Journal of Advanced Research in Geo Sciences & Remote Sensing
Volume 7, Issue 1&2 - 2020, Pg. No. 6-16
Peer Reviewed Journal

Research Article

Geology, Metamorphism and Structural Evaluation of Precambrian Basement Rocks in El Obeid Area, Kordofan Region, Sudan

Hassan A Mustafa[1], Mushal A Salih[1], Asim A Elmansour[1], Mohammed I Abdallsamed[1], Mohammed A Elhadi[2], Einas M Slama[1,3]

[1]Faculty of Science, University of Kordofan, El Obeid, P.O 160, Sudan.
[2]Faculty of Science, University of Aljazeera, Wad Madani, Sudan.
[3]Faculty of Earth Science, China University of Geosciences, Wuhan, 430074, China.

I N F O

Corresponding Author:
Hassan A Mustafa, Faculty of Science, University of Kordofan, El Obeid, P.O 160, Sudan.
E-mail Id:
ham3019@yahoo.com
Orcid Id:
https://orcid.org/0000-0002-0919-066X
How to cite this article:
Mustafa HA, Salih MA, Elmansour AA et al. Geology, Metamorphism and Structural Evaluation of Precambrian Basement Rocks in El Obeid Area, Kordofan Region, Sudan. *J Adv Res Geo Sci Rem Sens* 2020; 7(1&2): 6-16.

Date of Submission: 2020-04-14
Date of Acceptance: 2020-05-16

A B S T R A C T

The rock units in El Obeid area comprised gneisses and migmatites covering most of the area. The Supracrustal metasediments mica schist and lenticular lenses of amphibolites overlies unconformable these gneisses and migmatites. The acidic intrusive felsite and quartzite intruded due to the regional dynamic metamorphism. The amphibolite rocks indicated different petrogenesis displaying three mineral generations confirmed the polymetamorphism.

The first cycle of metamorphism represented by the oldest units, is of medium- to high-grade. This cycle associated by NW-SW, NE-SW trending fractures. The second cycle affects the pile and the Supracrustal metasediments; is of low-grade metamorphism grade. The third cycle which of dynamic nature affected all sequence units in the study area, is of greenschist facies conditions, generated the deformational shearing episode with NE-SW, NNE-SSW and rarely NW-SE and N-S trend.

The relationships between the metamorphism and structures in the area appeared in the conjunction of any cycle of metamorphism with deformations in response to its grade. The structures reflected the degrees of metamorphism which gradual retrograded from medium-grade to low-grade metamorphism.

Keywords: Metamorphism, Structures, Kordofan, Relationship, El Obeid

Introduction

The study area is situated in central Sudan (Figure 1), within the Precambrian Basement Complex, These rocks found in scattered outcrops, around El Obeid city dominantly in the southeastern part, such as J. Kordofan, J. Eleza'a, J. Kurbag Elabyad, J.l Kurbag Elazrag, J. Abu Khureis and J. Abu Uroug.

These rocks are gneisses and migmatites, schists, quartzites, and even amphibolites, indicating different grades of metamorphism. Polymetamorphic activities followed by different deformations phases of metamorphism had been proposed in the Northern part of the Nuba Mountains (El Ageed, et al., 1981). Typical to these activities also identified with three stages around Sodari, Mazroub and Umm Badr areas (Al Biely et al., 1986; El Khidir, 1997), also three stages of structural activities determined related to these polymetamorphic series n El Semeih area, (Khalil et al., 1987), same of the whole region structural system related to the Central African Fault Zone as a late Proterozoic dextral shear zone which extended from Cameroon through the Central African Republic, Southern Chad, Central Sudan, and Red Sea Hills (Schandelmeier et al.,1990). Even Brittle Shear deformation in Northern Kordofan State in the Basement of Umm Badr and Sodari and J. Nehud areas in four episodes had been recorded (Schandelmeier et al., 1991). Abdel Salam et al. (2002). It is also described the early ENE-WSW trend structural systems which are controlled the Saharan Metacraton in the Kordofan region. In this study, we conducted a detailed geological investigation through geological mapping, survey, petrographical studies that related to metamorphic processes to determine the geological characteristics of the rock units, metamorphism processes, macro-, micro-structures and the relationship between these structures and the metamorphism, according to the metamorphic cycles, grades, and facies by mineral assemblages and the metamorphic evolution.

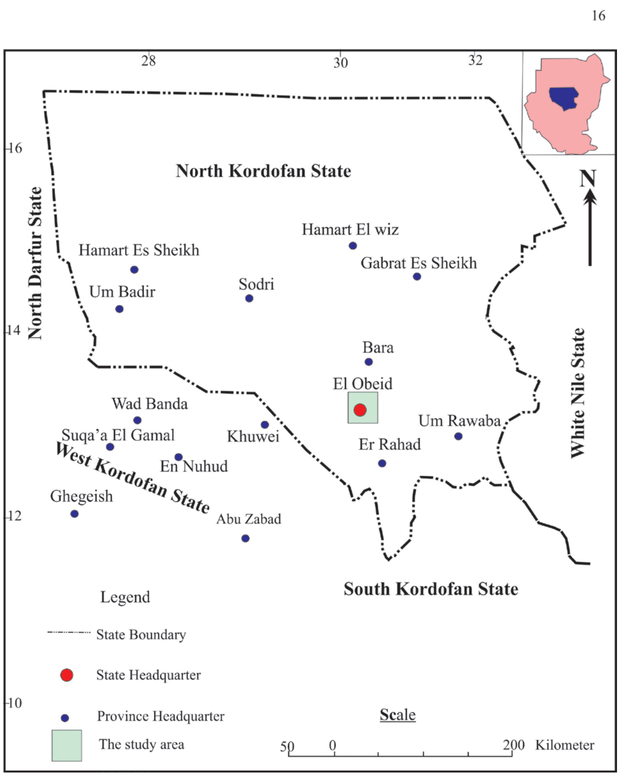

Figure 1.Location map of the study area (modified after El Mansour, 2005; Mustafa, 2007)

Regional Geology and Structures

Basement Complex is the extensive rock unit in the Kordofan region, covered and underlain all younger units consists of granites, gneisses and migmatites, schists, quartzites crystalline limestone and other igneous and metamorphic rocks (Rodis et al., 1964; Mustafa, 2007). In the Umm Badr-Sodari area, composed of weakly foliated N-S grey biotitic-granitic- pink augen gneisses, subdominant comprising Supracrustal meta-sedimentary groups in. These rocks intruded by syn- to late-orogenic granites, then by sheared felsitic extrusives and then post-orogenic intrusions including granites and syenites with volcanic equivalents (Khidir, 1997; Mustafa, 2007). In the eastern part of Nuba Mountain, most of the Basement rocks are also made up of granitic or granodioritic gneisses associated with metasedimentary rocks and regional dykes of felsite and quartz veins trending E-W (Vail, 1973). The Basement rocks in the study area are mainly metamorphosed rocks of amphibolite facies that mostly retrograde to greenschist facies. It composed of gneisses and migmatites, Supracrustal metasedimentary group including marbles, amphibolites, schists, and quartzites, these rocks intruded by syn-to late-orogenic intrusions (Rodis et al., 1964; Vail, 1973, 1978; El Mansour, 2005; Mustafa, 2007; Mustafa et al., 2018, 2020).

