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The study geological Structures by using Remote Sensing and Geographic Information Systems of Al- Sabaloka area ..River Nile state

دراسة التراكيب الجيولوجية باستخدام الإستشعار عن بعد ونظم المعلومات الجغرافية لمنطقة السبلوقة ..ولاية نهر النيل

A Research Submitted to College petroleum & Mining Engineering in partial fulfillment of Requirements for the Degree of B.SC in petroleum Exploration Engineering

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ا لإستـهـلال

وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ ۖ وَسَتُرَدُّونَ إِلَىٰ عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ تَعْمَلُونَ

صدق الله العظيم

سورة التوبة – الآية (١٠٥)

Dedication

It is our genuine gratefulness and warmest regard that we dedicate this work to our mothers for their kindness and devotion through days and nights.

To our fathers for their sacrifices and encouragement over a number of years for us fulfill what we have achieved.

To our brothers, sisters and families for they created the most hopeful environment to us.

To our university mates for the marvelous and joyful time that we spent with you.

To our dear friends who were always supportive and have a tangible influence on our lives.

To everyone who contributed positively in our lives even with a smile.

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Abstract

Sabaloka region comprises some of the old basement rocks in Sudan surrounded with Cretaceous sediments forming an inlier, extending between Khartoum and River Nile States. The study area is located inside this inlier between latitudes N 16 00′ -12 00′ and longitudes 33E and 33'00 36'00E. The digital image processing of Landsat 8 (OLI) oriented to enhance the satellite images to discriminate the boundary between the different rock units in the inlier and their dimensions. Also to explain the structural features at macro scale, recognize and analyze them.

From colour combinations discriminated the various rock types which is useful in delineating the geological boundaries. From filters image were able to interpret the image easily and obtain information about the drainage systems.

At this research interpolate GOCE (The Gravity Field and Steady-State Ocean Circulation Explorer) gravity data used IDW interpolation showed the gravity anomaly high in the northwestern increasing from south to north trend maximum value 49mGal at the region which has igneous rock at these represent high density Rocks, where the northwestern at the 33˚-34˚E ,16˚ 20'N have low gravity this indicate of low density sedimentary, in this area show very low anomaly in the eastern Sudan (31mGal) with faulted as contour show steep gradient at eastern and western for this anomaly.

المستخلص

تحتوي منطقة السبلوقة على واحد من صخور الأساس القديمة في السودان محاطة بالرواسب العصر الطباشيري التي شكلت ما يعرف بحصير السبلوقة القديم ، تقع منطقة السبلوقة في شمال ولاية الخرطوم وتمتد في الجزء الجنوبي من نهر النيل بين خطي طول 12 ' °16 و° 16 '24 بين خطي عرض °33 ' 36 E وجهة إلى تحسين صور الأقمار الصناعية للتمييز الحدود 00 '- 16 معالجة الصور الرقمية للقمر لاندسات 8 ومعرفة أبعادها .أيضا (OLI) بين الصخور المختلفة لتوضيح الظواهر التراكيب الجيولوجية في المنطقة لتمييزها وتحليلها.

من مجموعات الألوان تميزت أنواع الصخور المختلفة التي تفيد في ترسيم الحدود الجيولوجية .من صور المرشحات تمكن من تفسير الصورة بسهولة والحصول على معلومات حول أنظمة الصرف . في هذا البحث ، أظهرت بيانات الجاذبية المستخدمة GOCE (The Gravity Field and Steady-State Ocean Circulation Explorer) المستخدمة في الاستيفاء IDW أن شذوذ الجاذبية مرتفع في الشمال الغربي المتزايد من الجنوب إلى الشمال لقيمة قصوى تبلغ 49 مللي جالون في المنطقة التي بها صخور نارية في هذه تمثل الصخور عالية الكثافة ، حيث الشمال الغربي عند 33˚-34˚E ، 16˚ 20'N لها جاذبية منخفضة هذا تشير إلى انخفاض الكثافة الرسوبية ، في هذه المنطقة تظهر شذوذ منخفض جدًا في شرق السودان (31 مللي جالون) مع وجود عيوب حيث يظهر كفاف التدرج الحاد في الشرق والغرب لهذا الشذوذ.

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Chapter One

Introduction

Chapter One

Introduction

1.1The study area

Al-Sabaloka area has great geological diversity, it is characterized by geological enclosures, good field relations, in addition to its strategic location, easy of access and excellent rocky layers, all of which made it a good model for field teaching for students of earth sciences, and the area of scientific research and academic achievement, and a mat that does not extend a distance of 40 It is a km along the Nile from Al-Jili south to Wad Banga in the north, and its width is about 50 km.

1.2 Location

The Sabaloka area is located in the north of the state of Khartoum and extends in the southern part of the Nile River state between latitudes 16° 12' N and 16° 24'N north, and longitudes 33°E and 33° 36'E. It is approximately 80 Km north of Khartoum (Figure 1.1). The area is accessible through Et Tahadi Highway which extends from Khartoum, the capital of Sudan Republic, to Atbara passing through Sabaloka.

1.3 Accessibility

The study area it is characterized by easy access through the asphalt road from Khartoum to Shendi Fig (1.1), which is 3 km from Al-sabaloka by cars and others. There is also a railway passing through the area.

1.4 Statement of the Problem:

The area attracted the interest of many geoscientists. This is may be explained by the large number of scientific works that have been conducted in the area.

Despite this fact, the geological map of the area remained inundated and more enhancements have to be added. A few geophysical investigations have been conducted in the area. Nevertheless, the total coverage of the acquired data is relatively small. Accordingly, inference about the major structures in the area can hardly be made. From high pass filter detected lineament and trace drainage system

Figure (1.1): Location map of the Study area and accessible roads.

1.5 Objectives of the study

Main objectives of the present study are to carry out the following:

- Identification of the subsurface structure in the study area.
- To use remotely sensed data and apply GIS technique at the study area for regional tectonic evolution and create geological and tectonic map.
- Interpretation of remote sensing data and digital elevation model (DEM) Combined with field data to verify the result.

1.6 Climate and vegetation cover

Predominantly the semi-desert climate prevails in the Sabaloka region. The dry season is in summer and winter. The northeast dry wind prevails in the period of the month of November to February. The weather in this period is cold.

Most of the year the climate is hot in the period of eight months from March to October and the southwestern wind prevails in this period. The rains pouring down in the seasons at July-August. The rate of the rainfall is between 100 mm– 150 mm.

The Atmospheric pressure decreased during the daytime and increased at night, inversely proportional to the temperature. The lowest temperature recorded in the month of January and drops to 14 C˚ and the highest in the month of May reach to 42 C˚.

The prevailing climatic condition affected the quality of vegetation cover in the region. The spinose trees called Sial and Mimosa or Sonot of desert environment as well as a few short evergreen trees prevail in the region. They are found concentrated in the seasonal streams. There are some agricultural activities of local peoples along River Nile banks. The area is famous for the farming of onions, potatoes and some vegetables and represents one of the main feeders of the Khartoum market with these products.

1.7 Topography

The topography of the region is a mountainous area, in which there are many isolated mountains, (Inselbergs) , and the highest mountain in the region is Jabal Al-Royan, which reaches a length of about 225 meters from the surrounding surface fig (1.2).

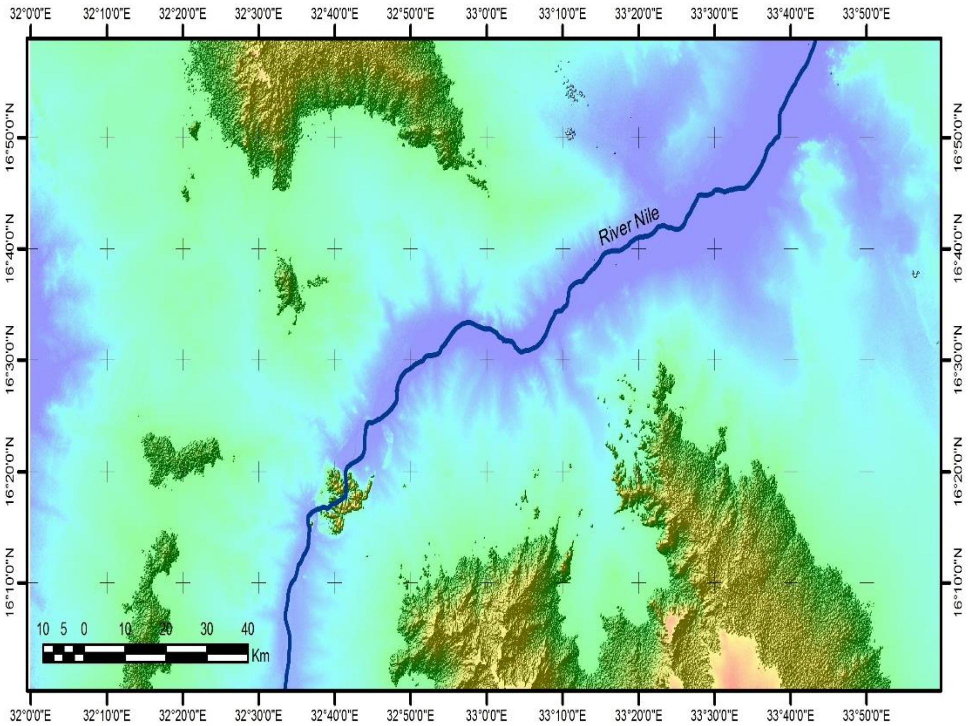


Fig 1.2 Show topgraphy at study area.

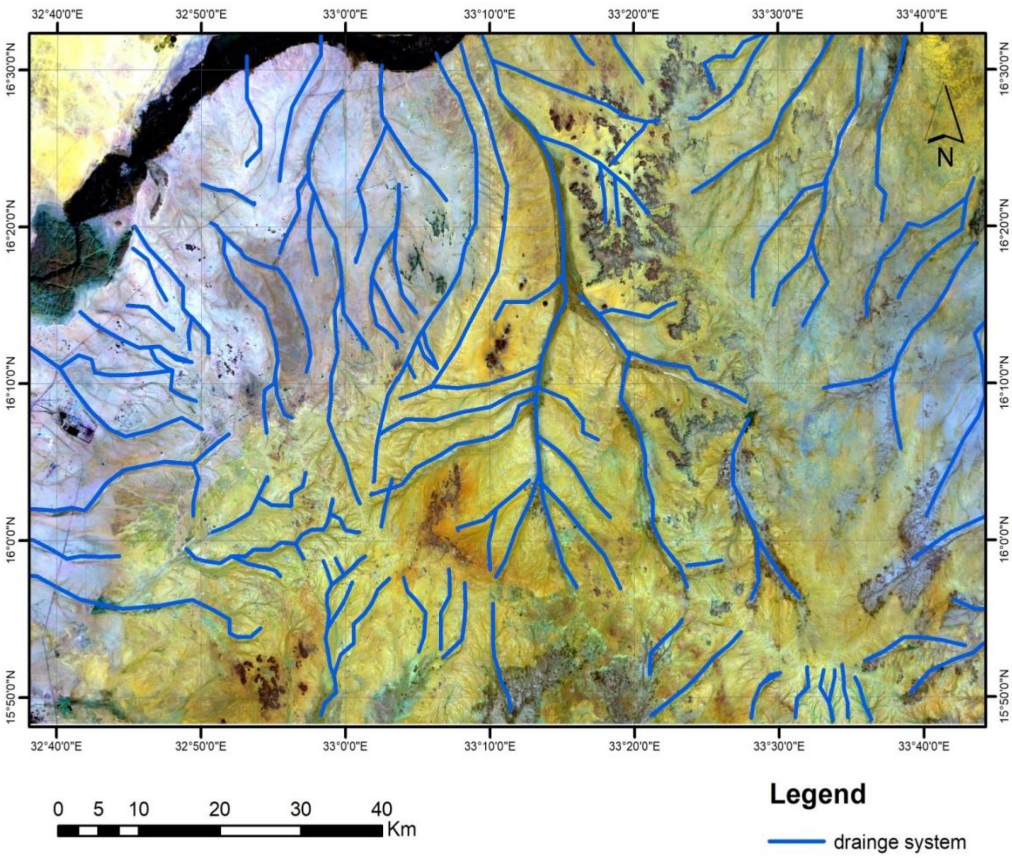
1.8 Drainage system:

It includes perpetual flow systems represented by the Nile River, which divides the slab into two semi-equal halves.

