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Geological and structural studies on the Dara and Um Balad areas, North Eastern Desert, Egypt

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ABSTRACT

Metavolcanic, metagabbro-diorite, granodiorite, Dokhan volcanic, monzogranite, and alkali feldspar granite rocks covered Dara area. In contrast, metagabbro-diorite, Dokhan volcanic and monzogranite rocks covered Um Balad area. The North Eastern Desert is dominated by tectonic faults and related joint sets system; the dominant trends are NE - SW and NW - SE structural trends. The Dara area was affected by the extensional deformation phases trending NNW - SSE, NW - SE, NE - SW, and NNE - SSW. While the Um Balad area is affected by extensional deformation phases trending NW - SE, NNW - SSE, and NE - SW directions. On the other hand, the Dara area is affected by the compressional deformation phases trending NE - SW, WNW - ESE, and ENE - WSW directions. Um Balad area is affected by compressional deformation phases trending WNW - ESE, NE - SW, and NNW - SSE directions. Mineralized tension joints are widely distributed with different trends in the study areas. Generally, the monzogranite is highly deformed rather than the metagabbro-diorite rocks in the Dara area. While the metagabbro- diorite rocks are the highly deformed rock type in the Um Balad area.

Introduction

The study areas are located between latitudes 27º 50′ - 27º 57′ N and longitudes 32º 26′ - 33º 06′ E, Northwest of Hurghada City on the Red Sea Coast, North Eastern Desert, Egypt. The study area (Fig. 1) comprises two mines areas: Dara area (Fig. 2) located between latitudes (27° 53' 00" - 27° 59' 00" N) and longitudes (32° 50' 30" - 32° 57' 30" E). Um Balad area (Fig. 3) located between latitudes (27º 49′ 02" - 27º 51′ 37" N) and longitudes (32º 44′ 31" - 32º 48′ 35" E).

Francis (1972) published a geological map of the basement complex between Latitudes 27º 30´ and 28º 00´ N and Longitudes 32º 30´ and 33º 40´ E, on a scale of 1:250 000, including the examined areas. He mapped G. Dara as Gattarian pink biotite granites, and recognized two types of granodiorites; pink biotite-hornblende granodiorite and white muscovite-biotite granodiorite. Pink biotite-hornblende granodiorite is older than the Dokhan Volcanics and Hammamat sediments, while the white muscovite-biotite granodiorite is younger than the Dokhan Volcanics and Hammamat sediments.

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Shalaby, M. H. (1986) and Shalaby et al., (1989) studied the structure of dykes crosscutting the basement complex of the Wadi Dara area. They assigned the dykes of Phanerozoic time and showed a pronounced relationship between the orientation of these dykes and the predominant fault sets. Shalaby, M. H. (1986) and Shalaby et al., (1989) differentiated the dykes into two groups; basalt, andesite, and rhyolite dykes mainly trending in the E - W, ENE - WSW, and NE - SW, and bostonite dykes trending in N - S, NNW - SSE, and NW - SE trends. They concluded that these dykes have been formed by simple differentiation from two magma sources.

Abdel Magid et al., (1998) studied the rock types in the Dara area. They concluded that the Dara gabbro-diorite rocks, cropping out in the northern, western, and central parts intrude into the metavolcanics with clear intrusive contact, but are intruded by monzogranites and alkali feldspar granites. El-Mansi et al., (2004) published a geologic map of the basement rocks between G. Dara and G. Gharib and considered the G. Dara granites are syenogranite whereas G. Gharib to be alkaline granite. They concluded that Dara granites are more differentiated and acidic rocks.

El-Mansi et al., (2004) suggested that the Dara and Umm Sawassi granites are peraluminous intruded by the anataxis of pre-existing crustal material during the late-collision stage. El-Sundoly (2021) showed that NW - SE extensional event is the main deformation phase responsible for the generation of the radioactive uranium anomalies in the pegmatite of the younger granites in the Dara area.

A geochronological study was carried out on diorite rocks in Dara area and delineated ages of 881 ± 58 Ma, and 620 ± 16 Ma for metagabbro-diorite, and granodiorite, respectively (Abdel Rahman and Doig, (1987). El-Desoky and Hafez (2018) suggested as an island arc rocks. Abd El- Monsef et al., (2018) discussed a petrographical and geochemical study on the different rock types in the Um Balad mine area and divided them into tholeiitic metagabbro-diorite rocks derived in continental margin regime and calc-alkaline granodiorite rocks derived in continental margin tectonic regime. Hegab et al., (2022) illustrated that the Um Balad mine area is covered by younger granite, Dokhan volcanic, hammamat sediments, older granites, and the dominant metagabbro-diorite rocks.

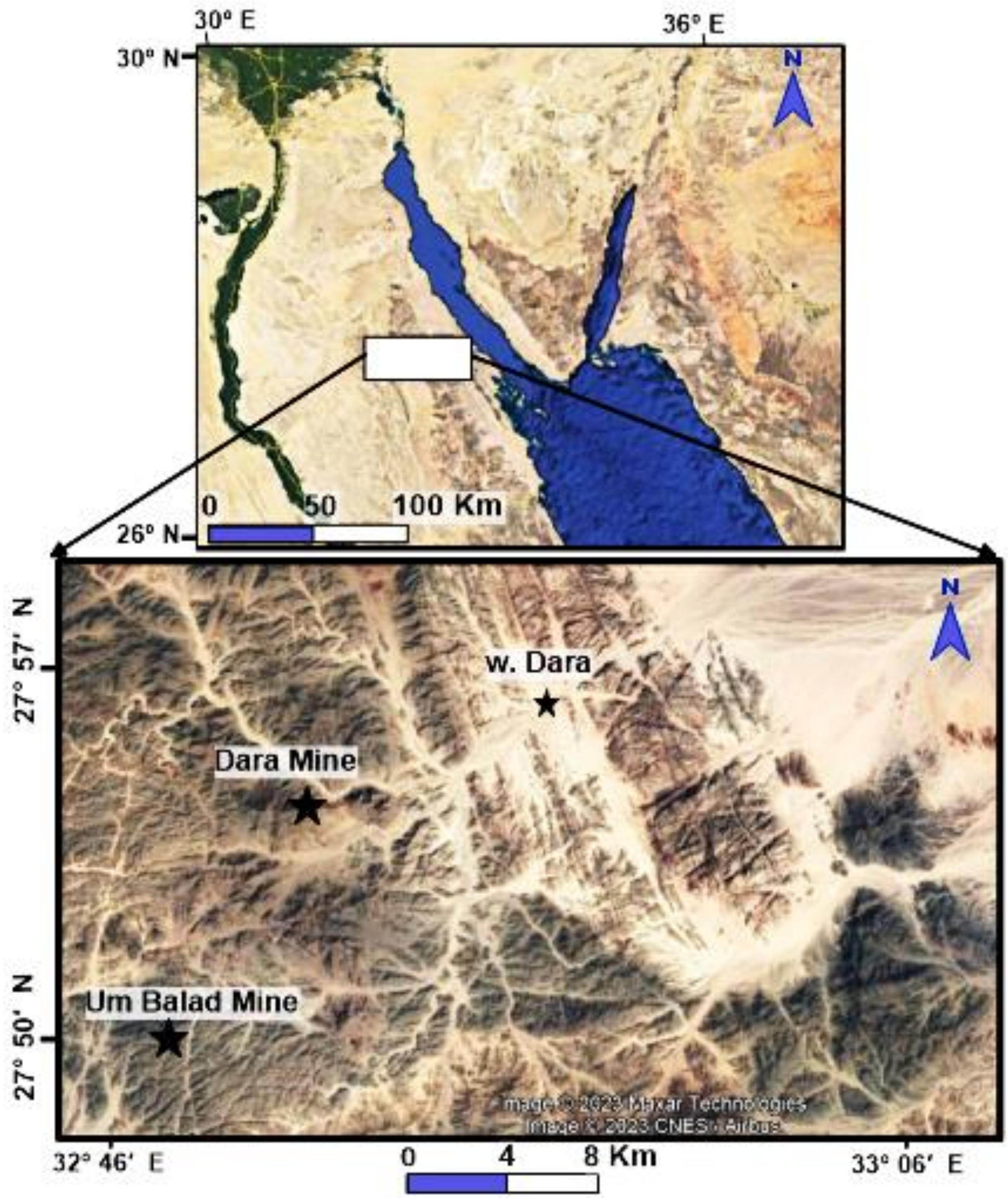

Fig. 1: Landsat image of the two mine areas (Um Balad and Dara), in the North Eastern Desert.