Nawa Formation is the least extensive sedimentary unit identified in the east-central Kordofan, (Rodis et al., 1964; Elrabaa, 1976; Vail, 1978 Mustafa, 2007). It consists of gently dipping and metamorphosed grits, sandstone, and mudstone (Whiteman, 1971; Abdalla, 1999). The Nubian Sandstone Formation does not crop out; only recorded in many parts with different depths (RRI&GRAS, 1990; Abdalla, 1999). Generally, it consists of sandstone, conglomerate, and mudstone with hard ferruginous and siliceous layers. The Tertiary sequence consists of a highly ferruginous layer of hematite and limonite ironstone that locally has an Oolitic vermicular texture. Umm Rawaba Formation is a widespread of continental largely unconsolidated or poorly consolidated sands, gravels, silt, and clay of variable thickness and probably Quaternary age (Andrew and Karkanis, 1945; El Mansour, 2005; Mustafa, 2007). Kordofan region is underlying directly by a mantle of unconsolidated Superficial Deposits, which consist of coarse residual desert soils and active sand dunes covering most of the area.

Geology and structural evolution of the study area and Northern Nuba Mountains have been described as a poly metamorphic activities followed by three deformations phases of metamorphism; M_1= High grade affected the early isoclinals folds (of amphibolite facies). The second phase M_2= Highly-greenschist facies, followed by folding and thrusting. The last phase is M_3= Dynamic metamorphism, deduced catalysis, and thermal activities (El Ageed, et al., 1981). In North Kordofan State (around Sodari, Mazroub, and Umm Badr areas) also a poly metamorphic activity is recorded with three stages; M_1 = High-grade (upper amphibolite facies). M_2 = low-grade (greenschist facies). M_3 = Dynamic metamorphism (Al Biely et al., 1986). The Precambrian W.N-S.W strike metasediments of the El Semeih area intruded by younger Post-Cambrian intrusions and reactivated by J. Dumbeir earthquake in 1966 (Khalil et al., 1987).

A Brittle Shear deformation in Umm Badr and Sodari area were recorded in four episodes; D1 = A late Proterozoic deformation which produced the isoclinal folds in the high-grade migmatitic gneissic. D2 = late Pan-African age intrusive NNE-SSW ductile shearing refolded the earlier structures in the metasediments. D3 = Lastest Pan-African age, dextral ENE-WSW brittle shearing which affected the metasedimentary belt of Umm Badr. D4 = late Carboniferous to Triassic brittle shearing which reactivated structures of the previous episodes of deformation reactivating the Umm Badr and J. Nehud areas event (Schandelmeier et al., 1991).

The evolution of the metamorphism in the Sodari-Umm Badr area also confirm the polymetamorphic event in the region, three phases of metamorphism had been recorded associated with three deformational episodes; M1 = high-grade rank of upper amphibolite facies associated with extension D_1. M2 = low-grade rank of greenschist facies associated with D_2 compression. M3 = Dynamic metamorphism of low-grade rank (greenschist facies conditions) associated with D_3 shearing.

Also, two structural systems controlling the Saharan Metacraton had been mentioned; the early ENE-WSW trend extended through Bayuda Desert, Nubian Desert, Kordofan, and Darfur. The N-S trend is similar to the N-trending upright folds which deformed by N-NW-trending strike-slip faults (Abdel Salam et al., 2002).

Materials and Methods

Geological survey and mapping were conducted in the El Obeid area in many phases to identify the regional relationships and distribution of the rock types and their characteristics. Samples of the different rock types were collected from J. Kordofan, J. Abu Uroug, J. Eleza'a a, J. Kurbag, J. Abu Khureis, and J. Ed Dago (Figure 2). The collected samples were prepared and analysed in the laboratories of Geological Research Authority of Sudan (G.R.A.S) and Central Petroleum Laboratories (CPL) for petrographical and structural investigations, for determining the index minerals of these metamorphic rocks and their textural and mineral generations. These index minerals used for the definition of mineral assemblages, grade and facies of metamorphism.

Result

Geology and Petrography

Gneisses and migmatites

These gneisses and migmatites had been described in different terms as grey gneisses, gneisses and migmatites and migmatitic gneisses (Rodis et al, 1964; Whiteman, 1971; Vail, 1973, 1978; Schandelmeier, 1990; El Khidir, 1997; Mustafa, 2007; Mustafa et al., 2018, 2020). This unit cropped out in J. Kordofan and J. Abu Uroug southeast of El Obeid and J. Kurbag Elazrag and J. Kurbag Elabayad northeast of El Obeid (Figure 2). They are whitish to grey and pinkish, coarse-grained, with dominant trend foliation NW-SE, gneissose structure with variable mineral composition. They composed of quartz, orthoclase, plagioclase, biotite, muscovite ± hornblende garnet, microcline and garnet (Figure 3).

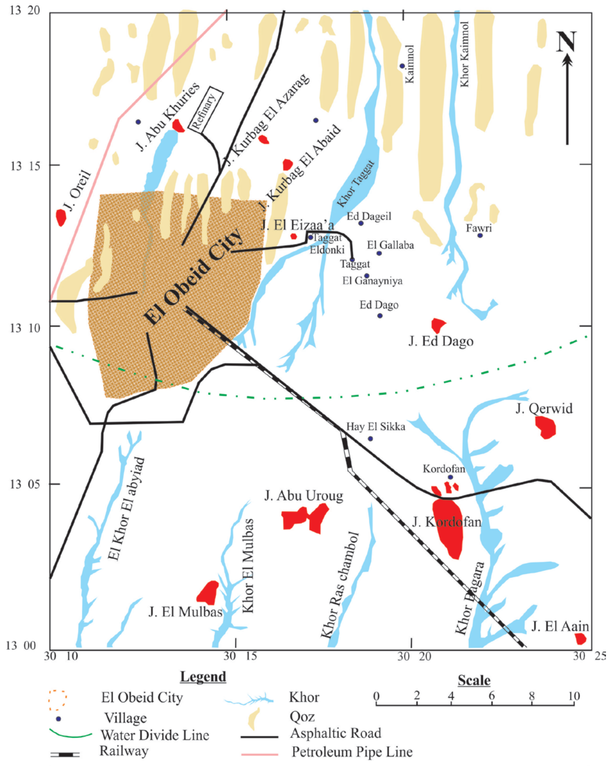

Figure 2.Geological sketch of the El Obeid area showing the outcrops where the samples collected (modified after Geological Research Authority of Sudan GRAS 2017)

