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Structural setting of Gebel Hamza, Northwestern sector of Cairo-Suez District, Egypt

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ABSTRACT* : *Detailed field geological mapping of Gebel Hamza, northwestern sector of Cairo-Suez District (CSD), Egypt, is achieved to figure out the structural setting of this area. This is done via detailed field mapping and high resolution satellite images interpretation. The exposed rock units at Gebel Hamza are represented by the Upper Eocene, Oligocene, Miocene, and Quaternary rock units. The regional structural geometry of Gebel Hamza is a SW-oriented plunged anticline which is affected by faults and folds. Consequently, these structures are also affected the lithological distribution of the exposed rock units in the area. Field observations and measurements reveal four main fault trends are represented by E-W, NW-SE, ENE-WSW, and NNW-SSE trends. The majority of these faults are highly dipping, with dip angle ranges between 70°-85°. In addition, the most of the investigated faults have left-stepping en echelon arrangements and form linked fault systems (i.e., zigzag fault patterns). On the other hand, the mapped folds are developed along the normal faults. They are mainly WNW-ESE to NW-SE and ENE-to-NE-trending folds. The structural analysis of Gebel Hamza revealed that the mapped folds are formed as fault-related folds. The findings of this research are crucial for understanding the structural geometries of fault-related folds in extensional regimes.

KEYWORDS:* *Gebel Hamza; Cairo-Suez District; Drag folds; Fault-related folds; Um Qamar-Shabraweet fault belt

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I. INTRODUCTION

Fault-related fold is a term which refers folds that resulted from the displacement along the fault plane. They are found in different geologic settings including; extensional, compressional, and strike-slip regimes. Folds that developed in extensional settings are the subject of this present study.

Many studies of fault-related folds have been described the mechanism of folding associated with normal faults in extensional settings. Among them, Schlische (1995) described folds that associated with faults in an extension regime in the Newark basin, eastern USA. Also, Gawthorpe et al. (1997) and Sharp et al. (2000) described the fault-propagation folding in the eastern part of the Gulf Suez rifting, Egypt. Moreover, Khalil and McClay (2002) have documented the extensional fault-propagation folds at the northwest margin of the Red Sea that developed in pre-rift strata. Extension-related folds include two major types of fold geometries: longitudinal and transverse folds. Longitudinal folds have axial lines parallel or sub-parallel to the fault plane (Schlische, 1995) and are represented by normal drag folds (i.e. hanging-wall synclines and footwall anticlines), reverse drag folds (i.e. hanging-wall anticlines and footwall synclines), rollover anticlines, and fault-propagation folds.

On the other hand, transverse folds have hinges perpendicular to the fault plane (Schlische, 1995) and are also associated with normal fault segments which include hanging-wall synclines and hanging-wall anticlines that are resulted from the displacement variations along the strike of the fault plane. Herein, Gebel Hamza area represents a fault-related fold in the northern part of the Cairo-Suez District (Fig.1).

The present study, Gebel Hamza offers an excellent outcrop example of fault-related fold structures (Fig. 1). The aim of the present work is to figure out the structural architecture of Gebel Hamza area and to highlight the structural relations between folds and faults.

II. Data and Methodology

In the present study, the surface structural data was collected on two stages. Stage I: interpretation of the major structures from the satellite images (ETM + of Landsat 8 and high resolution of Google Earth images). Stage II: field observations of the geological structures and discrimination of the lithological units to create a detailed structural map. The geometry of tilted beds (i.e., strike and dip) was measured in order to figure out the local changes in the attitudes of beds. Moreover, the geological structures of the study area were identified and recorded in their accurate position on the base map.