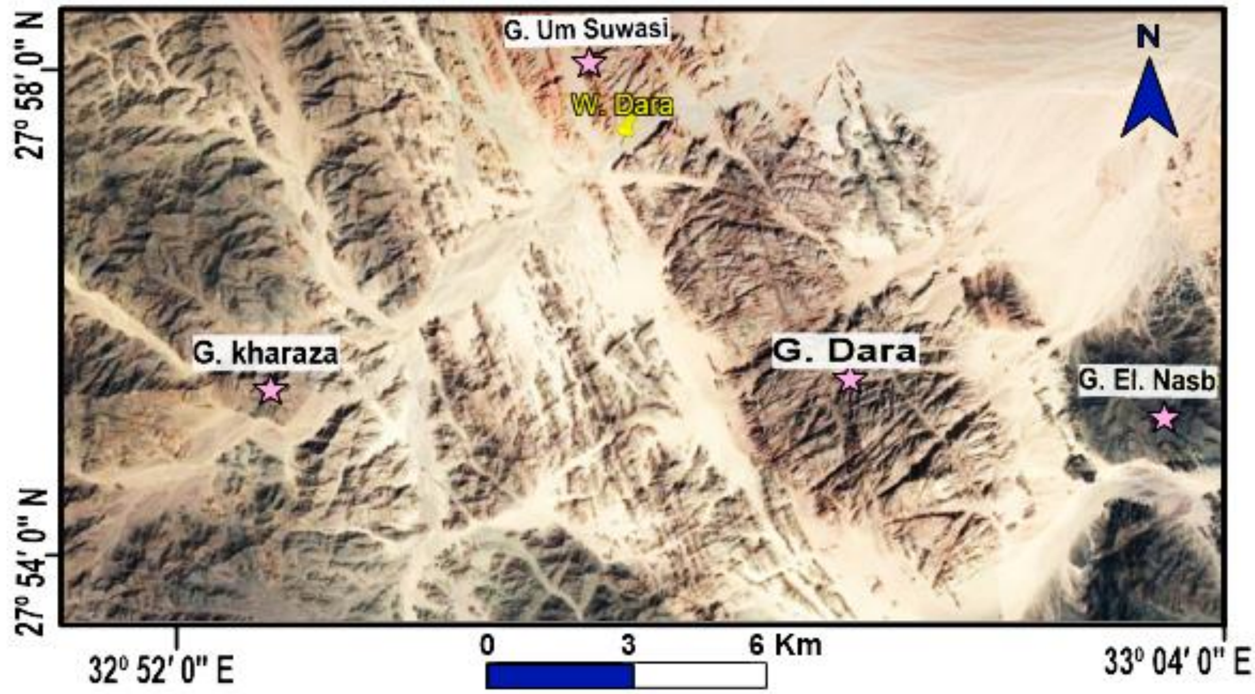

Fig. 2: The Landsat image of the Dara area.

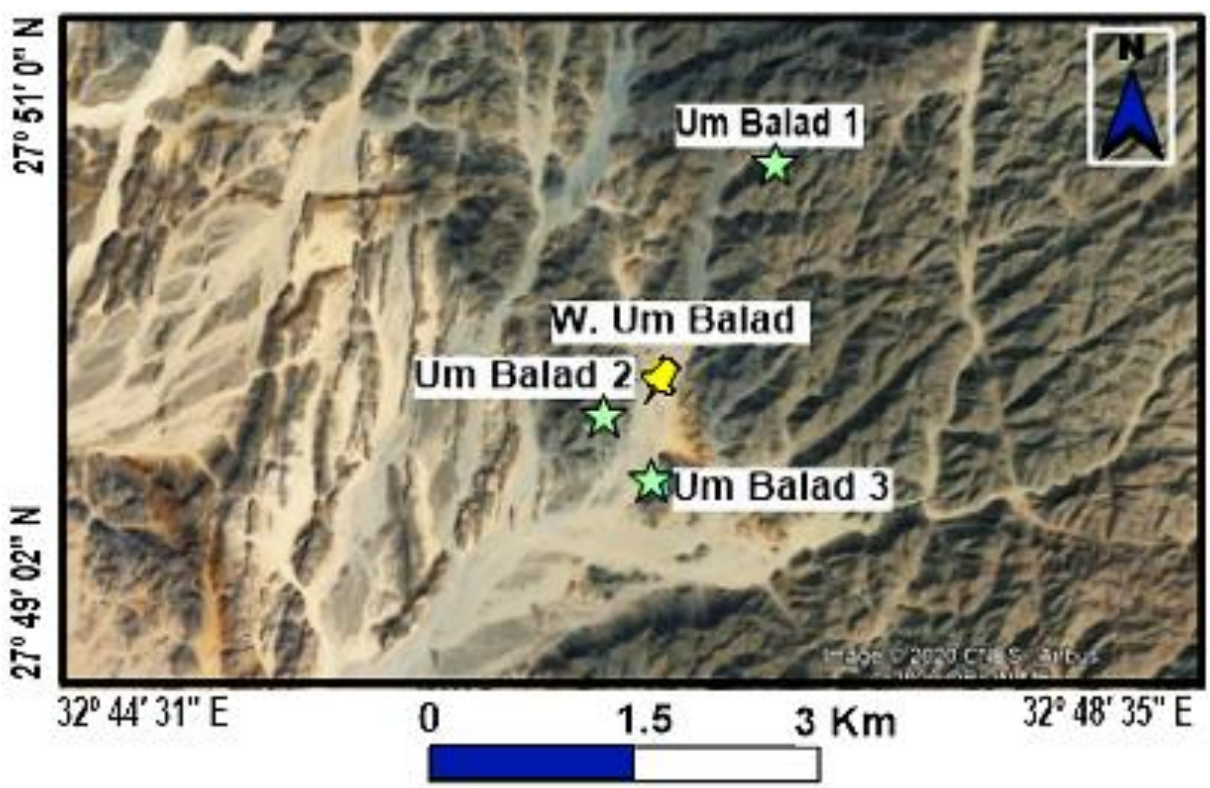

Fig. 3: The Landsat image of the Um Balad mine area.

The present work aims to illustrate detailed geological and structural studies of the Dara and Um Balad mine areas. A geological investigation was based on topographic maps of Um Balad and Dara areas (scale1:100000) and Google Earth satellite images. In addition, previous detailed- geological maps for the study areas (e.g. Abdel Monsef, 2018, El-Desoky and Hafez, 2018) have been used as guide maps. The field studies and the samples collection include reconnaissance work to fix locations with the help of the Global Positioning System (GPS) of the target sites and outcrops in the study areas. The collected data was used to identify the different rock types in the selected areas and the structural elements in order to construct a detailed geologic-structure map for the two areas.

Geological setting

The Egyptian Eastern Desert of Egypt has occupied the northwestern part of the Arabian Nubian Shield (ANS) (Fig. 4). The basement rocks of Egypt represent the northwestern segment of the ANS. They cover about 100,000 km^2 in the Eastern Desert over the coast of Red Sea, southern Sinai, and southwest of Aswan. Generally, the Egyptian basement rocks are considered an assemblage of volcanic arcs and the associated ophiolite remnants intruded by granitoids (e.g. Avigad et al., 2007; Meert, 2003; Stern, 1994; Stoeser and Frost, 2006). The tectonic evolution for the Egyptian basement rocks is divided into three stages, namely: pre-collisional, collisional, and post-collisional stages (Stern, 1994; Moghazi, 2003; Be'eri-Shlevin et al., 2009; Eyal et al., 2010; Stoeser and Frost, 2006).

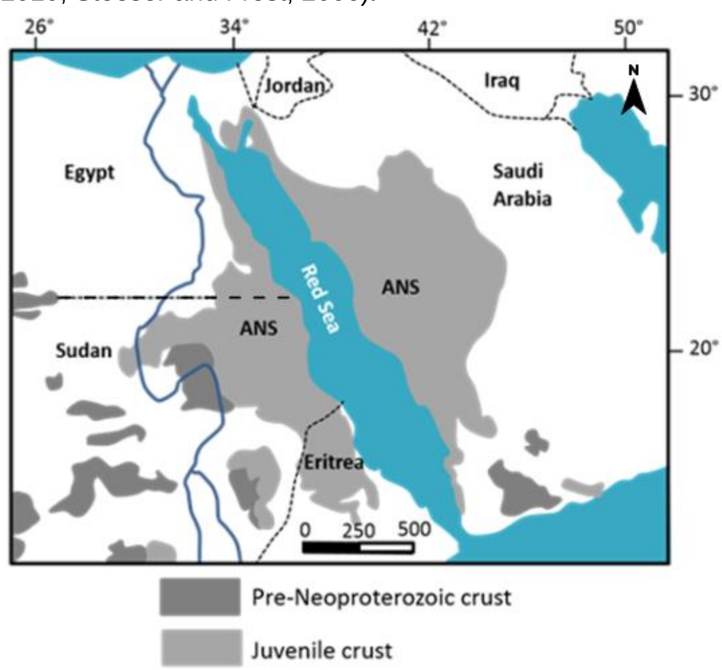

Fig. 4. The distribution of Arabian Nubian Shield (ANS), (after Fritz et al., 2013).

The pre-collisional stage during the Cryogenian Period (~850 – 650 Ma) is characterized by the formation of ophiolites and ophiolitic mélange, coeval arc assemblage (volcaniclastic and volcanic rocks intercalated with sedimentary rocks, El-Gaby et al., 1990) and intruded by metagabbro-diorite complexes and older granitoids (Stern & Hedge, 1985; Moussa et al., 2008). The entire rocks of this stage are all metamorphosed in the greenschist facies. Migmatites and gneisses occur in several metamorphic core complexes in the Eastern Desert and Sinai (Loizenbauer et al., 2001) and have been dated at (800 – 630) Ma (Stern & Manton, 1987) and are considered to be similar to metamorphic core complexes related to a crustal extension. This stage was followed by the production of magma with arc affinity (~ 670 – 635 Ma) that is represented by weakly deformed gabbros and granodiorites. The final stage is the Ediacaran post-collisional stage (~ 635 –580 Ma). This stage witnessed the formation of (630 – 592 Ma) K calc-alkaline Dokhan volcanic (Breitkreuz et al., 2010), (606 – 585 Ma) Hammamat Group molasse type sedimentary rocks (Moussa et al., 2008) and (620 – 550 Ma) alkaline to peralkaline younger granites (e.g., Stern and Hedge, 1985; Moghazi et al., 2012).

