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Geological and Structural Studies of Hammamat Sediments; Wadi Abu Hamr Area, Central Eastern Desert, Egypt

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ABSTRACT

Wadi Abu Hamr area is located between latitudes 26°34', and 26°36'N, and longitude 33° 31' and 33° 46'E, near the northern boundary of the Central Eastern Desert domain. It is characterized by a high rugged topography includes different mountains as Gebel (G.) Um Tagher, G.Abu Furad, G, Wasif, G.Wairah and G.Mohammed Rabah. The exposed rock types in the studied area can be classified as ultramafic rocks, metagabbros, metavolcanics, quartz diorites and tonalities, Dokhan volcanics, Hammamat Sediments, younger gabbros and monzogranites. The ultramafic rocks crop out in three parts of the studied area; the first one presents as elongated masses, extending NNE-SW on the northwestern corner of the area, and the other ones crop out as isolated two small masses in the central western part of the mapped area and cut by Wadi Abu Hamr and form hillocks of a moderate relief. The metagabbros are present in the western part of the studied area, and at the end of Wadi Safaga, as well as a small outcrop in the eastern part of the mapped area. The matavolcanic rocks covers the vast region in the central part of the mapped area and characterized by porphyro-blastic and amygdaloidal textures. The quartz diorite-tonalites crop in the western part of the studied area, and appear at the western part of Wadi El Pula. The Dokhan volcanics are cropping in the northeastern side of the mapped area. The Hammamat Group sediments well exposed at the east of the central part of the maped area, and occur as an elongated strip, covering an area of about 10km^2. The younger gabbros located at the mouth of Wadi Rabah and to the east of Wadi Safaga The monzogranites are located at the mouth of Wadi Rabah in the north and at the end of Wadi Waeara due south. The studied structures in the area are classified as: bedding geometry, bedding internal structures and gravitational deformation. The laminae thickness exceeds one cm in some outcrops of siltstones. The graded bedding shown in outcrops of sandstones. The cross-bedding is of "tabular type" Ripple marks are excellently exposed in the green siltstones, at the central part of Wadi Safaga. The folds in the study area are recognized as major and mesoscopic scales. The major folds are exposed in parallel, plunging major synclines. The axial traces are oriented in the E-W direction and extends for about 3km. The slaty and crenulation cleavage are recorded in the fine-grained tuffaceous metavolcanics, slates, phyllites and schists. The recorded linear structures in the study area are: 1-Mineral lineations parallel to fold axes, 2- Pencil-like lineations and 3- Boudinage. Strike-slip faults are the most effective type and are encountered in all the rock units with heavy concentration. These faults are represented as sinistral and dextral senses of movement. Fewer normal faults are also recorded.

Keywords: Wadi Abu Hamr, Structure, Bedding, Ripple Mark, Strike Slip, Metavolcanic, Hammamat, Wadi Safaga, Gebal, Eastern Desert.

1. Introduction

The basement rocks of Egypt cover an area of about 100.000 km^2. They are exposed mainly in the Eastern Desert along the Red Sea Coast as mountain chains, in southern part of Sinai, and as minor exposures at the extreme southwestern corner of the Western Desert of Egypt. In the Eastern

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Desert, the basement rocks extend as a belt parallel to the Red Sea Coast for a distance of about 800 km, between Latitudes 22° 00` and 28° 40`N. These rocks are, in parts, unconformably overlained on their western and eastern margins by Nubia sandstones and younger sediments. The basement rocks of the Eastern Desert and Sinai represent the tip of the Nubian Shield which in turn represents the western part of Arabian Nubian Shield.

Generally, the Arabian Nubian Shield covers the northeastern sector of the U-shaped Pan-African orogenic belt (Engel *et al*., 1980). The term "Pan-African" was originally introduced by Kennedy (1964), to denote a specific tectono-thermal event. The Pan_African orogenic belt displays evidence of a complex crustal evolution, which took place in several phases during the period of 1100 Ma to about 450 Ma age (Kennedy, 1964; Kroner, 1980). In this region, igneous and tectonic processes resulted in the development of primitive ensimatic crustal terrains, which were formed collapsed together and were engulfed by granites during the final 400 Ma of the Precambrian (Engle *et al*., 1980).

The construction of the Arabian-Nubian Shield during the Pan-African Orogeny offers an excellent opportunity to study the formation of continental crust. The Eastern Desert of Egypt comprises variably deformed and metamorphosed volcanic, plutonic, and sedimentary rocks of Precambrian age, unconformably overlained by Cretaceous sediments. The later magmatic stages activity were characterized by the emplacement of post-orogenic alkali granites and synchronous dykes during events of crustal extension, affecting wide areas of the Eastern Desert of Egypt and Central Arabia by the end of the Pan-African Orogeny (Stern, 1985; Stern and Hedge, 1985).