The Nile River in this area is considered unsuitable for navigation, due to the presence of waterfalls and cataracts.

As for the seasonal systems, they include valleys and creeks, where water flows in during the flood season fig (1.3).

They are either dependent (following breaks and faults) or any other form of short rivers, but in the end we find them flowing into the Nile River



Fig(1.3) Drainage system map of study area.

1.9 Population:

Al Jaalia tribes are considered as aboriginal residents of the area where they live in the region of Sabaloka beside Al shaigia, Al hasaania, and Abdalab.

Residents of Sabaloka area living on the River Nile banks, and they work in farming.

1.10 Material and Methods

In order to fulfill the objective of the present study, different materials and methods have been utilized.

1.10.1 Material

Different types of materials were used in this research to assist in fulfilling the purposes of this study.

- Landsat 8 OLI (Operational Land Imager)
- Satellite gravity grid data GOCE Gravity field and steady-state Ocean Circulation Explorer). data downloaded from the International Centre for Global Earth Models (ICGEM) data available at (https:// icgen.gfz.postdam.de/home).

1.10. 2 Software

The following software have been utilized during the course of the present study:

- ENVI 4.8 and Arc GIS 10.2, for digital image processing and ARC GIS for surface analysis and extracted maps
- Microsoft Word 2010.

1.10.3. Methods

The methodology adopted in the present work involves digital image processing of remotely sensed data which is directed towards the enhancement and image transformation procedures in order to increase the visual interpretability and produce images suitable for geological interpretation.

Different processing techniques were utilized such as color compositing, band rationing, spatial resolution enhancement, filtering. The enhanced images were all imported into the GIS environment for delineation of geological boundaries and structures, together with the joint analysis and interpretation which facilitated the production of the geological map of the study area.

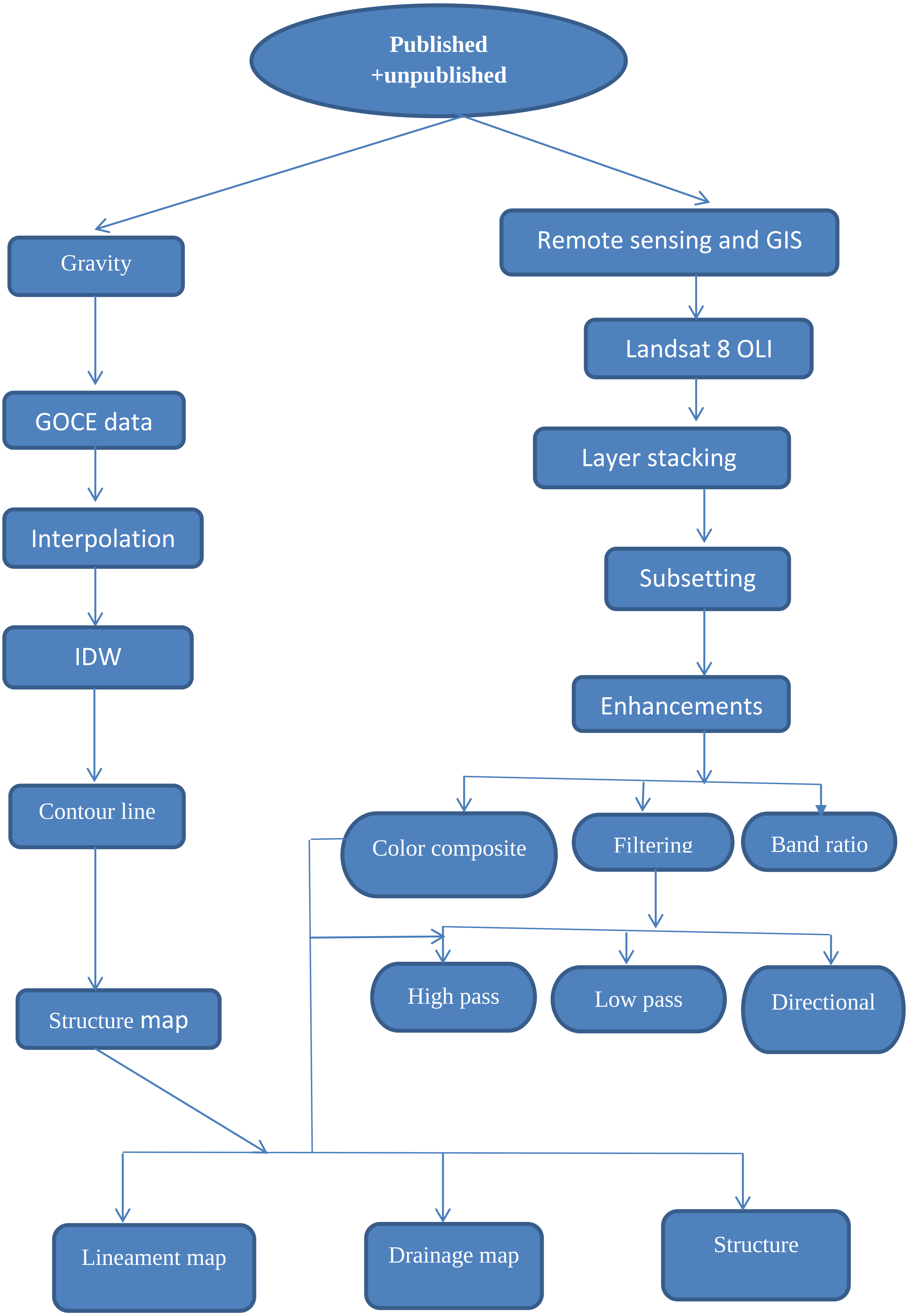


Fig 1.4 show flowchart of Methodology

1.11 Previous Studies:

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 is Precambrian.

Omer, (1975, 1978) give general descriptions of the Cretaceous sediments (the old term Nubian) between Khartoum and Shendi NE of Sabaloka.

Medani (1975) claimed that Jebel Hardan (near Naqa, 45 km E of Ban Gadeed) offers a typical section of what he prefers to consider as the Cretaceous Sandstone Formation of Sudan.

Dawoud (1970) and Almond (1977, 1980) showed that in the Sabaloka basement inlier granulitic facies rocks occur as lenses, bands and irregular bodies.

Almond (1977) mapped the Sabaloka igneous complex and found the complex has a volcanic phase that consist mainly of rhyolites, agglomerates, and ignimbrites forming a plateau and intruded by elliptical ring dyke of microgranite.

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 of Nigerian granites.

Almond (1980) also found the gneiss assemblage contains evidence that an early granulite facies metamorphism occurred and followed by retrogression 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 in relation to Jebel Sabaloka is entirely accidental.

Kroner et al. (1987) dated the granulite facies metamorphism in 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.

Dawoud and Sadig (1988) indicated the thrusting by structural and gravity data as the major cause of uplift for the granulite rather than by erosion only.

The geophysical measurements carried by Sadig and Ahmed (1989) across selected complexes of younger granite from Sudan indicate different gravity signatures, where the Sabaloka complex is characterized by low Bouguer gravity values.

Chapter Two

Geology and Tectonic Setting

Chapter Two

Geology and Tectonic Setting

2.1 Tectonic Setting

The Sabaloka rocky region of the Precambrian rocks is situated near the northeastern margin of ancient Africa itself only a part of an enormous super continental margin orogenic belt named East Africa Orogeny (EAO) (Stern, 1994; fig 2.1).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 beginning with rifting, and the evidence for rifting maybe preserved in sedimentary successions in the EAO that have been interpreted as passive margin deposits in Kenya (Vearncombe, 1983, Key et al., 1989, Mosley, 1993) and in Sudan (Kröner et at., 1987). Many of these collisions were between the arcs, as the oceanic crust between them was subducted, but a few collisions involved the addition of arcs and arc-complexes and continental micro-plates to the African margin (Almond et al., 1993).

The collisions led to low grade metamorphic facies in Nubian Arabian Shield (ANS) increasing in grade of metamorphism toward west in Bayouda Desert and reached the maximum in Sabaloka area (Dawoud, 1988). The sediments from Sudan were metamorphosed to granulite facies located in Sabaloka inlier at about 720 Ma (Kröner et al., 1987).

The crustal thickening produced pressure with about 6 to 8 Kbar and temperature with range between 600 – 800° C (Dawoud and Dobrik, 1993) that indicate the metamorphism in deep-seated root of this continental crust with depth between 20 - 30 Km, which led to metamorphose that complex rocks of 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 geochronological and isotopicstudy of granitoid rocks from the eastern boundary of the Saharan Metacratonindicate 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 Sabaloka area (Kröner et al., 1987).