The Dara area is covered by metavolcanic, metagabbro-diorite, granodiorite, Dokhan volcanic, monzogranite, and alkali feldspar granites were cutting by different types of dykes and quartz veins (Fig. 5). The Um Balad area covered by metagabbro-diorite, Dokhan volcanic and monzogranites intruded by different types of dykes and mineralized veins. All these rock units are well demonstrated on a geologic-structure map (Fig. 6).

The metavolcanic rocks are the oldest rock unit and occur as small masses dispersed in the northwestern part of the Dara area. The metavolcanic rocks generally form low hills or roof pendants covering an area of ~ 5 % of the total exposed rocks. They are massive to weakly foliated, characterized by dark grey colour, and composed of fine- to medium–grained meta andesites and meta rhyolite exhibiting low-grade greenschist metamorphism and cut by many basic and felsic dykes.

The metagabbro-diorite rocks are massive to weakly foliated, medium- to coarse-grained, and have dark green to black colours. They are generally metamorphosed to the greenschist facies and have mesocratic to melanocratic characters. In the Dara area, the metagabbro-diorite intrudes the metavolcanic and may occur as xenoliths in the monzogranite and alkali feldspar granites. Both metavolcanic and metagabbro-diorite rocks belong to the arc-related rocks of the NED (Abdel Rahman & Doig, 1987; Zaki, 1996). On the other hand, in the Um Balad area, metagabbro-diorite was recorded as three blocks in the central and eastern parts of the Um Balad area (Fig. 6). All of them intruded by quartz veins also have an intrusion of granodiorite (Fig. 7A) and monzogranite.

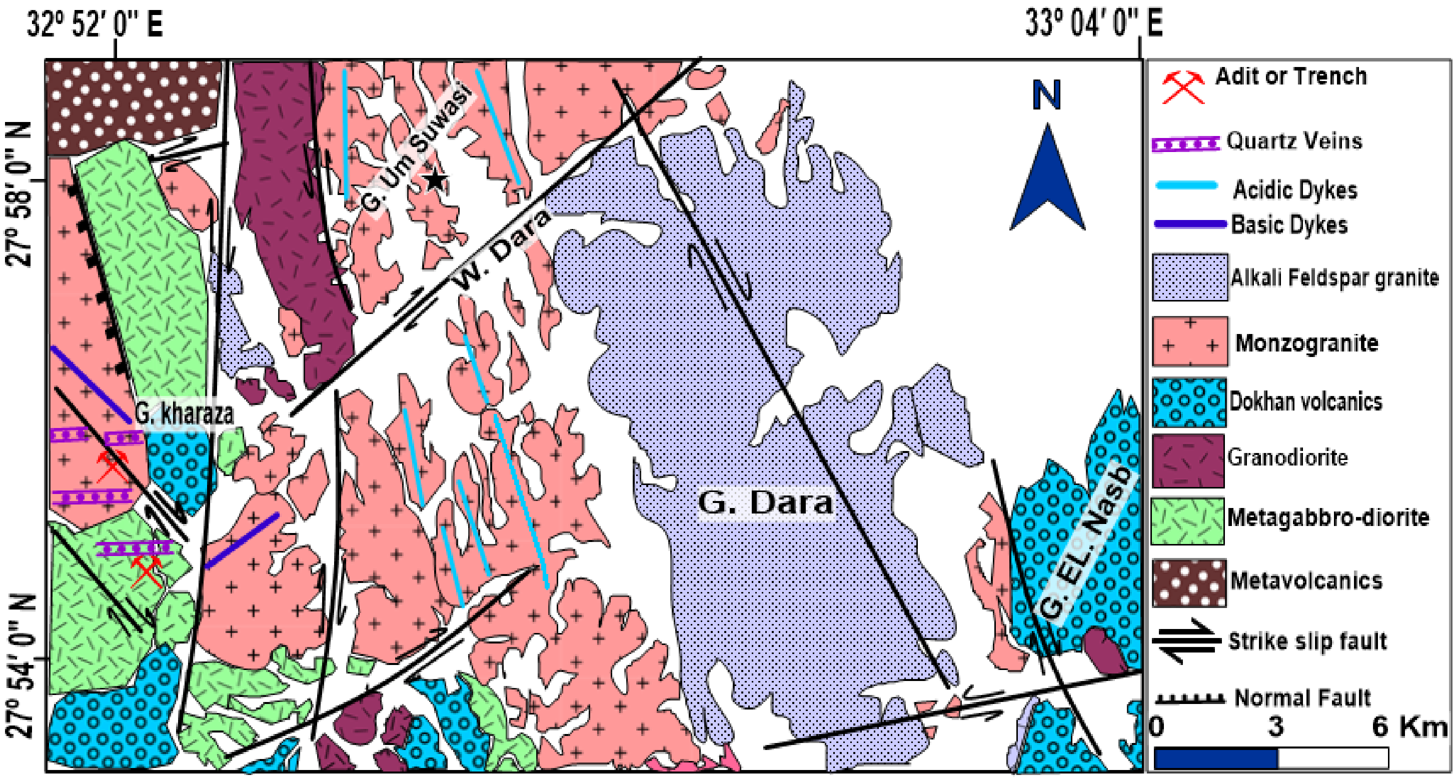

Fig. 5. Geological- structural map of the Dara area (modified after El-Desoky and Hafez, 2018)

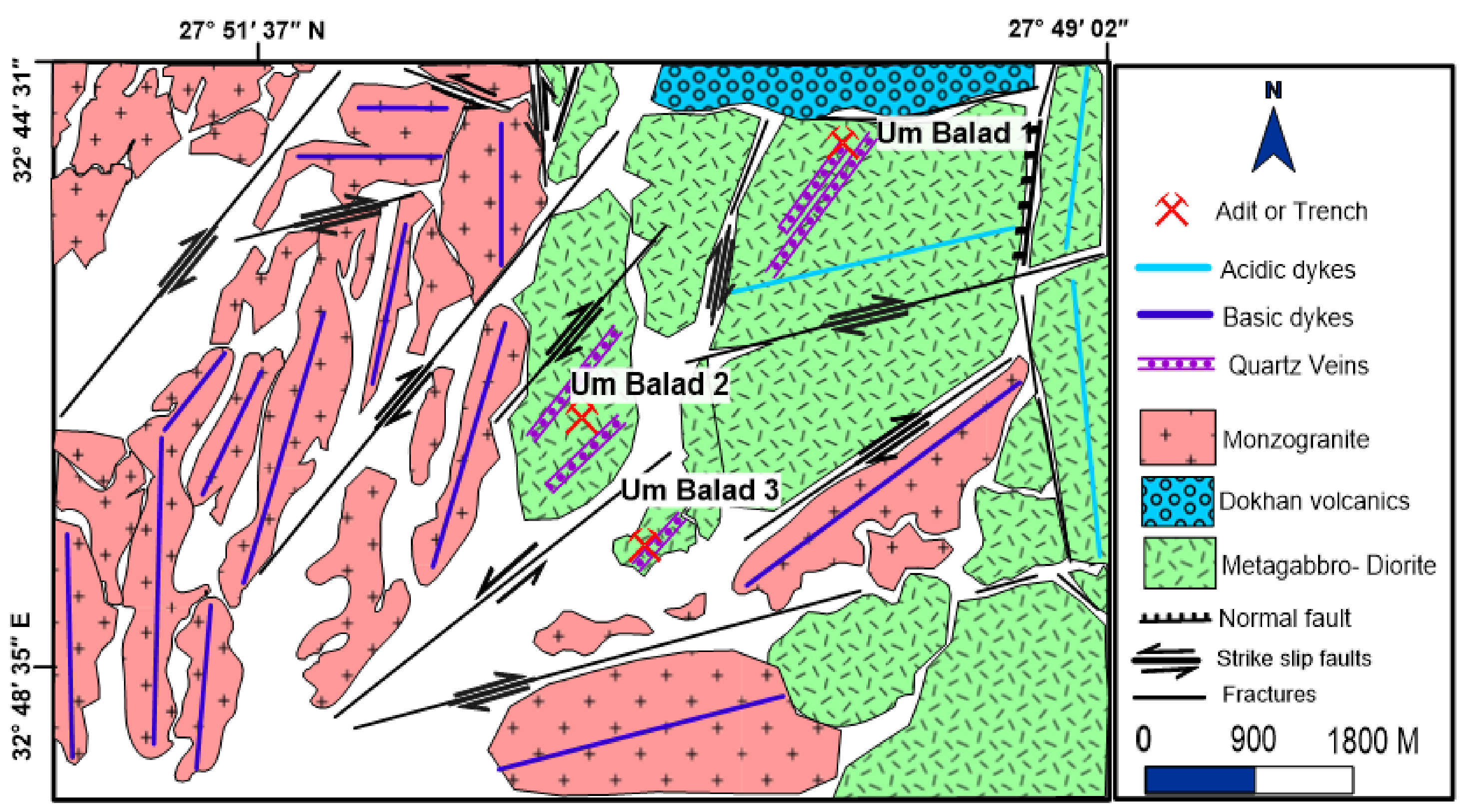

Fig. 6. Geologic-Structure map of the Um Balad mine area.

