# CHAPTER VI

# SUMMARY AND CONCLUSIONS

The Precambrian rocks of Egypt (100.000 $Km^2$) outcrop over an extensive area in the Eastern Desert, south western part of the Western Desert and south Sinai. The Precambrian belt represents the NE part of the Arabian Nubian shield which is exposed in both sides of the Red Sea , and belonging to the Pan-African organic belt.

The Egyptian Precambrian belt of the Eastern Desert is composed of an upper-Proterozoic volcano- sedimentary complex containing scattered ultramafic bodies and intruded by syn-to late – tectonic plutonites (mainly tonalite to granodiorite) with extensive series of calc-alkaline volcanic rocks. This sequence is unconformably overlain by molasse sediments of the Hammamat group. The sequences are cut by alkaline to sub-alkaline, late – to post tectonic granites.

In the central and southern Eastern Desert , the deformed and largely mylonitized rocks of the infrastructure crop out in gneiss domes disposed along the axes of genetic lines trending NNW-SSE which also functioned as magnetic area (El Gaby, 1983 ) .

Remobilize infrastructure rocks are well displayed at Wadi Feiran, SW Sinai ( El Gaby & Ahmed 1980), along the Qena Safaga road (Sabet et. al., 1972 , Akaad et al., 1973).

Wadi Beida area lies in the southern part of the Eastern Desert about 30Km west of Shalatein town between latitudes 22° 54' -23° 04' 30" N and longitudes 35° 10' – 35° 22' 30" E and covers an area 431.28$Km^2$

The present thesis involves detailed field, geological, geochemical, mineralogical and structural studies for the rock units at Wadi Beida area. These rock units comprise dismembered ophiolities, arc volcanic assemblage, Arc-grantitoid and younger gabbros.

The ophiolites occupy and extend in NW-SE direction in the northeastern part of the mapped area. They embrace ultramafic rocks, metagabbros, pillow lavas and cherts. These rocks are set, in places, inside a schistose matrix of highly sheared ultramafic rocks, foliated metasiltstone and metamudstone. Elsewhere, this matrix encloses small bands of quartz carbonates. All these components show tectonic contact in-between and alltogether were tectonically transported and intermingled with the metavolcanics. At Bir Beida, the contact of ophiolites against the metavolcanics is characterized by strong shearing in NW-SE direction. Veinlets of talc, chromite lenses and magnesite bands are aligned along this contact.

The Ultramafic rocks consist of intensively sepentinized hurzbergite, lherzolite and subordinate dunite. They are represented by main outcrop on the right side at the entrance of Wadi Beida and by unmappable slices east and southeast of G. Beida. These rocks are brown, dark grey to black and have a general NW-SE elongation. In localities, the ultramafics contain veinlets and pockets (5-11 cm thick) of chrysotile indicating the tectonic effect. Petrographically, the ultramafic rocks are represented by serpentinites (with relics of hurzbergite, lherzolite and dunite). The serpentinites are composed of antigorite, low contents of chrysotile, lizardite and ankerite together with opaques (about 15-20% of the whole rock). The opaques are mainly iron oxides and chromite with traces of sulfides. The iron oxides are represented by magnetite that is densely altered into goethite. The chromite occurs as disseminated crystals and is partly altered into magnetite.

The metagabbros are exposed in the east of the mapped area and cover an area of about 60 km$^2$. They form low to moderate relief and have, along their eastern and western sides, tectonic contacts against the ultramafics and their highly sheared derivatives respectively. In places, these rocks exhibit layering and rosette feature. The layering is mostly disturbed and is not continued for long distances. The layers are generally striking NW-SE and dipping at moderate and steep angles towards plagiogranites. The latter forms white bodies in the rocks. The metagabbros are coarse-grained but they are fine-grained in the uppermost parts.

Petrographically, the metagabbros are mainly composed of plagioclase, actinolitic hornblende and pyroxenes. Opaques and sphene are the main accessory minerals. Biotite, chlorite, epidote and calcite are the secondary minerals. Quartz is found in the strongly sheared varieties and is mainly of secondary origin.

Plagioclase (An $_{36\text{-}44}$) reaches to 60% of the rock. It shows lamellar and composite twinning and zoning. In samples, the core of plagioclae crystals are charged with epidote while the peripheries are clear indicating high and low calcic compositions respectively. Occasionally, these crystals are obscured by dense kaolinitization and sericitization. Actinolitic hornblende is partly or completely chloritized and still shows relics of pyroxenes. These relics include augite, enstatite and sometimes diopside; being altered to chlorite and epidote.