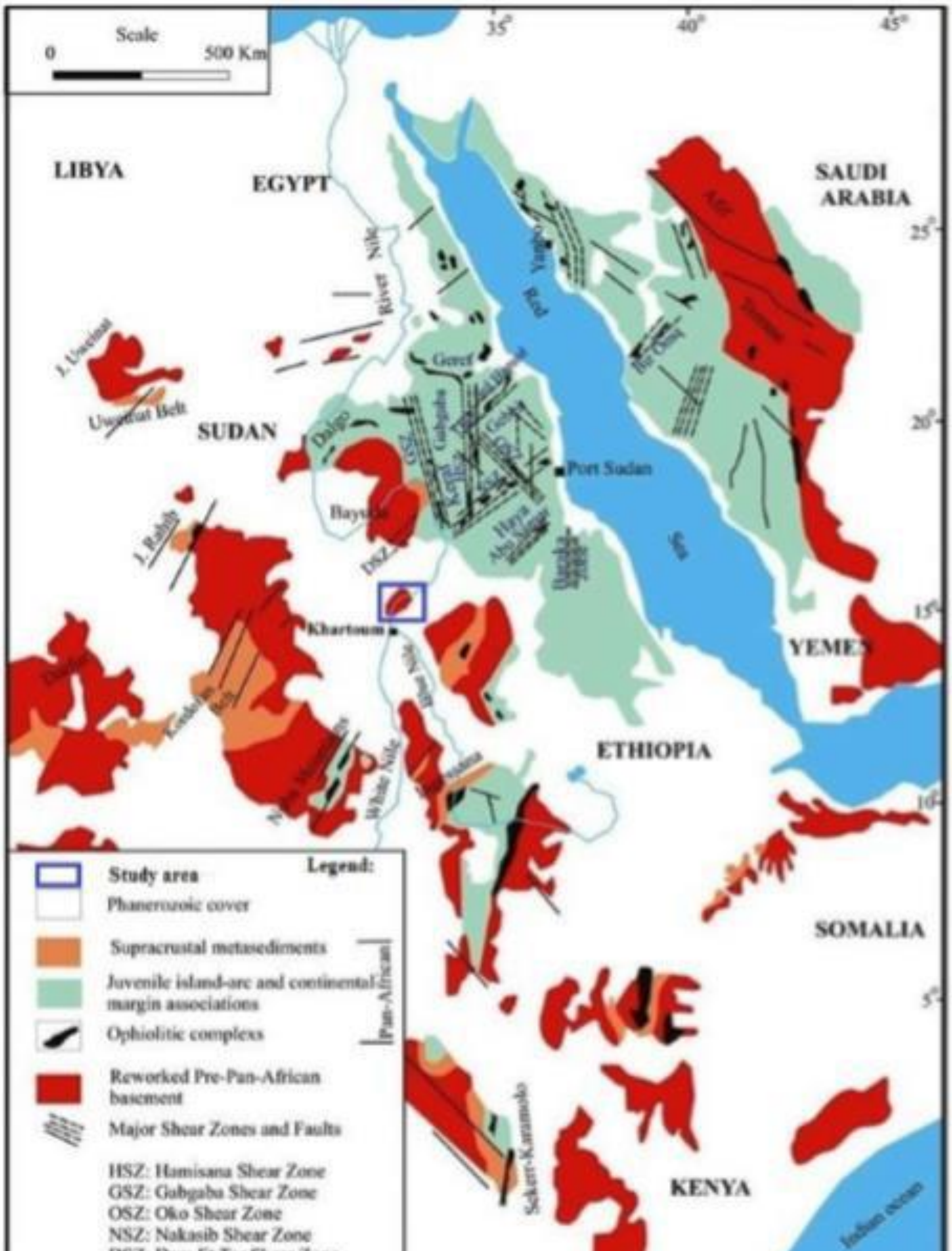


Figure (2.1): Geological sketch map showing the distribution of the basement units in Sudan and adjacent areas (Modified after Abdel Rahman, 1993).

The uplifting of granulite terrane was accompanied by hydration and retrogression under amphibolite facies condition that formed gneisses andmigmatites 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 these 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 effected 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 dextral ductile shear zone. This horizontal tectonic movement may have occurred after emplacement of older granites of Sabaloka inlier, and before 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 2 km, dextral shift of the sub-vertical structures of the Cauldron complex ring-fracture zone (Almond et al., 1980).

It may be rejuvenation of old fracture has a bearing on Ban Gadeed-Gamarab Shear Zone (BGSZ; Elyas, 2016). A part from the E-W strike-slip faults, there are also a number of 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).

2.2 Regional geology

The area around the Sabaloka igneous complex has been the subject of many research works and a litho-stratigraphic sequence has been adopting by the previous workers. This has been also adopted in this work, with some modification. Brief description of the various geological units is provided in the following sections.

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 within biotite gneisses and migmatites rocks (Almond, 1980). These rocks are of two types regarding the origin: met-igneous plate (2.1) and meta-sediments plate (2.2) according to (Alzubair et al., 2018).

The meta-sediments (para-granulite) are divided to meta-semi-pelitic rocks existing in the inlier as patches. The calk-silicate rocks are the second type of para-granulite also existing as patchy outcrops. In hand specimen, it has dark color and waxy luster Characteristic of granulite rocks (Almond, 1980). Kröner et al. (1987) dated this rocks at about 700 Ma, and suggests that they may have taken place in the root zone of an island arc at about this time, and in a dry environment. The granulite may have been metamorphosed at depth exceeding 25 Km and then later elevated along a thrust (Dawoud and Dobrik, 1993).

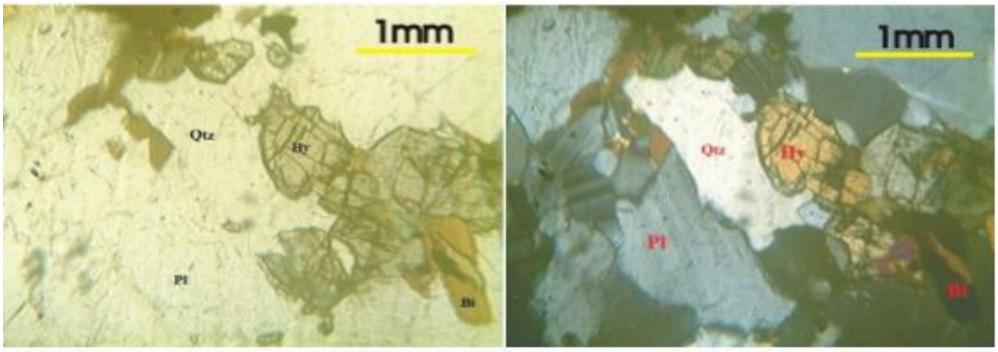
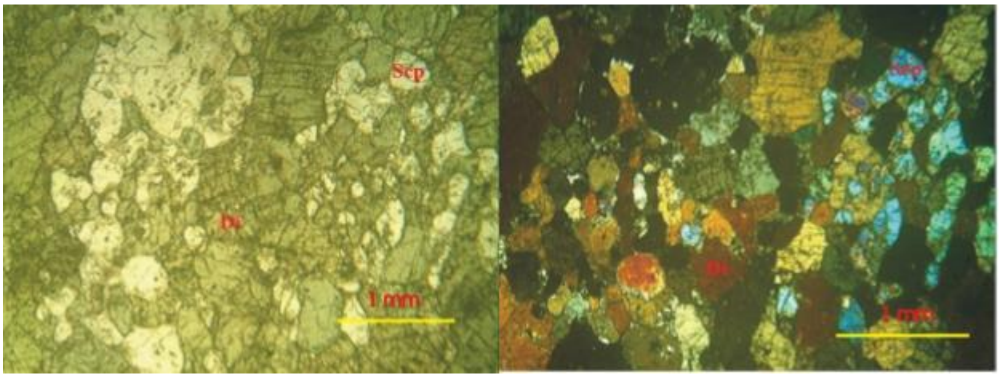


Plate (2.1): Enderbite rocks under microscope where (a) is ppl view and (b) is xpl view. Qtz=Quartz, Hy= Hyperthene, Bi=Biotite, and Pl= Plagioclase



(PPL view) (a) (XPL view)

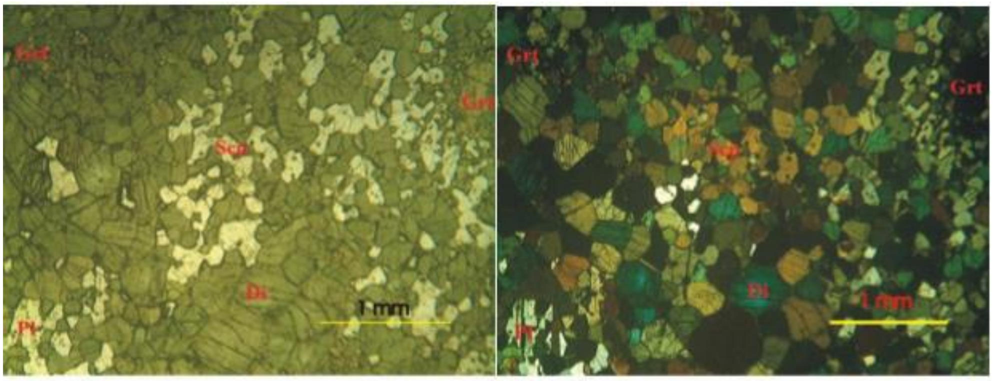


Plate (2.2): a, and b: Microscopic view of the calc-silicate rocks, where: (Di) diopside, (Scp) scapolite, (Pl) plagioclase, and (Grt) garnet.

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 are 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 as 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 obvious structural differences between the granulite and the enclosing gneisses and migmatites (Plate 2.3) according to (Alzubair et al., 2018).

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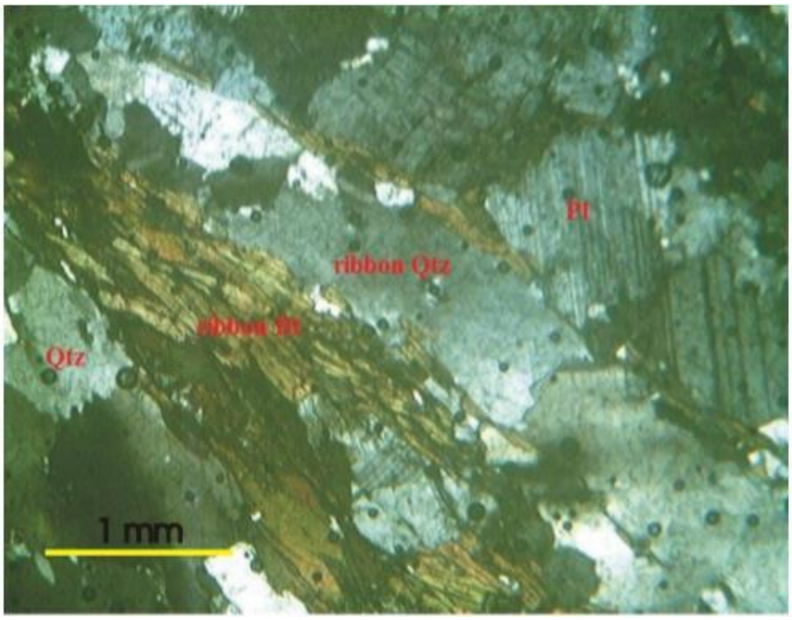


Plate (2.3): Microscopic view of biotite gneiss rocks (XPL view). Qtz= Quartz, Pl= Plagioclase, and Bio= Biotite.

2.2.3 The granitoid batholiths:

The migmatite rocks are characterized by the development of anatactic granitiod bodies carrying large porphyroblastic K-feldspar and garnet (Dawoud et al., 1993). They are characteristic of the basement complex of Sabaloka inlier, Ban Gadeed, Es Suleik, Babados, and Abu Gedium plutons.

