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GEOLOGY AND PETROGRAPHY OF MUBARAK AREA, CENTRAL EASTERN DESERT, EGYPT

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Abstract: The Mubarak region is covered by two major rock units: the Island Arc Association and granitoids. This Island Arc Association is represented by metaandesite, hornblende-actinolite schist, and amphibolite, which were metamorphosed up to amphibolite facies. Granitoids are classified based on the petrographic mineral composition into two phases: the syn- to late-orogenic phase and the post-orogenic phase. According to field observations and petrographic analyses, these granitoids are magmatic rocks with isotropic texture, as opposed to the Island Arc Association, which is strongly foliated, indicating that a NW shortening occurred prior to the emplacement of the weakly metamorphosed granodiorite and the non-metamorphic post-orogenic intrusives.

Keywords: *granite, Pan-African Orogeny, intrusive, Island Arc Association*

1. Introduction

The Neoproterozoic crystalline basement rocks of Egypt's Eastern Desert and Sinai comprise the northern edges of the Arabian-Nubian Shield (ANS) juvenile arc terrain, which was cratonized during the late Neoproterozoic Pan-African Orogeny (900–550 Ma) *(Figure 1a)* [1]. This section of the ANS is also covered by a diverse range of rock types, including gneisses and ophiolitic mélange, which have been intruded by syn- to late-orogenic tectonic granitoids with adjacent volcanic formations and are covered by molasse-type sediments of late Proterozoic age *(Figure 1b)* [2–4]. Gneisses and migmatites comprise the Egyptian basement complex's rocks, as well as the ANS [5, 6]. The ophiolites are variably dismembered and are divided into three units that display a sequence from mantle section upward through mafic crust to the overlying mafic volcanic rocks [7]. These units include (1) serpentinites, (2) meta-pyroxenites, and (3) metagabbro and metavolcanic rocks.

The rock assemblage of the Island Arc Association (IAA) is composed of (1) an intrusive gabbro-diorite-tonalite suite, (2) calc-alkaline metavolcanics and meta-tuffs and (3) rare sedimentary iron deposits and shallow-marine carbonate facies [8–11].

Granite rocks are divided into three categories: (1) older grey calc-alkaline granites, (2) younger pink granites, and (3) A-type (alkaline/peralkaline) granites [12–17]. Additionally, the ANS calc-alkaline magmatism is divided into two distinct series: syn- to late-orogenic island arc intrusive (625–650 Ma) and post-orogenic (590–625 Ma) with less deformation [18, 19]. Gabbroic rocks are found across the Eastern Desert basement complex and are classified into two age groups, the ophiolitic meta-gabbros and fresh post-orogenic gabbros.

The distribution of these lithologies structurally divides the Eastern Desert into three distinct regions, the northern, central, and southern Eastern Desert, along two structural axes: the ENE dextral Qena-Safaga shear zone and the WNW sinistral Kom Ombo-Houdin shear zone, respectively *(Figure 1b)* [20]. In comparison to the northern and southern Eastern Deserts, which are dominated by granitic rocks and low-grade cover nappe, respectively, the central Eastern Desert is dominated by massive gneissic rocks. Additionally, the exhumation of these gneissic rocks is controlled and limited laterally by the NW-trending sinistral Najd Fault System (NFS) [21–23].

