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AN INQUIRY INTO THE STRUCTURAL EVOLUTION OF THE NEOPROTEROZOIC SHAIT GRANITE COMPLEX, SOUTH EASTERN DESERT, EGYPT

M. A. El-Fadly, S. Hamid, M. A. Abu-Elrus and A. A. Khudeir

Geology Department, Faculty of Science, Assiut University, Assiut, Egypt
E-mail: geo.moh2015@gmail.com

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Geologic investigation on the basement rocks exposed around Wadi Shait revealed that they constitute part of a fold thrust nappes comprising Gardan ophiolitic mélange structural unit (GOM) exposed in a tectonic contact against the Shait granite complex (SGC). Both units are brittly to ductily deformed, and are partially intruded by the calc-alkaline Hamash granodiorite, Dokhan volcanics, post-orogenic alkali granite and the Natash volcanics.

Litholgically, the GOM builds up a stack of sliced sequence comprising low-grade regionally metamorphosed epiclastic, volcanogenic pyroclastic, basic and intermediate lava flows and structurally topped by metagabbro and hornblende metagabbro slices. On the other hand, the SGC is composed mainly of mesocratic tonalite, minor leucocratic trondhjemite, granodiorite and monzogranite. The latter occurs as dyke-like masses intruding the outcrops of the other rock varieties. This lithologic association denotes that the SGC constitutes a widely evolved complex in which the early members are deep-seated, calc-alkaline and I-type whereas the later members are shallower and clearly intrusive.

Field data revealed that the stacking nature and consequently uplifting of the SGC were related to late orogenic extension associated with shortening phases controlled by Najd transformed faults.

Detailed field mapping and petrographic studies carried out on the Wadi Shait area show evidence of polyphase deformation (D_1-D_4) affecting the SGC in addition to three metamorphic events (M_1,M_2 and M_3) affecting the GOM.

***Keywords**:* Shait granite complex,Structure, Gardan ophiolitic mélange, Deformation phases, Trondhjemite, South Eastern Desert.

1. INTRODUCTION

The area of Wadi Shait (Fig. 1), to be dealt with in the present study, represents one of the key areas similar to Wadi El-Mayit (Akaad and Mostafa, 1963), Wadi Beitan (Boghdady, 2000) and Wadi El-Shalul area (El-Taky, 1995) cropping out in the Eastern Desert, therefore it is selected to understand part of the architecture of the Egyptian basement in general and the tectonic history of its deformed granite masses in particular. The Egyptian basement is a part of the Arabian-Nubian shield which in turn constitutes a significant portion of the East African Orogeny (EAO). Besides, it forms a conspicuous geologic entity of Tonian-middle Cryogenian island arc terranes that developed in the Mozambique ocean formed between rifted blocks of the Rodinia supercontinent and other cratons (Stoeser and Camp, 1985; Genna et al., 2002; Johnson and Woldehaimanot, 2003; Stoeser and Frost, 2006), between East Gondwana (Australia-Antarctica-India) and West Gondwana (Africa-South America) during the "Pan-African" time (Kröner, 1979).

The granites of Wadi Shait area and the adjoining regions as well as the Hamash gold deposits were treated by several authors. Hume (1935) considered the Wadi Shait granites as old granites representing the "Metarchaean" granite cycle. Schurmann (1953) introduced in his classification of the Egyptian basement the Shaitian granite as representing an old period of plutonic cycle prior to the late Precambrian sediments separating the Eparchean from Metarchaean. El-Ramly and Akaad (1960) questioned the validity of separation of Shait granite as a new subdivision. Moustafa and Akaad (1962) and Akaad and Moustafa (1963) studied the Shait granite of Wadi Shait, however they were unable to settle a stratigraphic position of this granite. El-Sokkary (1970), El-Gaby (1975), El-Gaby and El-Aref (1977) published the geochemical characteristics of the Shait granite; besides El-Kaliuobi and El-Ramly (1991) viewed from the data of the geochemical analyses that the Shait granite was evolved in an immature ensimatic island arc.

The present work describes the geological and structural characteristics of the Shait granite and the neighbouring ophiolitic mélange unit to demonstrate the sequence of their deformation history and their relation with the other Pan-African nappes.

2. GEOLOGY

The Precambrian basement of Wadi Shait area (700 km^2) is located in the western margin of the South Eastern Desert section, 110 km east of Kom Ombo city located on the River Nile. (Fig. 1).