The predominant compositions of these minerals are quartz (30-40%) which has two generations; the first generation is coarse-grained size with undoluse extinction, xenoblastic crystals with sutured boundaries. The second generation is the recrystallized fine-grained size. K-feldspar is the subdominant representing (10-20%) and presents as microcline, perthitic microcline, perthite, and orthoclase, in medium to coarse-grained size, xenoblastic crystals with turbid appearance. Plagioclase representing (10-15%) and present as oligoclase-andesine, medium to coarse-grained size, xenoblastic crystals. Muscovite representing (5-10%) present in high interference colour, medium-grained size, lepidoblastic texture, with perfect orientation. Biotite, representing (5%) present as brown flakes, medium-grained size, lepidoblastic texture, oriented deformed. Minor hornblende constitutes up to 2% (Figure 4).

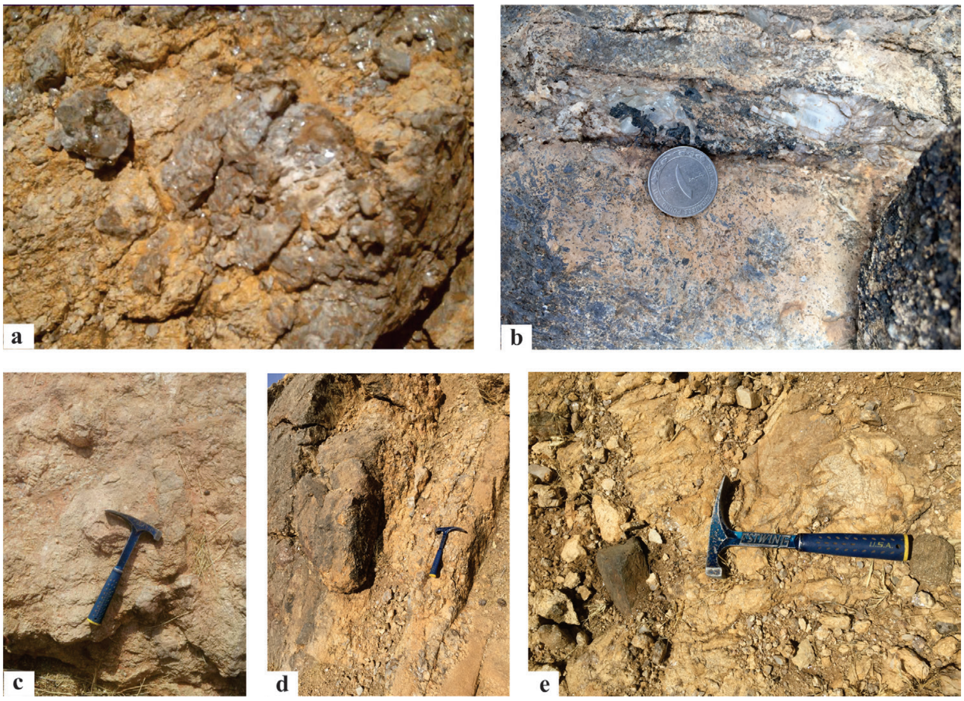

Figure 3.Outcrops and samples of the gneisses & migmatites in El Obeid area showing mineralization of muscovite, biotite, orthoclase and quartz

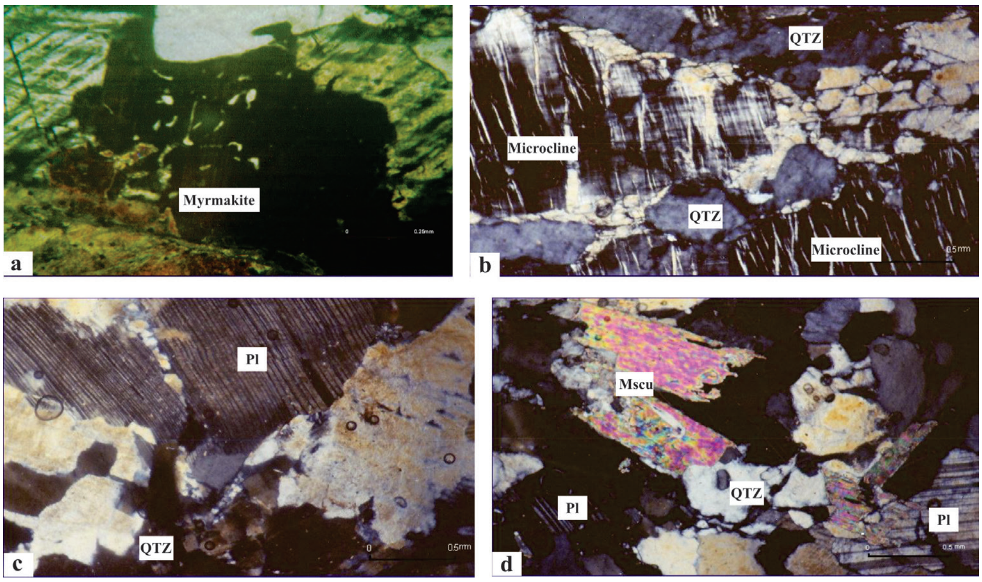

Figure 4.Photomicrographs gneisses & migmatites displaying: (a) myrmeckitic texture (b) cross-hatched twinning in microcline (c) twisted-lamellae of plagioclase and the intergrowth of quartz (d) gneissic and deformational texture

The rock displaying gneissic texture with observed deformation and twisted-lamellae of plagioclase (Figure 4c) also the intergrowth of quartz, myrmeckite, and cross-hatched twinning in microcline (Figure 4(a,b)). This mineral assemblage indicates high-grade metamorphism of amphibolite facies.

Amphibolites

They are supracrustal sequences found as lenticular lenses within the gneisses and migmatites, cropped out in J. Eleza'a and J. Kordofan (Figure 2). They are dark grey to blackish and greenish, medium to coarse with banded gneissose structure, composed of hornblende, plagioclase, quartz ± epidote (Figure 5).