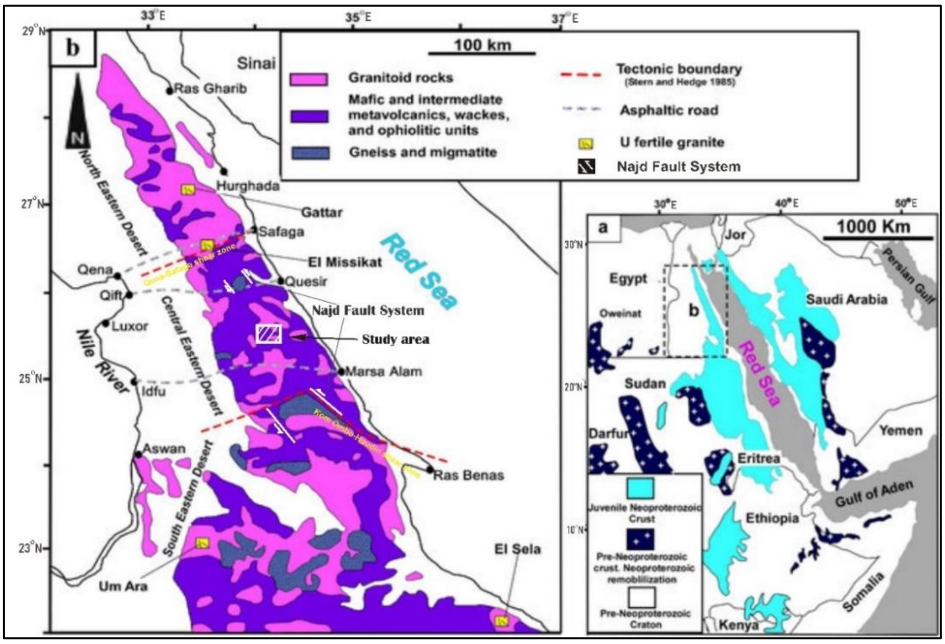

Figure 1

(a) Map of the Arabian-Nubian Shield (ANS) modified after [27]*, showing the location of Eastern Desert of Egypt (frame b) and regions of pre-Neoproterozoic crust outcrops; (b) Generalized map of Eastern Desert, showing the distribution of lithologies, and major tectonic boundaries, modified after* [28]

In sharp contrast to the NFS and associated structures, the Mubarak belt usually runs east–west to northeast–southwest *(Figure 1b)*. Based on this, Shalaby and his co-authors concluded that considering the Mubarak belt as a conjugate fault to the NFS provides the most convincing explanation for its deformation model and is consistent with the central Eastern Desert tectonic framework [24]. This belt is shaped like a wedge by post-accretionary lower greenschist facies surrounded by less deformed metavolcanics [25, 26]. It is composed mainly of a dense sequence of low-grade volcano-sedimentary rocks with arc and back-arc affinities. Furthermore, it contains significant granitoids of unclear tectonic origin. This belt is bisected by the Mubarak–Dabr Metagabbro–Diorite Complex from the south [26].

The aim of this study is to classify the rock types found in the Mubarak area of the central Eastern Desert of Egypt based on the lithological groupings that have emerged in the ANS and their petrographic descriptions. This study is based on field observations and sample collection from all lithologies exposed in the area for petrographic classification. The sampling sites are chosen along the Mubarak belt to represent the change in the grade of metamorphism and mineral composition, on the rim and core of the granitoid intrusions as well. This paper presents the rock types based on optical microscopy, which is a contribution to the comprehensive study of the larger Um Nar area. This area is currently investigated completely through the integration of structural, geochemistry, and remote sensing data to analyze its tectonic framework in greater depth [24].

2. LOCATION OF THE STUDY AREA

Wadi Mubarak is located in the central Eastern Desert and covers approximately 300 kilometers between longitudes 34º11'E and 34º28'E and latitudes 25º10'N and 25º22'N. It is located near the city of Mersa Alam and is accessible by the Mersa Alam-Idfu asphaltic road *(Figure 2a)*. Along with the arid climate and sparse vegetation, this area is characterized by rigid topography due to the presence of multiple steep peaks, especially Gebel El Mayit (830 m).

3. GEOLOGIC SETTING

The rocks of Wadi Mubarak can be classified into three major lithological units: (1) Pan-African nappe assemblages, (2) Syn- to late-orogenic calc-alkaline intrusives, and (3) Post-orogenic granitic and gabbroic intrusions.

3.1. Pan-African nappe assemblage

The Pan-African nappe assemblage is represented by the IAA of the Mubarak belt. Unlike the Najd Fault System and its accompanying structures, this belt extends east–west to northeast–southwest (see *Figure 4*). The Mubarak belt is typically shaped like a sliver border and possesses nearly vertical layers of a metamorphic association of volcanic and volcano-sedimentary origin including amphibolites, schists, and low-grade metaandesites *(Figure 2b)*.