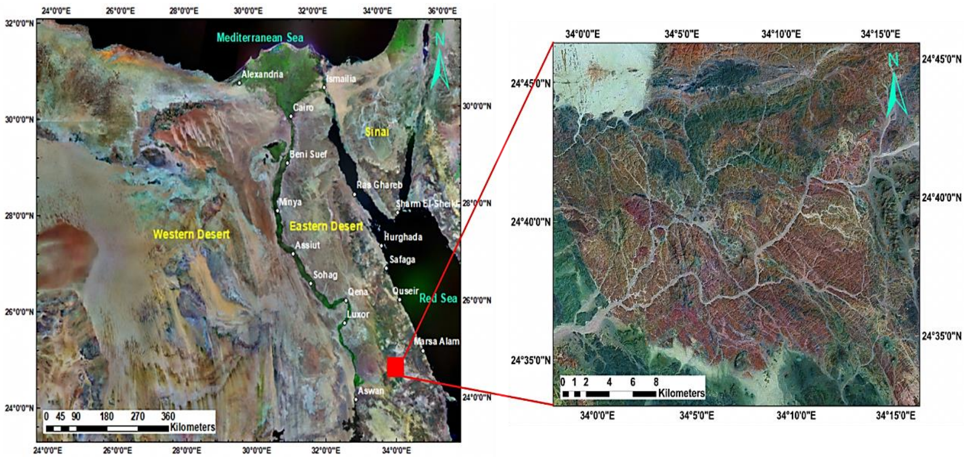

Fig 1. Location map of the studied area.

Detailed mapping revealed the occurrence of the following lithostratigraphic sequence (Fig. 2) which is shown below:

Trachytes.**(<u>youngest</u>)**

…………………………………………**Intrusive contacts**
Nubia sandstones.
…………………………………………**Non-conformity**
Alkaline granites.
Dokhan volcanics.
Hamash granodiorite. **Small mass with intrusive contacts largely obliterated by subsequent faults**
Gneissose Shaitian granite complex (SGC) ***Brittly to ductily deformed intrusive mass with*** **intrusive contacts obliterated by subsequent faults**
Gardan ophiolitic mélange **(GOM) (Ductily deformed rocks) (<u>oldest</u>)**.

Brief characterizations of these lithologies and their field relations are given below:

2.a. Gardan ophioltic mélange

The Gardan ophiolitic mélange is represented by a variably deformed tectonic sequence traversed from the west by Wadi Gardan. It consists of several conformable structural slices or nappes, started from below by bedded immature metasediments followed tectonically upwards or rather eastwards by metabasalt slices, which in turn is overlain by other slices composed of schistose metagabbros and hornblende metagabbros. The metasedimentary slices are dominated by siltstones, mudstones and greywakes with rare marls

Field mapping shows that the Gardan ophiolitic mélange is represented in the studied area by two occurrences as well as minor slices tectonically overlying the SGC or incorporated among the other fault rocks through the sinistral shear zones dissecting the SGC. The larger occurrence is exposed along the southern margin of the SGC. The smaller one occurs at the northeastern margin of the SGC.

The lithologies of the Gardan ophiolitic mélange are weakly regionally metamorphosed into the greenschist facies (M_1). Later on, were undergone a contact metamorphism (M_2) up to the hornblende hornfelse facies (Winkler, 1979) due to the Shait granite intrusion and finally were superimposed by a retrogressive dynamic metamorphism (M_3) during which the composing lithologies were pervasively sheared and diaphthorized into protomylonites, mylonites, augen schist and phyllonites. The microstructures associating this tectonic event (D_2) indicate a NW thrusting over the neighbouring Shaitian Granite Complex (SGC) (Fig. 3 a). These microstructures can be easily discriminated through the NW dipping granite mylonite present underneath the remaining nappes of the Gardan metabasalt occurring over the Shait granite at the northeastern slope.

In the light of the foregoing facts, it is plausible to conclude that the GOM represents a derivation of an ensimatic island arc.