Hornblende is predominant (50-60%) is present in medium-grained size, prismatic crystals, in nematoblastic texture. Plagioclase is subdominant representing (20-30%) is present in fine to medium-grained size with polysynthetic twinning of oligoclase - andesine composition. Quartz representing

(5%) and present as fine to medium-grained size, xenoblastic crystals, with sutured boundaries and undoluse extinction (Figure 6). Epidote (secondary) representing up to (2%) present as fine-grained size aggregates of epidote indicating replacement of hornblende (Figure 7a). Calcite is occurred locally due to the shearing processes in the area. Opaque iron oxides and apatite are present as accessories. The rock displays gneissic texture and the deformation observed from the undoluse extinction of quartz grains. Epidote replacing hornblende is encountered as fine aggregates. The rounded boundaries of the apatite grains indicate the sedimentary origin of these rocks. The mineral assemblage [indicates medium-grade metamorphism of amphibolite facies.

Figure 5.Outcrop photos for the amphibolites occurred: (a-b) Lenticular lenses of the amphibolites within the gneisses and migmatites, J. Eleza'a and J. Kordofan (c-d) amphibolites samples showing bedded gneissic structures with/ without anatexis leucotomies (c-d)

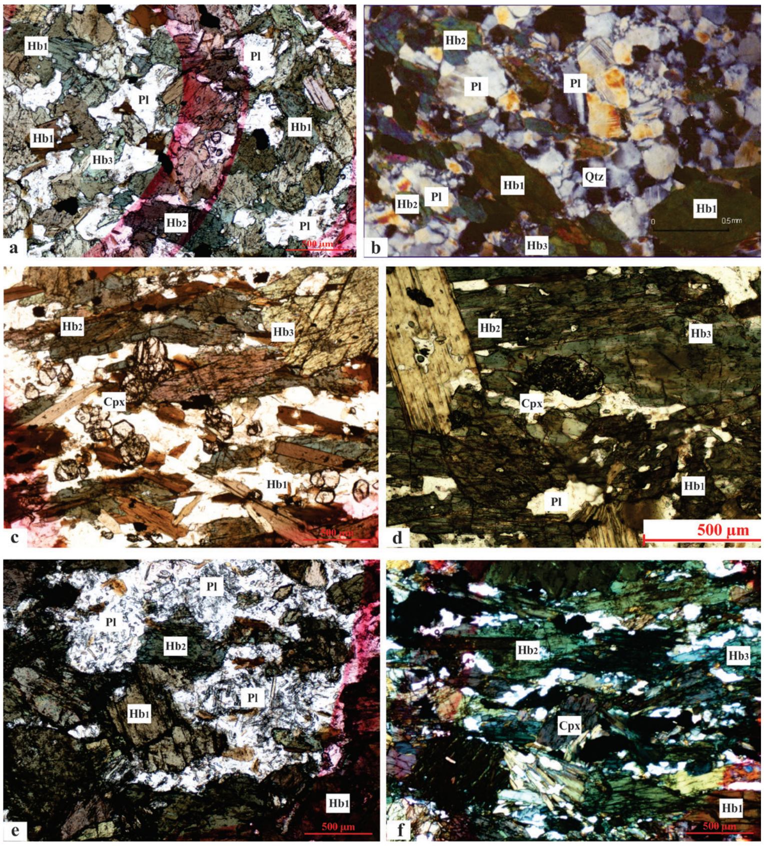

Figure 6.Photomicrographs of the amphibolites in El Obeid area, showing mineral assemblages and generations with their microstructures (a-f)

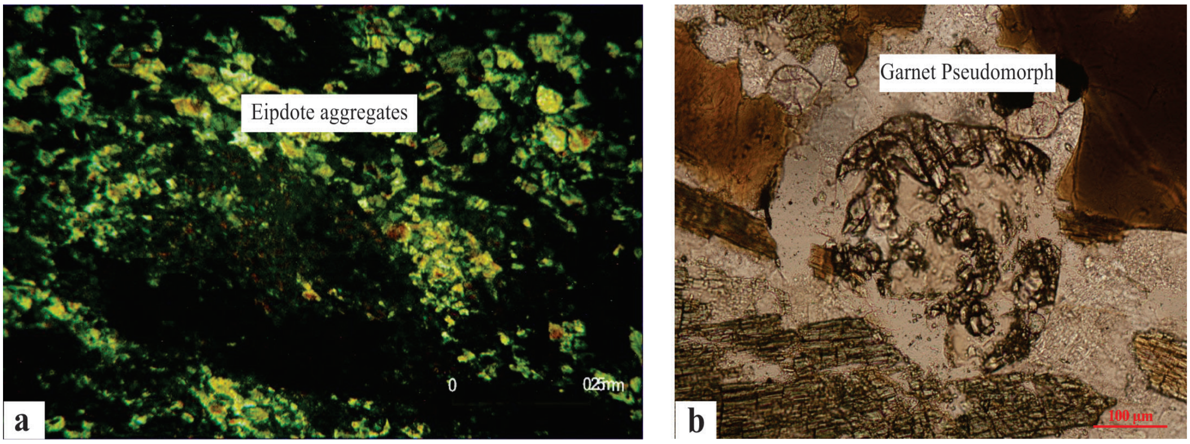

Figure 7.Photomicrographs of aggregates of epidote replacing the porphyroblasts of hornblende (a), and pseudomorph of garnet (b)

Schists

The Supracrustal metasediments cropped out in J. Kordofan, J. Abu Uroug and J. Kurbag (Figure 2). These rocks are grey, medium-grained, with dominant trend foliation NW-SE, composed of biotite, plagioclase, K-feldspar, quartz, and muscovite.

These rocks had been deformed too much showing zigzag folds in the eastern side of J. Kordofan (Figure 8c) which had been refolded strongly in some places (Figure 8d) and symmetrical alternate folds (anticline and syncline) in the western side of J. Kordofan (Figure 8(e,f)) representing elastic deformation, also brittle deformation was found in the area in the mica schist, which observed from the small faults in the folds of J. Kordofan as the presence of sharp contact between mica schist and the gneisses and migmatites somewhere, found only the slickenside as an indication of the faulting where the mica schists were eroded. These rocks cropped out in bands parallel to the outcrop trending 340ºC some of these bands are found unconformable with the gneisses and migmatites (Figure 8(a,b)).