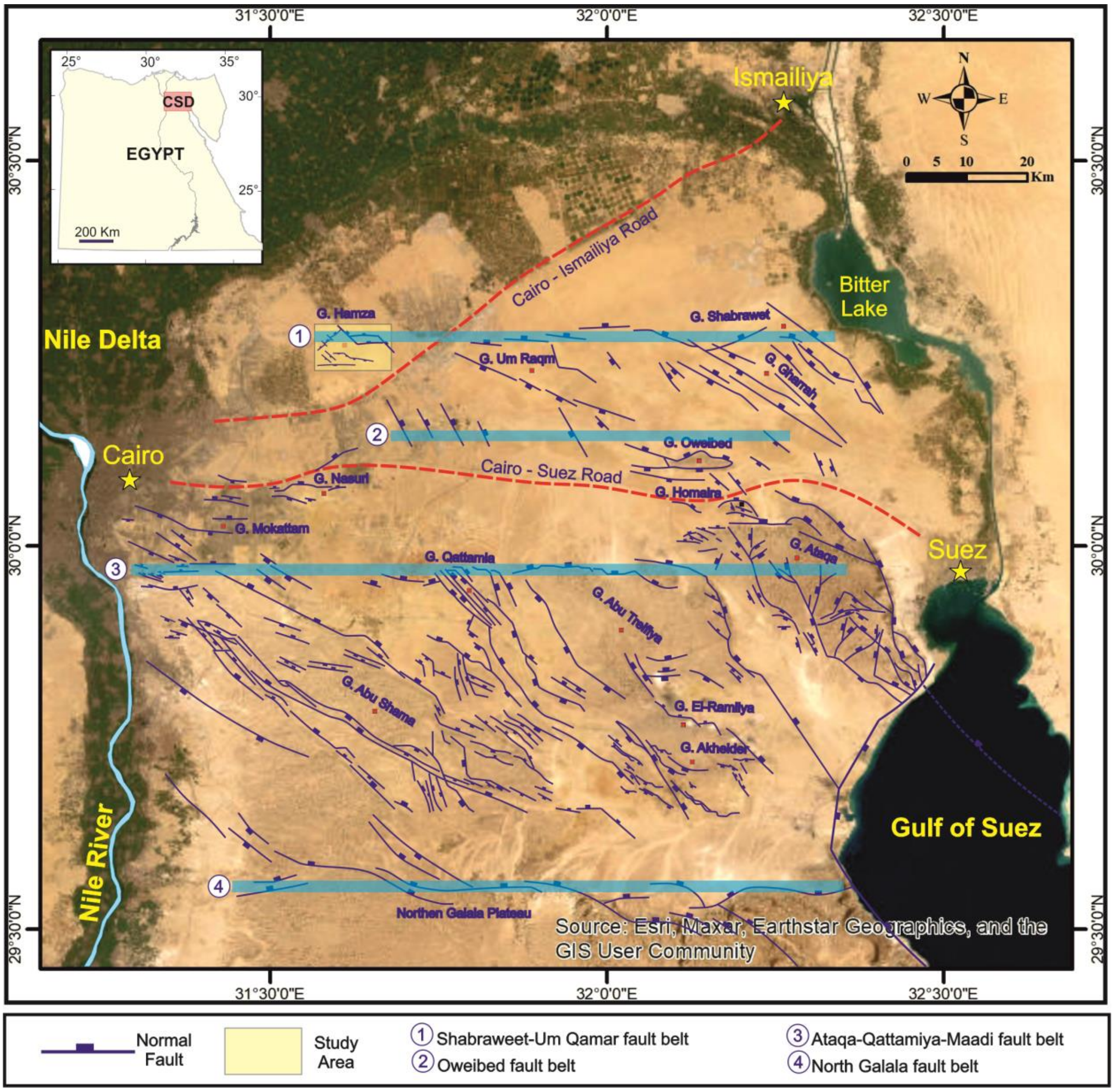

Fig. 1. Structural map of the major faults and structural blocks along Cairo-Suez District (CSD), showing the location of the study area (compiled from (Attwa et al., 2020; Gamal et al., 2021; Henaish and Kharbish, 2020; Moustafa and Abd-Allah, 1992).