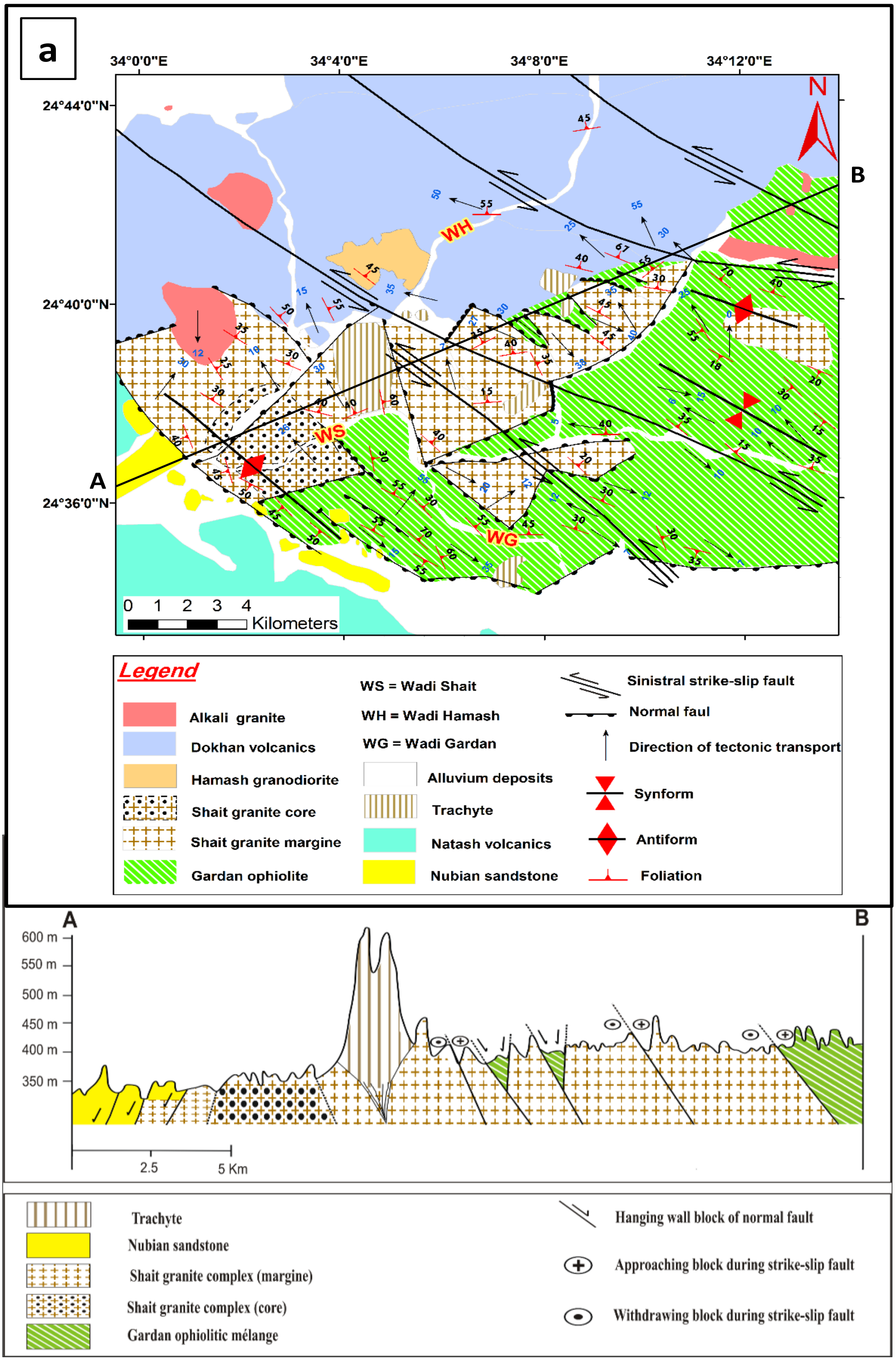

Fig. 2: (a) structural map and (b) cross section of Wadi Shait.

2.b. Gneissose Shaitian granite complex

The SGC was referred to simply as Shaitian granite (related to Wadi Shait) by Schurmann, (1953).It forms an E-W elongate mass intruding into the neighbouring GOM from the south, but itself is emplaced by Hamash granodiorite, Dokhan volcanics, alkali granite and Natash volcanics from the NW, N and NE. The composing granite varieties are variably sheared and possess medium to low relief hilly country. The SGC contains abundant basic inclusions of various sizes and stages of assimilation particularly along the southern contact (Fig. 3.b). The granite complex is differentiated in the field into two divisions on the basis of lithologic composition and the degree of shearing (1) the core and (2) the outer zone. The core consists of mesocratic tonalites which still retain the original magmatic hypidiomorphic-granular texture and generally lies in the western part of the granite complex. The tonalites of the core are medium to coarse-grained, mildy cataclased and occupy medium to high-relief country. They are frequently dissected by non-oriented fractures occasionally filled by secondary quartz, chlorite, and epidote or calcite associations.