On the eastern side of the Mubarak belt, the medium-grade schists and amphibolites are abundant, which are strongly foliated in contrast with the metaandesites, which are widely exposed on the western side and distinguished by being massive, weakly metamorphosed volcanic slabs (*Figures 3a* and *b*).

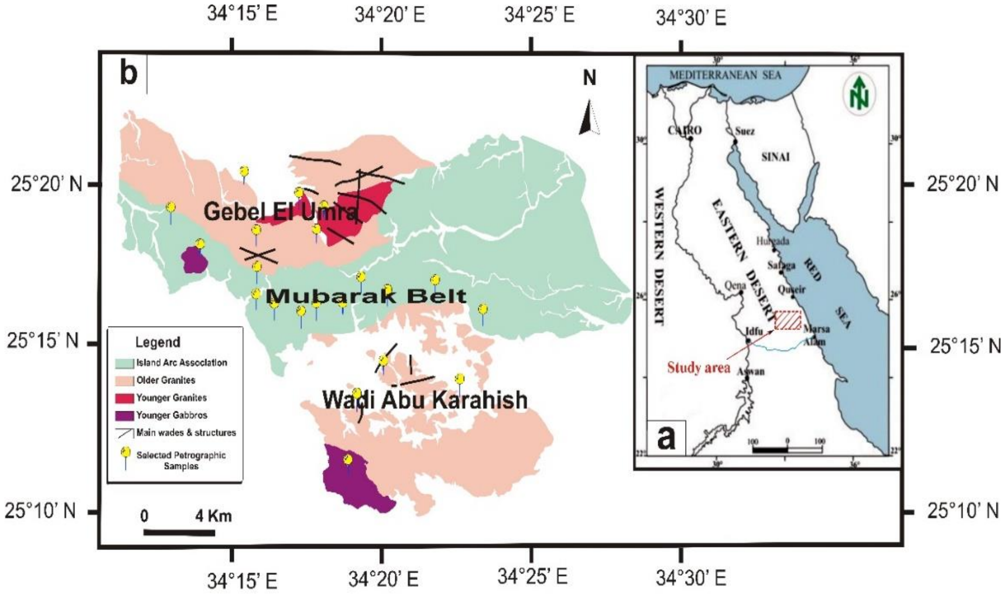

Figure 2

(a) Location map of the Eastern Desert of Egypt showing the study area,
(b) Geological map of the Mubarak area showing different lithologic units

3.2. Syn- to late-orogenic calc-alkaline granites

The older "grey" granites may be found in the areas of El Umra and Abu Karahish, which are located to the north and south of the Mubarak belt, respectively, and are considered to be younger than the Mubarak belt *(Figure 2b)*. Granitic bodies in El Umra have an E-W elongated ellipsoidal form, whereas Abu Karahish granite is exposed as irregular bodies which are covered mostly by sand deposits.

These rocks are coarse-grained equigranular magmatic rocks of granodioritic composition *(Figure 3d)*. These granodiorites are exposed as sporadic low hills showing extensive weathering features (e.g., exfoliation and fractures) and devoid of any features of metamorphism *(Figure 3c)*.

3.3. Post-orogenic intrusives

The Mubarak region exhibits numerous plutons of post-orogenic granitic and gabbroic composition. The post-orogenic granites are referred to as "pink younger granites" and are found in El Umra area as non-deformed irregular intrusive bodies forming sharp contacts with the previously formed older granites (*Figures 2b* and *3e*). The post-orogenic gabbros bodies have circular outlines. They are mostly exposed in the western and southern parts of the mapped area (*Figures 2b* and *3f*).

