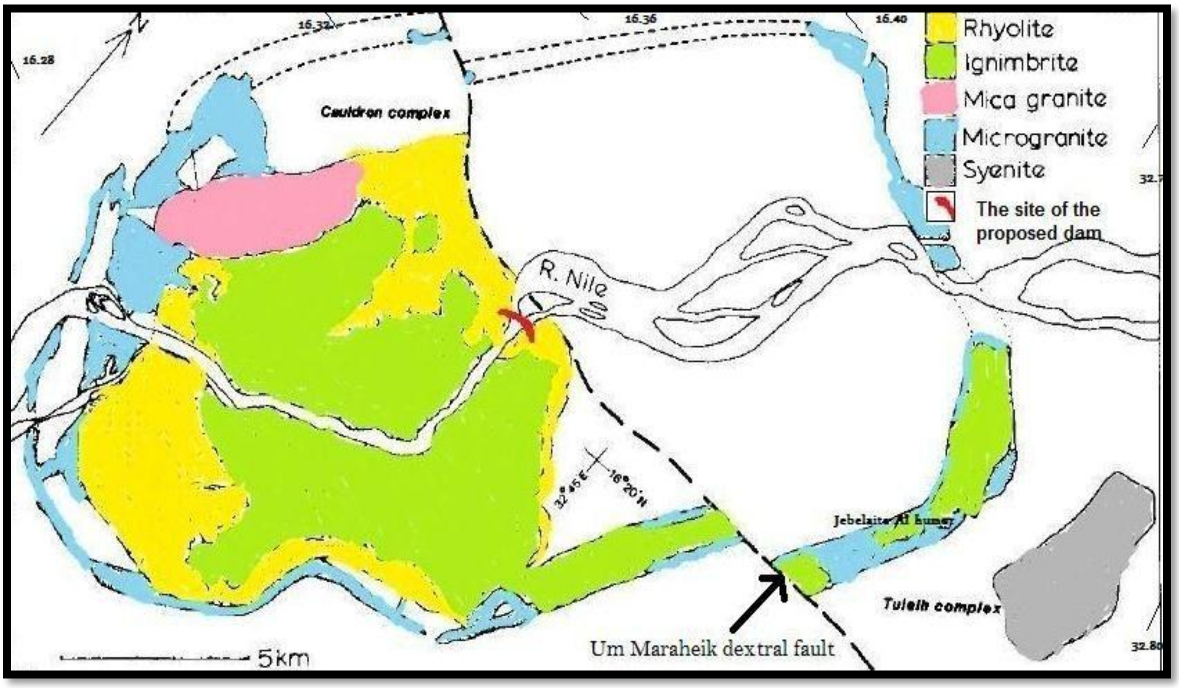

Fig..2.1 Geological sketch map of Sabaloka igneous complex (modified from Harris ,Duyverman and Almond 1983)

2.2.8 Dykes And Veins

These are found as low outcrops from quartz veins, felsite dykes, blue quartz micro-granite and some dolerite dykes. They are 10 m to several hundred meters in length. Quartz veins are ridges in appearance extending 40-250 m and (6-13) m in width. Felsite dykes are fine textured and represent the last stage of granitization. Some of them are faulted, like the Ban Gadeed area, which has a felsite dykes swarm (including an unusual dyke composed of glass). Blue quartz micro-granite is a porphyritic texture, attains a width of 20 m, and is of microgranite containing phenocrysts (up to 2 cm) of blue-tinted quartz and pink-white feldspar.

Stereographic projection of rose diagrams showing the general directions of dykes in Sabaloka inlier. Later isotopic dating has revealed a range from lower Ordovician to middle Jurassic for the Sabaloka area alone, and a recent K-Ar date on a glass dyke suggests the possibility of limited activity until the end of the Cretaceous (Almond et al., 1989).

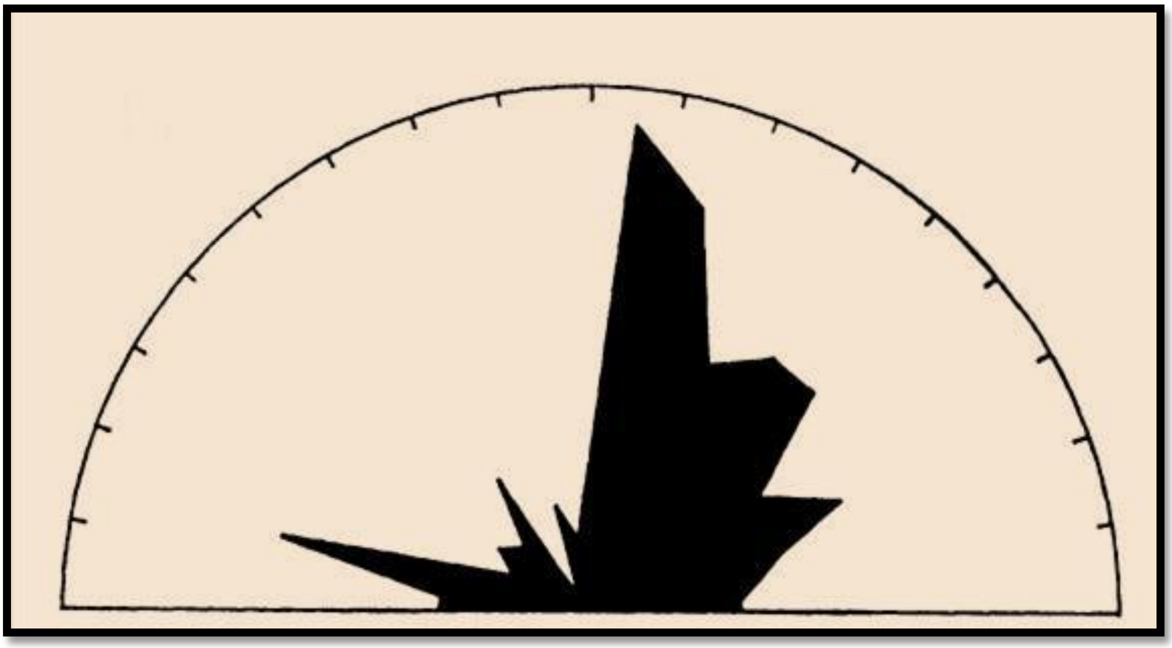

Fig..2.2 Rose diagram showing Dykes' directorates general in Sabaloka inlier. (Almond ,1977)

2.2.9 Cretaceous Sandstone

The Cretaceous Sandstone is the new name to the old name Nubian Sandstone (Prasad et.al., 1986) because the term Nubian describes the concept of the location only. It does not benefit to describe another unit with the same rocks in any location. Still, the Cretaceous is a term describing all sediments that have depositional time in any location in the world. Within the Sabaloka inlier, there are at least five small outliers of the Cretaceous cover rocks, for example Jebel Umm Marahik, Jebel Rauwiyan, and Jebel Ganam. The Cretaceous sediments of Jebel Umm Marahik are similar to those seen at Jebel Rauwiyan, though less firmly cemented and more ferruginous. Cretaceous Sandstones are usually bedded and flat-lying or very gently dipping. It comprises conglomerates, sandstone, and mudstone (Omer, 1975). Umm Marahik formation has Silicified Sandstone formed by the movement of a strike-slip fault known as the Umm Marahik fault, where that movement led to form the silicified sand stone from partial melt quartz, which became as cementing material for grains of quartz.

2.2.10 Superficial Deposits

The superficial deposits in the Sabaloka region include Nile sills, alluvial fans, aeolian sands, lag gravels, and wash-zone sands. They are Quaternary period sediments. River Nile silt is found in and along the line of the River Nile Bank.

Chapter three tectonic setting and Structure of Sabaloka Igneous Complex

3.1 Tectonic Setting

The Sabaloka rocky region of the Precambrian rocks is situated near the northeastern margin of ancient Africa, only a part of an enormous super continental margin orogenic belt named East Africa Orogeny (EAO) (Stern, 1994). The Ophiolites, granulite, and structures of the EAO are fossil fragments of a Neoproterozoic Wilson cycle, representing the opening and closing of an ocean basin that lay between the older crustal blocks of East and West Gondwanaland (Stern, 1994). The Wilson cycle of the EAO begins with rifting. The evidence for rifting may be preserved in sedimentary successions in the EAO that have been interpreted as a passive margin (Kröner et al., 1987). Many of these collisions were between the arcs, as the oceanic crust between them was subducted. Still, a few collisions involved the addition of arcs and arccomplexes and continental micro-plates to the African margin. (Almond et al., 1993).

The collisions led to low-grade metamorphic facies in the Nubian Arabian Shield (ANS) increasing in the grade of metamorphism toward the west of the Bayouda Desert and reaching a maximum in the Sabaloka area (Dawoud and Sadig, 1988). The sediments from Sudan were metamorphosed into granulite facies located in Sabaloka inlier at about 720 Ma (Kröner et al., 1987). The crustal thickening produced pressures of about 6 to 8 Kbar, and temperatures in a range between 00 – 800 (awoud and obrik, 199) indicate the metamorphism in the deep-seated root of this continental crust with depth between 20 - 30 Km, which led to metamorphose that complex rocks of the old continental shelf in this depth at granulite facies. The Sabaloka granulite facies metamorphism, dated at about 700 Ma by Kröner et al. (1987) may have taken place in the root zone of an island arc at about this time and in a dry environment. Also (Küster et al. 2008) dated by the geochronological and isotopic study of granitoid rocks from the eastern boundary of the Saharan Metacraton, indicate that the Bayuda Desert and Sabaloka region records orogenic events starting in the early Neoproterozoic (920 -900 Ma: Bayudian event) and ending during late Pan African times (ca. 600–580 Ma). This age is similar to the Mozambique belt, which extends northward to include the Sabaloka area (Kröner et al., 1987).

The uplifting of granulite terrane was accompanied by hydration and retrogression under amphibolite facies, the condition that formed gneiss and migmatite rocks. The scale time is evident at Sabaloka between the granulite facies metamorphism 720Ma and retrogression migmatites possibly subsequent to uplifting 570Ma (Kröner et al., 1987). This conversion of many dry granulite to amphibolite facies gneisses, which occurred about 150 Ma later, involved an abundance of hydrous solutions, and introduction of water into rocks hot dry rock caused extensive partial melting (Almond et al, 1993). This resulted in migmatization and the formation of small granite plutons, like Ban Gadeed, Babados, Es Suleik, and Abu Gedium. These events may have accompanied accretion of the arcs, and are assigned to the end of the Precambrian (Kröner et al., 1987).