The outer zone includes leucocratic trondhjemite, granodiorite and monzogranite; tonalite still persists but is poorer in mafic contents. The trondhjemite and granodiorite outcrops generally possess gradational contacts against those of tonalites, in contrast to the monzogranite outcrops present as dyke-like bodies emplacing the other exposures. Generally the granite rocks of the outer zone are fine to medium-grained with distinct pervasive gneissose and lineation structures. Moreover, the outer zone rocks are dissected by a set of NW trending sinistral shear zones (Fig. 3.c) through which gneissose granite rocks are superimposed by another pervasive deformation phase (D_3) leading to transformation of the gneissose granite rocks into protomylonites, mylonites and ultramylonites.

Occasionally, the dissecting shear zones are locally incorporated by elongate fragments of metabasalts characterized by a distinct schistose structure running conformably with that of the nearby Gardan ophiolitic mélange (Fig. 3.d). Deformation was accompanied by break-down of the constituent minerals of feldspar, quartz and ferromagnesian minerals and development of mylonite structures such as sub-parallel stretching, granulation and kinking of the porphyroclasts survived after mylonitization event.The eastern part of the SGC is intersected by two moderate to high relief trachyte masses whose axes trend approximately N- S direction (Fig. 3.e).

It is believed that the western part of the outer zone lying to the west of the core of the SGC is dissected by high-angle normal faults leading to its burial underneath the later unconformable deposition of the Nubia sandstones over the down faulted blocks.

2.c. The Hamash granodiorite

The Hamash granodiorite represents late to post-orogenic granite as suggested by Akaad and Noweir, (1980), El-Gaby and El-Aref, (1977). It forms a small brittly deformed lensoidal mass, 4 km^2, exposed on the northern bank of Wadi Hamash. It is intruded by the Dokhan volcanics at the northern part of the mapped area. The Hamash granodiorite mass sends numerous dykes and tongues cutting the deformed marginal rocks of the SGC. Generally the Hamash granodiorite mass is coarse-grained massive rocks, moderately cataclased and usually displays light pink colour, particularly along the dissected shear zones.

2.d. The Dokhan volcanics

The Dokhan volcanics cover the northern section of the map area. They possess dyke-like small bodies into both the SGC and Hamash granodiorite mass. Their extrusive sharp contacts are generally obliterated by subsequent normal faults. However foliated xenoliths akin to the SGC and massive xenoliths of Hamash granodiorite occur sporadically proximal to their contacts. The Dokhan volcanics occupy low to medium relief terrane possessing fine to medium-grained rocks of an intercalational sequence consists of lava flows and associated pyroclastics of numerous lithologies, colour and primary structures (Fig. 3.f).

2.e. The alkaline granites

The alkaline granites are related to the post-orogenic younger granites of Egypt (El-Ramly and Akaad, 1960; Akaad and Noweir, 1980). They occur as an intrusive and sub-rounded masses at the northeastern and the northwestern parts of the map area. All contacts are sharp and generally lacking contact thermal metamorphic effects on the skirting country rocks. Angular inclusions of deformed granite are encountered within the alkaline granite masses proximal to the contacts with the SGC