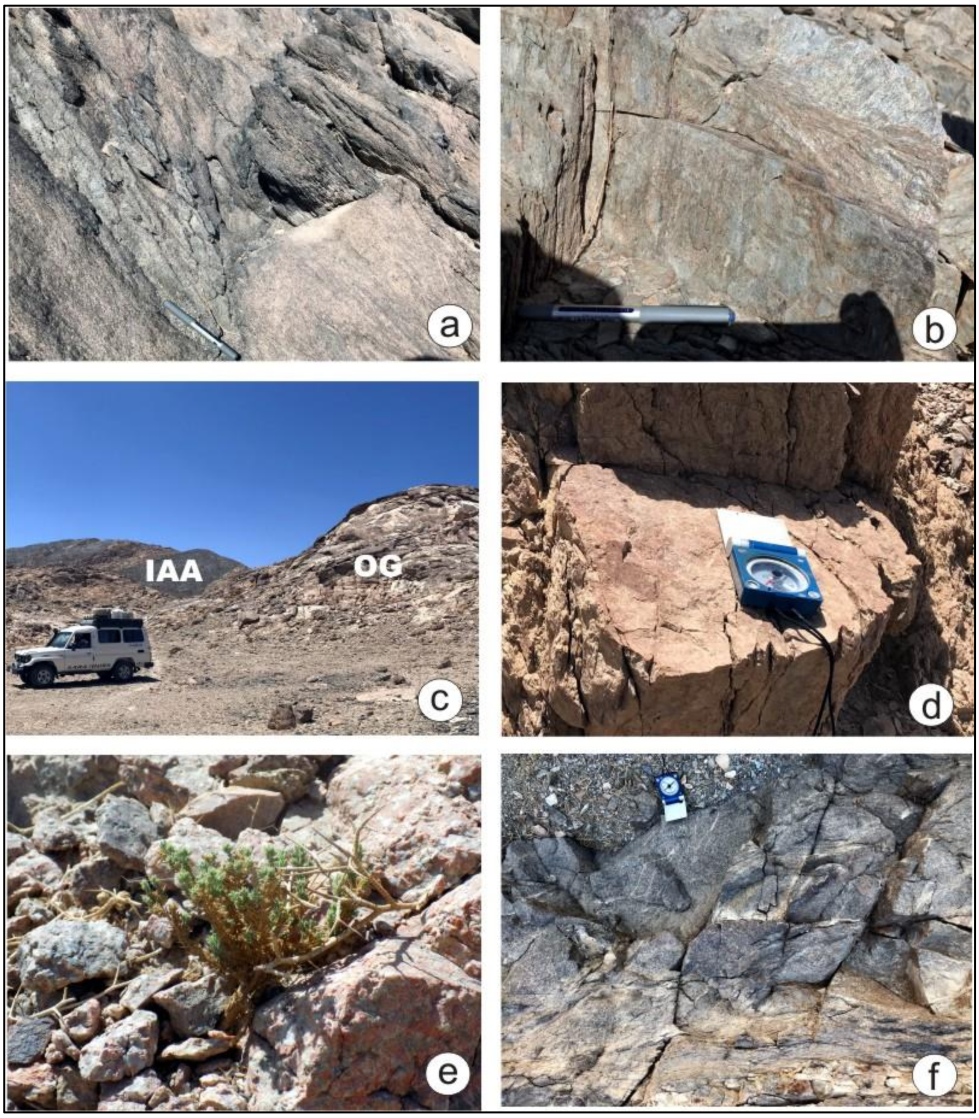

Figure 3
Field observations showing (a) the amphibolites and schists of the Mubarak belt, (b) the Island Arc metavolcanics, (c) older granites of Abu Karahish area, (d) older granites of Gebel El Umrah, (e) post-orogenic granites, and (f) post-orogenic gabbros

4. PETROGRAPHY

This description is based on twenty-three representative petrographic thin sections for the different lithologies dominating the Mubarak area *(Table 1)*.