The strike-slip tectonic movement of Ban Gadeed-Gamarab Shear Zone (BGSZ) which affected the Precambrian rocks of Sabaloka inlier is indicated by Ban Gadeed interfolial fold of Z-shape, and porphyroclasts of feldspar and quartz of augen gneiss, and miner interfolial folds in Al Gamarab area. Also, Abu Geidum shear (P-shear zone) supports that this shear is a dextral ductile shear zone. This horizontal tectonic movement may have occurred after the emplacement of older granites of Sabaloka inlier, and before the Abu Tulieh, Sabaloka, and Sileitat Es-Sufur igneous complexes, because the shear has not affected these igneous complexes. (Elyas, 2016).

Tectonic stability was, however, locally punctuated by outbursts of igneous activity, which, at long intervals, built up felsic volcanoes rising above the gneissose peneplain. The positions of these volcanoes are now marked by younger granite complexes, of which there are over 100 in Sudan alone (Vail, 1985). At Sabaloka inlier, the igneous activities are different in ages recently defined by isotope dating of the complexes of Tuleih, the Cauldron complex of Sabaloka, and Sileitat Es-Sufur (Almond et al., 1980).

The most prominent post-Cretaceous structure in the Sabaloka area is the Umm Marahik fault and its associated transtensional basins. The principal displacement on this fault is recorded by a 2 km dextral shift of the sub-vertical structures of the Cauldron complex ring-fracture zone (Almond et al., 1980). Rejuvenating old fracture may have a bearing on Ban Gadeed-Gamarab Shear Zone (BGSZ) (Elyas,2016). A part from the E-W strike-slip faults, there are also several normal faults of small throw trending approximately N-S. Several of these faults can be seen offsetting the Nubian basal unconformity to the S and SE of Ban Gadeed (Almond et al., 1980).

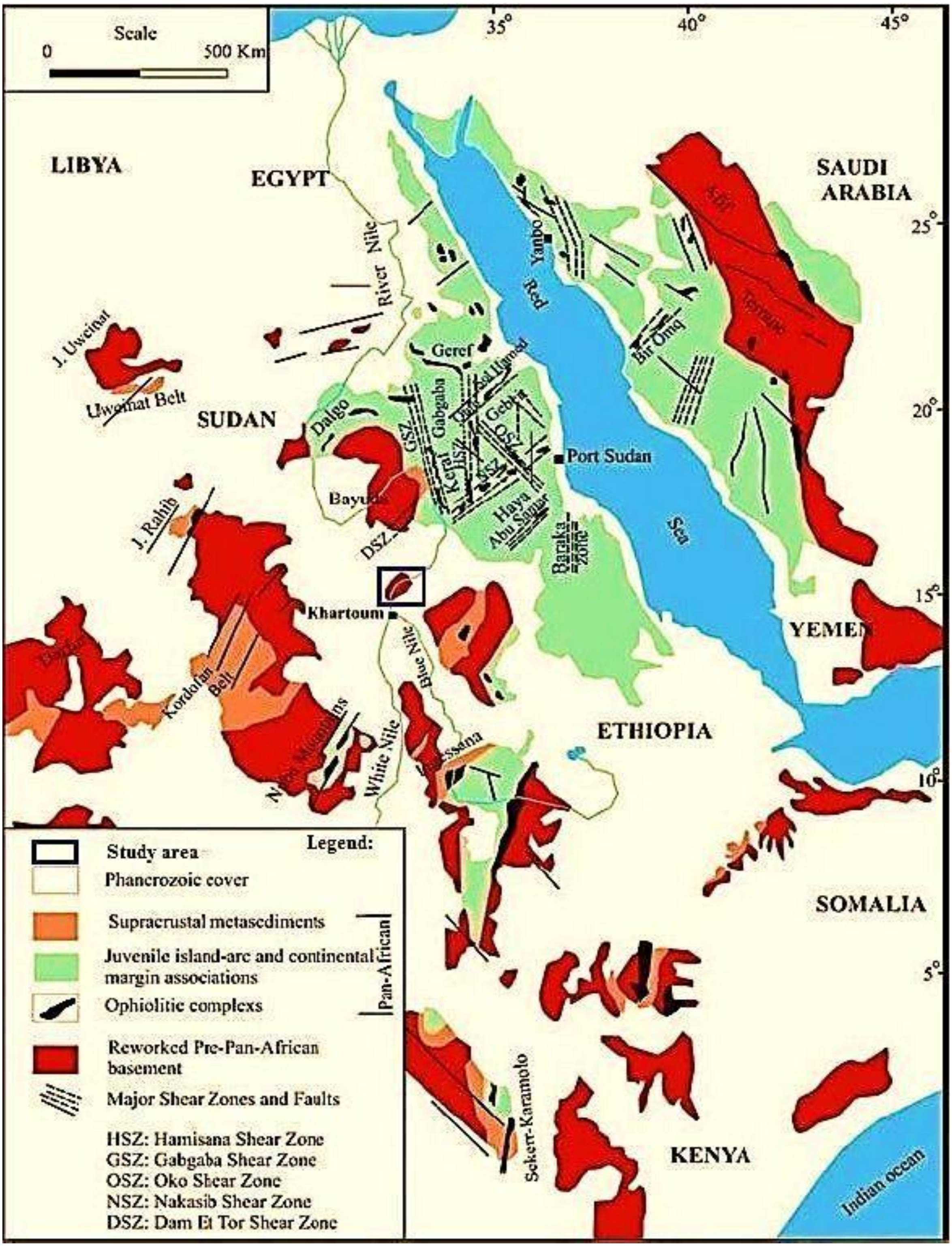

Fig. 3.1 The distribution of the basement units in Sudan and adjacent areas (Modified after Abdel Rahman, 1993).

3.1.1 Linear structures mapping

The term lineaments have been used in the literature to elect different meanings. It has been applied to the orientation of natural as well as man-made features. The geology field lineaments indicate shear zones, fold axial traces, joints, fractures, faults, dykes, streams, or layering. Terrain-related lineaments might occur as straight, curvilinear, parallel, or en-echelon patterns and are generally related to fracture systems, discontinuity planes, fault traces, and shear zones, the manifestation of the lineaments is dependent on the scale of the observation and dimensions involved (Gupta, 2003). The structural analysis of lineaments is an essential step in acquiring basic knowledge about the structural evolution of an area.

In the present study a Gram-Schmidt pan-sharpen image together with the spatially filtered images have been used within the GIS, where onscreen digitization has been conducted to draw a number of about 225 lineaments that range in length from 544 m to 2310m

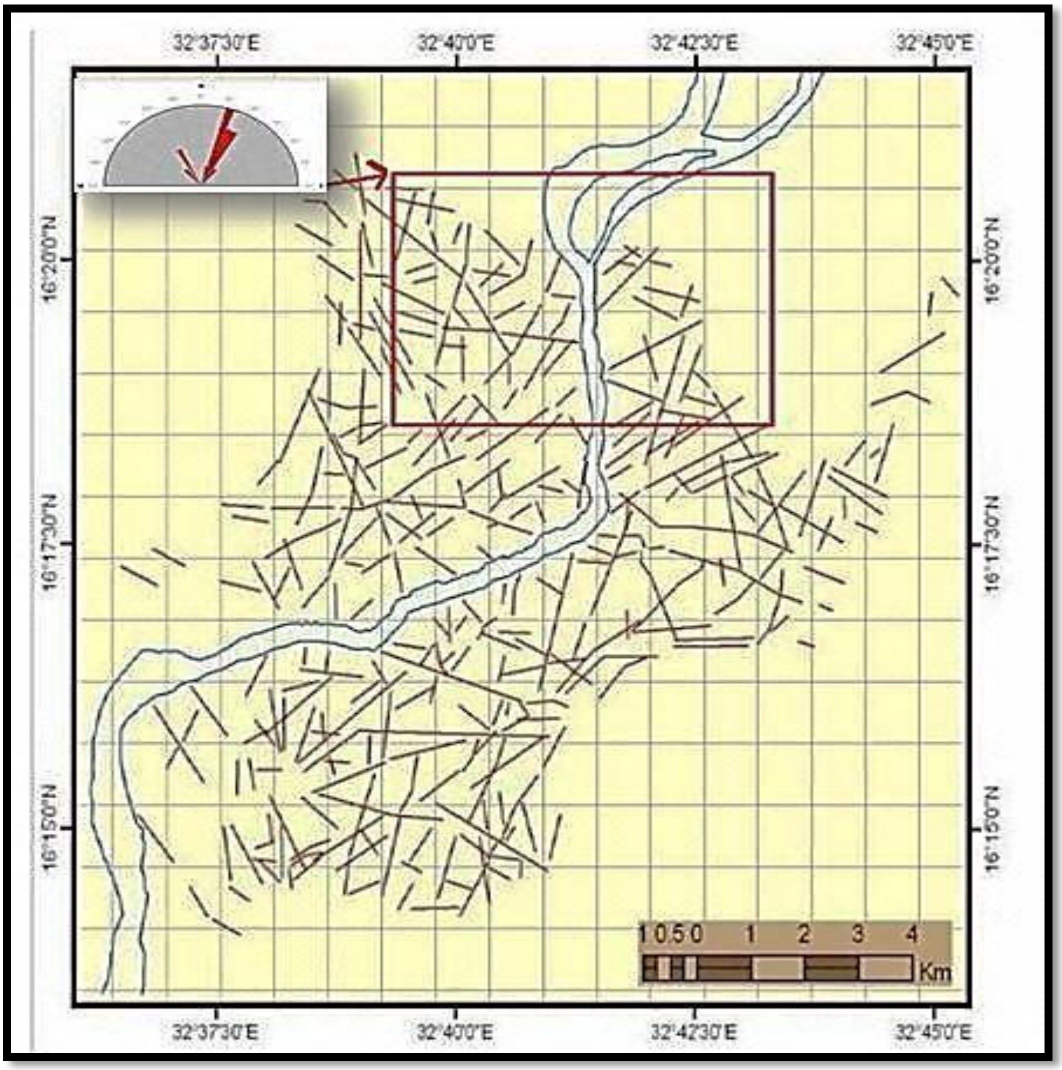

Fig. 3.2 Linear Map of the Sabaloka Volcanic Plateau. With the projection showing the predominant direction of those fractures.

Revised from Elsheikh. & Elsayed,(2010) Most outcrops of rocks exhibit many fractures that shows very small or unobservable displacement normal to their surface. Not all fractures in volcanic rock are of tectonic origin. They are mainly cooling joints whereby there is some fractures related to the post-cretaceous local faulting like Um Maraheik fault. Also, the derailing system in the area shown in lineament phenomena.

From the following geological map (Fig. 3.1), it can be seen that the area forms an inlier that consists of different types of rocks ranging from metamorphic (gneiss and migmatites) through igneous (Sabaloka Igneous Complex; and basaltic lava, rhyolite, agglomerate, ignimbrite, and microgranite to sedimentary (Cretaceous sandstone).