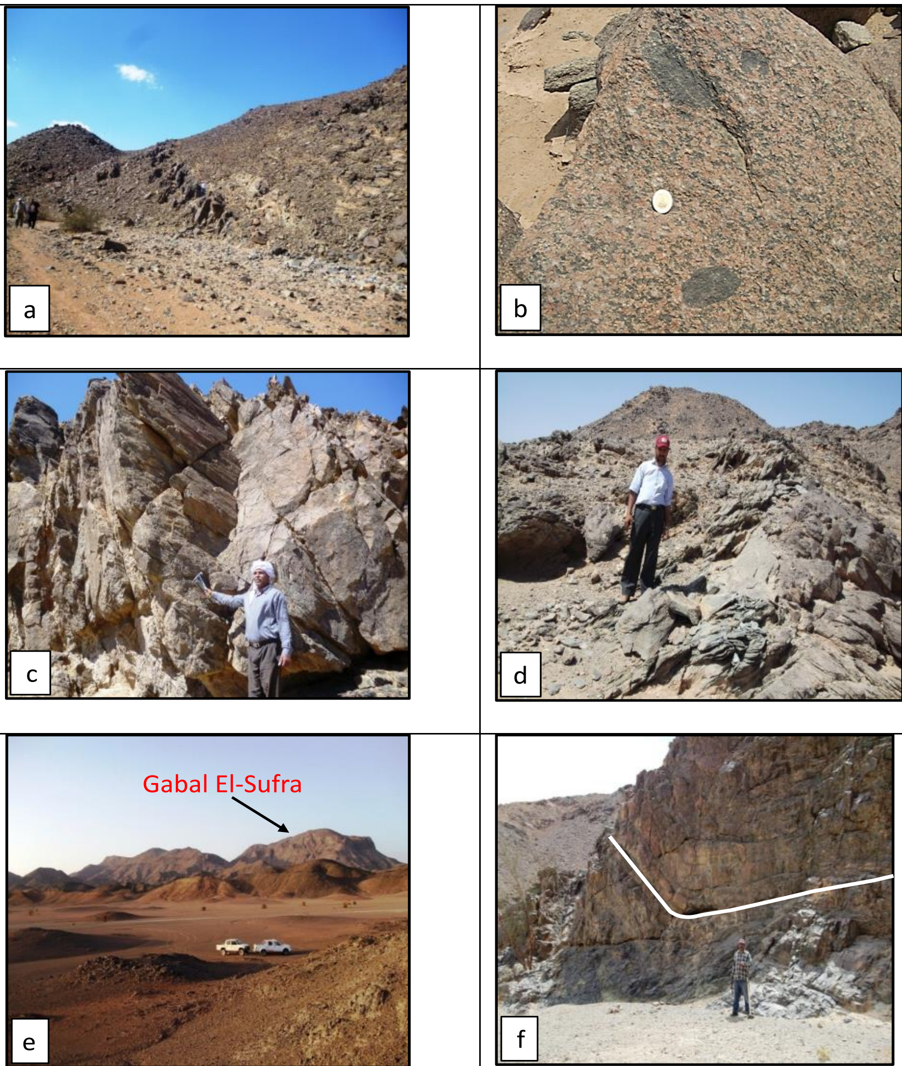

Fig. 3: (a) A general view showing the NW sliding of schistose metavolcanic slice over the northeastern part of the SGC, (b) Photograph at the southern margin of the SGC showing non-oriented sharp metabasalt xenoliths due to the liquidity of the granite magma, (c) Photograph showing NW trending sinistral shear zone belonging to D_3 deformation phase transecting the eastern part of the SGC. Note that the mylonite lineation is verging 10° toward the NW direction, (d) Photograph showing incorporation of intensely schistose metabasalt lenticles along one of the NW trending shear zones transecting the NE dipping SGC, (e) A view showing the NW trending of the large intrusive dyke-like mass of Gabal El-Sufra trachyte in the Shaitian granite mass and, (f) A general view in Dokhan volcanics showing open synclinal fold in andesite rocks invaded by by Dokhan basalt at the lower most part.

3. Deformation Phases

Structurally, the older two units of the GOM and SGC are brittly to ductily deformed and are intersected by NW trending shears, few meters to several meters wide, thereby these two units constitutes part of the fault and thrust belt exposed at the Central and the Southern parts of the Egyptian basement (Greiling et al., 1988; Greiling, 1997; Anderson et al., 2009; Anderson et al., 2010).

The sequence of the deformation phases inferred from detailed field work coupled with the petrographic investigation of the Wadi Shait area is given below in chronological order:

D_1 deformation phase

This deformation phase is related to the formation of the Late Tonian-Early Cryogenian of the GOM island arc. This is constrained by an age of ≈ 800 Ma (un-published data) obtained from U-Pb dating of the studied tonalites selected from the core of the SGC. This evidence runs in harmony with the conclusion that the SGC characteristics is also an old immature ensimatic island arc granite (El-Kaliuobi and El-Ramly, 1991). Through the light of these evidences one can conclude that the GOM and SGC are tectonically interrelated and both akin to an ensimatic island arc developed in the Mozambique Ocean between rifted blocks of the Rodinia Supercontinent and other cratons (Stoeser and Camp, 1985; Genna et al., 2002; Johanson and Woldenhaimanot, 2003; Stoeser and Frost, 2006). Metamorphically the main protoliths of the GOM were undergone marine metamorphism within the greenschist facies (M_1) prior to the contact metamorphism resulted from the intrusion of the SGC.