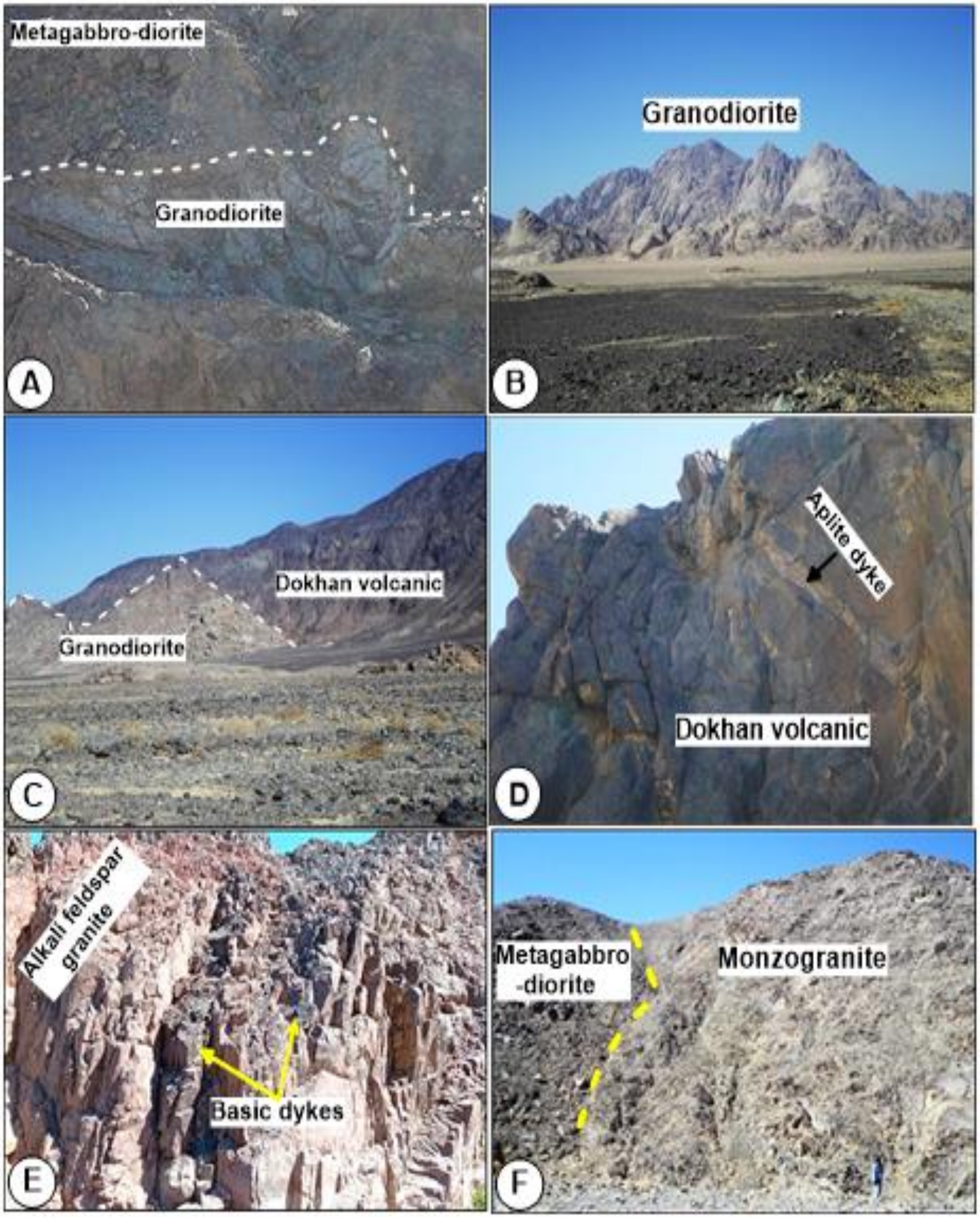

Fig. 7: Field photographs showing: A) Intrusive granodiorite onto the metagabbro-diorite rocks in the Um Balad area. B) The granodiorite rocks with low to moderate relief in the Dara area. C) Sharp Intrusive contact between Dokhan volcanic and granodiorite rocks in the Dara area. D) Dokhan volcanic affected by jointing and cut by aplites dyke, Um Balad area. E) The Alkali feldspar granite is well-jointed and dissected by basic dykes in several directions in the Dara area. F) Sharp contact between monzogranite and metagabbro-diorite, Um Balad area.

The granitoid rocks are widespread in the Dara and Um Balad areas (Fig. 6). The older granite is less common in contrast with the younger granite rocks. The older granites are represented by granodiorite. In the Dara area, the granodiorite suite consists of a highly sheared and eroded long belt extending N-S with low to moderate relief (Fig. 7B). It is mainly coarse-grained with whitish-grey color. The granodiorites have been intruded by the Dokhan volcanic (Fig. 7C) and younger granites are almost at sharp intrusive contacts. Mafic xenoliths of metagabbro-diorite are abundantly present in the granodiorite. The granodiorite is highly injected by quartz veins and numerous basic, intermediate, and acidic dykes. In the Um Balad area, granodiorites are of minor distribution and are found as off-shots in the metagabbro-diorite rocks.

Conversely, the younger granites are the dominant rock type in the Dara and Um Balad areas. In the Dara area, they cover an area of about 65% of the total area forming a large elongate belt trending NNW. The younger granite plutons in the Dara area form a rugged mountainous belt and are characterized by high relief compared to the surrounding country rocks. The contacts between the younger granites and the other rocks are sharp, where several offshoots of the younger granites occur in the older units.

Dokhan volcanic (Fig. 7C) was recorded as small masses in the Dara area at G. Kharaza and G. EL Nasb (Fig. 5). The Dokhan volcanic is composed of rhyolite and andesite varieties and alternates with banded tuffs. The tuffs are represented by thick stratified lava flow and are found as a thick sequence that has a variation in composition from acidic to intermediate. Rhyolite rocks are found in reddish-brown colours with fine-grained, aphanitic textures. On the other hand, the andesite variety has green and dark green colours with medium-grained and porphyritic textures. The Dokhan volcanic rocks have sharp intrusive contact with granodiorite and metagabbro-diorite. Acidic (Fig. 7D) and basic dykes intruded the Dokhan volcanic. In the Um Balad area, Dokhan volcanic rock type is limited and recorded in the northeastern part of the study area. Its colour varies from green and grey to reddish colour. Also, its composition varies from andesite, dacite, and rhyolite. It is noticed that in the hand specimen, andesite has milky porphyries in the green matrix. Also, dacite has grey with a light green colour. Rhyolite has a fine-grain texture with porphyritic components of quartz and k- feldspar, characterized by reddish-pink colour.

The younger granites are classified into monzogranite (575 to 589 ± 11 Ma, Abdel Aty, 2009) and alkali feldspar granite (545 – 562 ± 10/11 Ma, Abdel Aty, 2009) (Fig. 5). The monzogranites are characterized by whitish-pink colours, and coarse-grained, and have a sharp intrusive contact with Dokhan volcanic and granodiorite, but are intruded by alkali feldspar granites. The monzogranite masses are highly jointed. Alkali feldspar granites, on the other hand, mainly constitute the Gabal (G) Dara plateau (Fig. 5). These rocks are reddish pink to pink, medium- to coarse-grained, and are characterized by well-jointed and dissected by basic dykes in several directions (Fig. 7E), and exfoliation structure. On the other hand, the younger granite in the Um Balad area is represented by monzogranite rock-type crops out in the western and northwestern parts of the study area. They are recorded as pinkish-white colour. They have a sharp intrusive contact with metagabbro-diorite (Fig. 7F), also intruded by basic dykes that differ in thickness and trend.

Structure

Joints

The joints recorded in all rock types of the study area were very characteristic features. Joint density and pattern vary from one rock type to another. Joints in the study areas are divided into shear and tension joints based on their tectonic origin.

Shear joints

Shear joints are non-mineralized and represented by two major conjugate sets. The conjugate sets in the Dara and Um Balad areas were analyzed by using the win tensor program (Fig. 8) (Delvaux & Sperner, 2003) and the right dihedron program (Fig. 9), respectively, to determine the principle stress axes attitude and deducing the tectonic events. The attitudes of (σ_1 or σ_3) stress axes represent the deformational phases that affected the study areas, where σ_1 is the compressional deformation phase, and σ_3 is the extensional deformation phase. The directions of σ_1 trending 69° with a plunge 14°, 89° with a plunge 28°, 232° with a plunge 26°, 108° with a plunge 29°, 212° with a plunge 28° and 115° with a plunge 17°. On the other hand, Um Balad area is affected by compressional deformation phases trending in WNW - ESE, NE - SW, and NNW -SSE directions. The directions of σ_1 trending (289° with plunge 5°, 297° with plunge 27°, 295° with plunge 3°), 48° with plunge 18°, and 329° with plunge 27°.