These represent different stages of anataxis and include synorogenic foliated granitoids, partially foliated granitoids and weakly or non-foliated granitoids (Dawoud et al., 1988). Some varieties only show relict ghost foliation, migmatite border zones, and variable relict gneisses with no distorted foliation with respect to the prevailing regional foliation.

The older granitoids have a broad concordant relation with the enclosing gneisses and develops foliation particularly at the margins, but dykes of the same bodies cut across the gneisses and the earlier anatexis granitoids. With some of this type of granite, particularly the Es Suliek batholith, lenses and bands of retrogressed amphibolites are abundant probably as rafts (Almond, 1980). Ban Gadeed granite considered as the last stage of migmatization which is typical anataxis granite formed by partial melting. This is evidenced by the presence of garnet in some part of the intrusion, absence of sharp intrusive contact and the presence of ghost foliation inherited from the parent rock.

Es Suleik and Babados are syn-orogenic S-type granite Plate (2.4) according to (Alzubair et al. 2018)

They are broadly concordant with exposed dykes cutting sharply across the older structure. The two plutons are composed of adamellite rocks containing between 10 - 35 percent feldspar in addition to hornblende and biotite.

The contact of Suleik and Babados plutons are well defined in most phases, but locally are marginal migmatite (Almond et al., 1993). Abu Geidum granites are post-orogenic, strongly discordant and have very weak internal foliation Kfeldspar porphyroblast is absent. They are dark in color and contain angular xenoliths (Dawoud, 1970, 1980; Almond, 1980).

2.2.4 Late tectonic tholeiitic rocks:

Gabbro is a distinctive feature of the Ban Gadeed area. These basic rocks are primarily of tholeiitic affinity and, being mildly metamorphosed and weakly deformed (Almond et al., 1993).

Dawoud (1970) refers to it as a meta-gabbro and mapped several such small intrusions along a line parallel to the felsite dyke swarm. Several of these dykes cut the gabbro. The gabbro is a late tectonic member of the basement complex (Almond et al., 1993).

2.2.5 An-orogenic granites and sub-volcanic sediments:

The A-type granite suites vary in composition from quartz syenites to peralkaline granites and their respective volcanic equivalents.

These suites are emplaced into non-orogenic settings both within the plate and along plate margins during the waning stages of subduction-zone related magmatism (Eby, 1990).

As defined by Loiselle and Wones (1979) the A-type granite occurs
along rift zones and within stable continental blocks. In Sabaloka inlier there are three complexes of an orogenic A-type granite.

2.2.5.1 Abu Tulieh Igneous Complex

Abu Tulieh Complex is oldest igneous complex in the inlier, with an age of 465 ± 14 Ma in the middle Ordovician (Harris et al., 1983; Klemenic, 1987).

The predominant rocks are buff colored moderately coarse syenites with enclosures of country rocks and intrusions of microgranites (Almond et al., 1993).

2.2.5.2 Sub-volcanic sediments

An upward-fining sequence of clastic sediments about 75 m thick underlies the volcanic rocks on the NW contact of the Mica granite in the western part from Sabaloka igneous complex. The sediments strike NE and dip steeply SE, resting with strong unconformity upon Basement gneisses, which strike NW (Almond et al., 1993).

The sedimentary sequence begins with quartz conglomerates and passes upwards through flaggy and micaceous sandstone into black shale. All these rocks have been strongly metamorphosed by granite, and some of the pelitic hornfels contain andalusite and cordierite (Almond et al., 1993).

Considering their conformable relation to the overlying volcanic rocks and the radiometrically determined lower Devonian age of the Cauldron complex, it seems likely that the sediments are also of early Devonian age, and it is unfortunate that their metamorphosed condition makes it unlikely that they will yield any fossils (Almond et al., 1993).

2.2.5.3 Sabaloka Igneous Complex

Sabaloka igneous Complex is younger than Abu Tulieh complex, with an age of 383 ± 14 in the lower Devonian (Harris et al., 1983). The complex has thin sheets of trachytic-basaltic lava, which is the beginning of the volcanicity in the complex, early rhyolite lava, and volcano pyroclastic rocks.

It is fining upward beginning by agglomerate, light ignimbrite, dark ignimbrite, and ending with a thin unit of bedded tuffs. The last volcanic unit in Sabaloka complex is upper rhyolite which came finally and all the complex rocks are predominantly aluminous to slightly per-aluminous (Almond et al., 1993).

2.2.5.4 Sileitat - Es-Sufur Igneous Complex

The Sileitat Es-Sufur igneous complex lies on the eastern side of the Nile valley some 30 km N of Khartoum town. This is younger than Sabaloka igneous Complex. The age of this rock is middle Jurassic (169 ± 2 Ma; Klemenic, 1987).

The complex comprise riebeckite granite, syenite, and micro syenite, and it is peralkaline (Almond et al., 1993).

2.2.6 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 meter 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 Ban Gadeed area which has felsite dykes swarm (including an unusual dyke composed of glass). Blue quartz micro-granite is porphyritic texture, and attains a width of 20 m and is of microgranite containing phenocrysts (up to 2 cm) of blue-tinted quartz and pink-white feldspar. In fact, 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).

2.2.7 Cretaceous sandstone:

The Cretaceous sandstone is the new name to the old name Nubian Sandstone Formation (Prasad et al., 1986). Because the term Nubian described the concept of the location only and it does not benefit to describe another unit with the same rocks in any location, but 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 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 strongly cemented and more ferruginous.

Cretaceous Sandstones are usually bedded and flat lying or very gently dipping.It is composed of conglomerates, sandstone, and mudstone (Omer, 1975). Umm Marahik has silicified sandstone which formed by the movement of strike-slip fault know as Umm Marahik fault, where that movement led to form the silicified sandstone from partial melting of quartz which acted as cementing material for grains of quartz.

2.2.8 Superficial deposits:

The superficial deposits in Sabaloka area include Nile silts, 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.

Alluvial fans border the volcanic plateau and have spread a sheet of igneous gravel over the adjacent pediment of gneiss, and extensive alluvial fans sweep down from the foot of the Scarp towards the River Nile, skirting the small Cretaceous hill of Jebel Umm Marahik. Aeolian sediments are fine sands found in foots of mountains in the area.

They are considered windbreaks deposited at pediment of gneiss, and low areas in the region that are blocked. In most part of the area bedrock is thinly covered by lag gravels and gritty sands.

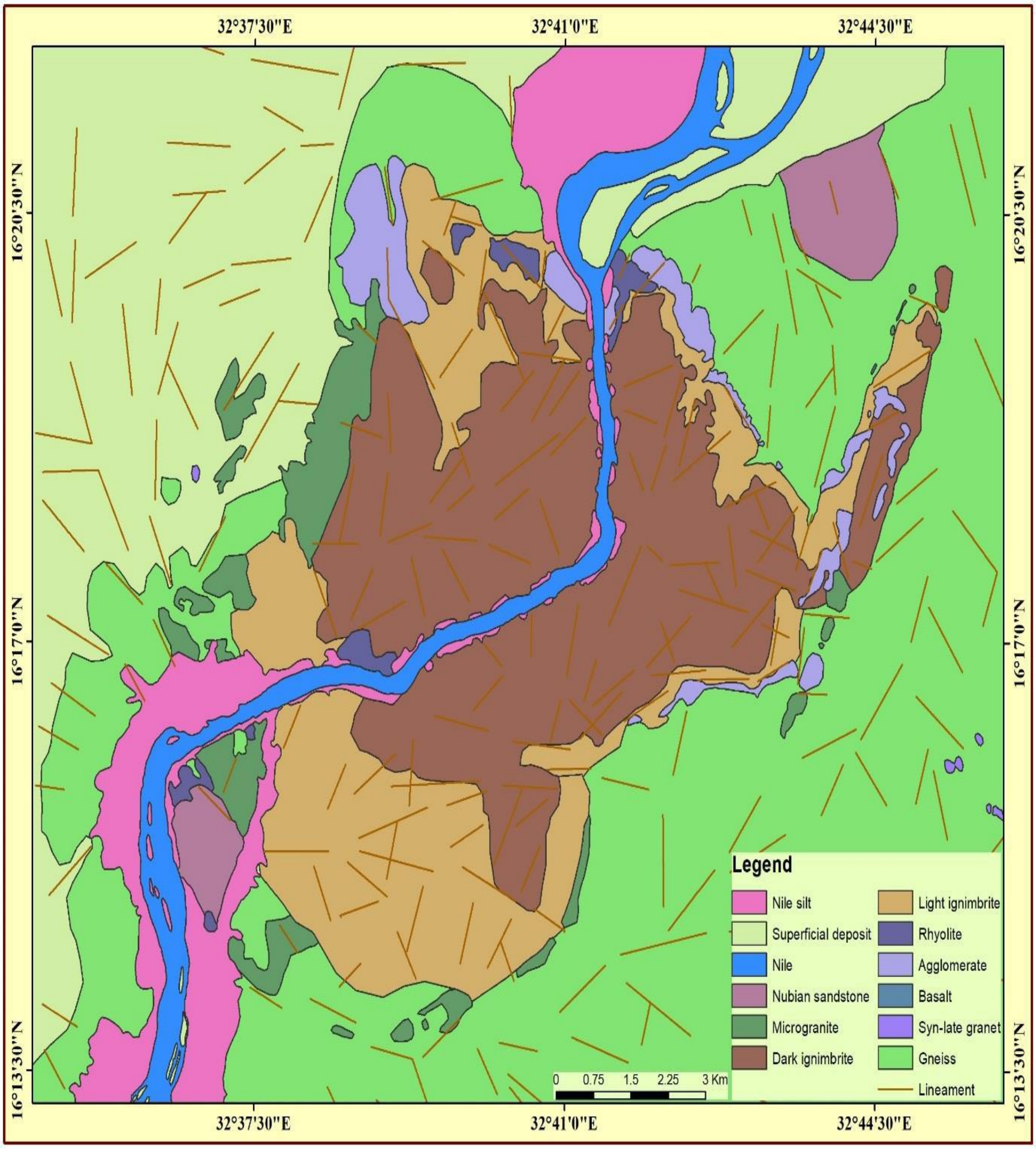


Figure (2.3): Geological map of Sabaloka Igneous Complex (Alzubair et al., 2018).

Chapter Three

Result and Discussion

Chapter Three

Result and Discussion

3.1 Remote sensing

3.1.1 Introduction

Remote Sensing is the science and art of obtaining information about an object, area, or certain phenomena through the analysis of data acquired by a device that is not in contact with the object, area, or phenomena under investigation .Normally, this gives rise to some form of imagery which is further processed and interpreted to produce useful data for application in agriculture, forestry, geography, geology and some other fields (Lillesand et al., 2003).

The primary objective of remote sensing is to extract environmental and natural resource data related to the earth (Lo, 1995). In remote sensing, the sun is the most obvious source of Electromagnetic Radiation (EMR), although all terrestrial objects are also sources.