3.6 Fractures Analysis

Fractures are surfaces along which rocks or minerals have broken. Most outcrops of rocks exhibit many fractures that show very small or unobservable displacement normal to their surfaces, such fractures are called joints. Because the cohesion of the rocks is lost across fracture surfaces, they are considered to be planes of weakness that may affect the dam's efficiency. From this point of view, the fractures in the dam site's volcanic rocks were studied in detail.

At the proposed dam site, the fractures in volcanic rocks are not of tectonic origin; instead, they are mainly cooling joints. Moreover, some fractures related to the post-Cretaceous local faulting, such as Um Maraheik fault. Um Maraheik fault is a rotational fault that bisects the cauldron complex with an E-W trend. The and most significant component of displacement is a dextral strike-slip movement of nearly 2 Km, with a significant element of down throw to the north. This vertical component increases westward fro Jebel Um Maraheik to reach a maximum value in the trans-tensional basin (graben) at the Elhugna area west of the Nile. According to gravity evidence, this basin maintains a vertical thickness of about 1.35 Km of sediment accumulations (Dawoud and Sadig, 1988).

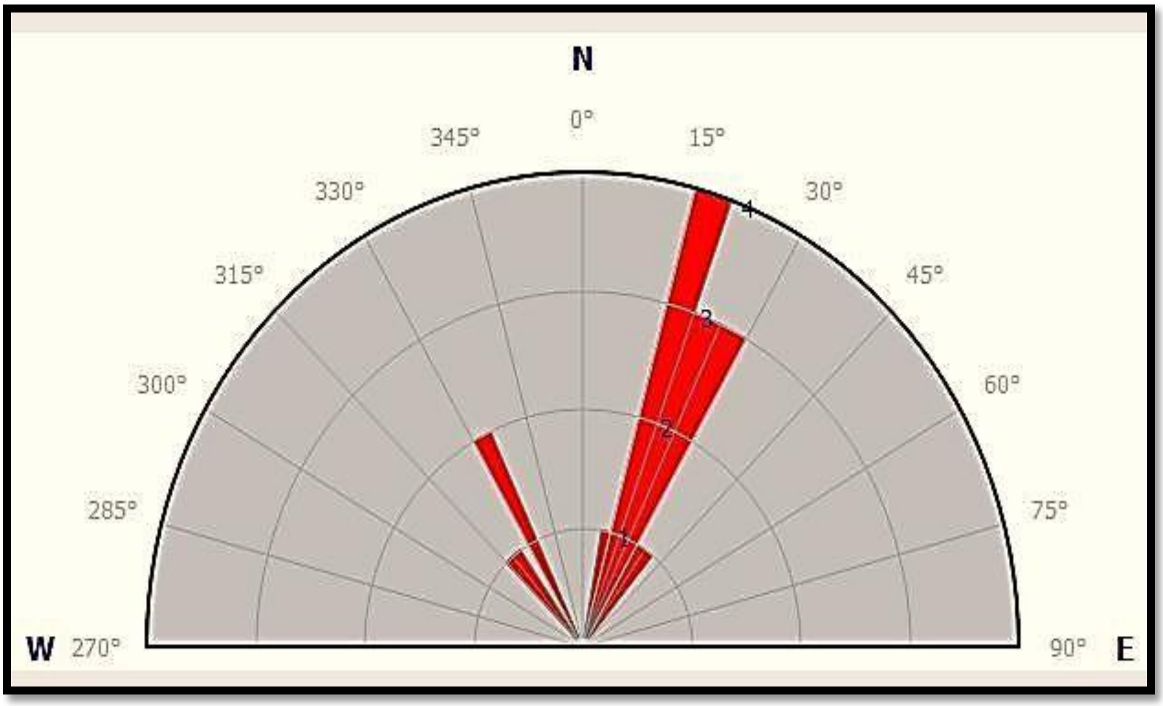

Fig. 3.3 Rose Diagram shows the main trends of fractures in the Sabaloka Plateau**.**

3.2 Structural setting

Deformation is the change in an object's shape formed due to the application of a force or forces, or the action or process of changing in shape or distorting, primarily through applying pressure. When rocks deform in response to imposed stress, they exhibit strain**,** which is the differential change in size, shape, or volume of a material. Materials differ in their responses to stress, depending upon composition, temperature and confining pressure conditions, and strain rate. However, regardless of intrinsic degrees of brittle or ductile qualities, all strained materials pass through three successive stages of deformation: elastic, ductile, and fracture (failure, or brittle deformation) (Fig 3.1). Provided that the strain rate is sufficiently slow to allow minerals to accommodate structurally, minerals can adjust to applied stresses by various mechanisms.

The events in Sabaloka inlier both basement recover rocks have primary structures. However, the deformation events in the inlier are and challenging to study from the isolated outcrops in the area despite that, at least five phases of folding and ductile shear can be deduced.

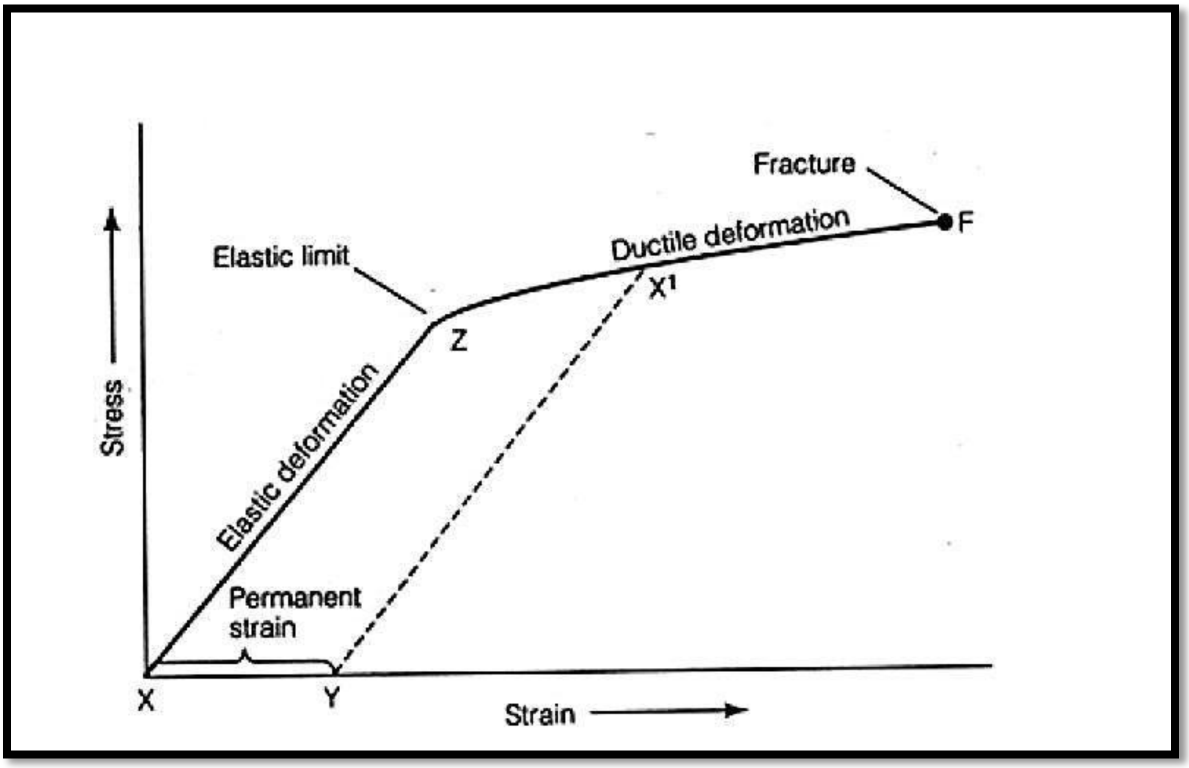

Fig. 3.4 Relationship between stress and strain (Billings, 1972).

3.2.1 Primary Structures in the Study area

Primary structures result from processes that form the rocks and do not relate to tectonic movements or deformations. The primary structure (S_0) in Precambrian basement rocks is unclear due to high deformation and metamorphism that formed the granoblastic texture of the polygonal mineral shape which obliterated old sediments' primary layering. Also, stigmatization cause becloud and deforming this primary structure (S_0). The primary structure (S_0) in sub-volcanic sediments is clear, because they are thermally metamorphosed. The old sediments of this unit are clastic, and it preserved the bedding of sediments which is an upward-fining sequence.

The Trachybasalt and pyroclastic rocks of the volcanic Plateau appear with the columnar joints. Also, Jebal El-Rawian and Jebal Um Marahik of Cretaceous sediments are positioned on the gneisses rocks with unconformity plane, and they have bedding planes. The rhyolite of the cataract area contains the flow banding structures due to the viscosity of acidic magma, and ignimbrite has a eutaxitic texture. The eutectic texture is formed by gravity compaction of volcanic overload material during eruption processes. It flattened the pumice to a lense shape. The volcanic rocks of the Sabaloka complex are positioned on the gneisses with an unconformity plane, and this structure is secondary formed without deformation. (Elyas, 2016)

Plate 3.1 The Columnar Joints in Agglomerate, Plateau area, Sabaloka Igneous Complex

3.2.2 Secondary Structures and phases of Deformations

These are four phases of deformation in the Precambrian rocks of Sabaloka inlier, beginning with the early and first progressive deformation (D1). It has three folding events the first of them is the upright tight fold (F1), the isoclinal recumbent fold is a second event (F2), and the similar recumbent fold is the last event (F3). The open concentric fold which is plunging to the East is the second phase of deformation (D2), and event four of folding (F4), the open fold which is plunging to the North is the third phase of deformation (D3), and event five folding. The ductile shear zone is the phase four of deformation (D4) whereas the interfolial fold which is formed due to deformation four is the six and the last event of folding in the region. The order of these phases of deformations and folding in the area will be described.

3.2.2.1 D1-Deformation

Progressive deformation is the accumulation of incremental strain elements within a body as a response to stress over time. The accumulated distortions and rotations within the body add to a final (Finite) strain state. The progressive deformation is the cause of the high grade of metamorphism in the Sabaloka region. It has three events of folding beginning with upright fold (F1), isoclinal recumbent fold (F2), and similar recumbent fold (F3).