III. REGIONAL GEOLOGICAL SETTING

Tectonically, the Cairo-Suez District represents part of the unstable shelf area, which occupies the larger part of northern Egypt. The deformational history of that district is characterized by its structural complexity as it represents a segment of the passive continental margin in the East Mediterranean region. The structural architecture of the Cairo-Suez District is controlled by three tectonic phases related to dramatic movements between the three tectonic plates of African, Arabian, and Eurasian plates (Meshref, 1990). The first deformation phase initiated during the Jurassic-Early Cretaceous time resulted in reactivation of the E-W deep seated faults along the Cairo-Suez District. The second phase of deformation started during the Late Cretaceous – Early Tertiary time led to the dextral wrenching on the E-W deep seated faults and associated with transpressional structures. The third phase started during the Miocene and post-Miocene times associated with reactivation the E-W deep seated faults along the Cairo-Suez District by several elongated E-W left stepping en echelon fault segments (Moustafa and Abd-Allah, 1991; Moustafa et al., 1998; Moustafa and Khalil, 1994), NW-SE normal faults, and transtension wrenching are evident due to the opening of the Gulf of Suez (Patton et al., 1994). A distinguishable zigzag fault pattern characterizes the CSD which is resulted from the linkage of NW-SE and E-W normal faults. There are four main E-W structural fault belts which are characterizing the Cairo-Suez District (Fig. 1): i) Shabraweet-Um Qamar, (ii) Oweibed, (iii) Ataqa-Qattamiya-Maadi and (iv) North Galala fault belts. The study area represents the western part of Shabraweet-Um Qamar fault-belt (Fig. 1).

Structurally, the Cairo-Suez District subdivided into two main sectors cross cut by the Cairo-Suez Road. These are Northern and Southern sectors. The Northern sector is controlled by folding and fault related folds and is mainly covered by Miocene rocks (e.g. Gebel Hamza, Gebel Um Raqm, Gebel Gharrah, and Gebel Oweibed). On the other hand, the Southern sector is mainly consisting of tilted fault blocks of the Eocene rocks (e.g. Gebel Ataqa, Gebel Abu Shama, Gebel Qattamiya, Gebel Akheider and Gebel El-Ramliya).

Stratigraphically, the Cairo-Suez District comprises Cretaceous, Eocene, Oligocene, Miocene, and Quaternary sediments. The Cretaceous rocks are limited and exposed at the eastern escarp of Gebel Ataqa and the core of the Gebel Shabraweet anticline(Said, 1962). The dominant sedimentary cover along the district is the Middle and Upper Eocene. The Eocene rock units are covered by Oligocene sediments. The above mentioned sedimentary sequences were intruded by some volcanic sheets mostly basalts. The assigned age of these basalt intrusions is the Late Oligocene-Early Miocene time (Aquitanian; 22±2 Ma.) by Meneisy and Abdel Aal (1984), using K/Ar method. At the study area, the basalt sheets were encountered at the northern and western slopes of Gebel Hamza but recently were eroded due to the urban growth (not mapped). The Miocene sediments are widely exposed along the Cairo-Suez District and characterized by siliciclastic- carbonate marine environments.

IV. STRATIGRAPHY

The stratigraphic outcrop of Gebel Hamza is mainly consisting of five main rock units (Fig. 2). The oldest unit is the Upper Eocene Wadi Hof Formation (Farag and Ismail, 1959) that has been observed in the subsurface boreholes (Attwa et al., 2020) which comprises of limestone interbedded with shale beds. The Oligocene sediments is represented by the Gebel Ahmar Formation (Shukri, 1953) which is covered by the basalt flows. This Formation is mainly consists of varicolored, cross-bedded, poorly-sorted, fine to coarse sands with gravel bands, brown to black with cobble to bolder grain sizes. The Oligocene sediments attains about 30 m thick at Gebel Hamza (Attwa et al., 2020). This Formation is underlain by the Upper Eocene sediments and overlain by the Miocene sediments.

The outcropped Miocene sections at Gebel Hamza attain a total thickness of about 90 m. They are differentiated into two main lithological units; the Lower siliciclastic- and Upper carbonate-dominated unites, representing the Lower Miocene Gharra Formation (Said, 1962) at the base and the Middle Miocene Geniefa Formation (Said, 1990) at the top. The Lower Miocene Gharra Formation attains a thickness of about 70m. It consists of sandstone, shale and sandy limestone. Sandstones are fine- to medium-grained, poorly-sorted, variably calcareous, partially dolomitizes, and cross-bedded. The Middle Miocene Geniefa Formation attains a maximum thickness 20 m. It made up of sandy, chalky limestones with marl and shale intercalations, topped by highly fractured, porous dolomite beds.

Quaternary deposits are distributed at the southern and eastern parts of the study area and attain a thickness of about 10m. They are faulted down against the Middle Miocene sediments and are represented by Wadi alluvium and aeolian deposits.