The basement rocks of the Eastern Desert of Egypt divided into three domains namely, the Northern Eastern Desert (NED), Central Eastern Desert (CED) and Southern Eastern Desert (SED) (Stern and Hedge, 1985). These domains were developed in different tectonic settings in an independent, but a very similar manner (Kroner *et al*., 1987) and show decreaseing in age from (SED) to (NED). Geologically, these domains also differ from each other, to their main exposed rock types. The Central Eastern Desert (CED) domain extends northward to the shear zone running along the Qena-Safaga road. The presence of Pan-African ophiolites increases and forms with the arc metavolcanics the main types in the CED. The ophiolites and the metavolcanics are occasionally unconformably overlained by Dokhan Volcanics and molasse sediments (Hammamat sediments). The older gneisses and migmatites form prominent domal structures, e.g. G. Meatiq (Struchio *et al*., 1983; Habib *et al*., 1985 and El Gaby *et al*., 1988), G. Sibai (Kamal, 1993; Khudeir *et al*., 1995 and Fowler *et al*., 2007), and G. El Shalul (Hamimi *et al*., 1994). The Older granitoids and younger pink granites are also present. Structurally, this domain is characterized by northwest trending shears, low-grade thrust and domal structures indicative of collisional tectonics (Abou Deif, 1992).

Many studies including mapping, geology, geochemistry, age dating, remote sensing and structure had been carried out on the studied area, e.g. Sampson (1906), Hume (1934 &1935), El Ramly and Akaad (1960), El Ramly (1972), EI Hakim (1972), Habib (1972), Akaad *et al*. (1973), Ammar (1973), Bishara and Habib (1973), Ivanovo *et al*. (1973), Noweir & Takla (1975), El-Gaby (1975), Takla & Noweir (1977), Bakhit (1978), Kamel and Bekir (1979), Grothaus, (1979), Kamel *et al*. (1980), Akaad and Noweir (1980), Shackleton *et al*. (1980), Takla *et al*. (1981), Ghobrial and Girgis (1982), Ries, (1983), El Gaby *et al*. (1988), Khalifa *et al*. (1988), Mostafa and Bakhit (1988), Elsevier (1988), Aly *et al*., (1991), The Egyptian Geological Survey and Minerals Authority (EGSMA), El-Mansi (1993), El-Sheshtawi *et al*. (1995) Ahmed and El-Mahallawi (1995), El-Debeiky (1995), Takla and Hussein (1995), Oraby (1996), Masoud (1997) and Noweir *et al*. (2001), Khalil (1997), Omran (2005), Mohamed A. Abd El-Wahed (2010), El Azab (2011), El Azab *et al*., (2012), and Hatem Aly (2017).

The main target of this paper is to evaluate the deformational history of the area, in order to establish its nontectonic and tectonic evolution. To reach this goal, study the geology of the area, synsedimentary structures, and a detailed structural map.

2. Geology

Wadi Abu Hamr area is occupied by igneous and metamorphic rocks belonging to late Precambrian units. It is located between latitudes 26°34', and 26°36'N, and longitude 33° 31' and 33° 46'E, near the northern boundary of the Central Eastern Desert domain. It is characterized by a highly rugged topography includes different mountain, as G.Um tagher, G.Abu furad, G, Wasif, G.Wairah and and G.Muhammed Rabah. The exposed rock types in the present studied area can be classified and arranged from oldest to youngest as; ultramafics (serpentinites and talc carbonates) and metagabbros, metavolcanics (metabasalts and metabasaltic-andesites, metaandesites and metadacites), older granites (quartz diorites and tonalities), Dokhan volcanics (basaltic-andesites, andesites dacites and rhyolite), Hammamat Sediments (conglomerate, sandstone, siltstone and mudstone), younger gabbros, and younger granites (monzogranites) (Fig.1).

The ultramafic rocks crop out in three parts in the studied area. The first one presents as elongated masses, extending NNE-SW at the northwestern corner of the map, and the other ones crop out as isolated two small masses in the central western part of the mapped area, cutted by wadi Abu Hamr and contacted with metagabbros, metavolcanics and quartz diorite-tonalites (Fig.1). They form hillocks of a moderate relief. The masses are composed of serpentinized peridotites. The serpentinized peridotites are olive-green to black on fresh surfaces. In some places they are cavernous, buff-colored talc-carbonate rocks. These rocks include few lenses of fresh, coarse-grained pyroxenites and have small chromite segregations. They are extensively sheared, and foliated. Their contact with the overlying metagabbros to the east is heterolithic, or a nonconformity surface and intruded by the granitoid rocks in the western side of the mapped area (Fig.2). Petrographically, the serpentinite rocks are massive, fine-grained and greenish black to dark green in color. Microscopically, they are composed of one or more serpentine minerals. Antigorite is the most common with variable amounts of chrysotile and lizardite. Chromite is the most abundant accessory mineral, beside chlorite, magnetite and hematite. The talc-carbonates rocks are finely to medium-grained and are reddish brown to yellow buff in color. Carbonate minerals are represented by magnesite and dolomite, which are represented as irregular grains. Talc appears as minute flakes or radiating bunches with a circular bladed habit. Antigorite is subordinate and forms fine flakes. Fine dusty grains of magnesite and hematite are sporadically dispersed throughout the rock.