Opaques (2-10%) are dominated by ilmenite (70 % of the opaques), magnetite (30 % of the opaques) and traces of pyrite. Ilmenite is occasionally homogeneous and shows two types of alterations; high temperature alteration to sphene and/or hematite-rutile graphic intergrowths and low temperature alteration to goethite. Magnetite is Ti-poor variety. Hematite-ilmenite exsolution intergowth (metamorphic origin; Takla et al., 1981) is widespread in most samples. Magnetite external granules in ilmenite are rarely encountered.

The pillow lavas are encountered near Bir Beida and trending NNW-SSE .The pillows are generally dark green and exhibit fine-grained basaltic composition with amygdales filled with epidote, carbonates and iron oxides. The individual pillows are circular or oval-shaped with massive cores and a zone of vesicles near the periphery. The pillows range in size from 25 cm to 1 m and show general dipping toward the NE.

Cherts occur as dark grey to grayish, yellowish and greenish gray bands. They are tectonically interleaved with the ultramafic rocks and pillowed basalt. The thickness of the chert bands vary from 5 to 30 cm. Petraographically, the pillow lavas are composed of plagioclase laths, tremolite, epidote and clorite together with few amounts of sphene, quartz, calcite and opaques. The opaques constitute about 5% of the rock and are dominated by magnetite which is partly martitized. They are characterized by schistose and amygdaloidal textures. Some amygdales are filled with calcite, epidote and chlorite.

The matrix which enclose the ophiolitic components are mainly represented by highly sheared ultramafic rocks with some metasiltstones and metamudstone. The highly sheared ultramafic matrix shows moderate to well developed foliations and, in some places, is defined by subparallel shear surfaces. Locally, this matrix displays chaotic foliations because of enclosing the aforementioned ophiolitic blocks. It forms bright metasomatic halos of Khaki colour and is composed of fine to coarse-grained tremolite schist, talc tremolite schist, talc schist, talc graphite schist and talc carbonates associated, in localities, with bands of quartz carbonates. The metasiltstones matrix is grey to black in colour and is highly foliated and sheared. Sometimes, the metamudstones are unsheared but fractured. In general, the foliation inside the matrix strike NW-SE, WNW-ESE, NE-SW and dip at the moderate to steep angles towads the NE, SW, NNE, NNW, NW and SE.

The metavolcanics occupy the central part of the study area . Minor exposures of the metavolcanics are recorded, to the north, at the entrance of Wadi Beida. In general, the metavolcanics strike NW-SE and have angles of dip between 40° and 55° towards the NE. Westward, they show an irregularity in the direction of strike and value of dip. This irregularity is due to the development of more than one phase of folding and intrusion of syn-tectonic granitoids. The metavolcanics are mainly represented by metabasalts and metabasaltic andesites. To the west, unmappable masses of metadacites are recorded. They have moderate to high relief and sometimes are pillowed (the metabasalts, in particular). Along the NW-SW faults, the basic varieties exhibit discontinuous bands (5 cm to 1 m thick) of hornblende and epidote chlorite schists which have grayish green to olive green colours.

Petrographic examinations reveal that the metabasalts are mainly composed of plagioclase, hornplende pyroxenes and opaques (~ 10%) Pyroxenes are mainly augite which is densely chloritized and epidotized. Metabasaltic andesites are composed of plagioclase phenocrysts in microcryptocrystalline groundrnass containing sericitized plagioclase, chlorite and opaque Carbonatizations of plagioclase along its cracks and carbonate veinlets are occasionally encountered. Metadacites, however, are composed of quartz, chlorite, plagioclase and opaques. Quartz occurs as micro- and cryptocrystalline grains of anhedral habit. Opaques and/or carbonates may form veinlets. Metarhyolite are mainly composed of phenocrystals of quartz and K-Feldspar sit in a fine-grain ground masses. K-Feldspar are represented by sanidine or/and orthoclase. In the varieties of metavolcanics, the opaques are high in content (6-11%) and are dominated by magnetite that partly shows marititization of normal type.

Volcaniclastic metasediments occur in the west covering an area 36 km$^2$ and extend to the east and southeast underlying the metavolcanics. They embrace graded-bedded and grayish green metatuffs and lapilli-metatuffs together with discontinuous small bands (few millimieters to 80 centimeters thick) of laminated metamudstone and metasiltstone as well as sericite schist, sillimanite sericite schist and cordierite sericite chlorite schist. The development of sillimanite and cordierite is most probably due to the instrusion of foliated syn-tectonic grantoids exposed in the west (i.e. thermal metamorphism, Miyashiro 1994). In places, lensoidal bodies of metadacite are also observed. In the field, the volcaniclastic rocks are highly deformed and generally strike NE-SW and dip 45° - 70° SE.

Under the microscope, the metatuffs are acidic to intermediate in composition and composed of medium-grained plagioclase, quartz and lithic fragments in a fine-grained matrix dominated by plagioclase, quartz, chlorite and carbonates.