Tension joints

Tension joints are mineralized joints and are related to different types of alterations. Structural analysis using the win tensor and right dihedron programs for tension joints were obtained (Fig. 10 & 11). The Dara area was affected by extensional deformation phases trending NNW - SSE, NW - SE, NE - SW, and NNE - SSW. The directions of σ_3 trending 340° with plunge 4°, 138° with plunge 0°, 40° with plunge 0°, 215° with plunge 15° , and 25° with plunge 2°. While the Um Balad area is affected by extensional deformation phases trending NW - SE, NNW - SSE, and NE - SW directions. The directions of σ3 trending 312° with plunge 6°, 150° with plunge 8° and 48° with plunge 20°.

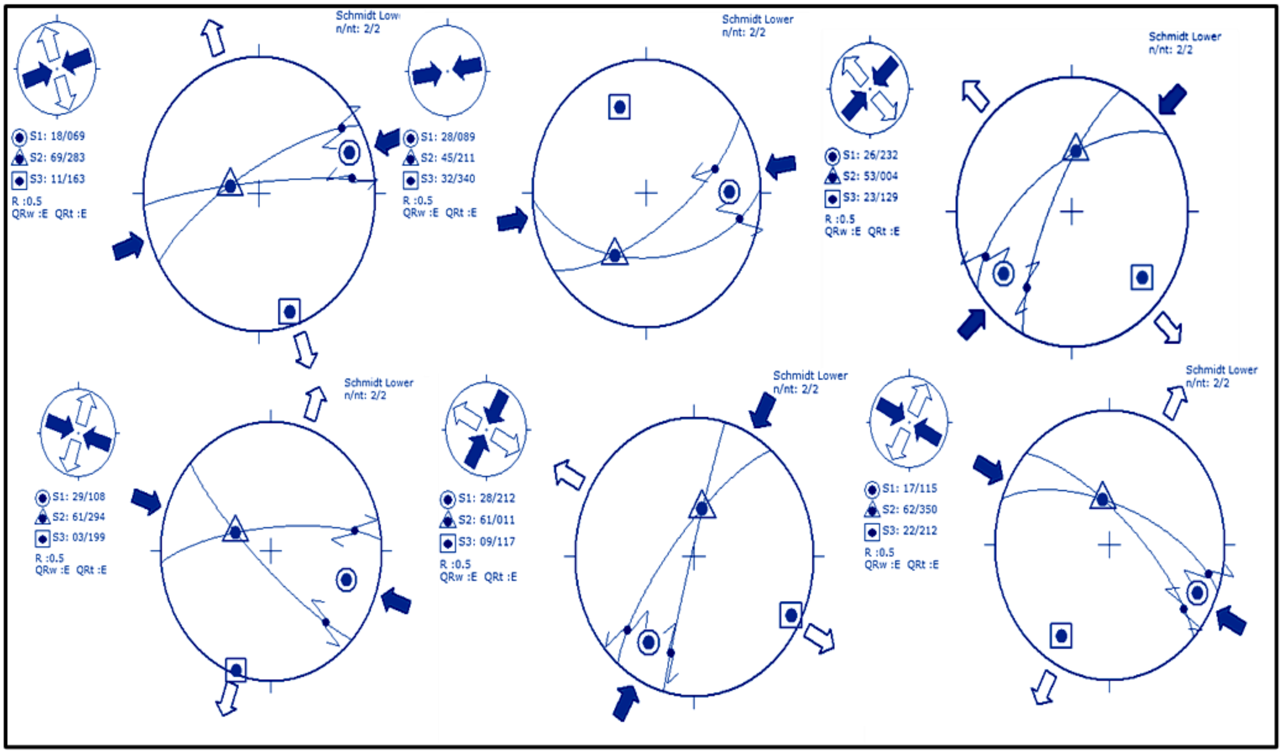

Fig. 8. Three principle stress axes of the two major conjugate sets for shear joints in the metagabbro-diorite of Dara area.

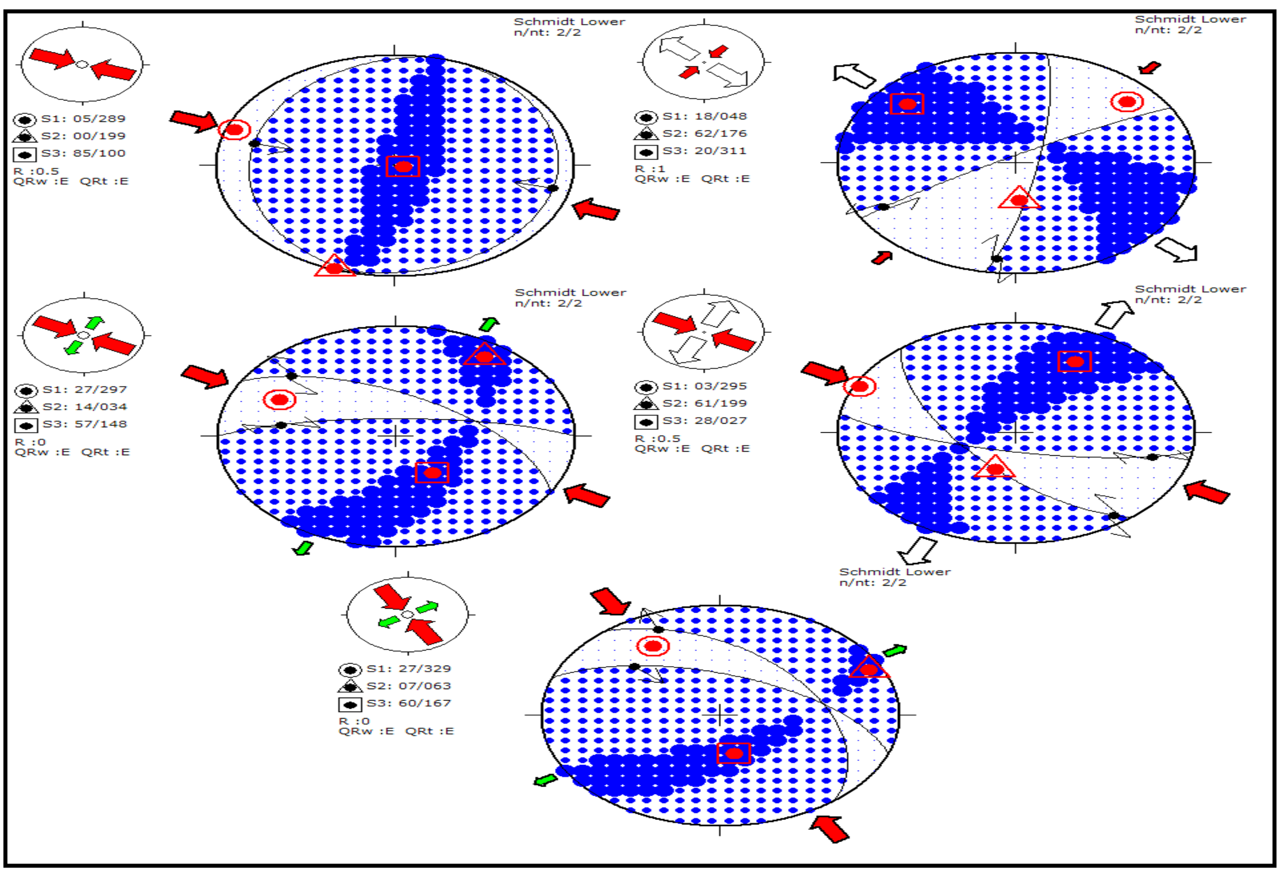

Fig. 9. Three principal stress axes of the two major conjugate sets for shear joints in the metagabbro-diorite of Um Balad area.