The metagabbros are present in the western part of the studied area (Fig.1), cutted by, Wadi El Pula, Wadi Abu Hamr and at the end of Wadi Safaga and contacted with serpentine. They are also present as small outcrop in the eastern part of the mapped area and traversed by W. Rabah. They are characterized by a moderate topography and occur as massive and compact rocks of medium- to coarse-grained sizes, with grey to dark-grey color. These rocks are commonly fractured and highly altered especially along their contacts and fault planes. They are intruded by the quartz diorite-tonalities, especially from the north with the occurrences of characteristic granitic offshoots and apophasis, (Fig.3). Petrographically indeed, these rocks are mainly of equigranular texture with subordinate ophitic and poikilitic varieties. They are formed mainly of altered plagioclases, amphiboles and very little relics of pyroxene, together with subordinate to accessory sphene, chlorite, epidote, carbonate, apatite and opaques. The mineral assemblage indicates metamorphism in the green schist-lower amphibolites facies similar to the ophitic metagabbros of the Eastern Desert of Egypt. (Takla *et al*., 1981 and 1990).

The exposed metavolcanics in the study area cover the vast area in the central part of the mapped area, and cut by Wadi Safaga and Wadi Abu Furad, as will as the mouth of Wadis Al Bulah (Fig. 1). The metavolcanics are intruded by quartz diorite-tonalites with sharp contact (Fig. 4) and fault contact with hammamat sediments (Fig. 5). These rocks are highly weathered, and jointed. They are of a low to moderate topography, fine-grained sizes and greenish black to dark black in color. Occasionally, they are highly sheared, fractured, and altered, particularly along fault planes where brecciation, mylonitization and kaolinitization are well developed.

At the eastern part, to the east of W. Rabah, the metavolcnics are intruded by younger gabbros and monzogranite and intersected by dikes and offshoots of them. The rocks are highly weathered, and jointed. The matavolcanic rocks in the studied area are distinguished to metabasalts and metabasaltic andesites, metaandesites and metadacites. The metabasalts and metabasaltic rocks are grayish green to dark green with brownish green weathered surface. These rocks are characterized by porphyro-blastic and amygdaloidal textures. They are essentially composed of plagioclases, hornblende and pyroxene phenocrysts, embedded in a fine-grained groundmass. The groundmass consists mainly of small plagioclases crystals, epidote, zoisite, saussurite, tremolite-actinolite and chlorite as well as iron oxides. Opaques are the dominant accessory minerals while chlorite, epidote and saussurite occur as secondary minerals.

Meta-andesites are greyish green and display brownish green weathered surface. They are commonly porphyblastic and essentially composed of plagioclase and hornblende phenocrysts, embedded in a fine-grained groundmass. The groundmass is composed of the same mineral constituents with little amounts of interstitial quartz and clusters of epidote as well as iron oxides.

The metadacites are generally porphyritic and made up of quartz, plagioclases and biotite. The phenocrysts are mainly consisted of large crystals of quartz and plagioclase. Chlorite and sericite are present as secondary minerals. They are represented by very fine grains forming the groundmass of the rock. The iron oxides are the opaque accessory minerals.

The quartz diorite-tonalites crop in the western part of the studied area, and cut Wadi Abu Hamr, and appear at the western part of Wadi El Pula, intruded the metagabbros and metavolcanics (Fig.1). They have a sharp contact with hammamat sediments as nonconformity, (Fig. 6). Quartz diorite-tonalite rocks are highly weathered, foliated, jointed, and fractured. They also have metavolcanic xenolithes. These rocks are cut by numerous acidic dikes.

The quartz-diorites rocks are massive, medium to coarse-grained and are grey in color. Microscopically, they are hollocrystalline with hypidiomorphic to panidiomorphic granular textures. These rocks are essentially composed of plagioclases, hornblende, quartz and potash feldspars with minute crystals of biotite. Epidote and opaque minerals as well as zircon, titanite and apatite are accessories.

Tonalites are mainly composed of plagioclases, quartz, hornblende, biotite and potash feldspars. Opaques, sphene and apatite are accessories. These rocks show a gneissic structure.

The Dokhan volcanics constitute a definite and well-marked association corresponding to the well-known basalt-andesite-rhyolite association. They represent an important stratigraphic unit in the basement complex of Egypt, relatively older than the Hammamat Group.

The Dokhan volcanics are exposed at the north eastern part of the studied area (Fig. 1) and represent a bimodal suite composed of basic eruption followed by a felsic eruption with their pyroclastics. They are followed unconformably by Hammamat sediments. The acidic varieties of these rocks generally have pink brownish-red and red colors. The basic rocks are grey greenish in colors. The Dokhan volcanic rocks form moderate relief ridges. They show banding generally striking E-W with a gentle dip either to the north and/or south at 30°- 40°, The Dokhan volcanics are generally massive, sometimes foliated especially those pyroclastic and tuff members. Open folds were recognized in the tuffaceous rocks. The upper and thinner sequence is intercalated with the Hammamat facies sediments in a fault bounded basin.

In the studied area, it is revealed that the Dokhan volcanics have porphyritic nature and form a thick sequence of volcanic flows and minor pyroclastics, that are predominantly basaltic and rhyolitic in composition. They are cropping out at the northeastern side and extending further east beyond the eastern limit.