D_2 Deformation phase

The D_2 deformation phase took place in the form of a large scale NW thrusting of the Gardan ophiolitic mélange during the late stage of the EAO, ~ 630 Ma (Shalaby, 2010). The thrusting was accompanied by mylonitization and retrogressive metamorphism of the higher levels of the SGC which still remained underneath the bottom parts of the remnants of the Gardan ophiolitic mélange nappes occurring along the northern slopes of the northeastern part of the SGC. The foliation trends NW and dips at 20-45° NW, whereas the stretching lineation trends NW and plunges at 2-40° NW (Figs. 5a,b and 6a,b). The NW direction of the tectonic transport is evidenced by S-C structures and geometry of strain shadows around rigid objects (Fig. 7). Moreover, Paschier and Sympson (1986) recorded in the metavolcanic and metagabbro remnant nappes of the Gardan ophiolitic mélange nappes.

D_3 deformation phase

D_3 deformation phase is exemplified by the transformation of the SGC into a structural high or antiformal structure similar to those occurring in the Meatiq, Hafafit and El-Sibai swells (Fig. 2 a). Fritz et al., 1996, 2002 explained the origin of these structures in the Central Eastern Desert through exhumation and extension associated with Najd faulting which involved a large component of oblique transpressional strike-slip shear with constriction across and extension along the intersected sinistral strike-slip shears. The formation of this acting E-W constriction leading incidence of the normal faulting in the northern and southern margins of the SGC. These normal faults dip steeply away from the SGC. The fold axis of the antiform structure trends generally NW. The foliation of the eastern limb dips at about 10-70° NE whereas the associated stretching lineation trends NW-SE and plunges at 5-40° NW and SE. On the other hand, the foliation and the lineation readings of the western limb are generally few due to its down faulting and burial underneath the bedded Nubia sandstone. The foliation strikes NW-SE and dips 10-30° to the SW whereas the associated lineation trends NW-SE and plunges 5-45° NW and SE (Figs. 8 a,b and 9a,b).

D_4 deformation phase

D_4 deformation phase is represented by faulting of the western part of the area forming the SGC and the Gardan ophiolitic mélange along NW and SW zones of normal faults dipping steeply away from the dislocation basement rocks (Fig. 2 b). These brittle faults generally precede the unconformable deposition of the Nubia sandstone and were rejuvenated. The recurrence of such rejuvenation can be noticed by disappearance of down thrown parts of the Gardan ophiolitic mélange and the SGC forming the western limb of the major anticlinal structure, as well as the western master sinistral fault bounding the area from the west underneath the Nubia sandstone unit (Fig. 2 b). These faults generally exhibit quick increase of the dip amount in moving westward away from the basement rocks. Causing the urgent burial of the basement units.

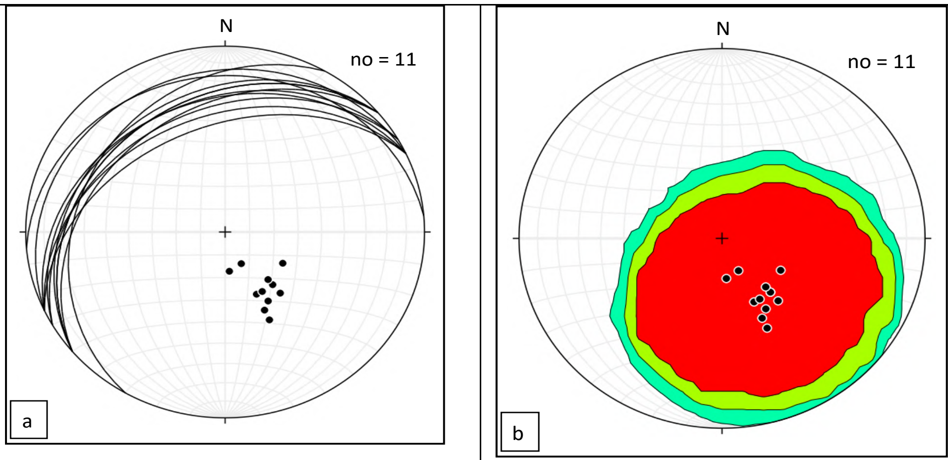

Fig. 5: Foliation planes with their poles (a) and poles contouring (b) related to D_2 deformation phase.

