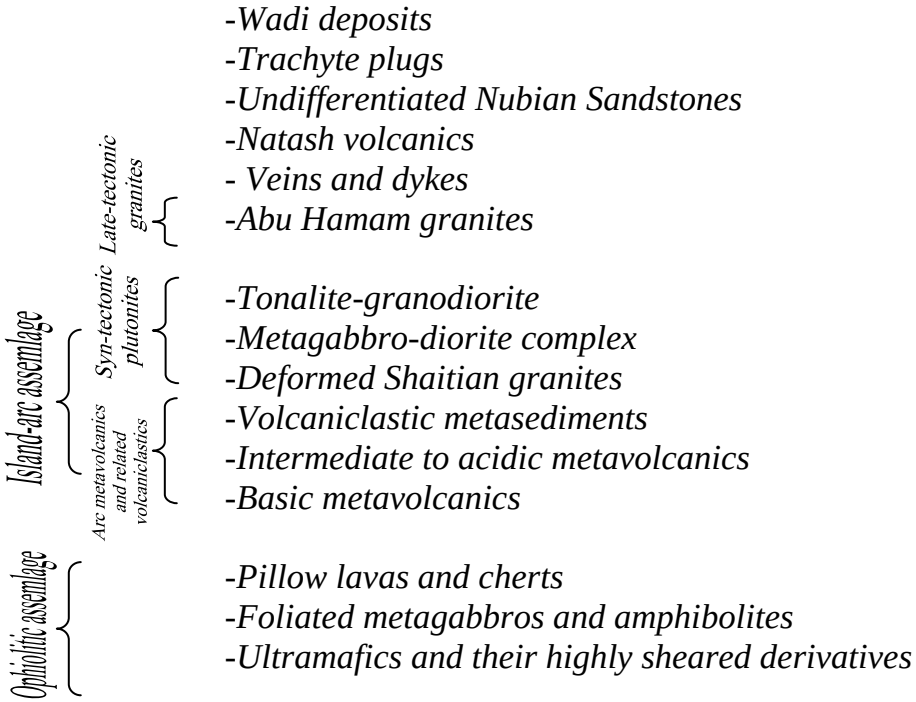
CHAPTER 6
SUMMARY, CONCLUSIONS AND TECTONIC EVOLUTION

General statement

The study area is a part of the exposed Pan-African basement rocks in the South Eastern Desert of Egypt, that is found around Gabal Sufra-Wadi Shait terrain, and delineated between Latitudes 24º 33' 00" and 24º 50' 00"N, and Longitudes 34º 02' 00" and 34º 15' 00" E.

Geologic fieldwork reveals that, this area contains several rock units, which show the following relative age succession with the youngest on the top:



Ophiolitic assemblage crop out at three separate localities, at Wadi El Humor, Wadi Abu Sidri and at the middle part of Wadi Hammash.

Ultramafics and their highly sheared derivatives occur as tectonic blocks associated with the other ophiolitic assemblage, which constitute a moderated mass at Wadi El Humor and huge conspicuous mountain at Gabal Abu Sidri. The lower horizons of the ultramafics are transformed into talc and talc-epidote schists.

Foliated metagabbros and amphibolites occur as small outcrops and as unmappable masses associating with the serpentinites. They have a cumulate nature characteristic of the ophiolitic metagabbros and occur as sheared and tectonized slices.

The pillow lava is encountered at the middle part of Wadi Hammash. The individual pillow is circular or oval-shaped with massive cores and a zone of vesicles near the periphery with size ranging from 25 cm to 1.5 m and generally spilitized and brecciated.

Chert bands occur either covered or tectonically interleaved with the pillowed metabasalts, have thickness ranging from a few centimeters to a few meters and sometimes folded encountered along Wadi Hammash.

Island-arc assemblage are represented by basic, intermediate and acidic metavolcanics and related volcaniclastics.

The basic metavolcanics and associated volcaniclastics exposed at the southern parts of the study area. They are predominantly basaltic to basaltic-andesitic in composition locally transformed into amphibolite and hornblende schist and sometimes intercalated with the Shaitian granites.

The intermediate metavolcanics and associated volcaniclastics are widespread and crop out along Wadi Hammash and its tributaries. They display intensive shearing, folding and linear stretching fabrics.