Petrographically, the basaltic andesite rocks have a distinctive porphyritic texture defined by abundant phenocrysts of plagioclases, together with amphibole and augite set in a fine grained groundmass of the same minerals. The accessory minerals include opaques and apatite. Secondary minerals include saussrite, epidote and chlorite. While the andesite rocks are the dominant variety of the Dokhan Volcanics in the studied area. They display colors ranging from dark gray to dark green. These lavas typically display a glomero-porphyritic texture and flow structure, defined by the parallel alignment of the tabular plagioclase phenocrysts. They are composed of plagioclase and hornblende phenocrysts embedded in a fine-grained groundmass.

The acidic variety of these rocks are represented by dacites and rhyiolites. The Porphyritic dacites are composed mainly of plagioclases, quartz, biotite and potash feldspars, as well as few hornblende phenocrysts embedded in a fine grained groundmass, which is formed of small laths of plagioclases, quartz, biotite, epidote and chlorite. Apatite, zircon, and sphene are common accessories. Saussurite, chlorite, and epidote are secondary minerals. This rock type sometimes fractured; the fractures are filled with secondary muscovite and quartz. While the rhyolites are porphyritic, leucocratic, and composed essentially of K-feldspar, quartz, with a minor amount of plagioclases, and some biotite phenocrysts embedded in a fine-grained groundmass of quartz and K- feldspar. Spherulites are common and are composed of radiating and fibrous aggregates of alkali feldspar intergrowths. The main accessories are opaques, apatite, sphene and zircon, whereas the secondary minerals are sericite, chlorite and kaolinite.

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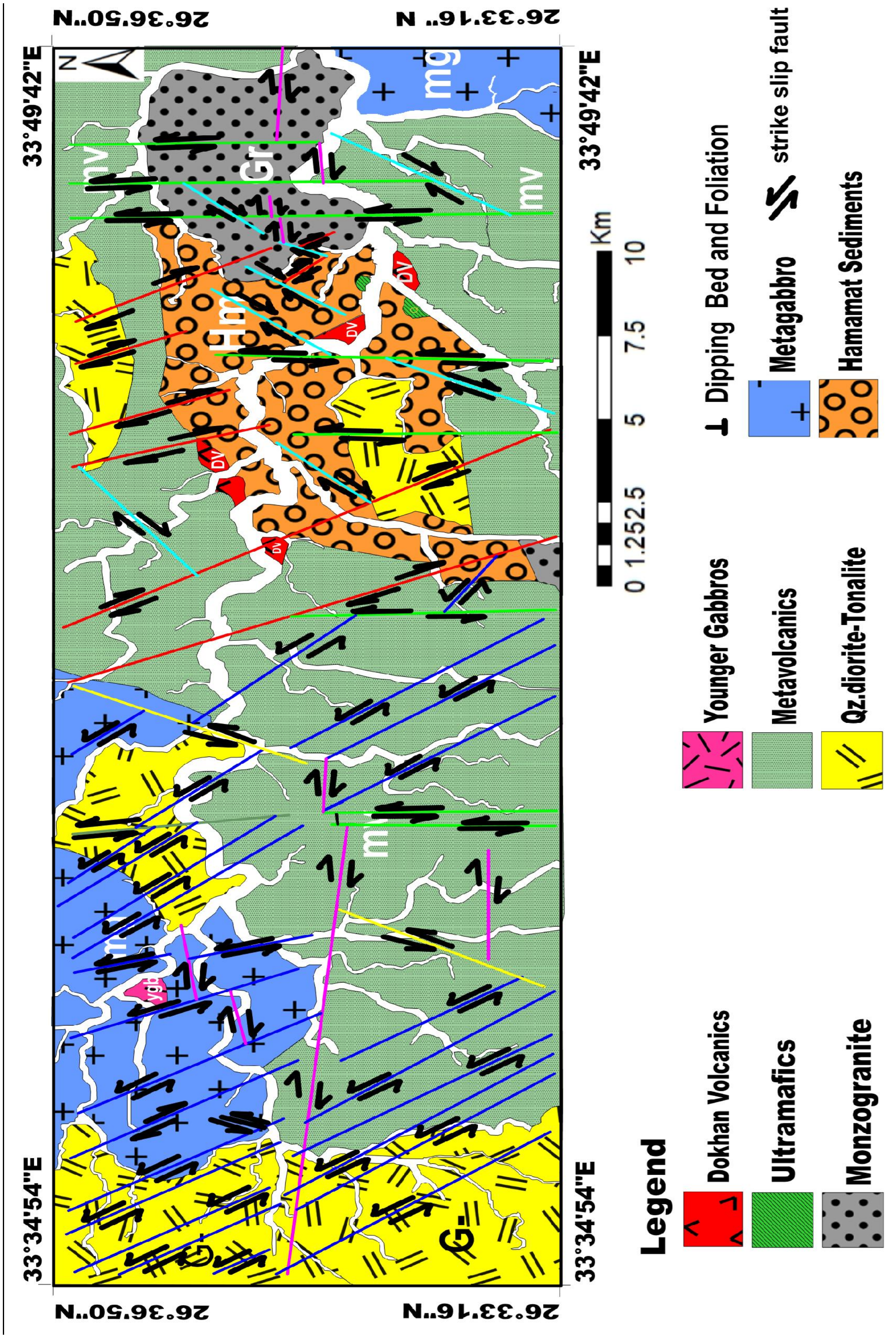

Fig. 1: Show structure map of the study area.