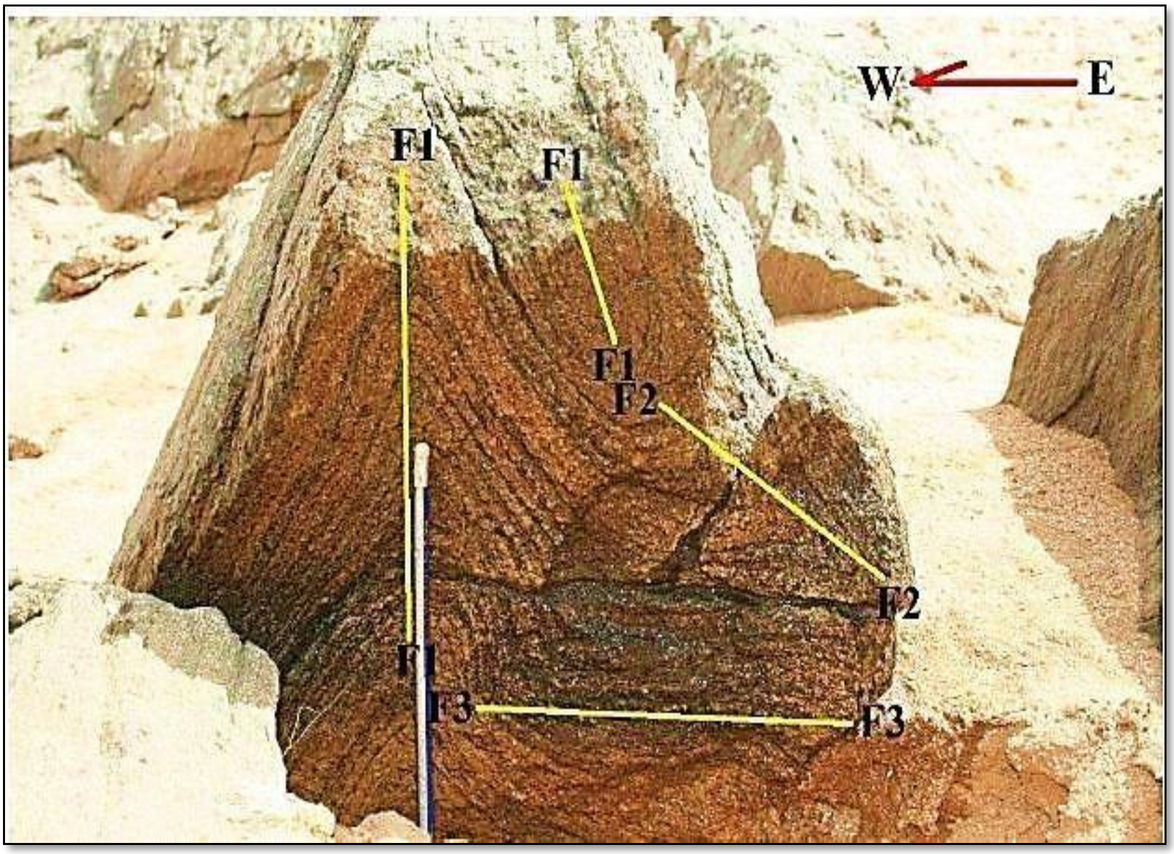

Plate 3.2 Upright tight fold (F1) refolded with isoclinal recumbent fold (F2), which was refolded by a similar recumbent fold (F3) (Elyas, 2016)

3.2.2.2 D2-Deformation

The second phase of deformation and phase four of folding in the region folded the early deformation in the area with an E-W trending axis. It is characterized by large-scale concentric open fold plunging to the east. The dips of the regional foliation are generally steep all over the area except in the hinge zones of folds. However, in one locality west of Ban Gadded, foliations show consistent low dips ranging between 10º-15º (Dawoud and Sadig, 1988)

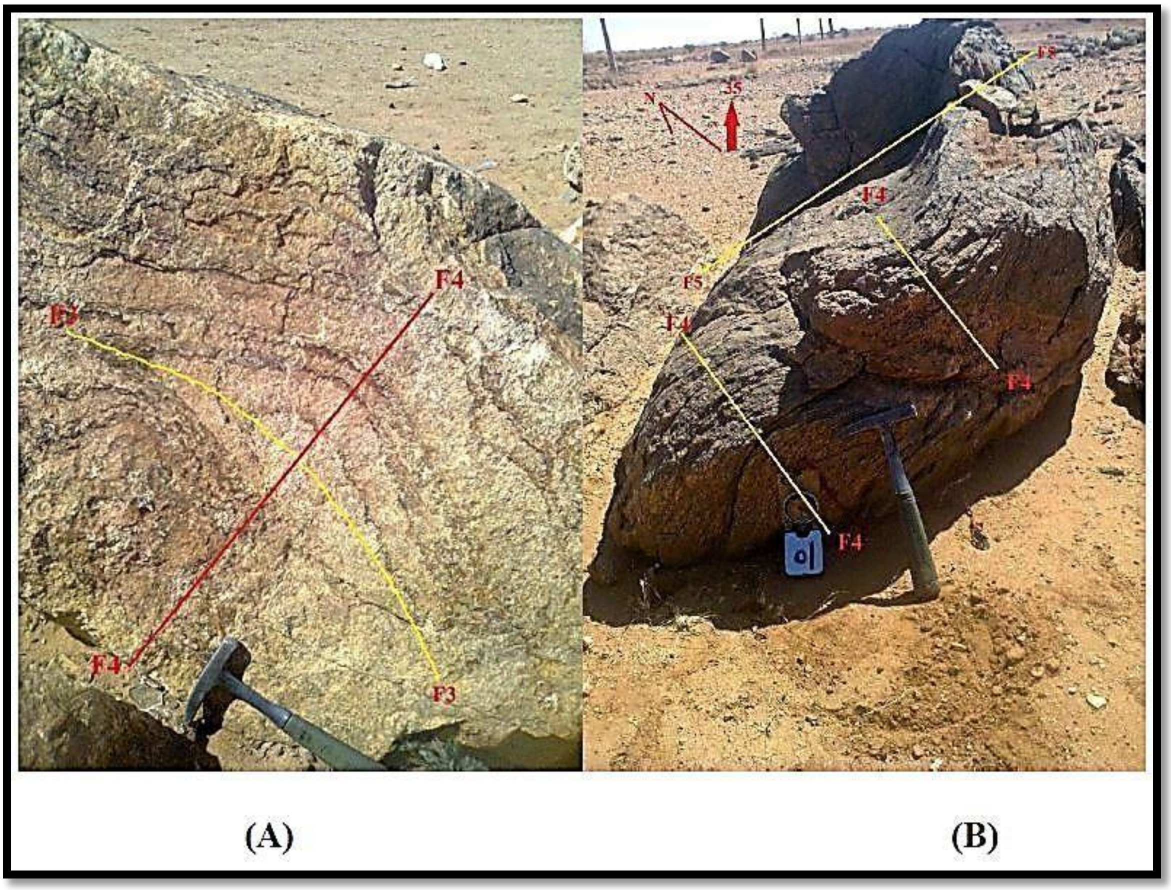

Plate 3.3 (A): The Mushroom pattern (D3) (F4) of folding which refolded (F3) Wad Bannaga area. (B): show (F4) folded by type five (F5) northeast Jebel Al Agar 3.5 Km (Elyas, 2016)

3.2.2.3 D3-Deformation

This phase of deformation is also characterized by large-scale open fold N-S trending and plunging northward with 30º as measured in the Wad Bannaga area at AL Tabol outcrops which has tectonic fractures considered as fractures formed due to folding parallel to the axis of the fold

3.2.2.4 D4-Deformation

Shear zones are the most ubiquitous features observed on planetary surfaces. They appear as a jagged network of faults at the observable brittle surface of planets. In geological exposures of deeper rocks, they turn into smoothly braided networks of localized shea displacement leaving centimeter-wide bands of mylonitized, reduced grain sizes behind (Regenauer-Lieb et al, 2003).

3.2.2.5 D5-Deformation (Brittle Deformation)

(Dawoud and Sadig, 1988) Mapped three major normal faults in the inlier that bound the cluster of granulite outcrops to the west, east, and north must have contributed to the uplift of the granulites, at least locally around the Ban Gadeed area. Two of this fault cross pond to steep gravity gradients (Dawoud and Sadig, 1988). Umm Marahik fault is one of Sabaloka's inlier. It is a dextral strike-slip fault, trending E-W, and the displacement of this fault is recorded as two kilometers (Almond et al, 1980)

Table 3.1 Summarize the phases of deformation in the study area

Deformation	Folding	field evidence	described by
1	F1	Upright tight fold	Elyas, (201)
	F2	refolded with isoclinal recumbent fold	Elyas, (201)
	F	refolded by similar recumbent fold	Elyas, (201)
2	F4	large scale concentric open fold plunging to the east	awoud and Sadig, (1988)
	F5	large scale open fold N-S trending and plunging northward with 0º (Wad Bannaga area at AL Tabol outcrops)	Elyas, (201)
4		Shear zones (They appear as a jagged network of faults at the observable brittle surface of planets)	Regenauer-Lieb et al, (200)
5		Brittle eformation (three major normal faults)	awoud and Sadig, (1988)

Chapter four

Geotechnical Investigation Of Sabaloka Dam Site

4.1 Introduction

Geotechnical work is usually performed to know the engineering geological properties of the site materials. This will help in the project design by using field tests (Stander Penetration Test, Permeability, Strength, rock Stability, Water Saturation, Porosity, and Layer thickness) performed in the borehole.

Three boreholes were drilled at the proposed site by rotary drilling, and geotechnical analyzes, and the results were as shown below.

4.2 Classifications Of Some Discontinuity Features

Discontinuity is any structural or geological feature that changes or alters the homogeneity of a rock, which may be technically joints, bedding planes, minor faults, or other surfaces of weakness, such as cleavage and schistosity planes. It excludes significant faults, since they are considered structural regions of their own.

Discontinuities constitute a tremendous range, from structures of up to several kilometers in extent down to a few centimeters, (Fig. 4.1) The two main groups are joints and weakness zones. These are described in the following:

- *A Joint* is a discontinuity plane of natural origin along which there has been no visible displacement. Joint is here used as a term for a break, fracture, or crack (Fig. 4.1)
- *Singularity* is a small weakness zone or a seam.
- *A weakness zone* is a part or zone in the ground in which the mechanical properties are significantly lower than the surrounding rock mass. Weakness zones can be faults, shears/shear zones, thrust zones, weak mineral layers, etc.