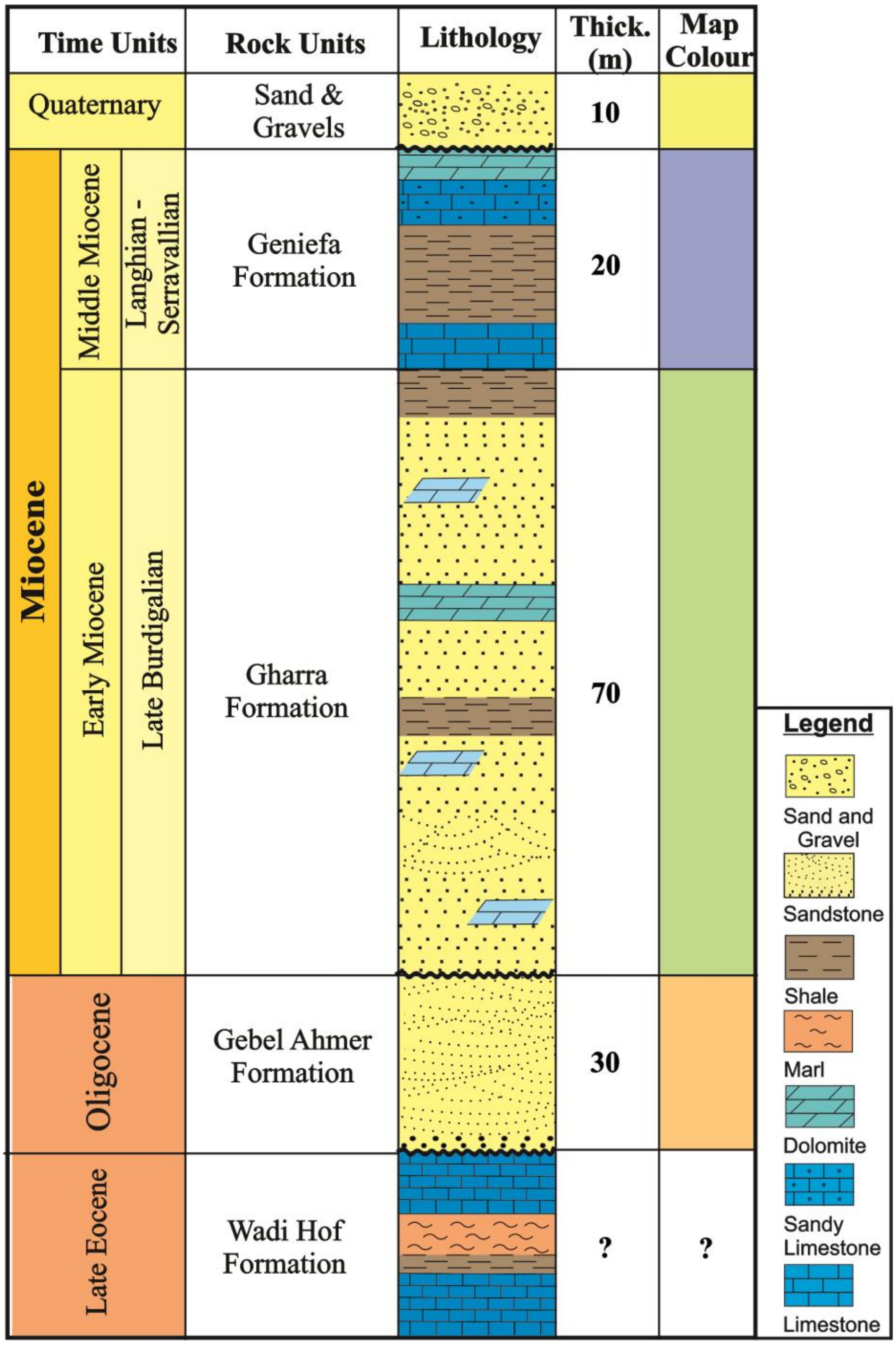

Fig. 2. Stratigraphic section in the Gebel Hamza, where the lithologies and thicknesses of rock units are compiled from Said (1962) and Abu-Zeid et al. (2004).