Atmospheric scattering is the unpredictable diffusion of radiation by particles in the atmosphere. There are three types of scattering, the first is Rayleigh scatter, which is common when radiation interacts with atmospheric molecules and other tiny particles that are much smaller in diameter than the wavelength of the interacting radiation. The second is Mie scatter, which exists when atmospheric particle diameters essentially equal the energy wavelengths being sensed. Water vapor and dust are major causes of Mie scatter. The last is nonselective scattering, which is non-selective in respect to the wavelength, i.e. all wavelengths of light are scattered, not just blue, green, or red (Lillesand and Kiefer 1999) In contrast to scatter, atmospheric absorption results in the effective loss of energy to the atmospheric constituents. This normally involves absorption of energy at given wavelengths. The most efficient absorbers of solar radiation in this regard are water vapor, carbon dioxide, and ozone (O3). Because these gasses tend to absorb electromagnetic energy in specific wavelength bands, they strongly influence spectrally with any given remote sensing system (Lillesand et al., 2003).

The earth surface is illuminated by solar energy. The reflected solar energy from the earth surface or the emitted electromagnetic energy by the earth surface itself is received by the sensor. The sensors are popularly known by the EMR region they sense. Remote sensing can be broadly classified as optical and microwave (Navalgund et al., 2007).

Remote sensing and its products were used extensively during the course of the present study to discriminate the rocks units and delineate their boundaries. Moreover, it was utilized to delineate and analyze the structural features in the study area. Many outputs have been used as base maps in the production of the geological, structural, and drainage maps of the area. More details about the different uses of remote sensing are provided in the respective section of this dissertation.

3.1.2 Historical background

The period from 1960 to 2010 has experienced some major changes in the field of remote sensing. The background for many of these changes occurred in the 1960s and 1970s. Some of these changes are outlined below

- First, the term “remote sensing was initially introduced in 1960 before 1960 the term used was generally aerial photography. However, new methods and technologies for sensing of the Earth's surface were moving beyond the traditional black and white serial photograph, requiring a new more comprehensive term be established.
- Second the 1960s and 1970s saw the primary platform used to carry remotely sensed instruments shift from air planes to satellites. Satellites can cover much more land space than planes and can monitor areas on a regular basis.
- Third, imagery became digital in format rather than analog. The digital format made it possible to display and analyze imagery using computers, a technology that was also undergoing rapid change during this period. Computer technology was moving from large mainframe machines to small microcomputers and providing more information in graphic form rather than numerical output
- Fourth, sensors were becoming available that recorded the Earth's surface simultaneously in several different portions of the electro - magnetic spectrum. One could now view an area by looking at several different images, some in portions of the spectrum beyond what the human eye could view. This technology made it possible to see things that occur on the Earth's surface looking at a normal aerial photograph one could not detect.

- Finally, the turbulent social movements of the 1960s and 1970s awakened a new and continuing concern about the changes in the Earth's physical environment. Remotely sensed imagery from satellites - analyzed and enhanced with computers - made it possible to detect and monitor these changes. Thus, societal support was and continues to remain strong for this technology, even though very few people are familiar with the term, remote sensing.

3.1.3 Concepts of Remote Sensing

3.1.3.1 Electromagnetic Radiation (EMR)

The most important component of Remote Sensing is the Energy source to illuminate the Target. The energy is in the form of Electromagnetic Radiation. It is either natural originating from the Sun or earth by emission, or by artificial means. Electromagnetic energy refers to all the energy that moves with the velocity of light in a harmonic wave pattern. EMR consists of an Electrical field and Magnetic field. The electrical field varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling and magnetic field oriented to the right angles to the electrical field.

The Electromagnetic Spectrum ranges from kilometers to nanometers. These are divided by ranges called Spectral bands. There are several regions in the Electromagnetic spectrum which is useful for Remote Sensing

3.1.3.2 Sensors

Remote sensor are the instrument which detects various objects on the earth's surface by measuring electromagnetic energy reflected or emitted from them; There are two types of remote sensing sensor.

A. Passive Sensors

The passive sensors measure reflected sunlight that was emitted from the sun . Passive sensors measure this natural energy at specific frequencies (v (i.e.wavelength). For example, sensors can measure visible (390-700 nm), infrared (750 nm - 1 mm), ultraviolet (100-400 nm) and more types of EM radiation. These wavelength ranges are known as “bands”. Sensors can have multiple bands (3 to 10 bands) known as " multispectral " imaging . Hundreds of finer bands are known as "hyperspectral" imaging. Passive sensors would miss the sun if it disappeared because it measures natural energy being reflected at specific frequencies.

B. Active sensors

The passive sensors have its own source of light or illumination and its sensor measures reflected energy. There are many advantages of Active Sensors summarized below :

- An advantage of active sensors is that they can be used at any time of the day because it does not require natural light. Active sensors can also produce microwave energy. This is advantageous because microwaves are generally not affected by any type of cloud cover.
- Two of the key advantages of active remote sensing are being able to collect imagery night and day, as well as through clouds and various weather conditions.

3.1.3.3 Landsat System

- The Landsat Program is a series of Earth - observing satellite missions jointly managed by NASA and the U.S. Geological Survey. The program aimed at gathering facts about the natural resources of the Earth from carth - observing satellites carrying sophisticated remote sensing observation instruments.
- In cooperation with NASA. On July 23, 1972, the Earth Resources Technology Satellite (ERTS - I) was launched. It was later renamed Landsat 1. Additional Landsat satellites followed in the 1970's and 1980's , and in 1999 , Landsat 7 was launched. Landsat 8 initially named Landsat Data Continuity Mission - LDCM) was the most recent satellite to be launched on February 2013. Landsat 9 is in development , with a scheduled launch for late 2020.
- The instruments aboard the Landsat satellites have acquired millions of images through the course of the missions , and the data are a valuable resource for global change research and applications in agriculture , forestry , geology , regional planning , and education .

3.1.3.3.1 Landsat 8

The Landsat 8 satellite images the entire Earth every 16 days in an 8 - day offset from Landsat 7. Data collected by the instruments onboard the satellite are available to download at no charge from Earth Explorer, GloVis, or the Landsat Look Viewer within 24 hours of acquisition ,

The spectral bands of the OLI sensor provides enhancement from prior landsat instruments, with the addition of two additional spectral bands table (3.1), a deep blue visible channel investigation (band 1) specifically designed for water resources and coastal zone, and a new shortwave infrared channel (band 9) for the detection of cirrus clouds.

Table (3.1) Landsat 8 bands properties

Landsat8 sensors	Band	Band Name	Wavelength (µm)	Resolution (m)
Operational Land Imager (OLI)	1	Coastal/Aerosol	0.433-0.453	30
	2	Blue	0.450-0.515	
	3	Green	0.525-0.600	
	4	Red	0.630-0.680	
	5	Near Infrared (NIR)	0.845-0.885	
	6	Short-wave Infrared (SWIR)1	1.560-1.660	
	7	Short-wave Infrared (SWIR) 2	2.100-2.300	
	8	Panchromatic	0.500-0.680	15
	9	cirrus	1.360-1.390	30
Thermal Infrared Sensor (TIRS)	10	Long-wave Infrared (LWIR) 1	10.30-11.30	100*
	11	Long-wave Infrared (LWIR) 2	11.50-12.50	
	BQA	Quality Assessment		
*TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter in delivered data product				

The TIRS instrument collects two spectral bands for the wavelength covered by a single band on the previous TM and ETM + sensors. Descriptions of the band designations for all Landsat sensors, and information about the comparisons between Landsat 8 and previous bands are also available.

These sensors both provide improved signal - to - noise (SNR) radiometric performance quantized over a 12 - bit dynamic range. (This translates into 4096 potential gray levels in an image compared with only 256 gray levels in previous 8 -

bit instruments) Improved signal to noise performance enable better characterization of land cover state and condition. Products are delivered as 16-bit images (scaled to 55,000 gray levels).

A Quality Assessment band is also included with each Landsat 8 data product. This band allows users to apply per pixel filters to the Landsat 8 Operational Land Imager (OLI) -only and Landsat 8 OLI Thermal Infrared Sensor (OLI TIRS) combined data products. This study used landsat 8 OLI image path 173 row 49 acquired on 15 August 2017.

3.1.4 Image subsetting

Subsetting refers to breaking out a portion of a large file into one or more smaller files. When image files contain areas much larger than a particular study area, it is helpful to reduce the size of the image file to include only the area of interest (AOI) fig(3.1).

This not only eliminates the extraneous data in the file, but it speeds up processing due to the smaller amount of data to be processed. This can be important when dealing with multiband data such as Landsat ETM+ images.

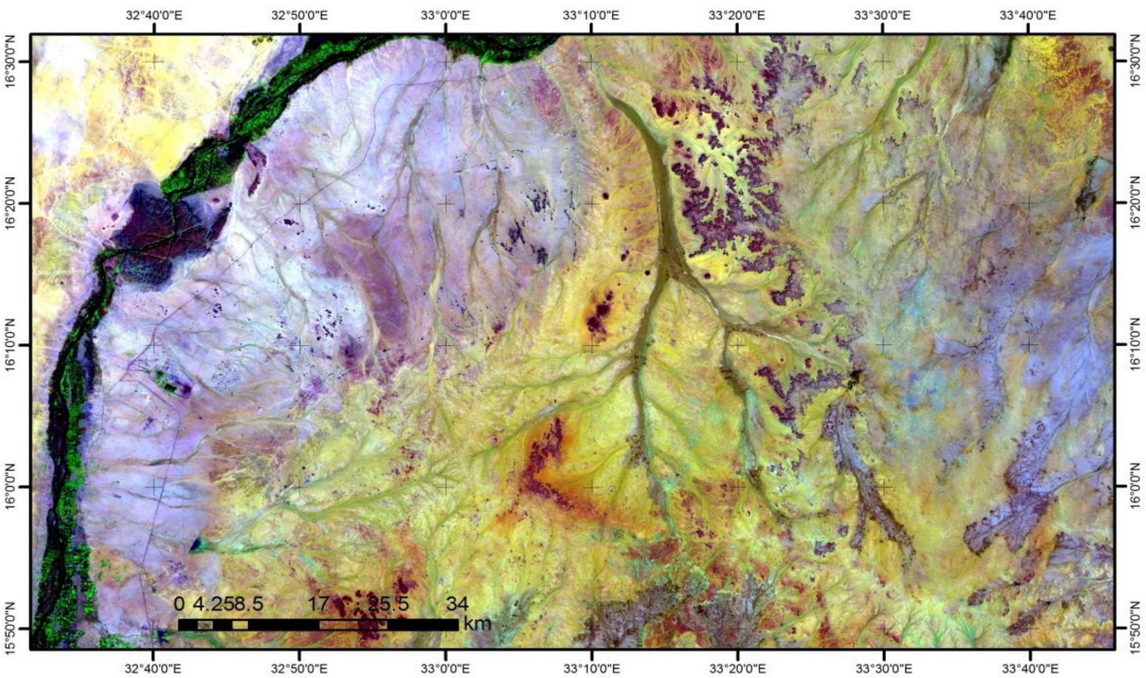
3.1.5 Enhancements

Image enhancement algorithms are applied to remotely sensed data to improve the appearance of an image for human visual analysis or occasionally for subsequent machine analysis. There is no such thing as ideal or best image enhancement technique because the result are ultimately evaluated by humans, who make subjective judgments as to whether a given image enhancement is the useful (Jensen, 1996). Enhancement techniques are often used instead of classification for extracting useful information from images. There are many enhancement techniques available. They range in complexity from a simple contrast stretch, where the original data file values are stretched to fit the range of the display device, to principal components analysis, where the number of image file bands can be reduced and new bands created to account for the most variance in the data. In this study both spatial and spectral enhancements were applied.