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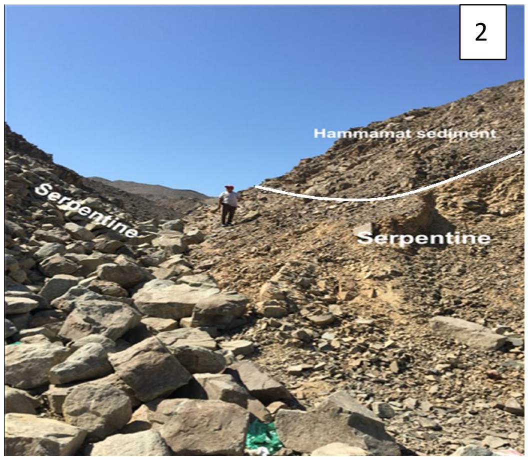

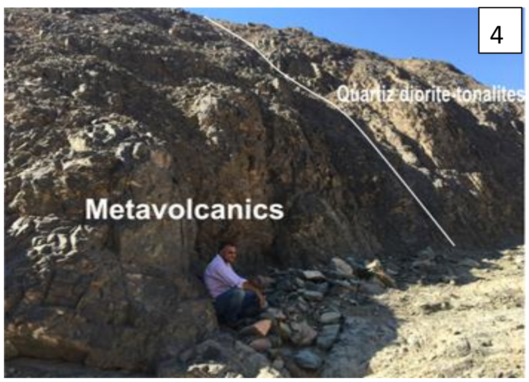

Fig. 2: Heterolytic, or a nonconformity between Hammamat sediments and Serpentine, photo looking South
Fig. 3: Roof Pendent of Metagabbro on the Older Granite in W. Safaga, photo Looking North
Fig. 4: Show the sharp contact between quartz-diorite-tonalites and Metavolcanics, photo looking southeast
Fig. 5: Fault contact between Metavolcanics Hammamat sediments, photo looking East.
Fig. 6: The Nonconformity contact between hammamat sediments and quartz diorite-tonalite, photo looking West.
Fig. 7: Contact between Hammamat and quartz diorite-tonalite, photo looking west.

The Hammamat Group sediments are well exposed in the east of the central part of the maped area cut by wadi safaga, (Fig.1). They occur as an elongate strip, covering an area of about $10km^2$ (2km wide and 5 km long), and trending in N-S to NNE-SSW direction. The sediments exhibit a relatively moderately topography. The contacts to the west and east with the metavolcanics and from the northeastern part with the quartz diorite-tonalites are sharp contacts, (Fig.7). The weathering products of the Hammamat sediments are blocks and spheroidal masses. The sequence of Hammamat sediments in the studied area are represented from bottom to top as: conglomerates, sandstones, green siltstones and green mudstones.

The conglomerates represent 5% of the Hammamat sediments, and are exposed at the contact with the monzogranite on the eastern and western shoulders of Wadi Safaga. The conglomerate represents the flanks of a major asymmetric syncline. These conglomerates vary in color from grey to reddish. They are polymictic: included clasts are mostly volcanic, and rarely granitic in Wadi Safaga outcrop. The clasts are angular to sub- rounded, ill-sorted, hard and compacted, in a fine-grained siliceous matrix. Normal graded bedding is recorded, particularly to the east and west sides. petrographically, the rocks are indurated, pebble and cobble conglomerates. The finer pebble conglomerates are hard, and reddish-grey in color. They consist mainly of pebbles of 1 cm to 3 cm in diameter, embedded in a reddish, hematitic or clayey matrix, in which chlorite is the major constituent. These clastics are mainly composed of angular to subangular quartz and plagioclase crystal fragments, and lithic clasts, the latter are mainly purplish porphyritic andesites and dacites porphyries.

The sandstones represent 5% of the Hammamat sediments and are present in the eastern, and western shoulders parts of Wadi Safaga. These beds are generally thin to thick, ranging from 10 cm to 100 cm in thickness; but in few outcrops the thickness of sandstones may reach 15m. The sandstones appear to be medium to coarse grained, moderately to poorly sorted, and frequently exhibit graded bedding. The sandstones vary from grey to green in color, (Fig.8). Petrographically, the sandstones are angular to subangular crystals with lithic fragments which are embedded in a matrix of sericite, chlorite, epidote and sphene. The clasts all exhibit undulose extinction and other deformational features. Plagioclase fragments are abundant and display sericitization, kinking, and bent twinning, equally abundant quartz exhibits a wavey extinction and incipient recrystallization. Cloudy orthoclase and bent chlorite flakes are recorded as accessories.

The siltstones-mudstones represent approximately 90% of the Hammamat outcrops. The mudstone is represented as thin beds in the eastern part of the main outcrop. The siltstones constitute the thickest Hammamat outcrops; the beds are generally very thin to very thick ranging from 3cm to 2m, and exceptionally may reach up to 70 m, (Fig. 9). They are well bedded and show color variation from green to purple, due to chlorite and hematite minerals respectively, while the mudstones are typically of greyish-green to dark green color. Numerous pyrite cubic are recorded in the green siltstones.