V. STRUCTURAL GEOMETRY

The structural geometry of Gebel Hamza represents an elongated NE-SW anticline (Fd1) measures about six km long and four km wide and plunges toward the SW (Fig. 3 A and B). The core of this plunged anticline at the outcrop is occupied by the Gebel Ahmar Formation and flanked by the Lower and Middle Miocene sediments (Fig. 3A).

Gebel Hamza plunged anticline is composed of two gentle limbs: the northern limb and southern limb. The Northern limb is formed from the Lower and Middle Miocene beds with gentle dip amounts that range from 7° to 16°. The dip data of most strata is increased near the fault surfaces to reach 31°. This limb is highly dissected by E-W and NW-SE trending normal faults (Fig. 3A). The E-W faults are dipping toward the N-direction and juxtapose the Lower Miocene Gharra Formation in the footwalls against the Middle Miocene Geniefa Formation in the hanging walls. These faults are arranged in a left-stepping en echelon pattern (e.g. F2, F5, F6, and F7) and terminated against NW-SE trending faults (e.g., F5 terminates on F16). The NW-SE trending faults are dipping toward the NE-direction in left-stepping en echelon arrangements (e.g. F1, F4, F16, and F17).

To the east of the northern limb F1 NW-SE normal fault juxtaposes the Lower Miocene Gharra Formation against the Middle Miocene Geniefa Formation and Quaternary sediments. These faults are affected the Lower and Middle Miocene sequences. The measured dip data of these E-W and NW-SE oriented fault planes range between 70°-85° and have planar surfaces geometries. The limb is also affected by small drag folds (e.g., Fd2 and Fd3) are developed along the footwall of F2 normal fault (Fig. 3A). On the other hand, the southern limb of Fd1 is covered by the Lower and Middle Miocene sediments. The measured dip data of strata ranges 5° to 14°. This limb is also dissected by normal faults of E-W and NW-SE trends (Fig. 3A). The E-W oriented faults developed in the Lower Miocene Gharra Formation (e.g., F21 to F27), all of these faults have planar geometries and are dipping toward the N-to-NNW-direction. Some of these E-W faults (e.g., F21) associated with footwall anticline Fd4 due to the drag of the Lower Miocene sediments along the fault plane (Fig. 4 A and C).

The limb is delineated by distinguishable zigzag fault pattern to the south. The E-W oriented faults (e.g., F12 and F14) linked with WNW-oriented fault (e.g., F15) and NW-SE oriented fault (e.g. F13). Another zigzag fault pattern links between F8 and F9. All of these faults juxtapose the Lower Miocene Gharra Formation against the Middle Miocene Geniefa Formation except F12 juxtaposes the Oligocene sediments in the footwall against the Miocene sediments in the hanging wall. In general, the all linked faults dip toward south. It is also bounded by the Quaternary fault F16 with few meters of displacement in the south and has approximately 10 km long that juxtapose the Quaternary sediments against the Middle Miocene Geniefa Formation sediments.