Table 1

Selected petrographic samples with their rock types and geographic coordinates

Rock Sample	Rock Name	Longitude	Latitude
D11	Amphibolite	34°23'16.44"E	25°16'0.91"N
D12	Amphibolite	34°23'25.07"E	25°16'8.22"N
D13	Amphibolite	34°23'22.55"E	25°15'54.81"N
D13 b	syn-to-late orogenic granodiorite	25°15'44.14"N	34°23'4.76"E
N15	post-orogenic gabbro	34°19'6.28"E	25°11'51.85"N
N17	syn-to-late orogenic granodiorite	34°19'24.15"E	25°13'49.69"N
N18	syn-to-late orogenic granodiorite	34°20'6.39"E	25°13'42.20"N
N20	Amphibolite	34°19'7.20"E	25°16'8.06"N
N22	post-orogenic gabbro	34°13'50.91"E	25°16'57.89"N
N25	Hornblende-actinolite schist	34°16'6.62"E	25°16'32.17"N
N29	syn-to-late orogenic granodiorite	34°17'7.60"E	25°18'7.29"N
N 30 b	post-orogenic granite	34°17'53.82"E	25°18'21.90"N
N31	syn-to-late orogenic granodiorite	34°13'4.58"E	25°21'54.69"N
N32	syn-to-late orogenic granodiorite	34°13'10.78"E	25°19'3.94"N
N34	Meta-andesite	34°14'13.97"E	25°17'26.72"N
N35	Meta-andesite	34°13'38.51"E	25°17'49.77"N
N36	post-orogenic gabbro	34°13'19.99"E	25°17'32.78"N
N37	Meta-andesite	34°11'26.43"E	25°18'47.08"N
N38	Meta-andesite	34°11'4.73"E	25°18'33.62"N
N39	Meta-andesite	34°10'56.33"E	25°19'0.37"N
5	Hornblende-actinolite schist	34°18'26.53"E	25°15'58.45"N
6	Hornblende-actinolite schist	34°17'47.52"E	25°16'10.03"N
7	Hornblende-actinolite schist	34°16'54.16"E	25°16'22.21"N

4.1. Pan-African nappe assemblage

4.1.a. Amphibolite

Amphibolite is foliated, hard, massive, and fine-grained rocks of dark green in color *(Figure 4a)*. This rock is essentially composed of amphibole phenocrysts embedded in a fine-grained groundmass of quartz, plagioclase, and minor biotite. Chlorite, epidote, sericite, and iron oxides are abundant as subsequent mineral phases overgrown on amphiboles. **Amphiboles** form subhedral, oriented prismatic crystals reaching up to (265 μm × 80 μm) in size and are mostly represented by actinolite and scarce hornblende. Felsic minerals fill the space between amphibole crystals aligned according to the foliation. **Quartz** occurs as equant crystals with undulate extinction (45 μm × 40 μm). **Chlorite** occurs frequently (700 μm × 274 μm) as large flakes surrounding amphibole crystals but are not oriented. **Sericite** is common within plagioclase relics. **Iron oxides** form anhedral crystals, partly concentrated on the cleavage planes of amphibole crystals.