3.1.5.1 Color composite

The rule of color composites is to set the most informative band for a particular purpose in the red the next in green, and the least informative band in blue guns (Drury, 1993). Color photographs and images have certain advantages stemming from

the fact that human eyes have better chromatic discrimination (Drury, 1993). Any three bands of six OLI multispectral bands can produce color composite image.
In the present study, the prepared color composites are exemplified by RGB, standard color composites that were created, Figures (3.1) show contrast-stretched color composite images of bands 7, 5 and 2 respectively. The creation of different (RGB) combinations was helped in the discriminate of the various rock types which is useful in delineating the geological boundaries for example Dark Ignimbrite abear as dark Violet colour at this Scene Figures (3.1).



Figures (3.1) show image enhanced used contrast-stretched color composite image of bands 7, 5 and 2 in red, green and blue respectively.

3.1.5.2 Filtering

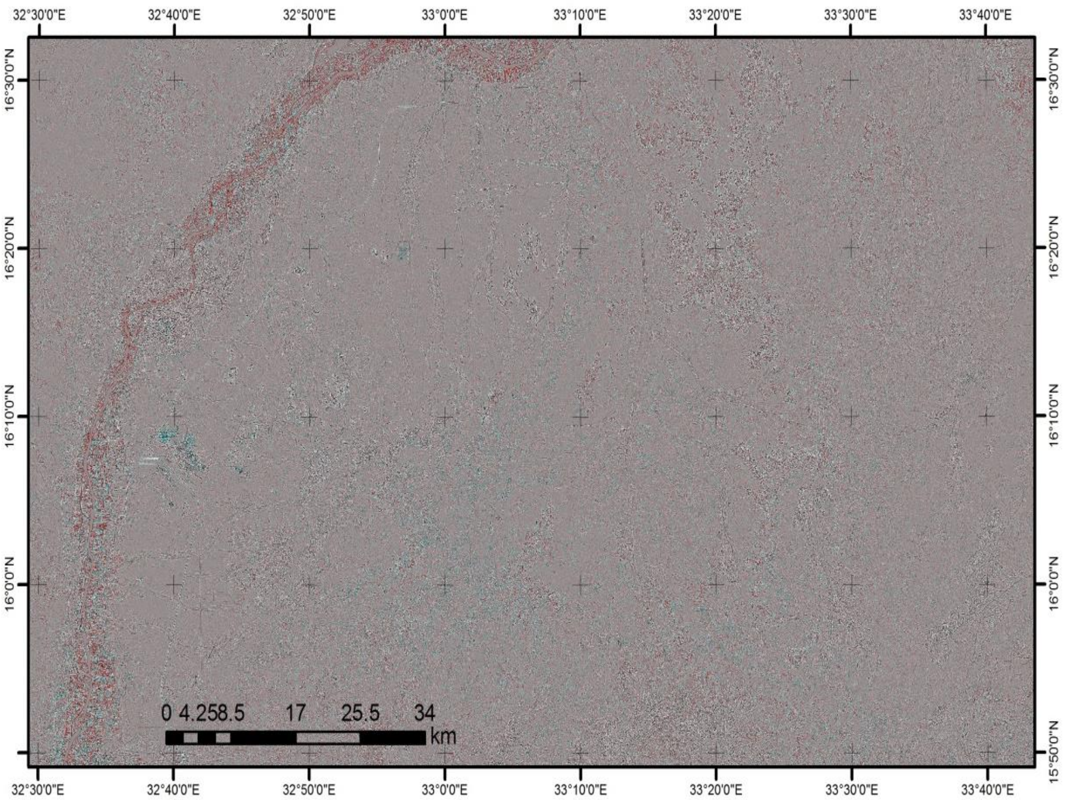
Convolution filters produce output images in which the brightness value at a given pixel is a function of some weighted average of the brightness of the surrounding pixels. Convolution of a user-selected kernel with the image array returns a new, spatially filters image. By selecting the kernel size and values, different types of filters can be produced. Standard convolution filters include:

• **High Pass**: Removes the low frequency components of an image while retaining the high frequency (local variations). It can enhance edges between different regions as well as to sharpen an image figure (3.2) this is accomplished using a kernel with a high central value, typically surrounded by negative weights. At this study high pass filter used to detect lineament and trace drainage system

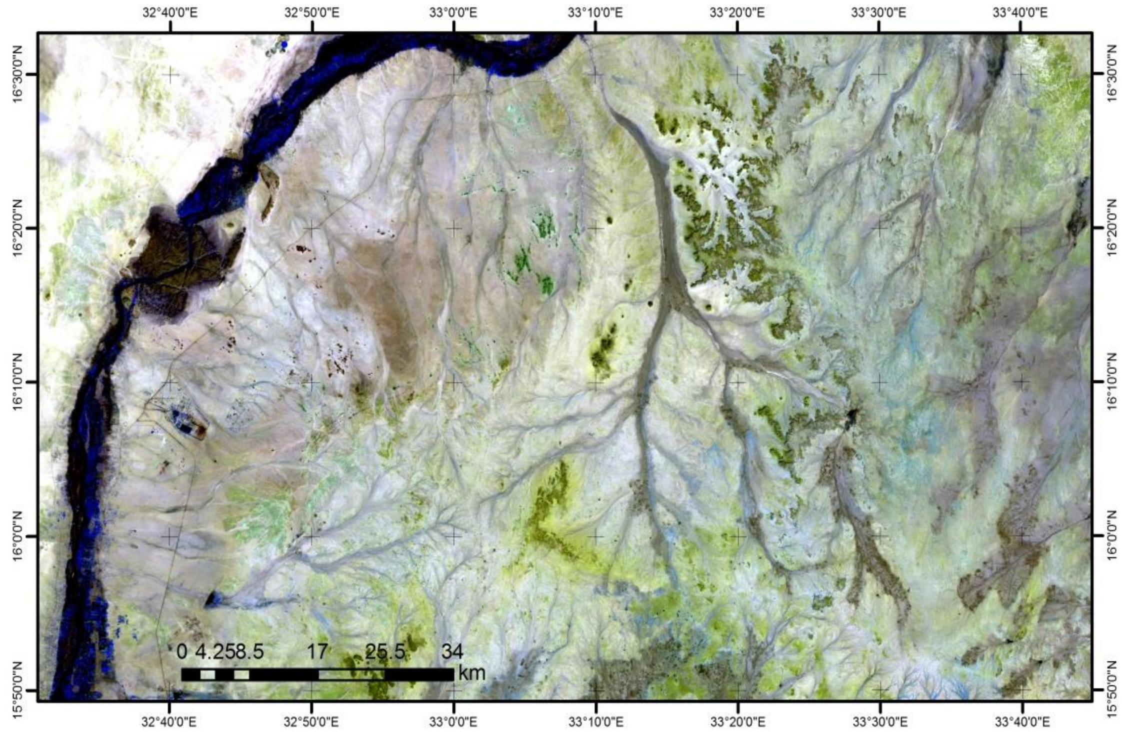
• **Low Pass**: Preserves the low frequency components of an image, which smooth's it (ENVI, 4.5). Filtering is a very important research field of digital image processing. All filtering algorithms involve neighborhood processing because they are based on the relationship between neighboring pixels rather than a single pixel in point operations. It can also enhance image texture for discrimination of lithology and drainage patterns (Liu and Mason, 2009). This study used digital filtering fig (3.3) is useful for enhancing spatial features such as lineaments and geological feature, the Dark ignimbrite abear as dark brown colour.

• **Directional Filter**

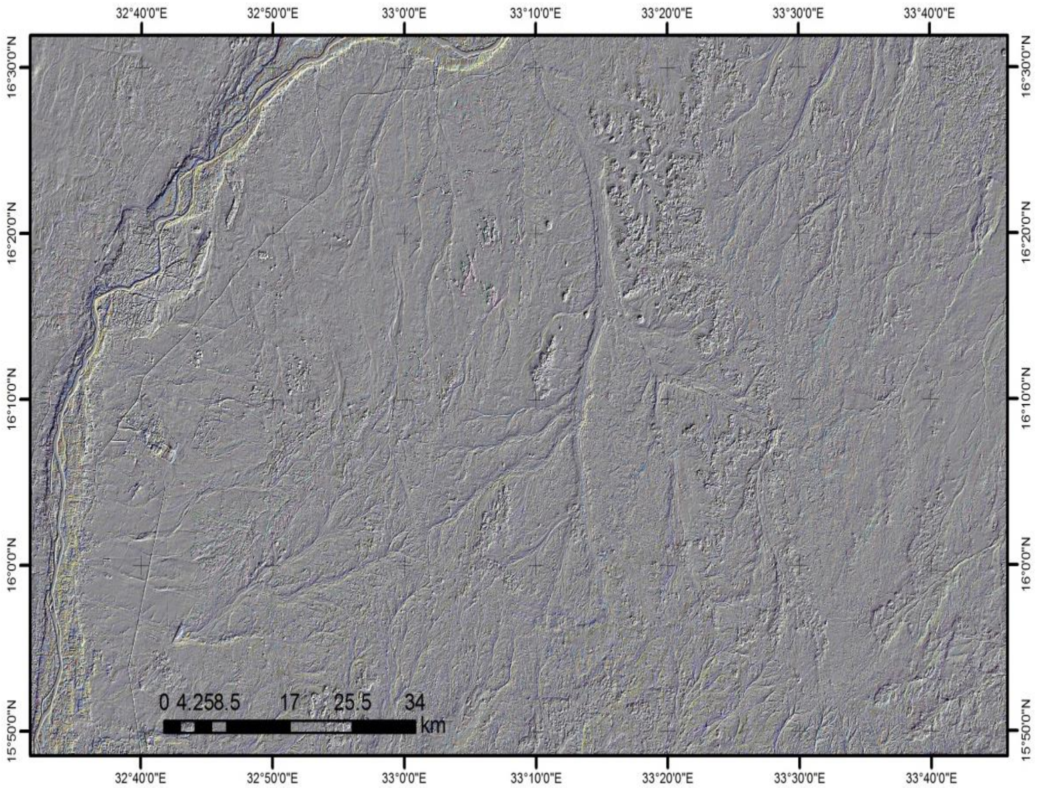
It is the edge detector that can be used to calculate the first derivatives of the image .where the first derivatives are more visible when there is a large change between the values of the neighboring pixel. The image was processed using the directional technique, and the result fig (3.4) was that we were able to interpret the image easily and obtain information about the drainage systems fig(1.3) and faults in the area , in addition to it clarified the geology of the area .