Crystal-lithic meta-andesitic tuffs are greenish grey rock composed mainly of crystal and lithic ashes, set in a much finer tuffaceous matrix. *Lithic meta-andesitic tuffs* are grayish green rock composed of lithic ashes set in a much finer tuffaceous groundmass.

The acidic metavolcanics and associated volcaniclastics crop out along Wadi Hammash and Wadi Ara West. They are characterized by intensively shearing, folding and linear stretching fabric.

Volcaniclastic metasediments are associated with the Abu Sidri ophiolitic rocks at the northern part of the mapped area. They composed principally of fine-grained, sheared metagraywackes, metasandstones, and laminated ash metatuffs and contain inclusions of fragments of ophiolitic rocks and basic metavolcanics.

Syn-tectonic plutonites include the deformed Shaitian granite, metagabbro-diorite complex and tonalite-granodiorite.

Deformed Shaitian granite is variably sheared rocks, ranging from mild cataclastic, fractured, brecciated, and gneissose to proper mylonite granite. It covers a large area in the south and southwestern part of the mapped area and occurs as low to moderate relief. It also intruded by the metagabbro-diorite complex at the entrance of Wadi Hammash.

The metagabbros-diorite complex is outcropping north of Gabal Sufra as a large elongated body.

Tonalites-granodiorites covers a considerable area and are outcropping in the middle part of the mapped area.

Hammash granodiorite represents the latest phase of the syn-tectonic granitoids exposed at Gabal Hammash. It is moderate relief, leucocratic rock of pale pink color and intensively jointed. It's bounded on both sides by faults along which the rock is sheared and even mylonitized, later

cutting by quartz vein and veinlets-rich in copper minerals and sulphides at Hammash-gold mine.

The late-tectonic granite (Abu Hamam granite) represented the youngest granitic intrusions and exposed mainly at Wadi Sibrit.

Quartz veins occur at the central part of the study area and concentrated in the granitic rocks around the Hammash gold mine with several system trends; The first set of veins trending NNE-SSW and dipping at about 60^{o} N, the second set trending E-W and dipping about 65^{o}N, the third set of mineralized quartz veins occur at Wadi Ara West trending ENE-WSW with dip 85^{o} SE, the fourth set of quartz veins cutting through the Shaitian granites trending NNW-SSE and dipping 72^{o} ENE, and the fifth set of unmineralized quartz veins trending NNE-SSW, dipping 62^{o} NW.

Basic dykes are recorded at Gabal Hammash (trending NE- SW and dip 60^{o} ESE) and at the northern part of the mapped area (trending NNE-SSW), which cutting through the Hammash granodiorite and island-arc metavolcanics respectively.

Acidic dykes a few minor porphyritic acidic dykes of an average thickness of 1.5 meters occur in the area of Wadi Ara West and trending NW-SE/ 70^{o} NE, while at Umm Hagalig area trending N 30^{o}E and dipping 80^{o}NW. They also represented by rhyodacitic, spheroltic rhyolitic and trachytic dykes, which have a red-brown color, extending for more than one kilometer, having NNW-SSE trend and possess a high angle of dip.

Natash volcanics are common in the southern part of the study area, invaded into most of the pre-exciting rocks and are dominated by trachyte.

***Nubian sandstone*:** A sequence of sedimentary rocks composed of a thick succession of sandstones, unconformably overlying the igneous and metamorphic rocks at the southern part of the mapped area.

Trachyte plugs and sheets of an alkaline nature cut through all other rock groups in the area under study, and are certainly later than the late-tectonic granites (Abu Hamam granite) forming Gabal Sufra with another a group of relatively smaller volcanic intrusions forming cones and minor plugs.

The petrochemical classification, nomenclature and tectonic setting of the above mentioned rock units revealed that:

Serpentinites

Geochemical classification using different diagrams show that the studied serpentinites derived from peridotite (harzburgite and lherzolite) matching with the metamorphic peridotites. They belong to the dunite and peridotite of Alpine-type and supra subduction zone (SSZ) ophiolite.