Biotite is predominant (30-40%) present as brown flakes in medium-grained size, lepidoblastic texture, sometimes present with muscovite. Plagioclase is subdominant (10-20%) present as a medium-grained size of albite-oligoclase composition due to albitic and polysynthetic twinning. Quartz representing (10-15%) and present in fine to medium-grained size, with sutured boundaries and undoluse extinction. Muscovite representing (10%) present as medium-grained size in high interference colour flakes, lepidoblastic texture, oriented. K-feldspar, representing (10%) present as orthoclase, fine to medium-grained size, with turbid appearance. Calcite is present as a secondary mineral due to the shearing in the area. Opaque iron oxides are present as accessories. The rock displaying schistosity and the foliation had been observed from two preferred orientations of biotite and muscovite C-S fabric (Figure 9c), deformation observed from undoluse extinction of quartz grains. The mineral assemblage indicates low-grade metamorphism of greenschist facies.

Quartzites

These rocks cropped out in J. Ed Dago and as dikes in J. Abu Khureis also in J. Kordofan and J. Abu Uroug (Figure 2). All outcrops of quartzites have the same trends NW-SE with sub-vertical dip. These quartzites composed essentially of quartz in fine to medium-grained in texture. In J.Ed Dago found fine crystalline (hexagonal) crystals of quartz indicating the recrystallization process. In J. Abu Khureis had been affected by the hydrothermal process (Figure 10 (a,b)). Microscopically these rocks are fine to medium-grained in texture, composed essentially of quartz. Quartz is the dominant or essential mineral in these rocks (100%) present as two-generation; the first generation is medium to coarse-grained with undoluse extinction and sutured boundaries, the second generation is fine-grained, polygonal, (sometimes hexagonal). The deformation had observed from the undoluse extinction of quartz grains and the two generations of quartz (Figure 10(c,d)).

Sheared Felsite

This rock is acidic intrusive intruded only in J. Abu Khureis within the quartzite, it is light brown, fine-grained, composed K-feldspar, plagioclase, and quartz. This rock intruded in the shearing zone due to the regional dynamic metamorphism in the area in the last cycle of metamorphism. K-feldspar is predominant (30-40%) present as orthoclase; fine-grained size, with a turbid appearance this orthoclase, gave this rock rhyolitic nature. Plagioclase is subdominant representing (20-30%) present in fine to medium-grained size, with turbid appearance, has albitic and polysynthetic twinning. Quartz is representing (10-20%) present as fine-grained size with wavy extinction, indicating the deformation of this rock. Calcite is present as a secondary mineral due to the shearing in the area (Figure 11).

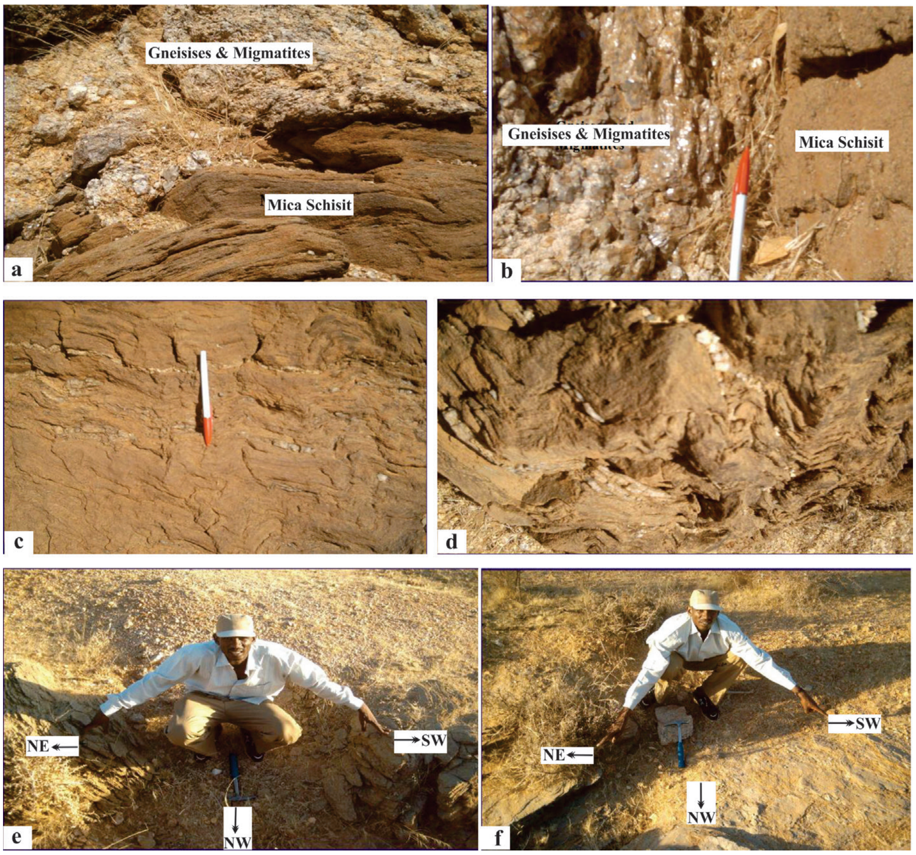

Figure 8.Outcrop photos for the mica schist showing: (a-b) unconformable sharp contact between mica schist and the gneisses and migmatites (c-d) zigzag and strong refolded folds in the eastern side of J. Kordofan (e-f) symmetrical alternate folds (anticline & syncline) on the western side of J. Kordofan