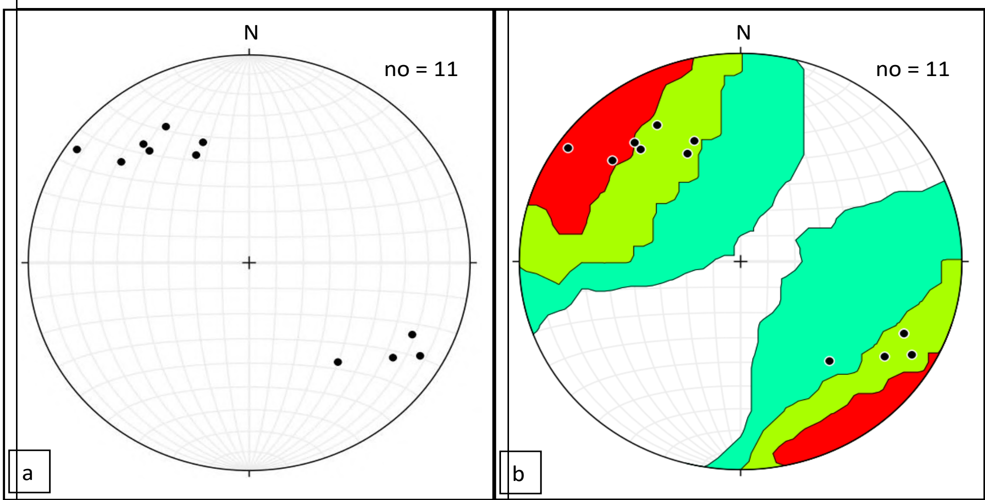

Fig. 6: Lower hemisphere equal area projection of 11 mylonite lineation points (a) and their contouring (b) of D_2 deformation phase.

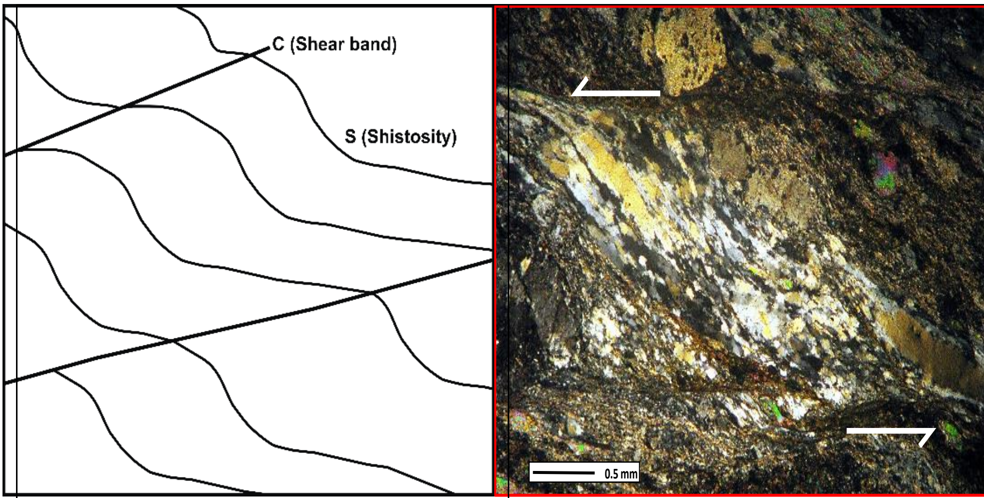

Fig. 7: C-type shear band cleavage (from upper left to lower right) transecting the S_1schistosity or foliation in mylonitized quartz metagabbro. Top movement is toward the NW. Section is parallel to the stretching lineation and normal to the foliation. Please correct schistosity on the left sketch.