These rocks are hard, and reddish-purple or green in colour. Few of these rocks are cut by quartz and calcite veins. Microscopically, the siltstones consist of minute, angular to subangular and poorly sorted grains of quartz and minor feldspar. The matrix is usually rich in iron oxides, chlorite, and sericite.

The younger gabbros are located at the mouth of Wadi Rabah and are located to the east of Wadi Safaga (Fig.1). These rocks are characterized by a low to moderate topography and intruded by the monzogranites from the north, through a definite sharp contact dipping away from the granites. The contact zone is characterized by the presence of several granitic offshoots carrying roof pendants from gabbros (Fig.10). Also, the younger gabbros intrude the quartz diorite-tonalites, amphibolites and metavlocanics from the northwest, west, south and east respectively. They show a bouldery appearance and spheroidal blocks and traversed by pegmatite veins and dike swarms. The younger gabbros of this mass intrude the quartz diorite-tonalites and sending several apophyses into them and carrying them as roof pendants. They are fine to medium grained size, and dark grey to light grey in color. These rocks are hypidiomorphic, a with dark greyish green color (meso-gabbro). They are composed of plagioclases, hornblende, opaques and relics of pyroxene. Zoisite and chlorite are secondary minerals. Ophitic and subophitic textures are the predominant features.

The monzogranites are characterized by a higher topography than the surrounding country rocks such as the quartz diorite-tonalites, the metavolcanics and the younger gabbros. These rocks are located at the mouth of Wadi Rabah in the north and at the end of Wadi Waeara due south (Fig.1). These rocks are reddish pink to pink in color, medium- to coarse-grained and are characterized by vertical jointing and bouldery weathering with monumental shapes, (Fig. 11) as well as cavernous weathering and exfoliations. They intrud all the previously described rocks and send several offshoots into them. They also take xenoliths of them of different shapes (irregular, oval or elongated) and sizes (from 5 to 20 cm in diameter) and of different degrees of assimilation and digestion. The monzogranite is mostly medium to coarse grained, grayish pink in color, and shows hypidiomorphic equigranular with myrmekitic texture. Microscopically, they are composed essentially of quartz, microcline perthite, microcline, plagioclase and biotite, whereas sphene and allanite are found as accessory minerals.

Structural studies of the studied area revealed that the structures are classified as: bedding geometry, bedding internal structures and gravitational deformation.

Bedding is the most important feature, being a primary planar structure, inherited in a certain rock from the time of its formation. In the study area, bedding thickness exceeds one cm in some outcrops of siltstones. On the basis of field observation, bedding is a more appropriate description than foliation, (Fig. 12). The strike of the beds varies from ENE-WSW and dip amounts are subhorizontal to subvertical. The graded bedding in the study area show in outcrops of sandstones. It is regularly well sorted, ranging from course at the base, to fine at the top. This indicates that the beds are right-way-up. The cross-bedding which is recorded in the study area, as a tabular type, according to Mckee and Weir (1953). It is bounded by ordinary horizontal subparallel bedding planes or strata with no cross- stratification, (Fig.13). Ripple marks are excellently exposed in the green siltstones, in the central part of Wadi Safaga, (Fig.14). The ripples are asymmetricand strike in the mean direction of E-W; they have a gentle slope of 40°N and a steep slope of 50°S. The ripple marks indicate normal position of the bedding, and the current direction is induced to be from south to north.

Gravitational deformation is concerned only with deformation which took place while the sediment was still in the environment of deposition, thus excluding tectonic and other later deformation. The resulting gravitational slide or slump produces folds and faults in the affected materials.

Folds are delineated in wide distribution over the study area. The folds are recognized on both the major and mesoscopic scales.

Major folds are exposed as parallel, plunging major synclines. The axial traces are oriented in the E-W direction, and plunge 15° towards the E-W, while the limbs dip by 40° to70° toward north direction, (Fig.15). The axial trace extends for about 3 km. The core of this fold is occupied by the Hammamat sediments. The folds are isoclinal, open, asymmetrical and of different wave lengths. The exposures of these major folds are well observed in Wadi Safaga.

The metavolcanics and Hammamat sediments show numerous fold exposures of different styles. The folds range in size from few centimeters up to few meters. The recorded fold styles are open concentric, closed, and tight, (Fig.16). The folds are generally asymmetric, and the axial planes show different inclinations. The hinges are generally rounded (Fig. 17).

Two types of foliations are principally recorded in the study area. The slaty cleavage is a penetrative foliation occurring in the fine-grained rocks, primarily the siltstones of the Hammamat Group, and some tuffs affiliated to the metavolcanics (Figs. 18 a and b, respectively). The second one is crenulation cleavage which is produced by microfolding (crenulation) of "preexisting, continuous cleavage" (Davis and Reynolds, 1996). This foliation is a penetrative and recorded only in the fine-grained tuffaceous metavolcanics, slates, phyllites and schists. It is a "zonal" crenulation cleavage (opt. cit.), as it is "marked by wider cleavage domains" (opt. cit.), on the limbs of the microfolds (Fig.19). A non-penetrative foliation consisting of persistent, closely-spaced fractures. May occur in sandstone, siltstone, (Fig. 20) and igneous rocks.