Ophiolitic and island-arc metagabbros

The ophiolitic metagabbros are mesocratic gabbro norite in composition with a tholeiitic affinity and have a transitional character from MORB/IAT characteristics retaining to back-arc basin basalt (BABB) characters. While, the island-arc metagabbros are mostly leucocratic gabbro norite with a calc-alkaline in nature and equivalent to calc-alkaline basalt (CAB).

Metavolcanics

Geochemical classification using different diagrams show that, the analyzed metavolcanics are basalt, basaltic-andesite, dacite and rhyodacite in composition with tholeiitic to mild calc-alkaline affinity. They have island arc characteristics kinking to the younger metavolcanics of Stern (1981) and obey the Cascades trend, except some samples have a MORB character.

They are young metavolcanic (YMV) with lower k-content than the Dokhan-type volcanics, and similar to the younger calc-alkaline metavolcanics of island arc geotectonic environment of Stern (1981).

Shaitian and Hammash granites

The Shaitian granites are metaluminous tonalite to granodiorite in composition, whereas the Hammash granites are peraluminous granodiorite and sometimes trondhjemite in composition. They belong to I-type and volcanic arc granites (VAG).

Late –tectonic granites (Abu Hamam granites)

The Abu Hamam granites are mostly peraluminous granodiorite to granite in composition matching with I-type and volcanic arc granites (VAG).

Structural elements of the basement rocks at the study area include three groups, namely:

- Structures pre-dating the Shaitian granitoids (D_1)
- Structures coeval or subsequent to the Shaitian granitoids (D_2)
- Structures post-dating the tectonic transport, concomitant with the emplacement of the late-tectonic granites and Natash volcanics (D_3)

Each group reflects intrinsically different styles manifesting these phases of deformation D_1, D_2 and D_3.

Faults represent the most characteristic structure elements, while folds occupy the second rank and range from centimeters to some kilometers in scale. The sequence of these faults are started by NW-SE, E-W to ENE-WSW which followed by N-S to NNE-SSW and NNW-SSE fault trends**.** Two major faults and elsewhere less common faults are confined to four trends; NW-SE, E-W to ENE-WSW, NNW-SSE and N-S

to NNE-SSW. The first trend is dominant close to the first major fault and is characterized by pure sinistral strike slip movement. The E-W to ENE-WSW faults exhibits the same sinistral strike slip movement and along their planes gold-copper mineralized zones are aligned. The NNW-SSE fault trends are characterized by a dextral sense of movement. On the other hand, the fourth N-S to NNE-SSW fault trends exhibit inconsistent cross-cutting relationship with the other fault trends and dislocate the rocks in a sense of sinistral movement. The intersection points of the NNW-SSE strike slip faults with the NW-SE and N-S to NNE-SSW consider a passageway for the extrusion of Natash volcanics and formation of most mineralized zones in the present area.

Three generations of folds (F_1, F_2 and F_3) are related to three phase of deformations (D_1, D_2 and D_3).

D_1 structures are less common and developed in the highly sheared ultramafic rocks and volcaniclastic metasediments. F_1 folds are developed as very tight, recumbent and intrafolial to rootless intrafolial folds, locally axial planar with S_1 foliations. S_1 foliations are striking NW-SE, WNW-ESE and, sometimes, E-W and dip moderately towards the NE, NNE and N.

D_2 structures are characterized by NW-SE and E-W to ENE-WSW major strike slip shear faults. These faults delimit commonly the contact between the ultramafics and their highly sheared derivatives from the arc metavolcanics and related metasediments and, elsewhere, the contact between the cataclastic Shaitian granitoids and both allochthonous terrains. Sinistral movement is characterized along the fault planes and associated, in places, with oblique thrusting indicative a transpression regime. Subsequent reactivation is noted, along strike slip faults was caused by the intrusion and alignment of metagabbro-dioritic rocks. F_2 folds are

asymmetric, overturned and tight best-developed in the highly sheared ultramafic rocks, volcaniclastic metasediments and highly sheared basic metavolcanics and, sometimes, gneissic Shaitian granitoids. S_2 foliations are essentially penetrative and mostly striking NW-SE, E-W to ENE-WSW and dipping at moderate to steep angles towards the NE, N and, locally, NNW. Their axes orient NW-SE to NNW-SSE and are plunging moderately NW and rarely SE to SSE. Locally and along the two major faults, these folds exhibit vergence towards the SW and, sometimes, WSW. L_2 lineations are extensive in the area and characterized by mineral lineations, quartz boudins, pinch and swell structures.