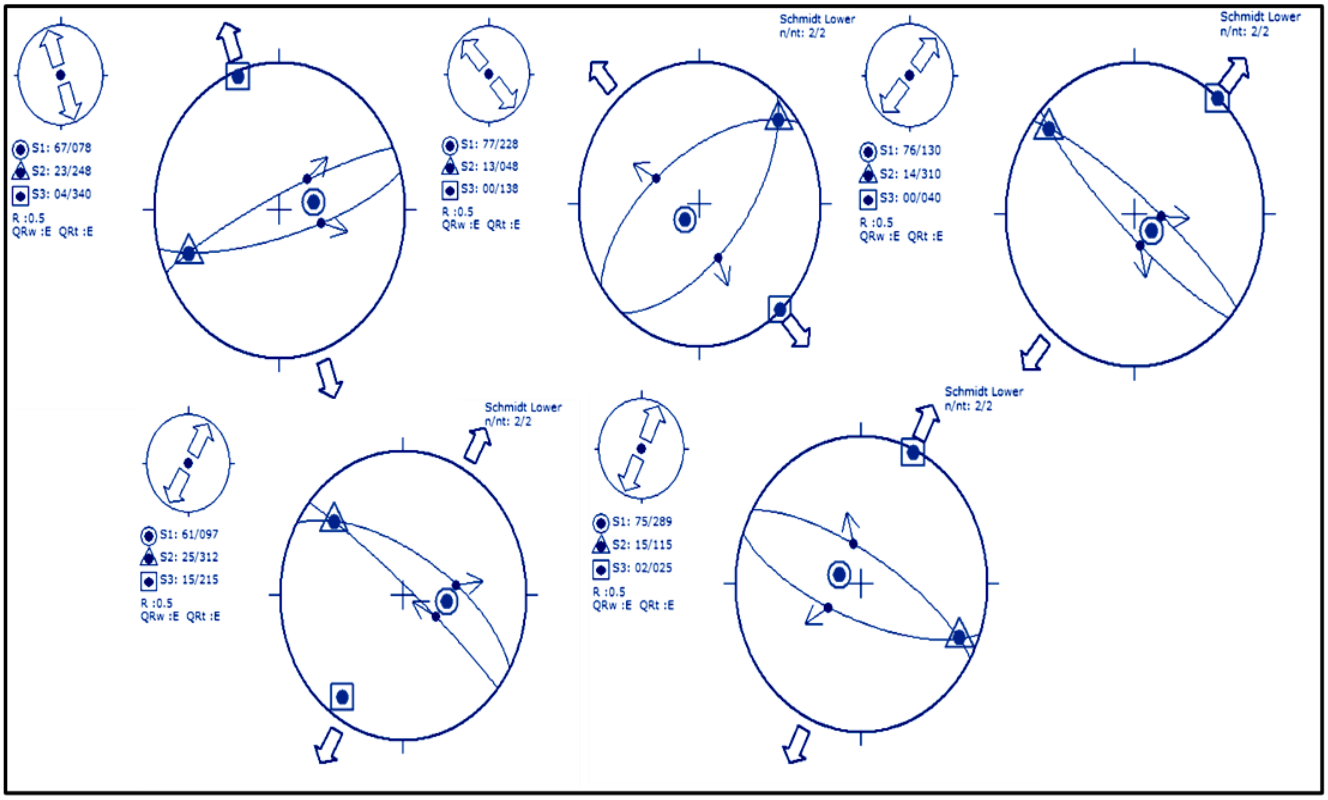

Fig. 10. Three principle stress axes of the two major conjugate sets for tension joints in the monzogranite of Dara mine area.

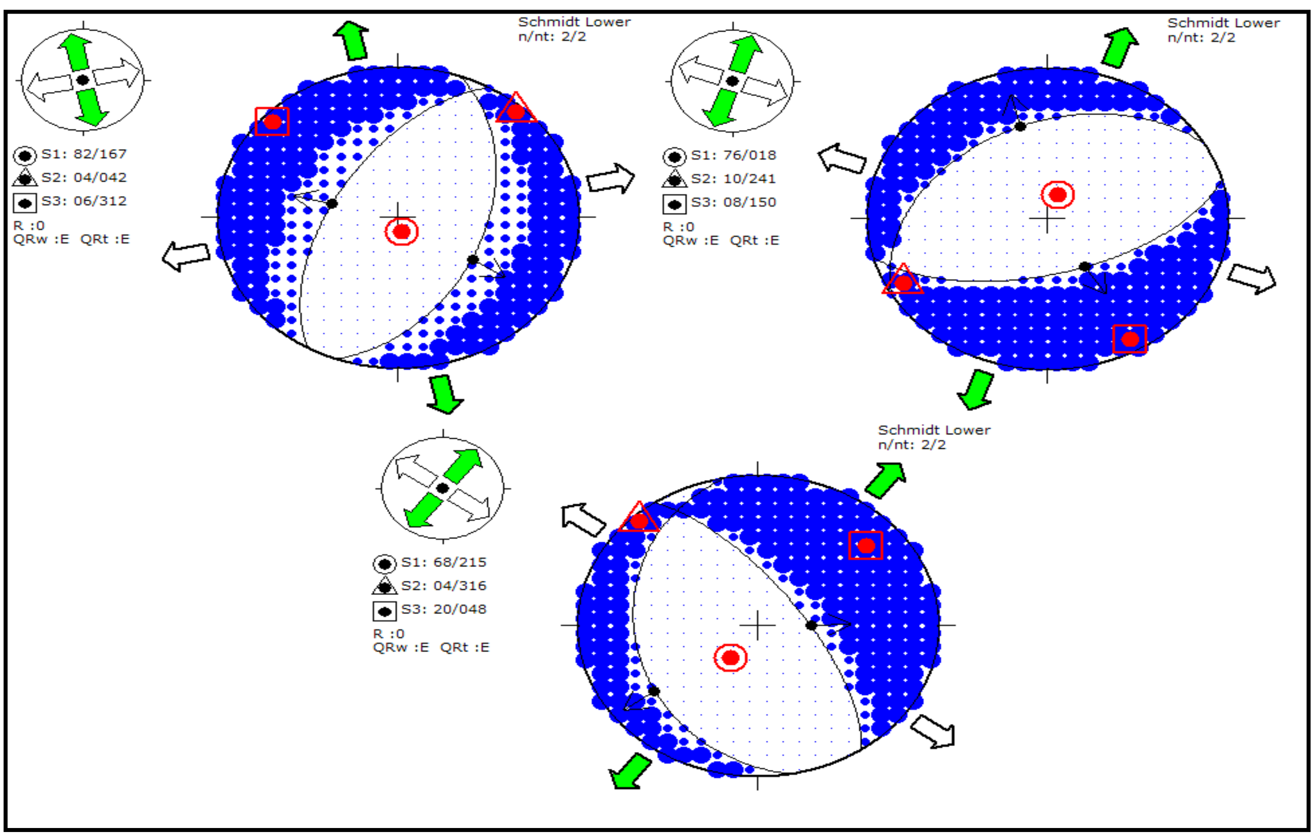

Fig. 11. Three principle stress axes of the two major conjugate sets for tension joints in the metagabbro-diorite of Um Balad area.

Surface lineaments analysis

In the Dara area, surface structural lineaments are traced on a google earth satellite image with a total length of 312 km (Fig. 12). The primary trend of surface structural elements in the Dara area is N - S with 32.4 % of the total number proportion and 26.8 % of total length proportion followed by the NE - SW Trend that found with 16.2 % of total number proportion and 7.7 % of total length proportion. On the other hand, the NW - SE trend is the least in number proportions. In the Um Balad area, 333 surface structural lineaments with a total length of 666 km are traced on a google earth satellite image (Fig. 13). Again, N - S is the primary trend of surface structural elements in the study area, with 32.3 % of the total number proportion and 20.4 % of the total length proportion, followed by NNE - SSW trend with 24.2 % of total number proportion and 6 % of total length proportion and the WNW - ESE, NW - SE and NNW - SSE are fewer trends in number and length proportions. The number and length proportions of all trends in the study areas are illustrated by a rose diagram (Fig. 14).

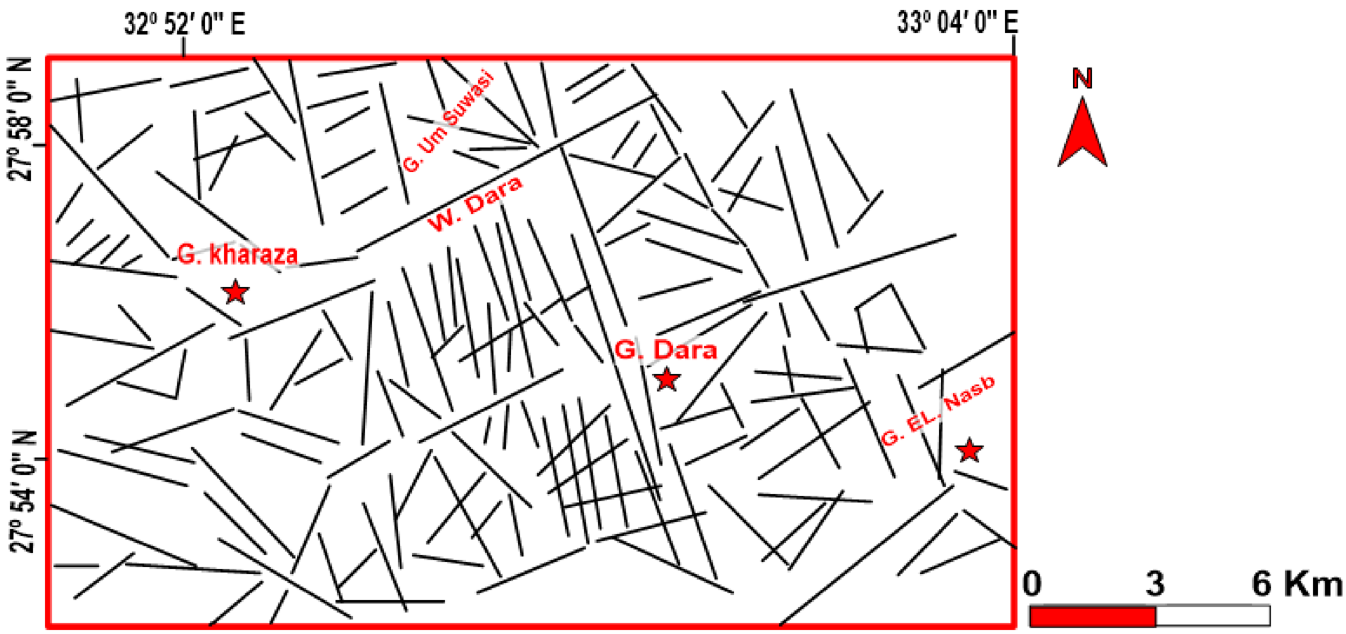

Fig. 12. Lineament map showing the distribution of structural lineaments in the Dara area.