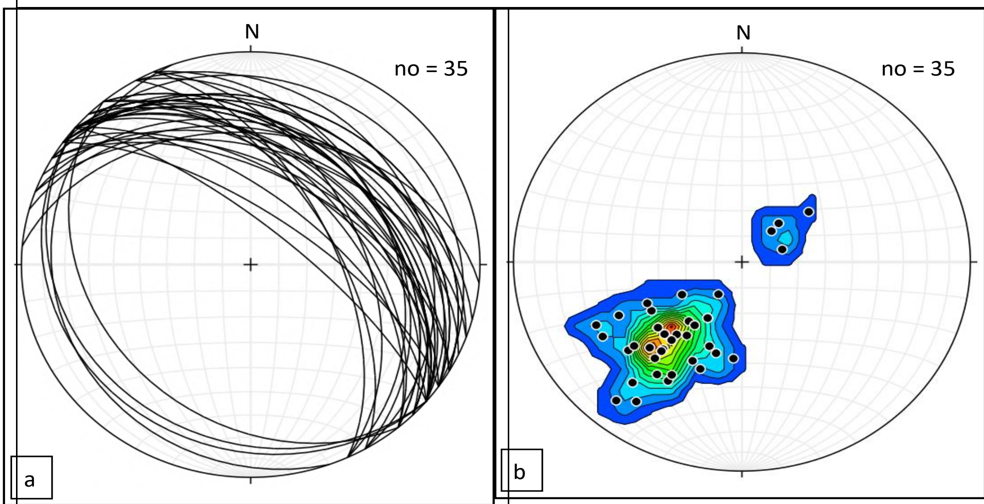

Fig. 8: Foliation planes (a) and their poles contouring (b) related to D_3 deformation phase.

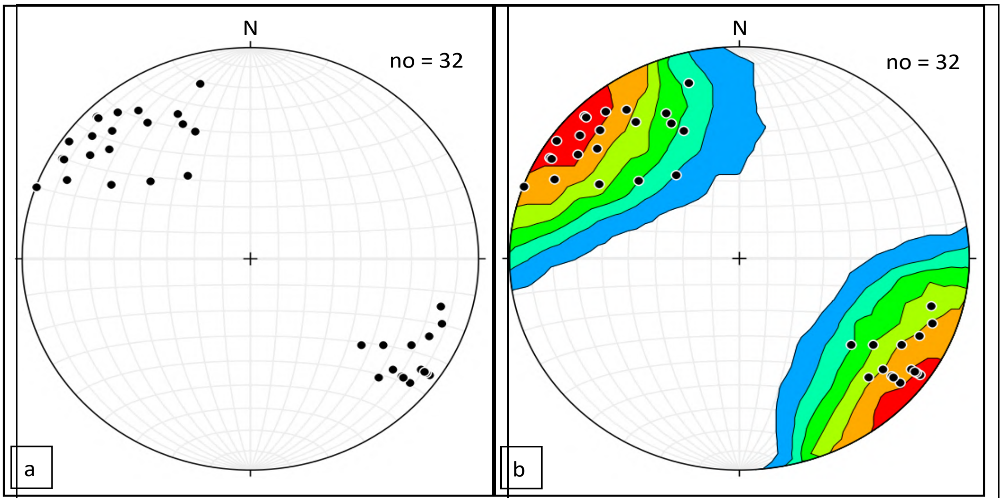

Fig. 9: Lower hemisphere equal area projection of 32 mylonite lineation points (a) and their contouring (b) of D_3 deformation phase.

4. SUMMARY AND CONCLUSION

The detailed field and petrographic studies carried out on the Wadi Shait area revealed the following points:

The SGC forms an E-W elongate mass was affected by four deformation phases (D1-D4) and underwent retrogressive dynamic metamorphism leading to transformation of their composing granite varieties of tonalite, trondhjemite, granodiorite and monzogranite into protomylonites, mylonites and ultramylonites. The field and microscopic structures within the deformed rocks assigned a NW direction of tectonic transport of some GOM slices.

The lithologies of the GOM document the presence of three metamorphic phases M1, M2 and M3, and their derivation from a less mature island arc.

The obtained U-Pb dating on zircon of 820 Ma for the tonalites from SGC and the conclusion that they represent part of an old immature ensimatic island arc (El-Kaliuobi and El-Ramly, 1991) may indicate that rifting and spreading of Mozambique Ocean was earlier than such dating.

Since the SGC under consideration is plastically deformed, therefore it must be included together with the other plastically deformed granite bodies such as Gabal El-Mayit (Akkad and El-Ramly, 1963), Abu Beit granite (Boghdady, 2000) exposed in the basement complex of Egypt. These granites are believed to belong to a granite cycle older than the non-deformed granite series (El-Ramly and Akkad, 1960), syn-to late-orogenic granites (El-Gaby et al., 1988) and Gr. A granitoids (El-Shatoury et al., 1984).

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