The Arc granitoids are represented by quartz diorites tonalites and granodiorites. They are exposed in the northwestern and southern parts of the study area. In northwestern part, the granitoids are mainly quartz diorite to tonalite and are sheared but show, in places, intrusive contact with the volcaniclastic metasediments. To the north of the present area, these rocks are strongly mylonitized and delimit a thrust contact against the ophiolites and arc metavolcanic rocks (El Amawy et al., 2000). They form low topographic feature and enclose xenoliths of mafic compositon. In the southern part, the granitoids comprise granodiorites with small masses of tonalites. In general, these rocks are massive except those found at Wadi Kreiga, where the rocks exhibit gneissose texture. The gneissosity planes strike NW-SE and are most probably developed due to effect of the major NW-SE fault westward, the gneissosity fade away from this fault.

Petrographically, these rocks show granitic texture but exhibit porphyritic and gneissose texture in densely altered and cataclased samples. The quartz diorites to tonalites are composed of plagioclae (50-65%), quartz (20-35%) and mafics (10-15%). Opaques (1-5%), sphene and apatite are the accessory minerals. Plagioclase ($An_{30-42}$) shows composite twining and is zoned and occasionally altered to kaolinite and sericite. Quartz is primary and undulated and sometimes has subhedral to equant crystals. Mafics are represented by hornblende with small amounts of pyroxenes (mainly augite) and biotite. The opaques are dominated by magnetite and traces of pyrite. Magnetite is partly altered to sphene and goethite. The granodiorites, on the other hand, are composed of plagioclase ($An_{12-23}$), quartz, orthoclase, hornblende, biotite, little amounts of sphene and opaques ( about 1-3% ).

Younger gabbros are represented by few numbers of hillocks intruding the per-existing rocks in the northwestern part, the northern flank of Wadi Kreiga and in the east and northeast of G. Beida.

Microscopically, these rocks show granitic textures and are mainly composed of plagioclase (40-60%), mafics (35-45%) and opaques (~ 10%). Plagioclase ($An_{55-65}$) has lamellar and composite twinning and is slightly altered to sericite. Mafic minerals are dominated by augite and partly altered to chlorite. Opaques are mainly represented by magnetite that is martitized (normal type). Some magnetite grains result from the transformation and alteration of pyroxenes.

Geochemically, the studied metagabbros are subalkaline and tholeiitic and lie in the gabbroic to dioritic fields. The metavolcanics are plotted in the island arc to MORB fields and reflect a marginal basin (back arc) tectonic environment. In the following are the farther aspects which reoncile the character of back are tectonic environment rather than the MORB to the metagbbros and the metavolcanics (the metabasalts, in particular):

1. The metabasalts are plotted inside or near the back arc field.
2. Both rock types (the metagabbros and basic metavolcanics) show wide range of $SiO_2$ content (49-54%) and higher contents of alkalies than the MORB.

3. They are enriched in large low-valency cations (K, Rb, Ba and Sr) than MORB.
4. Relatively, they show an increment in the contents of their trace elements.
5. The metavolcanics are located between MORB and arc basaltic field.
6. Rb/Sr value in these rocks equal 0.022-0.184. This value resembles, to some extent, the value in the back-arc varities (0.026-0.04) and is higher than that value determined by Wilson (1989) in MORB (0.0079-0.049).

The studied Arc granitoids are I-type, magnetite rich, calc-alkaline, mantle fractionate and exhibit the tectonic setting of VAG.

Detailed fieldwork and structural studies revealed three phases of deformations ($D_1$, $D_2$ and $D_3$). These phases induced in the area three generations of folding ($F_1$, $F_2$ and $F_3$) and two styles of faulting (thrust and strike slip faults). During $D_1$ and particularly D2, the ophiolitic components and the present island are assemblage are markedly transported. This is reconciled from the development of parallel and subparallel $S_1$ and $S_2$ forliations and the vergence of $F_1$ and $F_2$ folds towards the SW and WSW. By this movement, the ultramafic-mafic rocks, which represent remnants of oceanic crust, are dissected and tectonically re-emplaced displaying in the present area a thrust contact and strong shearing against the underlying metavolcanics. This contact is generally striking NW-SE. This tectonic regime brought in the area the rocks of medium to high grade metamporphism (e.g. hornblende schist in metavolcanics) against others of low metamorphic or greenschist facies (most of the present metamorphic rocks). It also reflects a subjection of the area to a compressive stress from NE to ENE directions. This is comparable with El Ramly et al. (1984), Kroner (1985) and El Gaby (1994) who considered that the accretion of the Nubian shield is the result of a compression force acting in E-W direction.

In comparison, the third phase of deformation $D_2$ is weak and accompanied with the formation of $F_3$ folds, N-S and NNE-SSW strike slip faults. $F_3$ folds are open and their styles emphasize a local shortening in the area in a direction more or less perpendicular to their axes (i.e. in NW-SE direction).