D_3 structures are dominated by non-penetrative S_3 foliations striking in a NE-SW direction and dipping with steep angles (70º-80º) towards the NW and SE. F_3 folds have minor scales and developed with open, asymmetric and symmetric style. Their axes trend NE-SW and, sometimes NNE-SSW and plunge at steep angle towards the NE-SW and rarely NNE and SSW. L_3 lineations are mainly represented by crenulation lineations and kinks, coaxial with F_3 folds and steeply plunging NE and SW. Faults involved in D_3 structures are represented by the N-S to NNE-SSW sinistral and NNW-SSE dextral strike slip faults.

Structural-mineralization inter-relationship

Mineralizations in the present area consider as one of the most important location for gold-copper production since the Pharaonic and Roman Times. Gold-copper mineralizations are the result of hydrothermal solutions accompanied with the calc-alkaline magmatic activity and generally formed at relatively shallow depths (Garson and Shalaby 1976 and El Gaby et al. 1988).

Best locations of gold-copper mineralized zones at Ara area are found at the intersection of the subordinate NNE-SSW to ENE-WSW faults with the main trend NW-SE faults. In field, some of the excavations revealed the association of sulphides, pyrite, chalcopyrite and sometimes galena with gold mineralizations. The andesitic metavolcanics are altered along the vertical and inclined fault planes to white and creamy alteration products stained with iron oxides. However, the granitic rocks are extensively kaolinitized along these planes.

In Hammash area, the old workings are found along the NNE-SSW, NNW-SSE and rarely E-W fault trends. Best location for the mineralizations lies at the intersection of these faults and within fine granodiorite and granites but less often in the surrounding metamorphic country rocks. Abundant quartz veins rich in sulphides and presence of iron oxides and malachite staining along fault planes.

Fault analysis of the Umm Hagalig area showed the effect of the WNW-ESE and less common NW-SE and ENE-WSW trends on numerous light gray to milky white quartz veins. The gold-copper mineralizations are mainly confined to the acidic igneous rocks in milky to smoky quartz veins. Extensively, these veins are accompanied with shearing and brecciation along the WNW-ESE shear faults.

In the Abu Tarda area, the faults in this subarea are dominated NW-SE and NNE-SSW trends. Commonly, gold-copper mineralizations are localized at the contacts between the metavolcanics and younger acidic intrusions and as these contacts are controlled by NW-SE faults. In the metavolcanics, the mineralized zones are mostly associated with ferruginous solutions and with kaolinitization in contact with the syn-tectonic granites.

Tectono-magmatic evolution

In order to visualize a framework of the tectono-magmatic evolution of the above described rock units of the study area, the following embraces the main events that have evolved through three phases of the deformation , based on the previously described geological, structural and metamorphic data.

The first phase of evolution (D_1) which probably of early Pan-African is considered to be pre-dating to the Shaitian granitoids and isodominated by regional height and recumbent major and minor folds (F_1) regional schistosity (S_1) and different types of lineations (L_1), during this phase the formation of dismembered ophiolites including serpentinites, metagabbros and pillowed spilites as remnants of the oceanic crust of back-arc basin are well developed .Followed by Island-arc metavolcanics development causing refolding and thrusting of the newly formed oceanic crust and volcanic island arc on the regional scale.

Accretion process during the D_1 event led to the formation of distinct highly deformed zone of ophiolitic and island arc assemblage (suture zone). This suture zone is mylonized and characterized by several kilometers ductile and brittle deformation zone (see chapter 5).

The second phase (D_2) which probably of middle Pan- African, is dominated by cratonization of the ophiolitic and island arc terrains onto the newly formed ocean in combination with the emplacement of calc-alkaline granitic and gabbroid intrusions. This phase is characterized by mega strike-slip faults and S_2 foliations, trending NW-SE, E-W and ENE-WSW.

The third phase (D_3) which probably of late Pan-African, was coeval with the emplacement of calc-alkaline granite intrusions which, completed the cratonization of the Precambrian basement within the study area.

The latest stage of magamatic activity was likely coeval with the emplacement of the alkaline recent volcanics (Natash Volcanics)