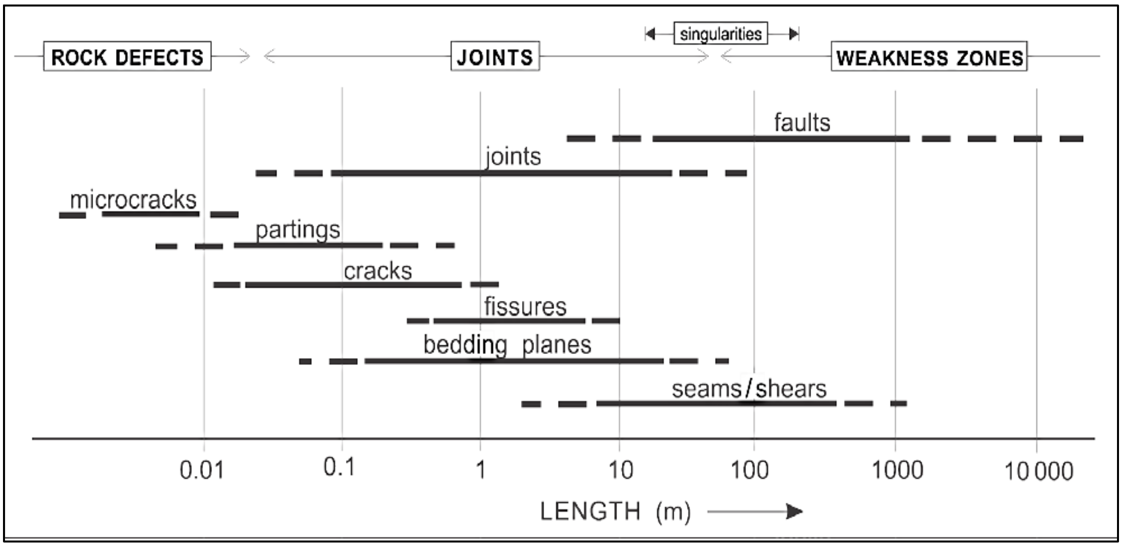

Fig. 4.1 The main types of discontinuities according to size (revised from Palmström, 1995)

Condition of discontinuities includes roughness of the discontinuity surfaces, their separation (distance between the surfaces), their length or continuity (persistence), weathering of the wall rock of the planes of weaknesses, and the infilling (gouge)

4.2.1 several joints (jointing)

- Jointing is the occurrence of joint sets forming the system or pattern of joints and the amount or intensity of joints.
- Detailed jointing is the network of joints in the massifs between weakness zones.
- The degree of jointing/density of joints is the general term for the number of joints in a rock mass. This includes block size, joint set spacing, joint frequency, and rock quality designation (RQD).

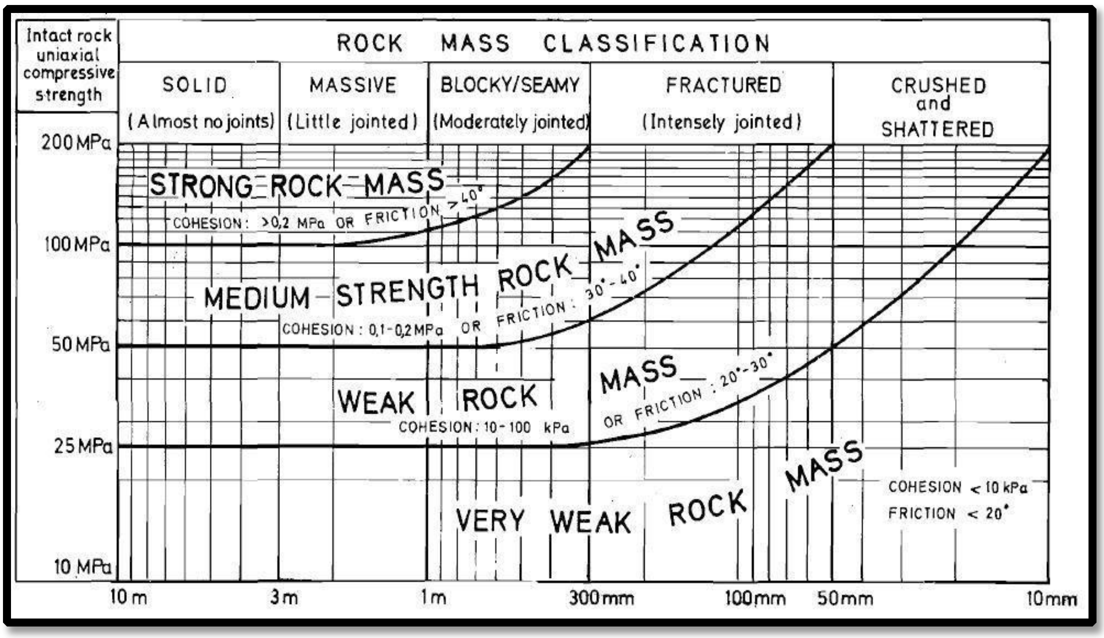

Fig. 4.2 Strength diagram of jointed rock masses, Bieniawski (1973)

4.2.2 joint spacing and degree of jointing

Joints are found in specific, preferred directions as joint sets forming the jointing pattern. One to three prominent joint sets and one or more minor sets often occur; several individual or random joints may also be present. Joint set spacing is the distance between individual joints within a joint set. Joint spacing and average joint spacing are often used in describing and assessing rock masses. Note: the term "joint spacing" does not indicate whether it is the "joint intercept" or the "joint set spacing. "Thus, there is often much confusion related to the use of joint spacing, which often leads to errors or inaccurate description/characterization and hence on the calculation results.

Joint intercept is drill lengths of core pieces between the joint. This is seldom true joint set spacing, as joints of different sets are included in the measurement. In material. Some of these are classified into the following Addition, random joints, which do not necessarily belong to any joint set, may occur

Table 4.1 Geomechanics Classification of Jointed rock masses, Bieniawski (1973)

Item	**Class No and its description**	**1**	**2**	**3**	**4**	**5**
		Very good	**good**	**Fair**	**Poor**	**Very poor**
1	Rock quality RQD %	90 – 100	75 – 90	50 – 75	25 – 50	<25
2	Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Completely weathered
3	Intact rock strength, MPa	>200	100-200	50-100	25-50	<25
4	Spacing of joints	>3m	1–3 m	0.3-1 m	50-300 mm	< 50 mm
5	Separation of joints	<0.1 mm	<0.1 mm	0.1-1 mm	1-5 mm	> 5mm
6	Continuity of joints	Not continuous	Not continuous	Continuous no gouge	Continuous with gouge	Continuous with gouge
7	Ground water inflow (per 10m of adit)	None	None	Slight <25 liters/min	Moderate 25-125 liters/min	Heavy > 125 liters/min
8	Strike and dip orientations	Very favorable	Favorable	Fair	Unfavorable	Very unfavorable

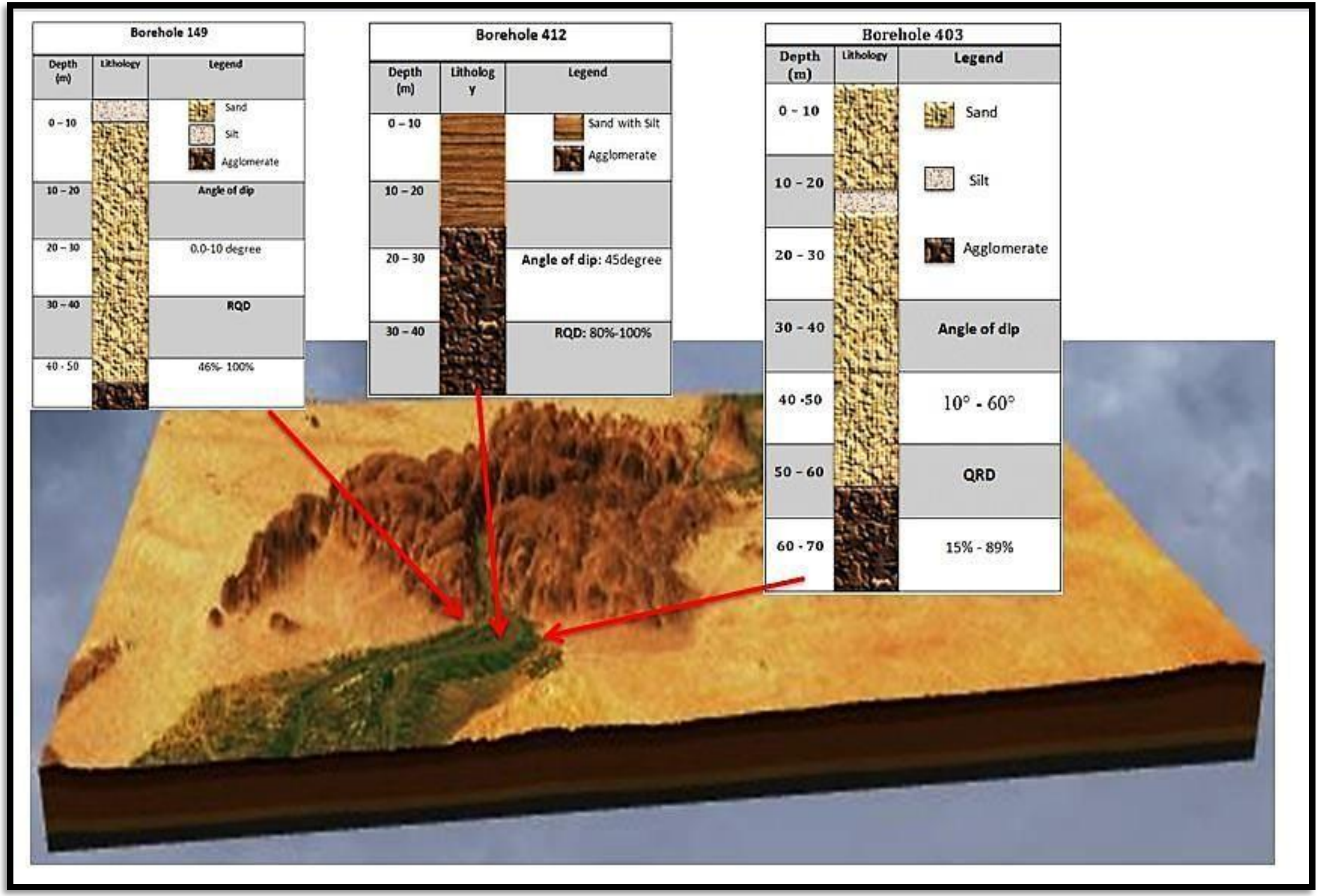

Fig.4.3 locations of the boreholes

4.3 Result of The Drilling Work

4.3.1 Borehole number (412)

This drilling was drilled in 2018 with a total depth of 35 meters by rotary drilling on the island of Misikitab, to identify underground geological formations and engineering– properties (Total depth **35.00 meters)**

4.3.1.1 Physical and Geotechnical Properties Of Agglomerate

Start drill from 1m to 17.87m rocks are **Silt** and **Sand** with variation in color and a change in the rock's physical properties.
The bottom of the well at a depth of 17.85meter formation is Silt described as Dark grey, wet, soft, and with low plasticity.
At a depth of 17.85 meters to 35meter, rock is the **Basement (Agglomerate**).