Penetrative planar fabric elements such as foliations and bedding are usually combined with penetrative linear fabric elements. These linear structures are considered as strain markers, defining the axes of folding in different phases (Hatcher, 1990). In the study area, the following lineation varieties are recognized: 1-mineral lineations parallel to fold axes, (Fig. 21), 2- Pencil-like lineations, (Fig. 22) and 3- boudinage.

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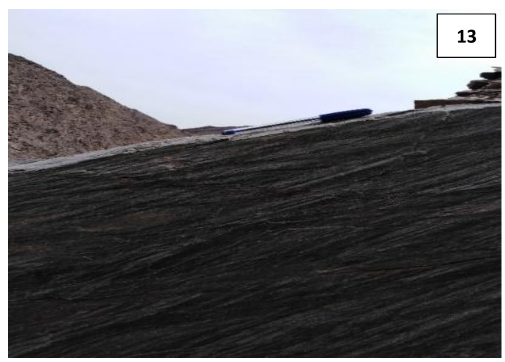

Fig. 8: The sandstones vary from grey to green in color, photo Looking south.
Fig. 9: The siltstone beds are ranging from 3cm to 2m , photo Looking East.
Fig. 10: Roof pendants from younger gabbro on monzogranite photo Looking north.
Fig. 11: Bouldery weathering with monumental shape in monzogranites. photo Looking north.
Fig. 12: Show the bedding in Hammamat Siltstone, photo Looking South.
Fig. 13: Tabular type of Cross Bedding in Hammamat Group siltstone Wadi Safaga, photo Looking West.
Fig. 14: Show Ripple mark trend E-Won the Hammamat Group Siltstone.
Fig. 15: Show the major fold and the trace of fold axis in wadi Safaga. photo Looking south west.

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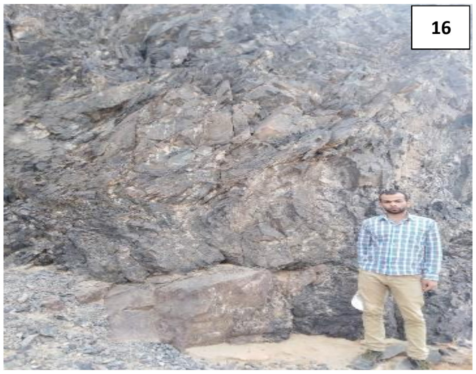

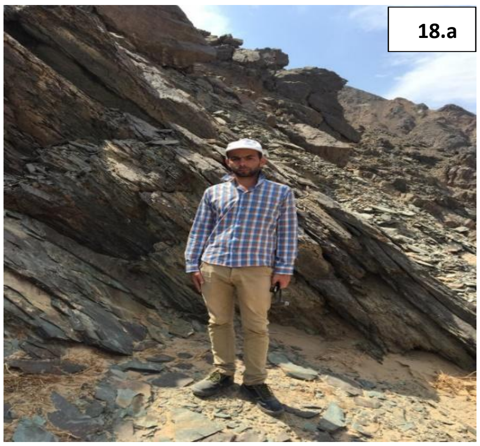

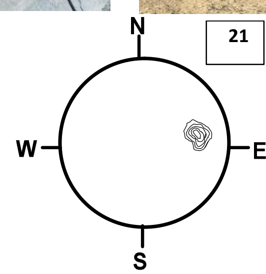

Fig. 16: Show closed tight mesoscopic fold, photo Looking south.
Fig. 17: Show the mesoscopic fold with rounded hinge photo Looking sourh.
Fig. 18a: Show Slaty cleavage in Hammamat siltston, photo Looking West.
Fig. 18b: Show Slaty cleavage in Metavolcanic, photo Looking south.
Fig. 19: Crenulation cleavage (parallel to penknife) formed by micro-folding of inter-bedded pelites (originally muddy units). The limbs of the crenulation microfolds in the silt layers are disrupted and show partial dissolution features (pressure solution) that result in a preferential concentration of hyllosilicates in bands that define the crenulation cleavage planes. photo Looking east.
Fig. 20: Well-developed fracture cleavage consisting of closely-spaced array of vertical fractures in Hammamat Siltstone. photo Looking south.
Fig. 21: Show stereonet of Mineral Lineation parallel to fold axes in Metavolcanics.

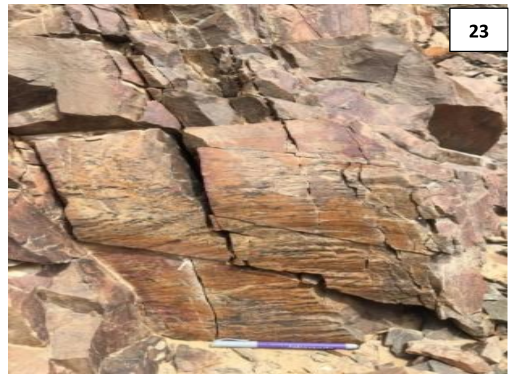

Fig. 22. Show Pencil-Like Lineations. photo Looking east.
Fig. 23: Horizontal Slickensides are often composed of fibrous crystals that stretch from one side of the fault plane to the other, photo Looking north.
Fig. 24: NS Left Lateral Strike Fault, photo Looking North.
Fig. 25: NW-Right Lateral Fault, photo Looking North West.
Fig. 26: Normal Fault in Hammamat Siltstone, photo Looking North.