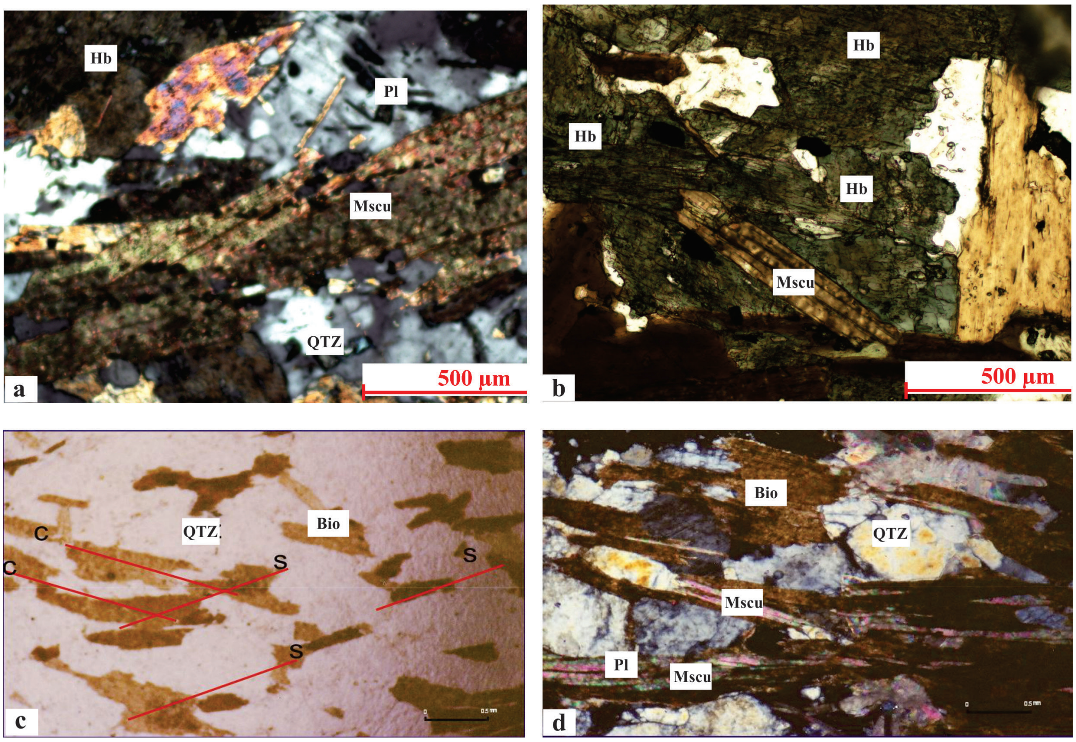

Figure 9.Photomicrographs of mica schist displaying (a-b) schistosity and the foliation (c-d) the two preferred the orientation of biotite and muscovite C-S fabric

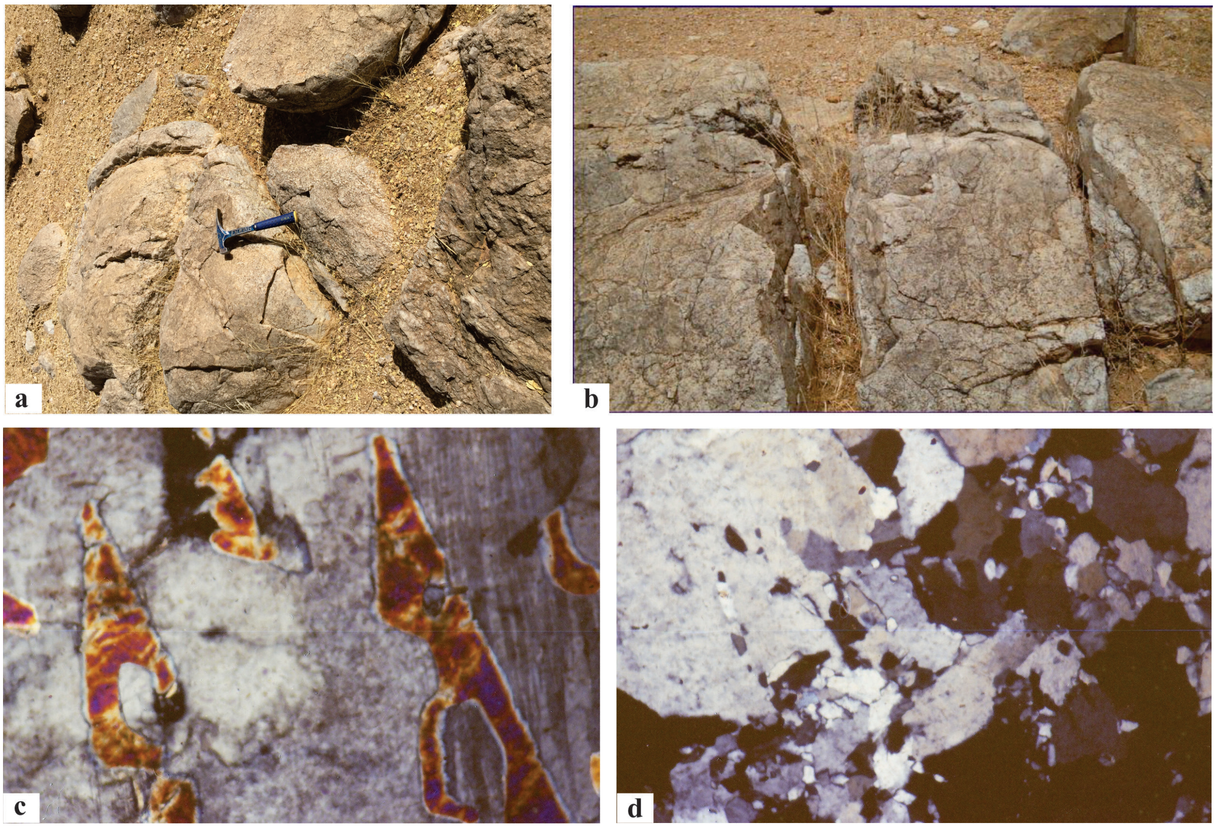

Figure 10.Outcrop photos of the quartzites showing (a-b) the directions and dimensional fractures (c-d) Photomicrographs of the quartzites displaying the undoluse extinction of quartz grains and the different generation of quartz