- **Color:** Reddish brown.
- **Grain:** Coarse-grained
- **Hardness:** Massive
- **Support:** Grain supported
- **Sorting:** Poorly sorted
- **Granular:** Composed welded angular to sub-angular fragment, mainly rhyolite.

4.2.1.2 Engineering Properties of Agglomerate

- **Weathering:** Variation from Fresh to Slightly weathering
- **Strength:** Range from very low to highly strength related to depth
- **RQD:** 80%-100%
- **Fresh water return:** 0%-20%

4.2.1.3 Joint Characteristics

- **The angle of the dip: is** 45degree
- **Shape:** Irregular
- **Roughness:** Rough
- **Coating:** Calcite / Iron oxid**e**

• **Spacing:** Close

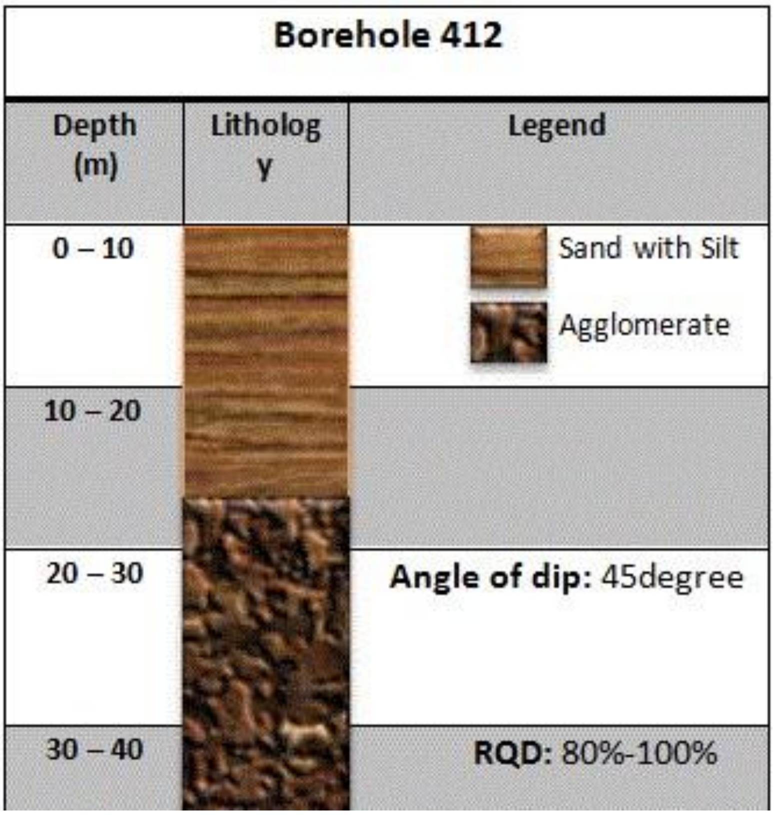

Fig. 4.4 Lithological profile showing the rock layers in borehole 412

4.3.2 Borehole number (403)

This well is a drill with a (total depth of **61.10 meters**) Start Sand is dominate rock with a thin layer of Silt.

4.3.2.1 first layer (Sand) describes as follows:

- **Color:** variation in color
- **Grain:** Fine to Coarse grain
- **Shape:** Sub-rounded to angular
- **Graded:** Poorly grad
- **Homogeneity:** Homogenous rock
- **Composition:** Composed of sand and feldspar

4.3.2.2 Second layer (Silt) In-depth 16meter to 19meter rock is composed of minor Sand, minor Clay, and trace Gravel, described as:

- **Color:** Dark grey

• **Moisture:** Wet • **Hardness:** Soft • **Plasticity:** Medium

4.1.2.2.3 Third layer (Sand) at 19meter to 56.10meter**,** describe as:

- **Color:** variation in color
- **Grain:** Fine to Coarse grain
- **Shape:** sub rounded to angular
- **Graded:** Poorly grad
- **Homogeneity:** Homogenous rock

4.3.2.4 Basement (Agglomerate rock) at 56.10meter to 61.10meter describe as:

- **Color:** Reddish brown.
- **Grain:** Coarse-grained
- **Hardness:** Massive
- **Support:** Grain supported
- **Texture:** Heterolithc
- **Sorting:** Poorly sorted
- **Granular:** Composed welded angular to sub-angular fragment, mainly rhyolite.

4.3.2.5 Engineering Properties of Agglomerate

- **Weathering:** Slightly weathering along the joint plane, spacing fracture 7mete along a joint plane by drilling
- **Strength:** Highly strength
- **RQD:** 15%- 89%
- **Fresh water return %:** 99%

4.3.2.6 Joint Characteristics

- **The angle of dip:** 10-60 degrees
- **Shape:** Irregular
- **Roughness:** Rough
- **Coating:** Kaolinite / Calcite
- **Spacing:** very wide, i.e. more than 2 meters
-

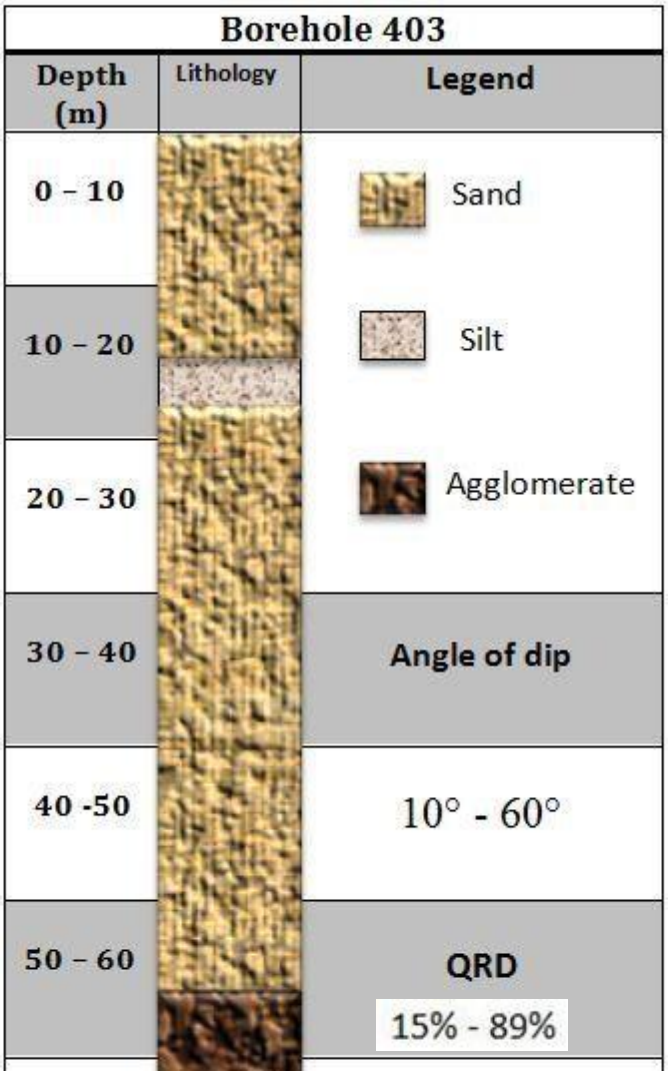

Fig. 4.5 Lithological profile showing the rock layers in borehole 403

4.3.3 Borehole number 149 (Total depth **50.30meter)**

4.3.3.1 first layer (Silt) is described as:

- **Color:** Dark grey
- **Moisture:** Wet • **Hardness:** Soft
- **Plasticity:** Low plasticity

4.3.3.2 Second layer (Sand) founds in 2.70meter to 45.30meter and describes as:

- **Color:** dark grey to grey
- **Grain:** Fine to Coarse grain with some silt
- **Shape:** Sub-rounded to angular
- **Graded:** Poorly graded
- **Homogeneity:** Homogenous rock

- **Composition:** Quartz & Feldspar
- **Grain shape:** subrounded to subangular

4.3.3.3 Basement (Agglomerate rock) at 45.30meter to 50.30meter describe as:

- **Color:** Reddish brown.
- **Grain:** Coarse-grained
- **Hardness:** Massive
- **Support:** Grain supported
- **Texture:** Heterolithc texture
- **Sorting:** Poorly sorted
- **Granular:** Welded angular to sub-angular fragment, mainly rhyolite and part of ignimbrite.

4.3.3.4 Engineering Properties of Agglomerate

- **Weathering:** Slightly weathering along the joint plane
- **Strength:** Highly strength
- **RQD:** 46%- 100%
- **Fresh water return:** 95% - 99%

4.3.3.5 Joint Characteristics

- **Angle of dip:** 0.0-10 degrees
- **Shape:** Irregular
- **Roughness:** Rough
- **Coating:** Kaolinite / Calcite and Iron oxide
- **Spacing:** very wide, i.e. more than 2 meters

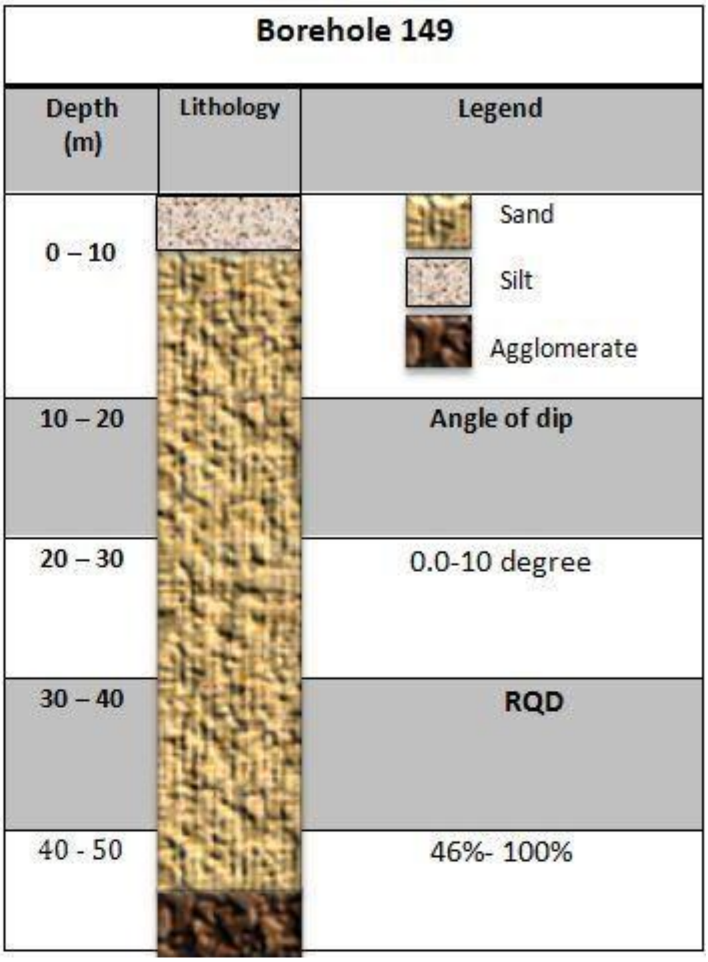

Fig. 4.6 Lithological profile showing the rock layers in borehole 149

4.3.3 Summery of Drilling Results

The drill borehole at the study area can identification of geological characteristics and engineering properties of the ground by knowing the structures and stability with types of joint characteristics that are summarized in **table 4.5** showing the orientation, material filling, degree or spacing and all of this information can help to identification the characteristic of the basements and which stable area for a building project, subsurface layers various into sand and silt formation with basement rock type is Agglomerate**.**