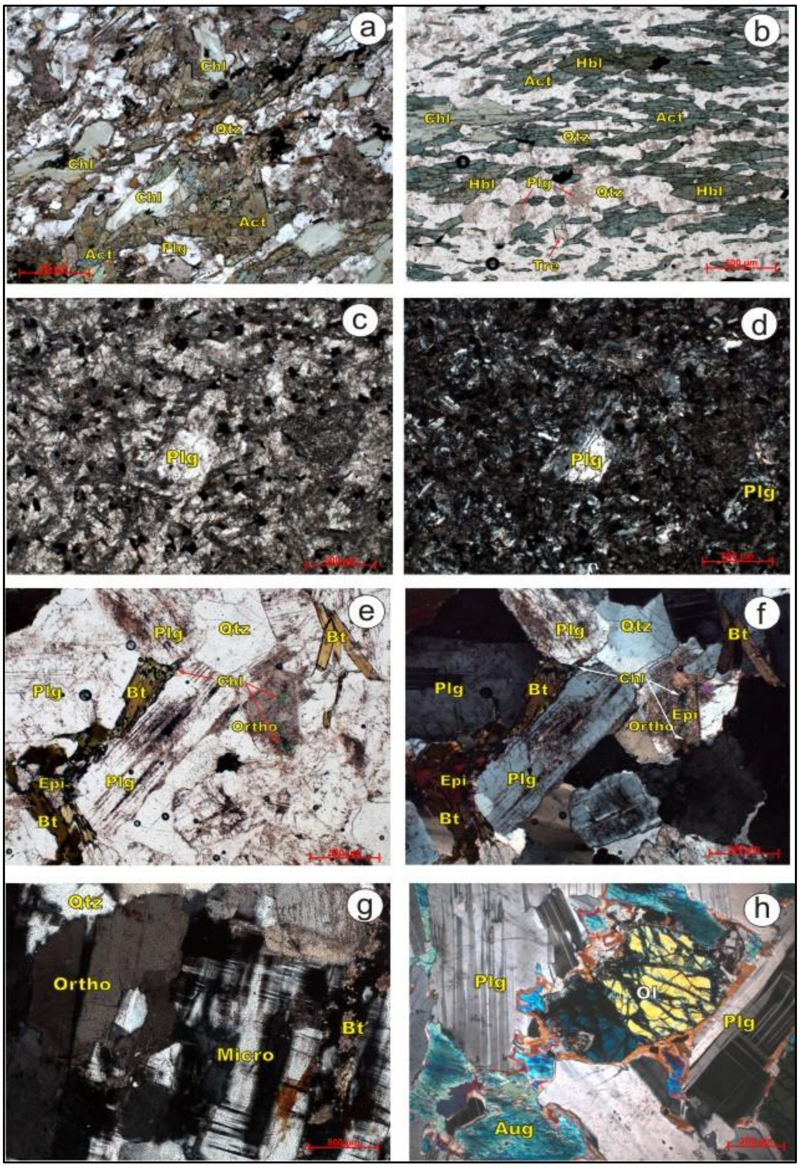

Figure 4

Thin-section photomicrographs of the lithologies of Mubarak area showing (a) foliated and heavily altered amphibolite (ppl), (b) foliation of Hbl schist (ppl), (c&d) plagioclase phenocryst embedded in the fine-grained groundmass of meta-andesite (ppl&xN), (e&f) partial alteration of primary minerals of granodiorite (ppl&xN), (g) cross-hatching and simple twinning of K-feldspars of younger granites (xN) and (h) younger gabbro (xN). Abbreviations, Qtz: quartz, Plg: plagioclase, Hbl: hornblende, Act: actinolite, Trem: tremolite, Bt: biotite, Chl: chlorite, Epi: epidote, Ortho: orthoclase, Micro: microcline, Aug: augite, Ol: olivine.

4.1.b. Hornblende-actinolite Schist

Hornblende-actinolite schist is strongly foliated rocks of greyish green color *(Figure 4b)*. It is composed of 50% of mafic minerals: hornblende and actinolite with minor tremolite, and 50% felsic minerals dominated by quartz with minor plagioclase. Chlorite and iron oxides represent subsequent mineral phases overgrown on amphiboles. The distinctive feature from amphibolite is the higher proportion of felsic minerals and the amphibole composition. Amphiboles occur as aggregates elongated in one direction. **Hornblende** occurs as relics of heavily fractured subhedral to anhedral prismatic crystals (400 µm-250 µm), where these fractures extend along its long axe and parallel to the foliation. **Actinolite** occurs as tabular subhedral crystals (600 µm × 75 µm). Minor tremolite occurs as subhedral short prismatic crystals. **Quartz** is frequent as anhedral subrounded crystals of serrated edges (30 µm-20 µm) filling the space between amphiboles. **Plagioclase** is rare and occurs as anhedral short prismatic crystals and are heavily sericitized. **Chlorite** is frequently present (700 µm × 275 µm) overgrown on amphiboles.

4.1.c. Metaandesite

This rock is hard, massive, fine-grained of a dark green color (*Figures 4c* and *d*). It is composed essentially of plagioclase, biotite, quartz, hornblende, and chlorite. Accessory minerals include iron oxides and epidote. Plagioclase phenocrysts are embedded in fine grained groundmass of plagioclase, biotite, chlorite, epidote, and iron oxides. **Plagioclase** phenocrysts (700 µm × 400 µm) occur as subhedral prismatic crystals of andesine composition (according to the Michel-Lévy diagram) that are partly fractured and altered to sericite.

4.2. Syn-to-late orogenic granodiorite

This rock is coarse-grained and grey in color, composed mainly of plagioclase, quartz, biotite, and K-feldspars (*Figures 4e* and *f*). Sericite, epidote, kaolinite, chlorite, and iron oxides represent the metamorphic phases. **Plagioclase** (up to 1450 µm × 450 µm in size) occurs as prismatic subhedral crystals of andesine composition. It shows faint lamellar zonation while alteration to sericite partly destroys its crystal lattice. **Quartz** (620 µm × 600 µm) occurs as strained anhedral crystals, exhibiting uneven, wavy and undulose extinctions. **Biotite** (250 µm × 50 µm) occurs as flaky and elongated crystals. It is commonly altered into chlorite and iron oxides, particularly on the peripheries and along its cleavage planes. **Kaolinite** is very common due to the heavy weathering indicating complete alteration of K-feldspars. **Chlorite** occurs as pale green, small flake-like crystals, or irregular patches.