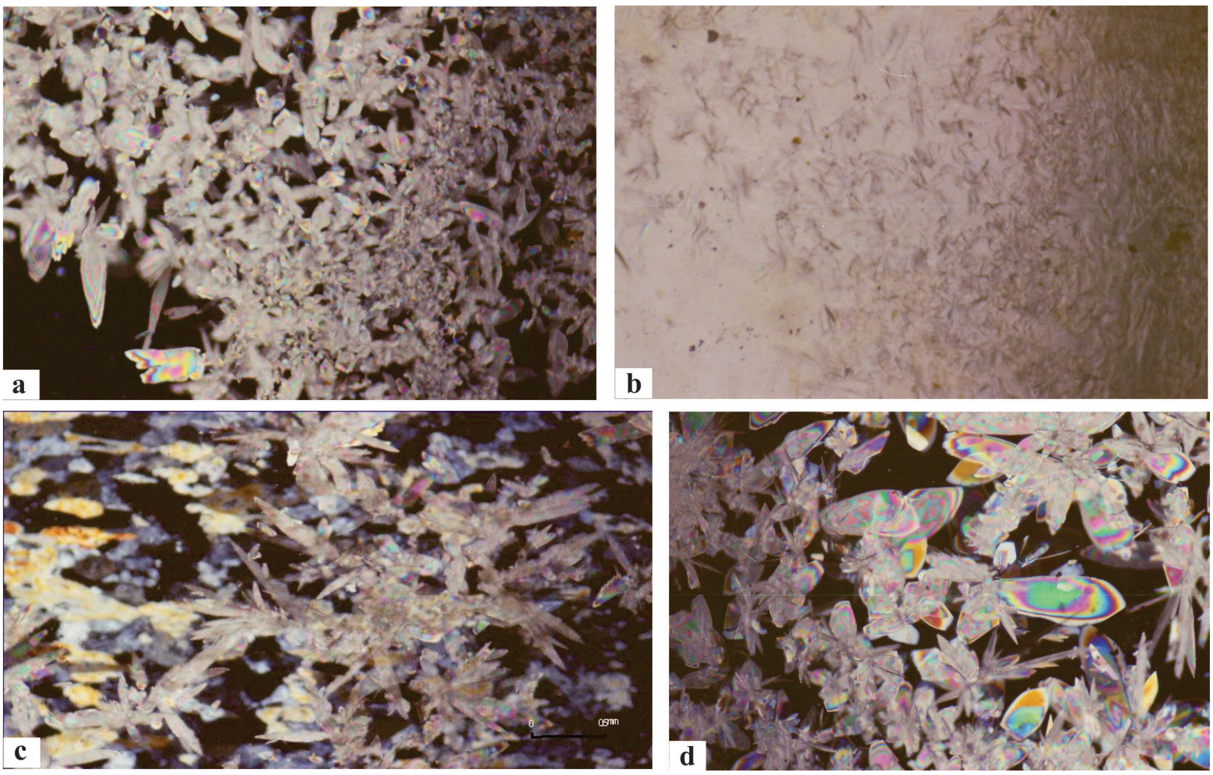

Figure 11.Photomicrographs of the felsite displaying fine-grained size quartz, with secondary calcite due to the shearing processes in the area

Figure 12.Set of fractures majorly with N-S strike in the most outcrops in the study area

Discussion

Microstructures and Mineral Generations

The study area containing different types of rocks the gneisses and migmatites, mica schist, quartzite, and 1-20 m thick lense-like layers amphibolites within the gneisses and migmatites. Some of these amphibolites developed felsic leucosomes, indicating anatexis and multiple origins. Three generations for these amphibolites had been reported (Mustafa, 2007; Mustafa et al., 2018, 2020).

Their minerals composition indicated many mineral generations. The first mineral generation composed of quartz, plagioclase (Pl_1), hornblende (Hb_1), and garnet Grt_1. The hornblende (Hb_1) displayed anhedral prismatic shapes with pleochroic dark green to pale yellow-green color. The Grt_1 is in contact with matrix and inclusion quartzes and monocrystalline plagioclase. Pl_1 is believed to exist but is unable to distinguish from the second mineral generation plagioclase due to modification or continuous growth following the peak metamorphism. The first-generation mineral assemblage is closely constrained to be formed at a condition of ~500-600°C and ~ 6-8 Kbar because hornblende and plagioclase (albitic) will turn to clinopyroxene and garnet.

The second mineral generations are presented by the rose-colored core of the porphyroblastic garnets (Grt_2), usually with embayment margin, and matrix hornblende (Hb_2), plagioclase (Pl_2), muscovite ($Musc_2$) and quartz (Qtz). Formation of the second-generation minerals need low temperature ~ 300Cº and ~3.5 Kbar because of muscovite appearance and interpreted through the following reaction format:

$Pl_1 + Hb_1 + Qtz$ ® $Grt_2 + Musc_2 + Pl_2 + Hb_2$

The third-generation mineral assemblage is represented by fine-grained hornblende (Hb_3) and plagioclase (Pl_3), occurring as intergrowth or symplectite around the embayed margins or as pseudomorph of the Grt_1. Growth of the Hb_3-Pl_3 intergrowths or symplectites interpenetrated as the result of hydration reaction forming the pseudomorph of garnet (Figure 7b).

Because growth of this generation consumed much of calcium in the second generation garnet, the Calcium content of the third-generation plagioclase increased. This implies that true pressure condition for the third generation mineral assemblage must be ~7.5 Kbar, also the temperature

$Grt_2 + Hb_2 + Qtz + H_2O$ ® $Pl_3 + Hb_3$

Metamorphic Cycles

The study area is a poly metamorphic terrains with an agreement with the idea of the others (e.g. El Ageed, et al., 1981; Al Beily, et al., 1986; El Khidir, 1997; Mustafa, 2007; Mustafa et al., 2018, 2020). The investigations of the rock units confirmed the various metamorphic grades, which subjected to poly-episode deformational history. Three cycles of metamorphism have been realized. The first M_1 affected the oldest units of the sequences probably of Precambrian age (Mustafa et al., 2018). It is medium- to high-grade of amphibolite facies. This cycle had been associated with the deformation of F_1 that dominated by fractures which were trending NW-SW, NE-SW. M_1 (Fig 12) and F_1 subjected to tectonic quiescence whereby the area was probably uplifted and exposed to an intensive erosional-depositional cycle producing a pile of sediments in the rift basins (El Khidir, 1997, Mustafa, 2007; Mustafa et al., 2018, 2020). The mineral composition and structures of the gneisses and migmatites which covered most of North Kordofan State represented this cycle are the second cycle; M_2 affects the pile and the Supracrustal metasediments due to the collision of the Saharan Metacraton and Arabian-Nubian Shield which known as Pan-African. It is of low-grade in greenschist facies conditions. This cycle represented by the mica schist and quartzite rocks and locally due to the P-T conditions of the metamorphism produced the pockets and lenses of amphibolites (Figure 5(a,b)). This cycle especially in J. Kordofan had affected by migmatization processes in the gneisses and migmatites carrying mineralization of mica and feldspar (Figure 3(a,b)) indicating retrograde metamorphism. The field evidence and Petrographical investigations and observations indicate that the second deformational episode F_2 is compressional and also had been observed from the symmetrical folds in the western side of J. Kordofan (Figure 8(e,f)) and the zigzag folds in the eastern side of this outcrop, in the mica schist (Figure 8(c,d)).

The third cycle; M_3 is dynamic, which affected all sequence units in the study area, of greenschist facies conditions, generated the third deformational episode F_3 which seem to be a shearing processes trending NE-SW, NNE-SSW and rarely NW-SE and N-S, according to regional extent due to reactivation processes in the Central African Fault zone (El Khidir, 1997, Mustafa, 2007; Mustafa et al., 2018, 2020). The extrusive felsitic rocks in J. Abu Khureis and the secondary calcite which came from the activities of the hydrothermal are a good characterization of the shearing.

The Relation between Metamorphism and Structures

The investigations show relationships between the metamorphism and deformations. These relations appear in the conjunction of any cycle of metamorphism with some deformations that have the same characteristics.

In the first cycle of metamorphism, a set of fractures was formed mostly with N-S strike (Figure 12), sometimes a different of NE-SW is found in the area. In this cycle, regional metamorphism can be deduced and so compressional deformation in the rocks will be expected such as folding and faulting, which filled the rift basins with pile sediments and Supracrustal sediments which metamorphosed during the Pan-African orogeny as the second cycle of the metamorphism.