Table 4.5 Correlations between boreholes no. 403, 412 and 149

Description / **Location**	**Left of Spillway channel**	**Misikitab island**	**Right of Spillway Channel**
Borehole number	403	412	149
Total depth	61.10meter	35.00meter	50.30meter
Rock types	sand / silt agglomerate	sand / silt agglomerate	sand / silt agglomerate
Agglomerate depth	56.10 meter	17.85 meter	45.50 meters
Rock Quality Designation (RQD)	15% - 89%	80% - 100%	46% - 100%
Basement Weathering	slightly	fresh to slightly	fresh to slightly
Joint Characteristics			
Angle of dip	10° - 60°	0.0° - 45°	0.0° - 10°
Shape	Irregular	Irregular	irregular
Roughness	Rough	Rough	rough
Coating	kaolinite /calcite/iron oxide	calcite/iron oxide	calcite/iron oxide
Spacing	very wide	Close	very wide
Fresh water return	99%	0%-20%	95% - 99%

The selection of three boreholes is based on the location of the dam, and it surveyed the area of the project with given complete information at. That we observation the ground of the three boreholes is typically matched but there are some different in the thickness of a layer such as Agglomerate in the borehole number 412 is more than other, and it found at shallow while in the other borehole is found deep in the bottom it with thickness 5meter and in 412 is 50% of total depth is Agglomerate and sediment formation in top Sand, and Silt formation at drilling we test the strength of rock during drilling and used SPT test with permeability and joint characteristic to measurement the engineering properties of rock and that gives good evidence of the study area with complete data concerned to project, the drilling borehole by rotary rig with geotechnical engineering method and test.

Chapter five

Building material of the proposed sabaloka dam

5.1 Introduction

Aggregate is an aggregation of non-metallic minerals to form a solid particle. Aggregates can be natural or artificial. Natural aggregates are formed by weathering, and disintegration on parent rocks. Pebbles, sand, and gravel are examples of natural aggregates. Natural aggregates are round, flaky, and platy in shape. Similarly, an artificial aggregate is obtained by crushing the parent rock.

To obtain numerical scientific values, which assist in acquiring good quantitative and qualitative evaluation, many tests (8 samples) have been carried out based on international standard methods (table 5.1), such as British standard (BS), American standard for testing Material (ASTM) and the American association of state High and transportation officials system (AASHTO) Rock samples are tested at the laboratory of building and road research institute (BRRI, University of Khartoum). Geological research Authority of Sudan (GRAS, Khartoum) and Road And Bridges Public Corporation (RBPC, Khartoum).

Table.5.1 limits for physical, chemical, and mechanical properties of aggregates for concrete, AASHTO Designation (1990)

Kind of requirement	Test method		Permissible limits	
	Bs 812	**Astm**	**Fine**	**Coarse**
Grading	**Part 103**		**Std**	**Std**
Materials finer than 0.075 mm Nateural , uncrushed / crushed Crushed rock `	Part 103		Max. 3 % Max. 7 %	Max. 1 % Max. 1 %
Clay lumps & friable particles		C 142	Max. 1 %	Max. 1 %
Light weight pieces		C 123	Max. 0.5 %	Max. 0.5 %
Organic impurities test 8 of bs1377			Max. 0.5 %	
Water absorption		C 128 / C 127	Max. 2.3 %	Max. 2 %
Specific gravity (apparent)	Part 106	C 138 / C 127	Min. 2.6	Min. 2.6
Shell content in aggregates coarser than 10 mm Between 5 mm & 10 mm Between 2.36 mm & 5 mm Finer than 2.36			Max. 10 % Note 1	Max. 5 % Max. 15 %

Particle shape Flakiness index Elongation index	Part 105.1 105.2			Max. 25 % Max. 25 %

Table 5.1 Continue

Acid soluble chlorides, Cl For reinforced concrete Made with srpc Cements Opc & msrpc cements	Part 117, appen. C		Max. 0.03% Max. 0.05%	Max. 0.01% Max. 0.02%
For mass concrete made with srpc cement Opc & msrpc cements			Max. 0.03 % Max. 0.05 %	Max. 0.02 % Max. 0.04 %
For prestressed concrete & steam cured structural concrete			Max. 0.01 %	Max. 0.01 %
Acid soluble sulphates so_3	Part 118		Max. 0.03 %	Max. 0.03 %
Soundness, $mgso_4$ (5 cycles)		C 88	Max. 12 %	Max. 12 %
Mechanical strength 10 % fine value or impact value	Part 111 Part 112			Max. 12 %
Los angeles abrasion		C 131 / C 535		Max. 30 %
Drying shrinkage	Part 120			Max. 0.5 %

Potential reactivity note 2 Of aggregate, chemical method of cement aggregate. Combination		C 289 C 227	Innocous 6month expansion 0.10 % max	Innocous 6month expansion 0.10 % max

5.2 Rock Geotechnical Tests

5.2.1 Specific gravity and Water Absorption Test

Specific gravity and Water Absorption Test of Aggregates are important tests to perform on aggregate. These two parameters or aggregate properties play an essential role in the concrete mix design. As we know, aggregate occupies 70 to 80% of concrete, and its testing becomes essential before use.

"Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water."

The specific gravity usually shows the material's strength and quality**.** The specific gravity of aggregates test is usually used identify stones or aggregates.

Aggregates with low specific gravity values are weaker than those with higher specific gravity values.

Water absorption of aggregates is the % of water absorbed by an airdried aggregate when immersed in water at 27°C for 24 hours.

Water Absorption of Aggregate **(WA%)** = % by weight of water absorbed in terms of oven-dried weight of aggregate **WA = A – B / A 100%**

Where : **A**: weight of dry sample in air.

B: weight of saturated sample in air.

A coarse aggregate lab report's specific gravity and water absorption is prepared after calculating the above values.

According to (tables 5.1 and 5.2), it is clear that dark ignimbrite, Trachybasalt, Babados granite, and Suleik Granite can be used as aggregate for concrete from a specific point of view. Still, some of them can be neglected for their alkali reactivity as dark ignimbrite or for their hazardous mineral as Babados granite. **(** Water absorption shall not be more than **0.6 per unit by weight)**

Table.5.2: Water Absorption for rock samples

Sample No	Rock Type	WA%
1	Light Ignimbrite	0.48
2	Dark Ignimbrite	0.16*
3	Upper Rhyolite	0.75
4	Trachybasalt	0.35*
5	Lower Rhyolite	0.48
6	Suleik Granite	0.20*
7	Babados Granite	0.15*
8	Prophyirtic Microgranite	2.63

* Suitable for use at standard values

5.2.2 Aggregate impact value (AIV) Test

AIV test is conducted to determine the Aggregate Impact Value of Coarse aggregate. The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from Its resistance to a slow compression load. The ratio of the Weight of the fraction passing through 2.36-mm IS Sieve to the total weight of the oven-dried sample.

AIV = W2/W1*100

Where: W1: Weight of Aggregate Sample Filling in Cylinder (gm)
W2: Weight of Aggregate Passing the 2.36 mm Sieve after the test (gm)

Table 5.3 classify the stones in respect of their toughness property, (Deere 1989)

Aggregate Impact value	*Classification*
<10 %	Exceptionally strong
10-20%	Strong
10-30%	Satisfactory for road surfacing

>35%	Weak for road surfacing

Fig. 5. 1 Aggregate Impact Value Testing Machine

Table 5.4 Aggregate impact value (AIV) %

Sample No	**Rock Type**	**(AIV) %**
1	Light Ignimbrite	9.11
2	Dark Ignimbrite	7.52
3	Upper Rhyolite	3.72
4	Trachybasalt	3.80
5	Lower Rhyolite	3.72
6	Suleik Granite	9.78
7	Babados Granite	8.66
8	Prophyirtic Microgranite	8.00

From (tables 5.3 and 5.4) all the rocks type can be used as concrete

5.2.3 Aggregate crushing value (ACV) Test

It is the ability of aggregates to resist sudden impact or shock load. Also, it can be defined as the resistance of aggregate to failure by impact load, known as the Impact Value of Aggregate.
The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load.
With an aggregate aggregate crushing value of 30 or higher, just Babados Granite is suitable for use

Table.5.4 Aggregate Crushing Value (ACV) %

Sample No	Rock Type	Aggregate Crushing Value (ACV) %
1	Light Ignimbrite	19.50
2	Dark Ignimbrite	14.80
3	Upper Rhyolite	17.60
4	Trachybasalt	13.77
5	Lower Rhyolite	19.46
6	Suleik Granite	27.56
7	Babados Granite	44.39*
8	Prophyirtic Microgranite	23.65

*Suitable for use at standard values

5.2.4 Soundness Test

Separated size fractions of the fine and coarse aggregate sample are immersed for timed cycles into a sodium sulfate (Na_2SO_4) or magnesium sulfate ($MgSO_4$) solution, then oven-dried and immersed again. Crystals of the salt solution grow in voids and fissures of the aggregate particles during the immersion and drying cycles, simulating the expansive force of ice crystals and causing degradation of the particles.
After completion of the test cycles and a final washing, each size fraction is again sieved and weighed to determine the percentage of mass lost by degradation during the process. A qualitative examination of the coarse aggregate classifies the degree of damage sustained by the particles. Test results between the sodium and magnesium solutions do not correlate.
The aggregate sample fractions selection and preparation must strictly follow the ASTM or AASHTO standard test procedures. The bulk

samples are thoroughly washed over specified sieves and oven-dried before separating into the specified size fractions.

The rest is the total percentage loss over various sieve intervals for a required number of cycles. Maximum loss values typically range from 10% to 20% for five cycles.

When referring to(tables 5.5 and 5.1) all the rock types exceeded the soundness test, and are suitable as concrete aggregate material, And the best one is Suleik granite.