Figures (3.2) show image enhanced used high pass filter image of bands 7, 5 and 2 in red, green and blue respectively.



Figures (3.3) show image enhanced used low pass filter image



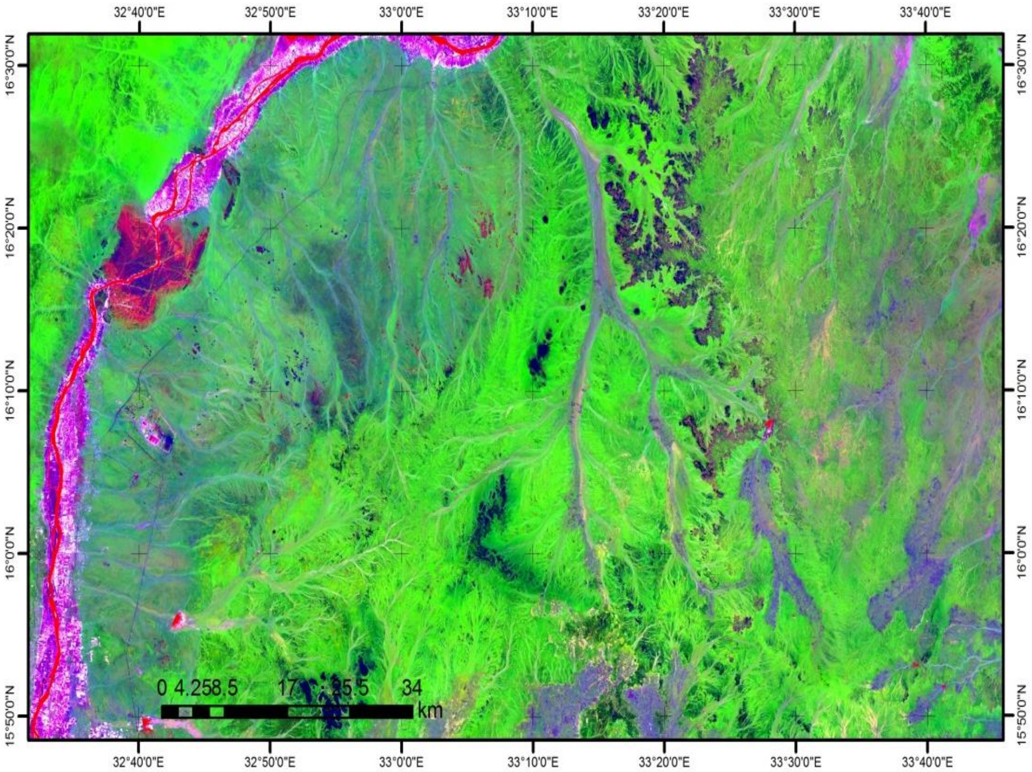
Figures (3.4) show image enhanced used directional filter.

3.1.5.3 Band ratio

Topographic slope, aspect shadows or seasonal changes in sunlight illumination angle and intensity cause differences in brightness values from identical surface materials (Jensen, 1996). Ratio images are prepared by dividing the DN value in one band by the corresponding DN value in another band for each pixel (Sabins, 1996) where resulting values are representing the ratio image. Ratioing two spectral bands negate the effect of any extraneous multiplicative factors in remote sensor data that act equally in all wave bands of analysis (Lillesand and Kiefer, 1994).

The ratio images have two important properties. First, strong differences in the intensities of the spectral response curves of different features may be emphasized in rationed images. Second, ratios can suppress the topographic effects and normalized differences in irradiance when using multi date images (Singh, 1989).

The individual ratio images of (band 5/band 7, band 5/band 1 and band 5/band 4 x band 3/band 4) were prepared for the geological interpretation in the study area figure (3.5) that may represent significant geological structures such as faults, veins or dykes.



Figures (3.5) show image enhanced used ratio (band 5/band 7, band 5/band 1 and band 5/band 4 x band 3/band 4) in red, green and blue respectively.

3.1.6 Geographic Information System (GIS)

Geographic Information Systems (GIS) can be defined as a computer-based systems that enable users to collect, store, process, analyze, modeling, display/output and present spatial data (Trisurt, 2002).

It provides an electronic representation of information, called spatial data, about the Earth's natural and man-made features. A GIS references these real-world spatial data elements to a coordinate system. These features can be separated into different layers. A GIS system stores each category of information in a separate "layer" for ease of maintenance, analysis, and visualization.

The development of GIS is the result linking parallel developments of several other spatial data processing disciplines such as cartography, computer aided design, remote sensing technology, surveying photogrammetry.

GIS software acts as an interface, or window, for viewing and manipulating GIS data. Each GIS file is georeferenced, meaning that the file is actually tied and related to real locations on the earth. GIS file has also been created based on a particular projection and coordinate system which means that files that share the same reference system can be laid on top of each other. Since projections and coordinate systems are highly standardized, GIS data can easily be shared.

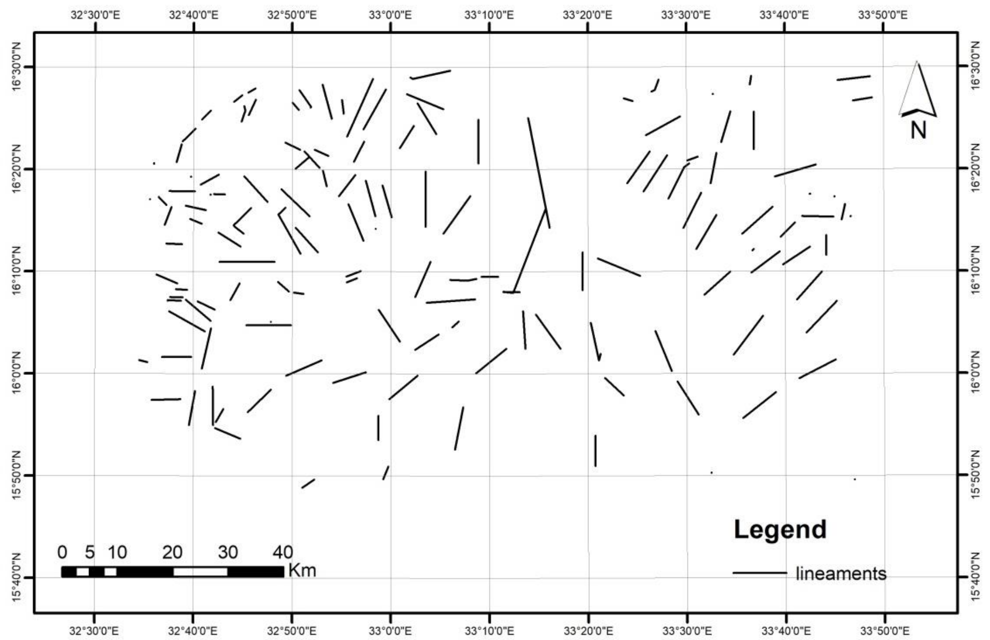


Figure (3.6) Lineament map of the study area based on the interpretation of satellite images.

3.2 Gravity

3.2.1 Introduction

The gravity method is a non-destructive geophysical technique that measures differences in the earths' gravitational field at specific locations. It has found numerous applications in engineering, environmental and geothermal studies including locating voids, faults, buried stream valleys, water table levels and geothermal heat sources. The gravity method depends on the bulk density so the differing in gravitation field due to different earth materials have different bulk density.

These variations can then be interpreted by a variety of analytical and computers methods to determine the depth, geometry and density that causes the gravity field variations. The data are processed to remove all these predictable effects. The most commonly used processed data are known as Bouguer gravity anomalies, measured in mGal. A gravity meter or gravimeter measures the variations in the earth's gravitational field, the gravimeters have to be very sensitive so as to measure one part in 100 million of the earth's gravity field (980 gals or 980,000 mgals) in units of mgals or microgals.

3.2.2 Gravity Field and Steady-State Ocean Circulation Explorer (GOCE; pronounced 'go-chay')

The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE; pronounced 'go-chay') is measuring Earth's gravity field and model the geoid with extremely high accuracy. It was launched on 17 March 2009. Owing to its sleek shape, GOCE is often cited as one of ESA's most elegant space probes.

The mission ended on 11 November 2013 after a planned destructive re-entry into the atmosphere.The geoid, defined by Earth's gravity field, is a surface of equal gravitational potential. It follows a hypothetical ocean surface at rest (in the absence of tides and currents). A precise model of Earth's geoid is crucial for deriving accurate measurements of ocean circulation, sea-level change and terrestrial ice dynamics, all of which are affected by climate change.

3.2.2.1 The mission

The geoid is also used as a reference surface from which to map all topographical features on the planet. An improved knowledge of gravity anomalies will contribute to a better understanding of Earth's interior, such as the physics and dynamics associated with volcanism and earthquakes and also further our knowledge of land uplift due to post-glacial rebound.

The scientific objectives of the mission require GOCE to be operated in an extremely low orbit at altitudes down to 224 km, lower than any other Earth observation mission.

3.2.3 Satellite gravity

The Radar altimeter measurements provided the scientific community with valuable information about the earth interior (Nabigian et al., 2005.). From this, the sea-surface topography from radar altimeter data was used to calculate the vertical component of the gravity field. This significantly helped in improving the knowledge of the earth's tectonic (Hwang et al., 1998; Sand well and Smith, 1997). Consequently, the gravity field measurements were moved from only calculating the marine gravity field from radar altimeter measurements to measuring the global gravity field using new satellite missions.

This step led to improving the quality of the available data and also improving our understanding of the overall earth tectonic history (e.g. Tapley and Kim, 2001).

Satellite gravity is gravity field measurements that were available recently in the last decade. Recent satellite missions were launched such as CHAMP in 2000, GRACE in 2002, and GOCE in 2009 to map the Earth's gravity field (Tapley and Kim, 2001; http://www.nasa.gov). The global coverage and the

consistent data quality are the most significant advantages of the satellite gravity data (Nabigian at al., 2005).

Gravity anomaly is calculated in the region of interest by using satellite gravity gradiometry data observed by GOCE (Gravity field and steady-state Ocean Circulation Explorer). The following paragraph explain the analysis and interpretation of GOCE gravity data.

3.2.4 Interpolation

Interpolation is a method of constructing new data points within the range of a discrete set of known data points. No one method works universally as the best for all the data set .Selection of a particular method depends on the distribution of data points and the study objectives. The process of interpolation can be conceptually very simple, but is requires an a priori assumption before we begin working with surface data (Schatzman, 2002). The simplest interpolation method is to locate the nearest data value. Two interpolation methods were utilized in the current study. These are

Inverse Distance Weighted (IDW) and Spline methods.at this study used IDW to interpolate gravity points data.

3.2.5 Inverse distance weighted interpolation (IDW)

In this interpolation method, observational points are weighted during interpolation such that the influence of one point relative to another declines with distance from the new point. Weighting is assigned to observational points through the use of a weighting power that controls how weighting factors drop off as the distance from new point increases. The greater the weighting power, the less effect points far from the new point has during interpolation. As the power increases, the value of new point approaches the value of the nearest observational point.