The second cycle of metamorphism affects supracrustal sediments. Although elastic deformation as folds is present, brittle deformation is the common effect in this cycle as observed from the small faults in the mica schist in sharp contact with the gneisses and migmatites (Figure 8(a,b)) and somewhere found the slickenside as an indication of these faults due to the erosion of the mica schist. This cycle also had limited and horizontal distribution that deduced the mineralization of mica as an indication of the retrograde metamorphism in the gneisses and migmatites forming weak zones in this unit. The foliation of the mica schists and amphibolite rocks are characterized by NW-SE trending parallel to the axis of the folds in the area, which locally in J.Kordofan formed zigzag folds and somewhere had been strongly refolded (Figure 8(c-f)).

The third cycle of metamorphism M_3 is the more effective one in the study area due to dynamic nature, which affected all abundant sequences forming widespread joints having different orientations in all outcrops and reactivate the previous structures due to the regional shearing let the hydrothermal took place and carried mineralization such as the secondary calcite (Figure 11), which found in some outcrops and also the extrusive rocks in the sheared zones such as the felsite in J. Abu Khureis.

Generally, we suggest that the study area subjected to medium-grade amphibolite facies (medium-grade metamorphism) which locally retrograded to greenschist (low-grade metamorphism). The structures generally reflect the degree of metamorphism and the physical characteristics in the metamorphosed rocks. This relation is cleared by the conjunction of some structures with the different cycles of metamorphism.

Conclusion

The study area belongs to the Basement terrain of the recratonization zone the Saharan Metacraton of Pre-Pan-African age, where poly metamorphic terrains are contained in medium- to high-grade gneisses and migmatites of amphibolite facies. These rocks represented the first cycle, overlaid unconformably by supracrustal metasediments of low-grade greenschist facies comprised of mica schist rocks and locally of medium-grade of amphibolite facies represented by the amphibolite rocks. These rocks represented the second cycle of M_2. The third cycle M_3 is of dynamic nature and represented by the sheared felsitic rocks and the secondary calcite. The rock units in the area subjected by three deformational episodes F_1, F_2 and F_3 with its extensional, compressional, and shearing characteristics consecutively. Three mineral generations had been discriminated according to these three cycles helped in determining metamorphic characteristics.

Any of these cycles are in conjunction with deformations that formed the structures reflect the nature and the effects of the metamorphism on the rocks. The fractures and folding in the first cycle produced and the joints in the last cycle. Generally, the relationship between the metamorphism and the structures is in conjunction with any cycle according to its nature and grade.

Acknowledgment

The authors acknowledge with gratitude to who helped in the fieldwork and financial support.

References

1. Abdalla O.A.E. Ground Water Hydrology of the west-Central Sudan, Hydrochemical and Isotopic Investigations Flow Similuuation and Resources Management, Verlag Dr. Koster Berlin. 1999.
2. Abdel Mageed A. Sudan Industrial Minerals and Rocks, Center for Strategic Studies, Khartoum, Sudan. 1998.
3. Abdelsalam MG, Liégeois JP, Stern RJ. The Saharan

Metacraton: *Journal of African Earth Sciences* 2002; 34: 119-136.

4. Al Biely AI, Farwa AG, Gism ElSid NE. A Geological, Geophysical and Hydrogeological Investigation In North Kordofan, Department of Geology, University of Khartoum, Khartoum, Sudan. 1986.
5. Andrew G, Karkanis GY. Stratigraphical Notes. Anglo-Egyptian. *Sudan notes Rec* 1945; 2: 157-166.
6. El Ageed AI, Elrabaa SME: The Geology and Structural Evolution of The Northeastern Nuba Mountain Kordofan Province, Sudan, Bulletin No 32, Ministry of Energy and Mining Geology and Mineral Resources Department, Sudan. 1981.
7. El Khidir SOH. Metamorphic Evolution of Sodari-Umm Badr Area-North Kordofan, Sudan, M.Sc. Thesis, University of Khartoum. 1997.
8. Elmansour AA. Hydrogeological Study of Western Bara Basin North Kordofan State, M. Sc. Thesis, University of Kordofan. 2005.
9. El Rabaa SM. The Geology of Late Cambrian and Early Paleozoic Sediments in Sudan. African geology Society, Khartoum. 1976.
10. Khalil B, Kheir TM, Suliman ME. Prillnmary Report of Marble Deposit of Semeih Area as A raw Material for cement Industry. 1987.
11. Mustafa HA. A concept of the relationship between metamorphism and structures in El Boeid area, North Kordofan State, Sudan. M.Sc. Thesis, University of Kordofan. 2007.
12. Mustafa HA, Chen NS, Salih MA et al. Geochemistry and Petrogenesis of the amphibolites from Jebel Kordofan - El Obeid Area, North Kordofan, Sudan. *African Journal of Geosciences* 2018; 1: 40-59.
13. Mustafa HA, Salih MA, Abdelsamad MA et al. Significance of the Geochemistry, Petrogenesis and Tectonic Evolution of the Neoproterozoic amphibolites groups within the Gneisses and Migmatites from El Obeid Area, North Kordofan State, Sudan, to be published. 2020.
14. Rodis HJ, Hassan A, Wahadan L. Ground Water Geology of Kordofan Province Bulletin No. 14, Ministry of Mineral Resources, Geological Survey Department, Khartoum, Sudan. 1964.
15. Robertson Research International (RRI & GRAS): The Geology and Petroleum Potential of Southern, Central and Eastern Sudan, Geological Research Authority of Sudan, Khartoum, Sudan, Unpublished reports. 1990.
16. Schandelmeier H. and Richter A. Brittle Shearing Deformation in Northern Kordofan, Sudan: Late Carboniferous to Triassic Reactivation of Precambrian Fault Systems. *Journal of Structural Geology* 1991; 13:711-720.
17. Schandelmeier H, Richter A, Harms U et al. Lithology and structure of the late Proterozoic Jebel Rahib fold-and-thrust belt (SW Sudan). Berliner Geowissen Abher. 1990; 1: 15-30.
18. Vail JR. Outline of the geology and mineral deposits of the Democratic Republic of the Sudan and adjacent areas. Overseas Geology and Mineral Resources, London; 1978; 49-67.
19. Vail JR. Outline of the Geology of the Nuba Mountains and Vicinity Southern Kordofan Province, Sudan, vol. 23. Bulletin of the Geological and Mineral Resources Authority of the Sudan. 1973.
20. Whiteman AJ. The Geology o the Sudan Republic, Oxford, England. 1971.