Faults are essential structural features in the study area. These faults have been well studied in the present work, with emphasis on fault slip. Slickensides and grooves are commonly associated with brittle faulting. These kinematic indicators indicate the direction and sense of maximum resolved shear stress in that plane (Carey and Brunier, 1974). Slickensides are often composed of fibrous crystals of chlorite, epidote, calcite, and quartz that stretch from one side of the fault plane to the other side, (Fig. 23). Strike-slip faults are the most effective type and are encountered in all the rock units with a heavy concentration. Of NS, and NE trends are left-lateral (Fig. 24), while those of E-W and NW trends are right-lateral faults (Fig. 25). Fewer normal faults are also recorded and are mainly appear in the Hammamat sediments (Fig. 26).

Conclusion

The exposed rock types in Wadi Abu Hamr area are classified and arranged from oldest to to youngest as: ultramafic rocks, metagabbros, metavolcanic, quartz diorites and tonalities, Dokhan volcanics, Hamamat Sediments, younger gabbro, monzogranites and daykes.

The ultramafic rocks are composed of serpentinized peridotites and crop out in three parts in the studied area. The first one presents as elongated masses, extending NNE-SW on the northwestern corner of the maped and the area other ones crop out as isolated two small masses in the central western part of the mapped area and cut by Wadi Abu Hamr, contacted with metagabbros, metavolcanics and quartz diorite-tonalites. The masses have few lenses of fresh, coarse-grained pyroxenites and have small chromite segregations.

The metagabbros are present in the western part of the studied area, cut by Wadi El Pula and Wadi Abu Hamr and at the end of Wadi Safaga they contacted with serpentine, they are also present as small outcrop at the eastern part of the mapped area and traversed by W. Rabah. They are characterized by a moderate topography and occur as massive and compact rocks of medium- to coarse-grain sizes, with grey to dark-grey color.

The metavolcanics in the study area cover vast area in the central part of the mapped area and cut by Wadi Safaga and Wadi Abu Furad as will as the mouth of Wadis Al Bulah and Abu Furad. These rocks are distinguished to Metabasalts and metabasaltic andesites, metaandesites and metadacites. These rocks are characterized by porphyro-blastic and amygdaloidal textures.

The quartz diorite-tonalites crop in the western part of the studied area and cut Wadi Abu Hamr, and appear in the western part of Wadi El Pula intruded the metagabbros and metavolcanics.

The Dokhan volcanics constitute a definite and well-marked association corresponding to the well-known basalt-andesite-rhyolite association. They are cropping out in the northeastern side on mapped area.

The Hammamat Group sediments are well exposed in the east of the central part of the maped area cut by Wadi safaga, where they occur as elongate strips, covering an area of about 10km^2, trending in N-S to NNE-SSW direction. The sediments exhibit a relatively moderately topography.

The younger gabbros are located at the mouth of Wadi Rabah and located to the east of Wadi Safaga. These rocks are characterized by a low to moderate topography, and intruded with the monzogranites from the north, and intrude the quartz diorite-tonalites and metavlocanics from the northwest, west, south and east respectively.

The monzogranites are characterized by a relatively higher topography than the surrounding country rocks. The rocks are located at the mouth of Wadi Rabah in the north and the end of Wadi Waeara in the south. They send several offshoots into the surround rocks.

The structures in the studied area are classified as bedding geometry, bedding internal structures and gravitational deformation. The bedding thickness exceeds one cm in some outcrops of siltstones. The graded bedding show in outcrops of sandstones. The cross-bedding is of "tabular type" according to Mckee and Weir (1953). Ripple marks are excellently exposed in the green siltstones, in the central part of Wadi Safaga. Gravitational deformation is concerned only with deformation which took place while the sediment was still in the environment of deposition, thus excluding tectonic and other later deformation. The resulting gravitational slide or slump produces folds and faults in the affected materials.

The folds in the study area are recognized in both major and mesoscopic scales. Major folds are exposed in parallel, plunging major synclines. The axial traces are oriented in the E-W direction, and plunge 15° towards the E-W, while the limbs dip by 40° to70° toward north direction. The axial trace extends for about 3km. The core of this fold is occupied by the Hammamat sediments. The folds are isoclinal, open, asymmetrical and of different wave lengths. The exposures of these major folds are well observed in Wadi Safaga.

The Slaty and crenulation cleavage are recorded in the fine-grained tuffaceous metavolcanics, slates, phyllites and schists. It is "marked by wider cleavage domains"on the limbs of the microfolds. The linear structures are considered as strain markers defining the axes of folding in different phases (Hatcher, 1990). In the study area, the following lineation varieties are recognized: 1-Mineral lineations parallel to fold axes, 2- Pencil-like lineations and 3- boudinage. Faults are essential structural features in the study area. These faults have been well studied in the present work, with emphasis on fault slip. Slickensides and grooves are commonly associated with brittle faulting. These kinematic indicators appear the direction and sense of maximum resolved shear stress in that plane (Carey and Brunier, 1974). Strike-slip faults are the most effective type and are encountered in all the rock units with heavy concentration. These faults are represented in both orders of sinistral and dextral senses of movement. Fewer normal faults are also recorded.

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