4.3. Post-orogenic intrusives

4.3.a. Post-orogenic granite

This rock is coarse-grained and red in color *(Figure 4g)*. It is composed mainly of quartz, orthoclase, microcline, biotite, and minor plagioclase. Kaolinite, epidote, sericite, and iron oxides represent the metamorphic phases. **Quartz** occurs as an essential mineral, generally anhedral, medium-grained crystals up to (300 μm × 200 μm) deformed into wavy extinction. **K-feldspars,** represented by orthoclase and microcline (1000 μm × 700 μm – 1400 μm × 1050 μm), exhibit simple twinning and cross hatching twinning and are slightly altered to dusty kaolinite. **Biotite** occurs as subhedral flakes associated with epidote and iron oxides. **Plagioclase** is rare and occurs as prismatic subhedral crystals that are mostly zoned and exhibit albite twin lamellae. Granophyric and perthitic textures are common due to intergrowth of quartz and K-feldspars and between albite and K-feldspars, respectively.

4.3.b. Post-orogenic gabbro

This rock is hard, massive, and very coarse-grained of dark green to greenish black in color *(Figure 4h)*. It is composed of plagioclase, augite, and olivine. Iron oxide, calcite and epidote are accessory minerals. **Plagioclase** (2260 μm × 890 μm) occurs as euhedral to subhedral lath-shaped crystals that are partly altered to fine sericite scales and shows strong lamellar twinning of labradorite composition. **Augite** (915 μm × 670 μm) in size exists as subhedral crystals that are occasionally replaced by secondary amphibole, iron oxides, and chlorite. Augite crystals enclose plagioclase laths, forming ophitic and sub-ophitic textures. **Olivine** is commonly found as rounded crystals (up to 1250 μm × 900 μm in size), with a distinctive mesh texture where serpentine is an alteration product. Iron oxides occur as anhedral crystals replacing augite or along its peripheries and cleavage planes.

5. CONCLUSIONS

Field observations of the Mubarak area reveal that the Pan African nappe assemblage and syn- to late-orogenic granodiorites are the dominant rock units. The rocks representing the Pan African assemblage in the area belong to the IAA, outcropping as nearly vertical, E-W striking sheets. Ophiolites of the ANS were not found here.

The IAA rocks encompass a range of medium-grade metamorphic rock units of amphibolite facies, indicated by the presence of amphiboles defining the foliation in amphibolites and schists. Amphiboles appear as relic minerals supplanted by low-grade minerals (e.g., chlorite and epidote), implying a retrograde phase. Additionally, the extensively fragmented hornblende and serrated quartz in the schist reflect the late stage of compression at a shallow crustal level as a result of the NW tectonic escape [21] related to the Pan-African Orogeny.

Granitoids are commonly found in the area, and they are aligned with the Mubarak belt from north and south. These granitoids are classified into two distinct phases: (1) syn- tolate- orogenic and (2) post-orogenic granitoids. Although granodiorite seems to be petrographically the plutonic equivalent of the IAA rocks, particularly the metaandesite, it belongs to the late orogenic group, emplaced after the NW shortening tectonic phase. This is clearly shown by the isotropic texture devoid of any elongation and foliation features. Additionally, the quartz grains reveal undulate extinction and interior fractures, indicating that they were subjected to brittle deformation at a shallow crustal level. According to that, the IAA rocks were deformed ductilely at a deeper crustal level prior to the emplacement of granodiorite. Post-orogenic intrusive rocks do not bear the low-grade metamorphic assemblage of the previous groups. These granitoids show a higher grade of differentiation than the granodiorite, according to their mineral composition. The non-metamorphic gabbros of the area belong to the fresh post-orogenic gabbros of the Eastern Desert.

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