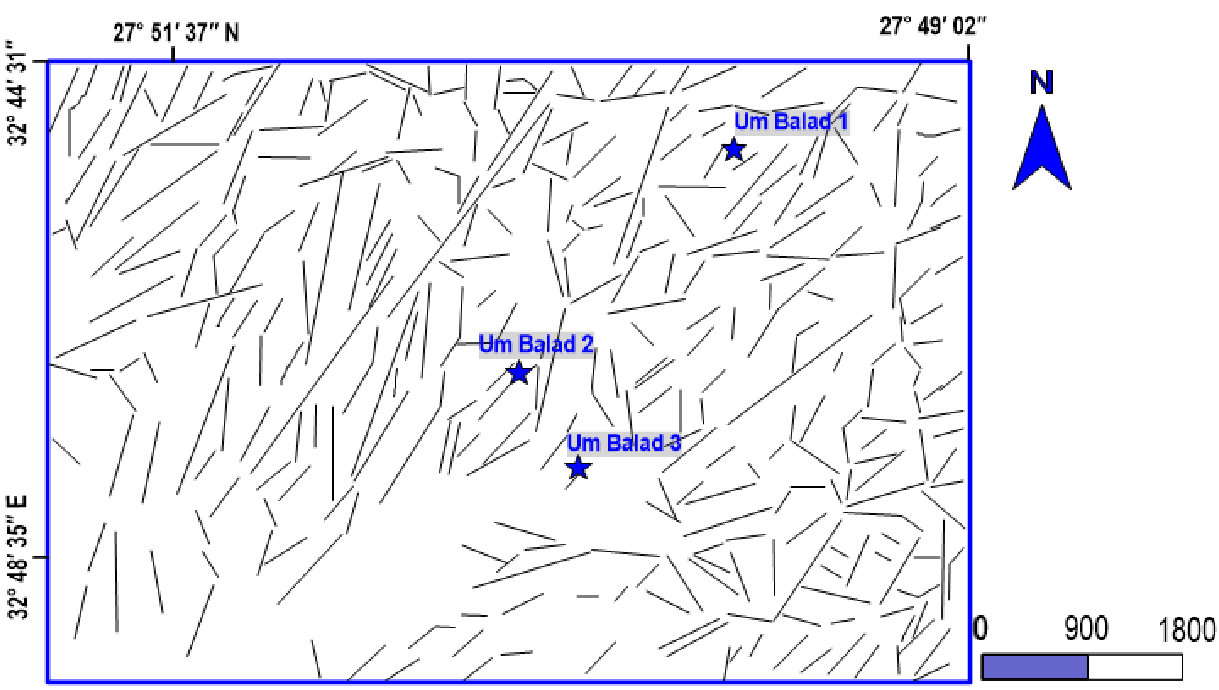

Fig. 13. A lineament map showing the distribution of structural lineaments in the Um Balad area.

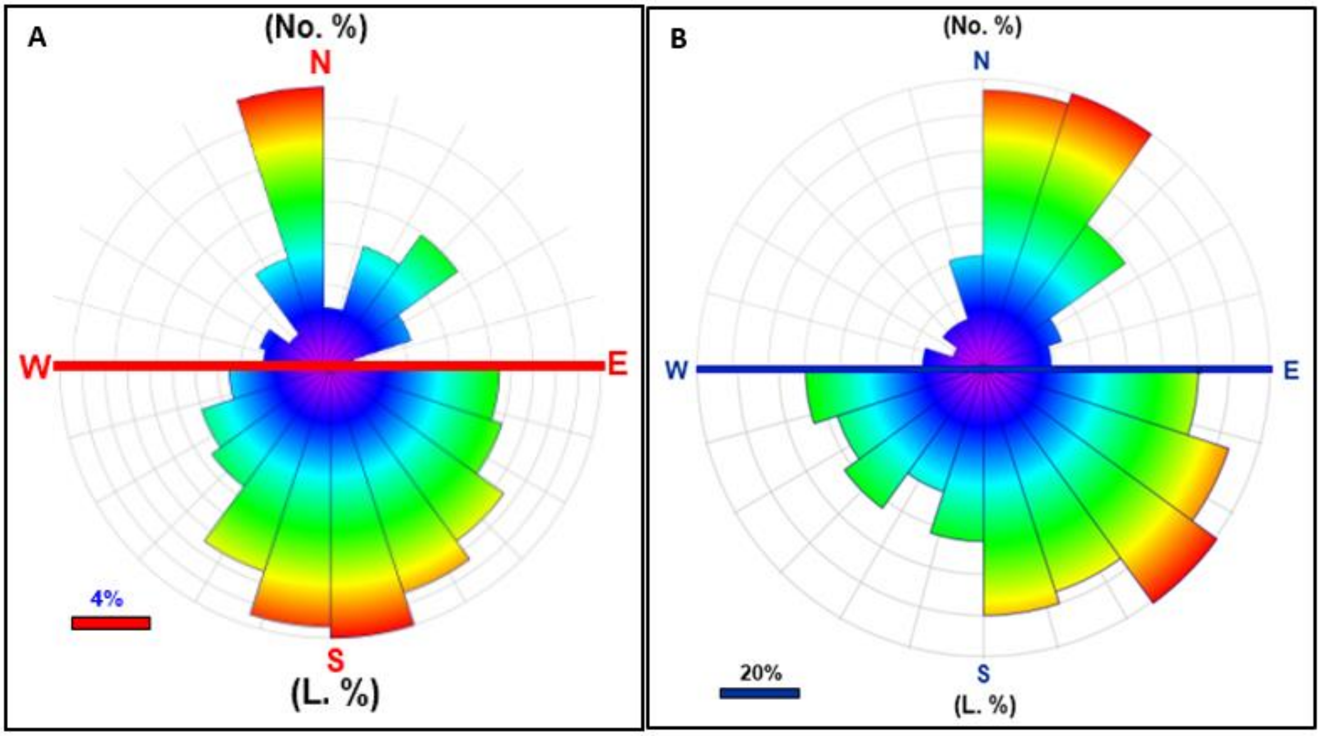

Fig. 14. Rose diagrams displaying the master trends of number (N) and length (L) proportions of surface lineaments: A) In the Dara area and B) In the Um Balad area.

Faults

Faults in the Dara area varied in the trends, indicating more than one tectonic event. NW - SE fault trend is a strike-slip fault (Fig. 5 & Fig. 15A), and normal faults are the main fault type of this fault trend. In the Dara area, the NW - SE fault trend cut the metagabbro - diorite and monzogranite. NW - SE normal faults (Fig. 5 & Fig. 15B) were detected on the contact between metagabbro-diorite and monzogranite.

On the other hand, the NNW - SSE fault trend is one of the main trends in the Dara area. The faults of this trend are normal faults detected at the contact between tonalite-granodiorite and monzogranite rocks. While the NE - SW fault trend is represented by Wadi Dara as one of the major faults of this fault trend, also these fault trends are detected at the contact between the monzogranite and Dokhan volcanic. The NE - SW fault trends are dextral strike-slip faults (Fig. 5 & Fig. 15C). The N - S fault trend represents a dextral strike-slip fault in the study area, cutting all different rock types (Fig. 5).

In the Um Balad area, Fault trends are NNW - SSE, NW - SE, NE - SW, ENE - WSW, and NNE - SSW. NNW - SSE fault trends are sinistral strike-slip faults (Fig. 6 & Fig. 15D), cutting the metagabbro-diorite and on the contact between metagabbro-diorite and monzogranite in the study area. Also characterized by the displacement of some basic dykes, which intruded all the rock types in the study area. NW - SE fault trend, the faults of this trend are sinistral strike-slip faults related to the Najd fault system. Few NW - SE fault trends were found to cut the NNW - SSE fault trend in the monzogranite and the NE - SW fault trend in metagabbro-diorite.

NE - SW fault trends and NE - SW fault trends are the main fault trends in the study area. The faults of these trends were found as dextral strike-slip faults. The NE - SW fault trends affect all rock types in the Um Balad area. Wadi Um Balad represents the major fault trend in the study area. Its displacement was observed in the metagabbro-diorite. These fault trends were found cutting the NNW - SSE fault trends, also characterized by the presence of slickenside, and displacement of some basic dykes in monzogranite. ENE - WSW fault trends, these faults of these trends are dextral strike-slip faults, cutting metagabbro- diorite, and monzogranite (Fig. 6). ENE - WSW fault trends were found cutting the NNW - SSE and NNE - SSW fault trends, also characterized by the presence of displacement of some acidic dykes in metagabbro-diorite (Fig. 6). The NNE - SSW fault trends represented by normal faults (Fig. 15E) and shear zones (Fig. 15F), also characterized by the presence of slickenside and displacement of some acidic dykes.

Summary and Conclusion

This study had shed some lights to the structural elements present in the study areas, their type, their distribution in time and space, their geometry, and, to some extent. The structure of the Dara and Um Balad areas was recorded as a brittle deformation represented by significant faults, shear zones, fractures, and joints. In addition, acidic and basic dykes cut all different rock types of the study areas.