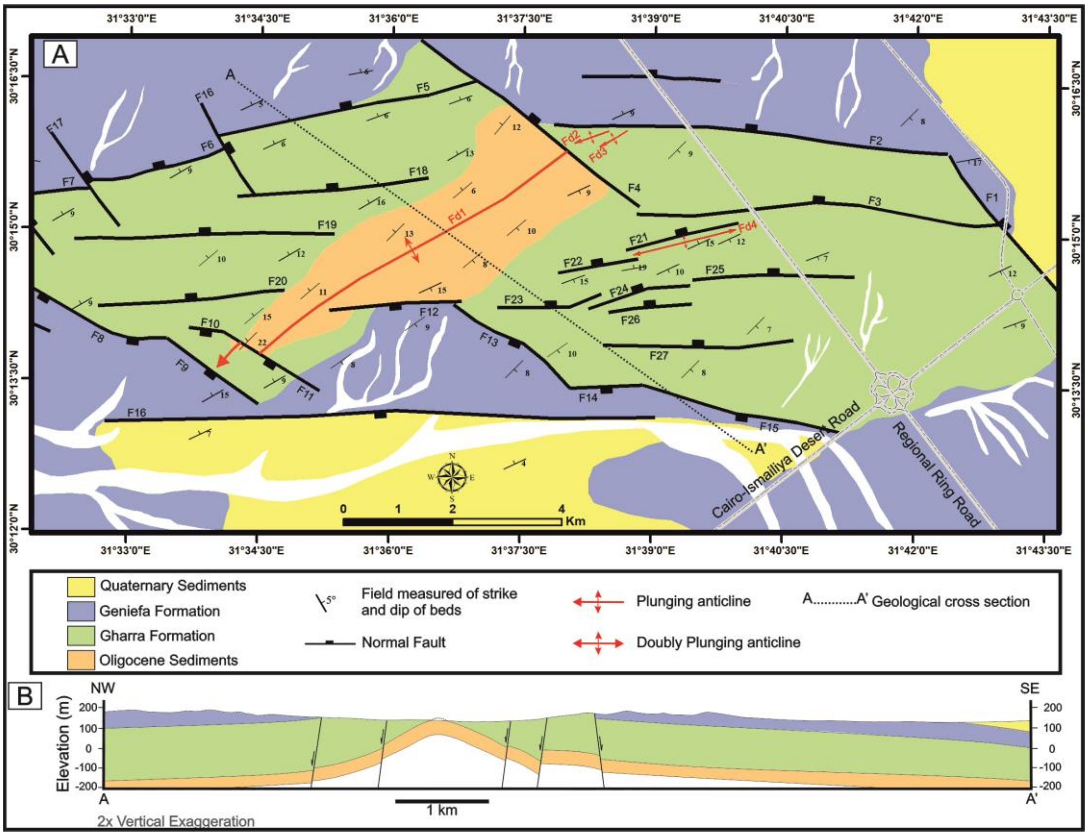

Fig. 3. A) Detailed structural map of Gebel Hamza, at the western sector of Um Qamar – Shabraweet fault belt, B) geological cross-section (A-A') of the study area.

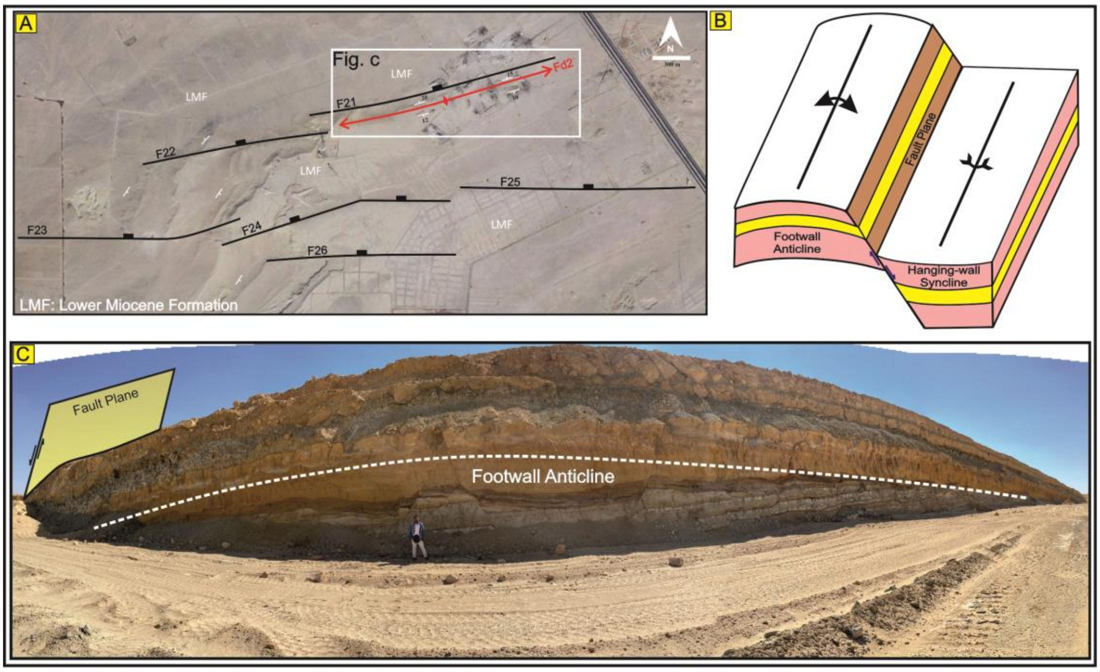

Fig. 4. A) Google Earth satellite images © 2007, ENE- to E-W normal faults associated with footwall anticline developed at the southern limb of Gebel Hamza, B) schematic model shows the geometry of drag folds along the fault plane, C) Field photo of an anticlinal drag fold along the footwall of an ENE-WSW normal fault at Gebel Hamza (looking towards N).