Table 5.5 Soundness Value (SV) %

Sample No	**Rock Type**	**Soundness Value (sv) %**
1	Light Ignimbrite	9.00
2	Dark Ignimbrite	5.80
3	Upper Rhyolite	7.40
4	Trachybasalt	6.70
5	Lower Rhyolite	7.40
6	Suleik Granite	6.00
7	Babados Granite	8.80
8	Prophyirtic Microgranite	6.95

5.2.5 Density Test

The unit weight is determined by the formula below. Subtract the weight of the measuring base from the combined weight of the measuring base and the concrete it contains. Next, divide this weight (in pounds) by the volume of the measuring base (cubic feet) to obtain the density expressed as lb/ft3:

D = (Mc – Mm) / Vm

D = Density of the concrete, lb/ft3

Mc = Weight of the measure holding the concrete

Mm = Weight of the empty concrete measure (base of air meter(

Vm = Volume of the measure (usually about 0.25 ft3 for a pressure meter base)

Table 5.6 Density g/cm^3

Sample No	**Rock Type**	**Density g/cm^3**

1	Light Ignimbrite	2.53
2	Dark Ignimbrite	2.61*
3	Upper Rhyolite	2.53
4	Trachybasalt	2.75*
5	Lower Rhyolite	2.53
6	Suleik Granite	2.77*
7	Babados Granite	2.59
8	Prophyirtic Microgranite	2.59

*Suitable for use at standard values

5.2.6 Point Load Test

The Point load test is an index test by which the rock is classified according to its strength. The test can estimate other characteristics of intact rocks with which it correlates, such as uniaxial compressive and tensile strength. The test determines the strength index values at a point (Is (50)) and the anisotropy index (Ia (50)). The anisotropy index represents the strength ratio at point load in the directions with the lowest and highest values of the strength index.

The test device consists of the sample load and force gauges, and sample dimensions (length scale) are also measured during the test.

Point load strength index ($\mathbf{I_s}$) = $\mathbf{(P*1000)/D^2}$ Mpa

Where: **P** is breaking load in kN

D is the distance between platens in mm

The corresponding point load strength index for the standard core size of 50 mm ($\mathbf{I_{s50}}$) diameter is given by the following equation

I_{s50} = (P*1000)/($D^{1.5}\sqrt{50}$) MPa

Fig. 5.2 Digital Point Load Tester

Table.5.7 Point Load Test (PL) KN/M^2

Sample No	**Rock Type**	**Point Load Test (PL) KN/M^2**
1	Light Ignimbrite	12.52
2	Dark Ignimbrite	-
3	Upper Rhyolite	11.58
4	Trachybasalt	8.14*
5	Lower Rhyolite	8.61
6	Suleik Granite	2.74*
7	Babados Granite	10.48
8	Prophyirtic Microgranite	7.82*

*Suitable for use at standard values

5.2.7 Los Angeles Abrasion (LAA)

The Los Angeles (L.A.) The abrasion Test is widely used as an indicator of the relative quality of aggregates. It measures the degradation of standard gradings of aggregates when subjected to abrasion and impact in a rotating steel drum with an abrasive charge of steel balls.
The drum is fitted with an internal shelf that lifts and drops the charge and sample with each revolution, generating impact forces. After the machine has completed the required rpm, contents are removed, and the percent loss is measured

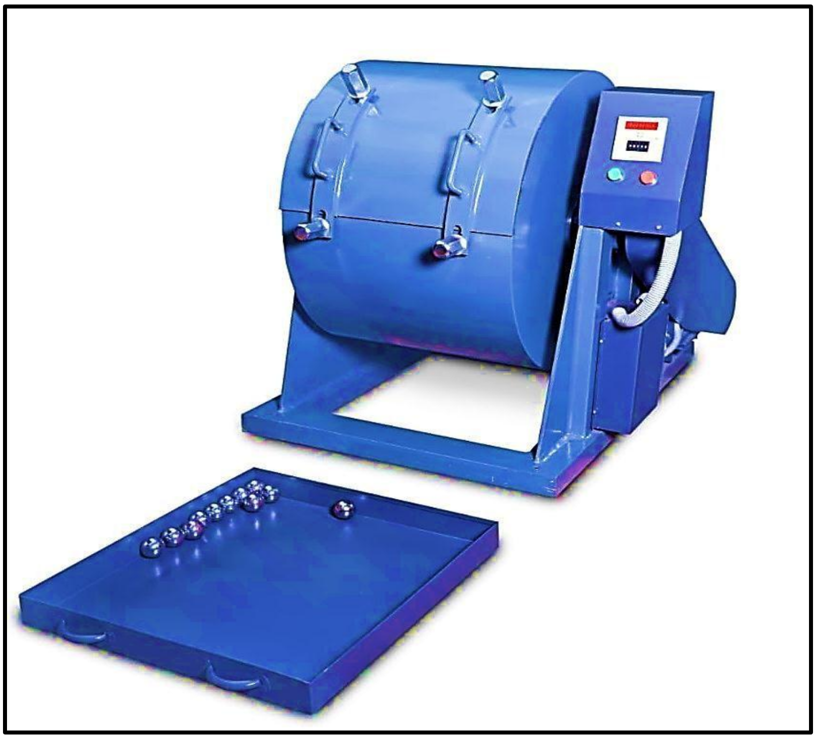

Fig. 5.3 Los Angeles test machine

Table.5.8 Los Angeles Abrasion (LAA%)

Sample No	Rock Type	LAA%
1	Light Ignimbrite	19.50
2	Dark Ignimbrite	19.45
3	Upper Rhyolite	19.16
4	Trachybasalt	12.50
5	Lower Rhyolite	15.32
6	Suleik Granite	27.56
7	Babados Granite	44.38
8	Prophyirtic Microgranite	23.34

5.2.8 Uniaxial Compressive Strength Test (UCS) A measure of a material's strength. The uniaxial compressive strength (UCS) is the maximum axial compressive stress that a right-cylindrical sample of material can withstand before failing. It is also known as the unconfined compressive strength of a material because confining stress is set to zero.

The procedure of this test is as follows:

a) Cut the samples into cubes; the length of each polygon is 50mm.

b) Put the specimen under vertical pressure effect, the result from two cylindrical shape metallic plates that the specimen put between them.
c) Record the applied power at the moment of the rock specimen starts collapsing and divide by the specimen section to get the uniaxial compressive strength, as the following:

UCS = P_{max} N Where:

V=D= length of cube polygon that equals 50mm

The results of this test for all rocks samples are shown in (Table 5.9)

Table.5.9 Uniaxial Compressive Strength Test (UCS)

Sample No	Rock Type	(UCS) kPa
1	Light Ignimbrite	-
2	Dark Ignimbrite	7.52
3	Upper Rhyolite	40.4
4	Trachybasalt	-
5	Lower Rhyolite	7.2
6	Suleik Granite	15.35
7	Babados Granite	12.2
8	Prophyirtic Microgranite	44.3

5.3 The Results of Geotechnical Tests

The low value of (AVI), (LAA), and (ACV) means higher resistance to impact, abrasion, and crushing, reversing the maximum value, witch means less quality.

In general, these rocks have shown high durability in geotechnical tests, and the size and shape of the cut may positively or negatively affect the purpose for which the study was conducted.

Table 5. 10 Summary of the results of the geotechnical test on the rock sample

Rock Name	AIV %	LAA%	ACV%	Specific gravity	WA%	SV %	PL KN/M^2	UCS
Light Ignimbrite	9.11	19.50	19.50	2.53	0.48	9.00	12.52	-
Dark Ignimbrite	7.52	19.45	14.80	2.58	0.16	5.80	-	7.52

Upper Rhyolite	3.72	19.16	17.60	2.49	0.75	7.40	11.58	40.4
Trachybasalt	3.80	12.50	13.77	2.70	0.35	6.70	8.14	-
Lower Rhyolite	3.72	15.32	19.46	2.49	0.48	7.40	8.61	7.2
Suleik Granite	9.78	27.56	27.56	2.77	0.20	6.00	2.74	15.35
Babados Granite	8.66	44.38	44.39	2.57	0.15	8.80	10.48	12.2
Prophyirtic Micrograni te	8.00	23.34	23.65	2.66	-	6.95	7.82	44.3

Chapter Six

Conclusion And Recommendations

6.1 Conclusion

- The study was conducted to examine the suitability of the selected site for the proposed hydro-power dam is located on the River Nile about 80 km north of Khartoum town. The site is located at the narrow gorge of the River Nile on the volcanic plateau that is mainly occupied by acid volcanic rocks characterized by highly jointed rocks.
- Different sets of joints are widespread throughout the dam site's various lithologies. Different faults oriented averagely N-E are dominant in the study area. Moreover, some fractures related to the post-cretaceous local faulting, such as Um Maraheik fault.
- The main fractures trends are in NW and NE. The dam axis is located on the relatively less fractured Agglomeratic rocks. Still,

the existence of the tensional fractures related to Um Maraheik fault may affect the efficiency of the dam wall. These fractures cross the eastern flank of the dam axis in the NE direction, where they cross the western flank in the NW direction.

- ❖ Three borehole is typically matched, but there are some different in the Depth of the Basement (Agglomerate)
- ❖ The boreholes, 403 and 149 (RQD) value was low Compared to 412, due to the presence of intersecting fractures with the dextral fault.
- ❖ The collected samples of rock were subjected to the following laboratory tests for specific gravity, water absorption, impact value (AIV), crushing value (ACV) soundness, and point load. The field and laboratory tests indicated that only Trachybasalt and Suliek granite are suitable as concrete aggregate
- ❖ Research is by no means final, and comments and constructive criticism will be welcome.

6.2 Recommendations

The following points are recommended from this study:

- ❖ This research work suggested that the engineering geologist should take worry of horizontal lithological variation by taking photos and mapping the foundation geology during construction phase.
- ❖ During construction, the shear strength of the dam foundation and the rock deformation behavior of the dam foundation should be evaluated using different field methods and correlated with the results in this research work
- ❖ The faults that are recognized in the dam site are very close to the dam axis; therefore, engineering geological measurements have to be taken to ensure water tightness and foundation stability condition of the dam
- ❖ The high-density fractures areas shown in the maps must be tackled through the engineering solution and the expected seepage in the NW and ne fractures systems across the dam axis must be considered and solved
- ❖ Lineaments that represent the fractures pattern are essential factors that must be taken into account when constructing a dam because they affect both the foundations and the storage capacity of the dam lake resulting in collapse and seepage, respectively
- ❖ The impact of the project on the population of the area and their activities, as well as existing projects in the area, especially those

involving geological or mining activities, must be taken into account

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https://3d-mapper.com The platform provides the service of converting two-dimensional maps and terrain maps into three-dimensional maps

https://worldweather.wmo.int/en/city.html?cityId=249 This global website presents OFFICIAL weather observations, weather forecasts, and climatological information for selected cities supplied by NMHSs worldwide. The NMHSs make official weather observations in their respective countries