The brittle deformation structure especially the mineralized structure elements which affected on the Dara and Um Balad areas associate with the rejuvenation of NW – SE compressional event of Najd fault system to the NE – SW and E - W faults of extensional event. The resulted major faults allowed a pathways for the upwelling hydrothermal solutions that highly enriched in mineralization and therefore the mineralization deposited in the NE –SW and E – W trends in their Dara and Um Balad host rocks.

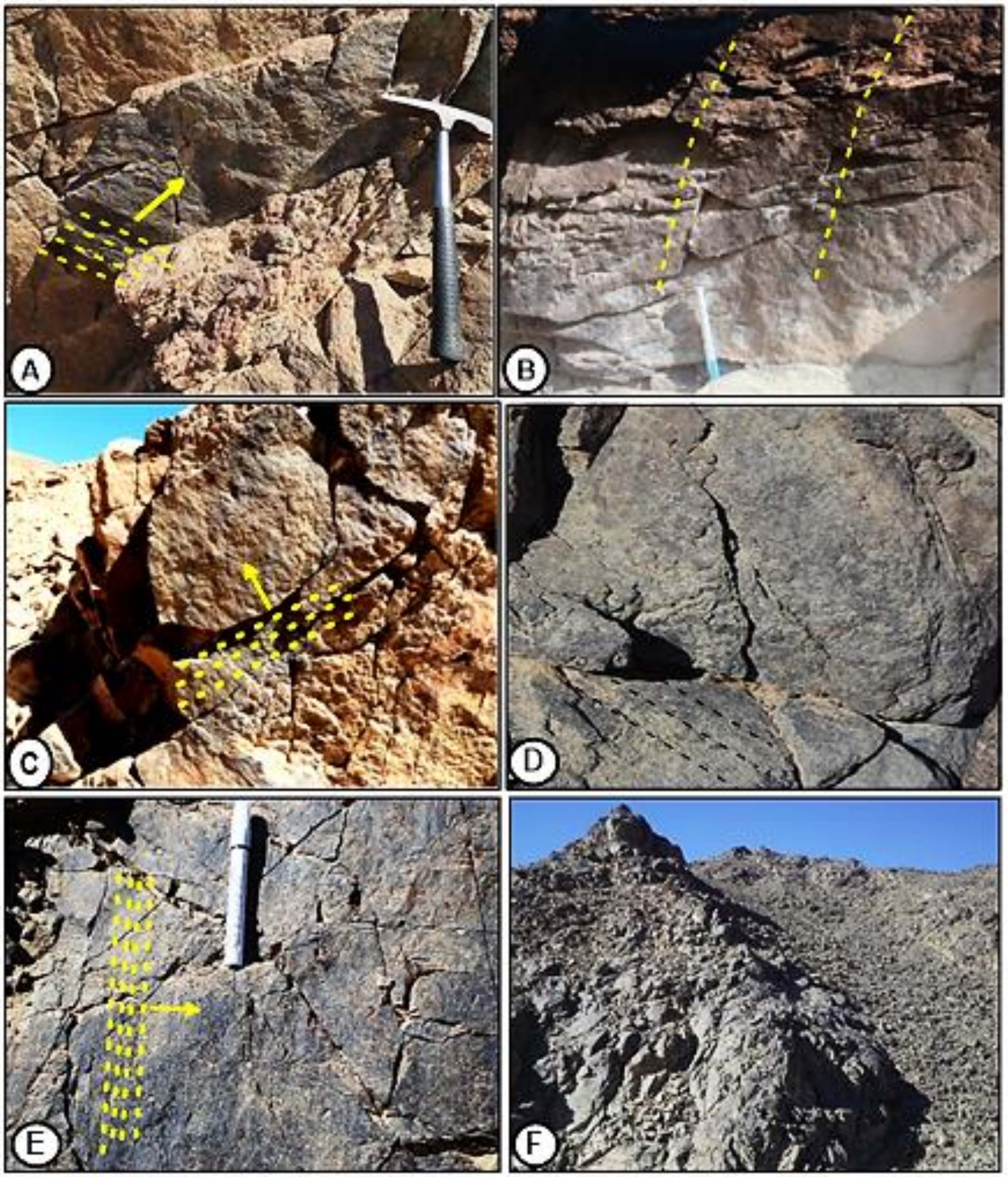

Fig. 15. A) Slickensides of sinistral NW-SE fault along monzogranite, Dara area. B) Slickensides NW-SE normal fault on the contact between metagabbro-diorite and monzogranite, Dara area. C) Slickensides of dextral NE-SW fault at the contact between the monzogranite and Dokhan volcanic, Dara area. D) Slickensides of sinistral fault along metagabbro-diorite**,** Um Balad area. E) Slickensides of the normal fault along metagabbro-diorite, Um Balad area. F) NNE-SSW Shear zone along the contact between metagabbro-diorite and monzogranite Um Balad area.

The tectonic evolution model (Fig. 16) of the Dara and Um Balad area is clarified by analysis of structural elements founds in the study areas as follows: This model comprises three stages

A) Subduction stage (Island arc gabbro-diorite): The early phase of the tectonic history was started with the subduction of oceanic crust beneath another one of continental crust that causes the formation of island arc magmatism for gabbro-diorite rocks by partial melting of lithospheric mantle.

B) Orogenic stage (older granitoids): granodiorite formed from melting of lower mafic crust.

C) Post collision stage (younger granitoids): The continuation of tectonic processes including the oceanic subducted slab break-off led to mantle upwelling and influx of hot asthenosphere, then melting of lower crust and formation the monzogranite and alkali feldspar granite.

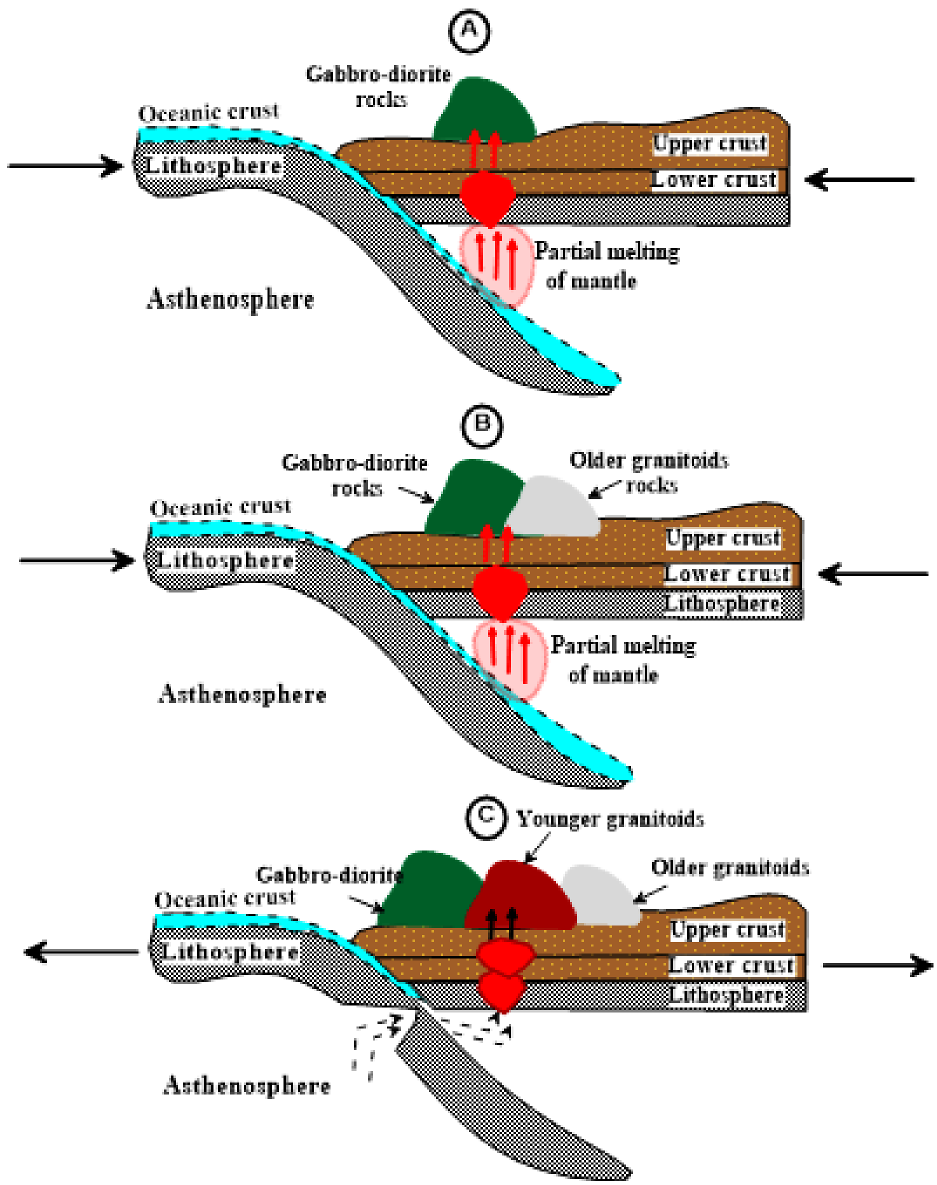

Fig. 16. Demonstration model for the tectonic evolution stages for the different rock types in Dara and Um Balad areas: A. Subduction stage (Island arc gabbro-diorite), B. Orogenic stage (older granitoid), and C. Post collision stage (younger granitoids).

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