VI. STRUCTURAL ANALYSIS

The structural analysis of Gebel Hamza reveals that this area is affected by brittle-ductile deformations. The geometrical characteristics of the present folds and associated faults indicate their development as fault-related fold structures. The total number of mapped faults in Gebel Hamza plunged anticline is 27 normal faults. These faults are belonging to four main sets in a descending order of frequency are: E-W, NW-SE, ENE-WSW, and NNW-SSE trends (Fig. 5A).

Detailed field mapping of the investigated area indicates dip-slip faults with strike-slip components. Most of these mapped faults are arranged into left-stepping en echelon patterns which indicate the dextral transtension on deep-seated faults (e.g., F2 and F5). The total number of the mapped folds is four folds. These folds are mainly WNW-ESE and ENE-to-NE-trending folds (Fig. 5B). On the other hand, the present fold geometries are developed mainly on the footwalls of the normal faults (e.g., Fd1 related to F4 and Fd4 related to F21). Fd4 footwall anticline represents drag fold (Fig. 4C) that is formed as the result of frictional drag of the Lower Miocene Gharra sediments along the normal fault F21 (Fig. 4C). Moreover, the detection of small plunged folds as Fd2 and Fd3 are arranged in right-stepping en echelon arrays may be resulted from the dextral wrenching on E-W deep-seated faults. Consequently, from the present structural data analysis, Gebel Hamza which is a SW-plunged anticline may be related to strike-slip tectonics, which need further work.

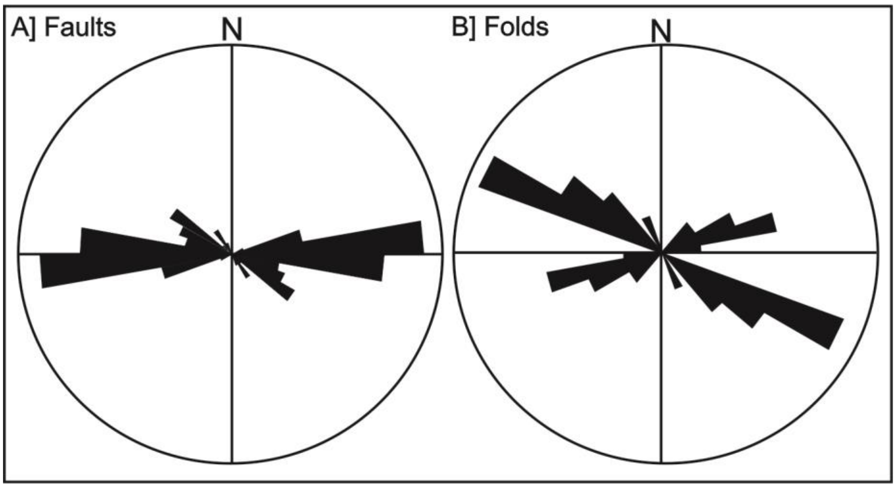

Fig. 5. Rose diagram shows A) the main fault trends, and B) the main fold trends in Gebel Hamza area.

VII. CONCLUSION

The present study concerns with studying the structural architecture of Gebel Hamza which is related to the western sector of Um Qamar – Shabraweet fault belt through surface investigations and structural analysis. The main aim of the study is delineating the main structural features (i.e. faults and folds) and discriminate the lithological units to output detailed structural map.

Stratigraphically, the sedimentary succession of the area is represented by five main rock units: the Upper Eocene of the Wadi Hof Formation which is observed from the borehole data in subsurface. In addition, the exposures of the Oligocene sediments that underlie the Miocene sediments of that are differentiated into Gharra and Geniefa formations. Quaternary sediments are dominated in the southern part of the area.

Structurally, Gebel Hamza SW-plunged anticline is formed as fault-related fold in extensional settings. It is composed of two gentle limbs: northern and southern limbs. Faults that are affected this drag fold have left-stepping en echelon arrangements and are characterized by zigzag fault patterns. Folds are dragged along the normal fault planes.

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