The simplicity of underlying principle, the speed in calculation, the ease of programming, and reasonable results for many type of data are some of the advantages associated with inverse distance weighted interpolation. The disadvantages are: choice of weighting function may introduce ambiguity, especially when the characteristics of underlying surface are not known; the interpolation can easily affected by uneven distribution of observational data points since an equal weight will be assigned to each of the data points even if it is in a cluster; maxima and minima in the interpolated surface can only occur at data points since inverse distance weighted interpolation is a smoothing technique by definition. The result is shown in In figure (3.7) gravity anomaly high as green colour in the northwestern increasing from south to north trend maximum value 49mGal at the region which has igneous rock at these represent high density Rocks, where the northwestern at the 33˚-34˚E ,16˚ 20'N have low gravity represented as white colour this indicate of low density sedimentary, in this area show very low anomaly in the eastern Sudan (31mGal) with faulted as contour show steep gradient at eastern and western for this anomaly figure (3.8).

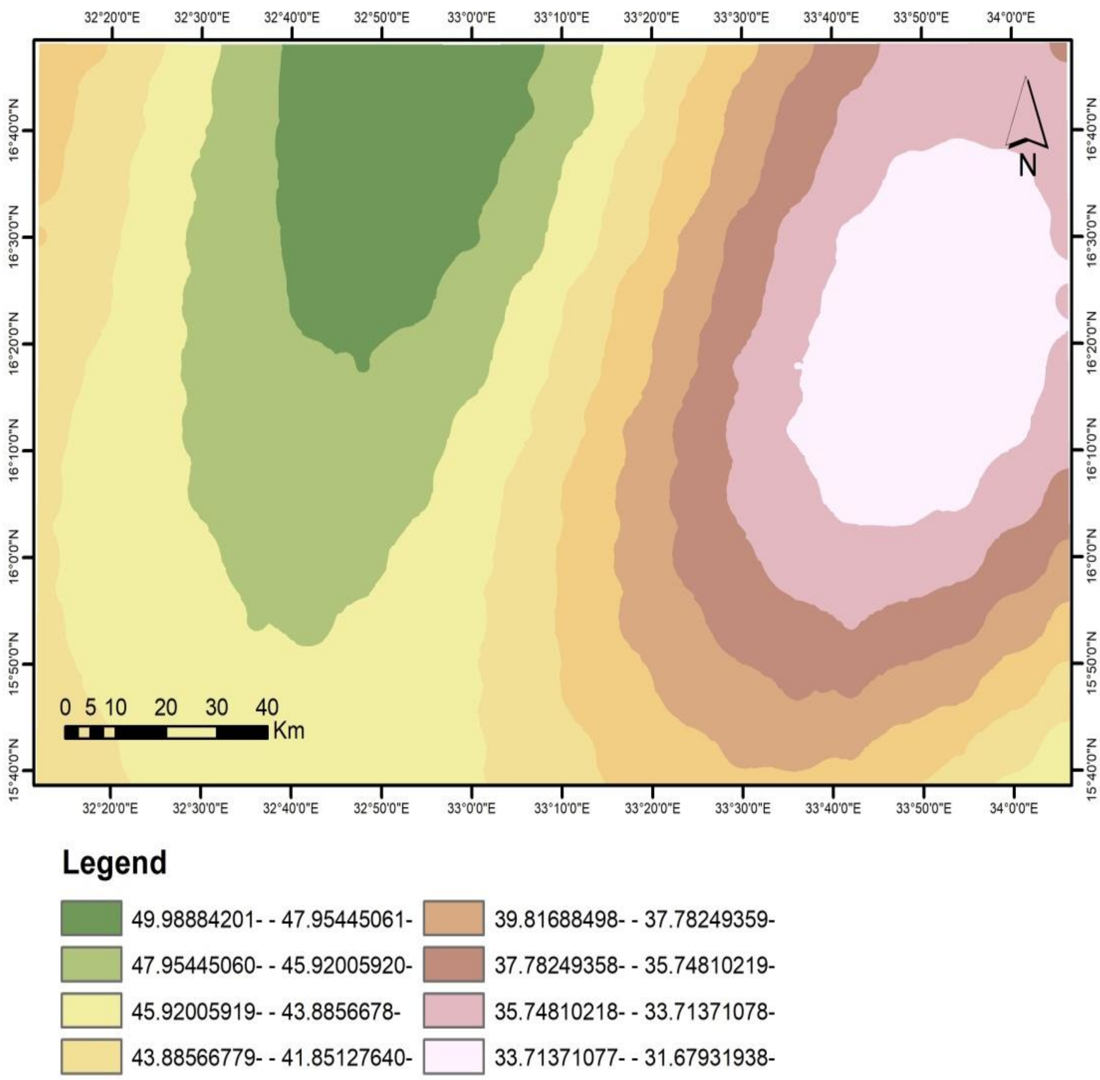


Figure (3.7) IDW interpolation in the study area.

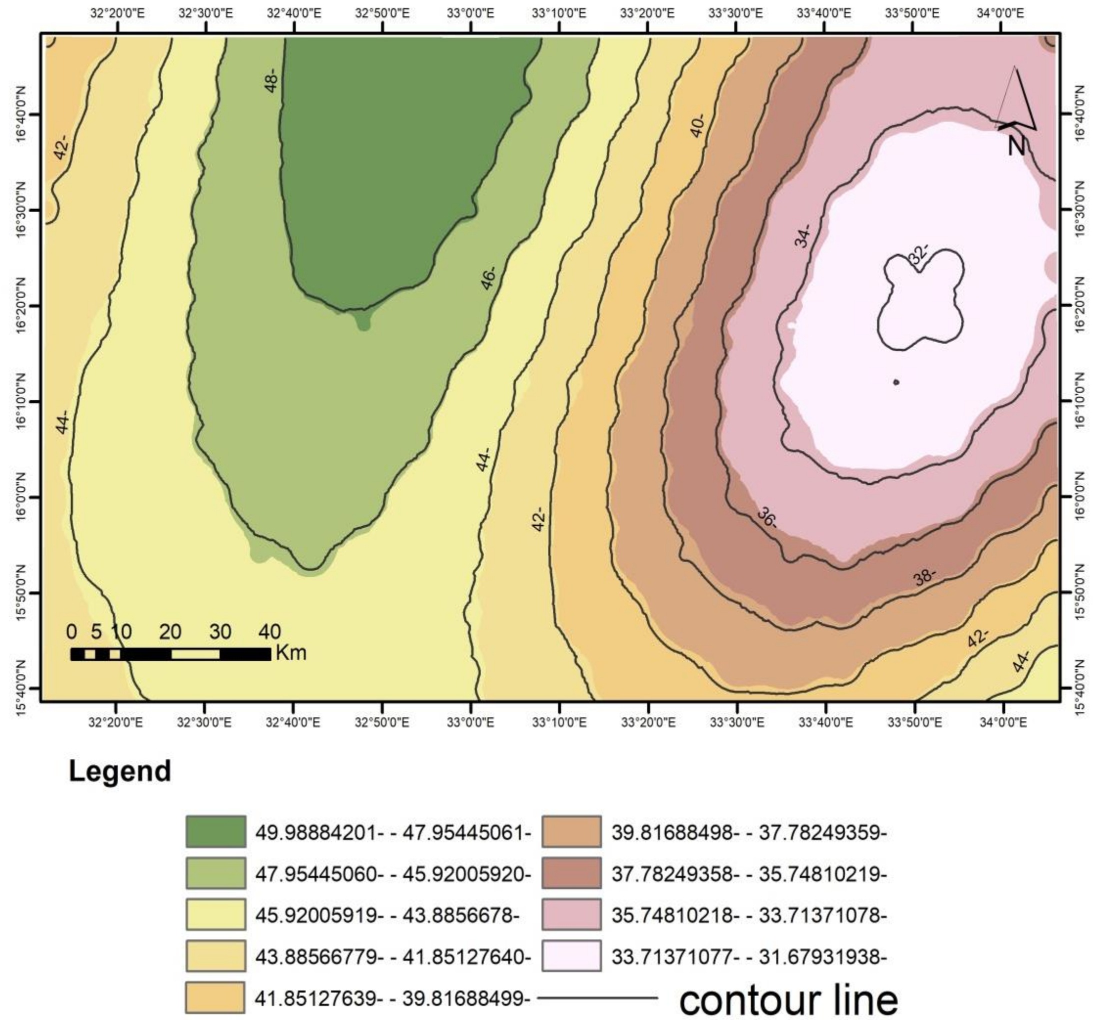


Figure (3.8) gravity anomaly with contour line in the study area.

Chapter Four

Conclusion and Recommendations

Chapter Four
Conclusion and Recommendations

4.1 Conclusions:

This work covers a large area of the Precambrian rocks in the Sabaloka inlier. The current work represents an attempt to map the area through the use of digital image processing techniques of satellite data and satellite gravity. Different digital image processing techniques have been applied to Landsat 8 OLI image in order to increase the discrimination between various lithological units. Image sharpening was performed to enhance the spatial resolution of the image for more detailed information.

Several ratio images were prepared, combined together and displayed as RGB color images. The creation of different (RGB) combinations was helped in the discriminate of the various rock types which is useful in delineating the geological boundaries.

The image was processed using the directional technique was that able to interpret the image easily and obtain information about the drainage systems and faults in the area , in addition to it clarified the geology of the area

All the images, obtained through the above mentioned processes, have been used simultaneously to produce the geological map of the study area in the GIS environment.

Gravity data points was used in the present study. Gravity anomaly is calculated in the region of interest by using satellite gravity gradiometry data observed by GOCE (Gravity field and steady-state Ocean Circulation Explorer). The following paragraph explain the analysis and interpretation of GOCE gravity data. The result is shown in In study of gravity anomaly for the area of study shown high gravity as green color in the northwestern increasing from south to north trend maximum value 49mGal at the region which has igneous rock at these represent high density Rocks, where the northwestern at the 33˚-34˚E ,16˚ 20'N have low gravity represented as white color. This indicate of low density sedimentary, in this area show very low anomaly in the eastern Sudan (31mGal) with faulted as contour show steep gradient at eastern and western for this anomaly.

4.2 Recommendations:

1. The present work generated new information about the Sabaloka inlier. The conducted gravity investigations are not adequate and still more information can be obtained about the subsurface structure. Accordingly, more detailed gravity study is recommended to provide new information about the structure history of the area.
2. Some companies are exploiting the mineral resource of the area, i.e. rocks as building materials. Care must be takes when exploiting the resource so as not to destruct the geological environment of the area.
3. The area is one of the most important geological site in the country and may be in the world that is characterized by a variety of rock units and structures. It represents an ideal area of field training for students. Accordingly, the area must be preserved as a geo-park.
4. The geopark may activate the tourism in the area. This may be supported by the existence of the sixth cataract (Sabaloka cataract), and the development of the economic return of the country.

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