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Tectonic Model of the Sinai Peninsula Based on Geophysical Investigations

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1. Introduction

Sinai Peninsula lies in the northern part of Egypt, between the Gulfs of Suez and Aqaba at the southern end, and the Mediterranean Sea at the northern end. This region is considered to be an active seismic area due to the presence of the triple junction of the Gulfs of Suez and Aqaba and the Red Sea (Khalil, 1998).

Many studies have been undertaken toward understanding the subsurface geological structure of this area. It is considered as a part of a Tertiary cratonic rift between north-eastern Africa and the Arabian Peninsula. The rifting phase essentially ceased during the early-middle Miocene (18-14 Ma), when continental separation became more oblique due to the predominant movements of the left-lateral transform fault that extends north-eastward through the Gulf of Aqaba to the Dead Sea (Patton, et al., 1994; USGS, 1998; and Robert et al., 2006). The dynamics of the Sinai Peninsula based on the geometrical configuration of the basement rocks as revealed by magnetic analysis, the pressure-tension tectonic forces resulting from seismological focal mechanism solutions, as well as the horizontal movements detected by a GPS network (John and Peter, 1969; Mcintyre, 1991; Rabeh and Miranda., 2008).

2. Geological setting

The geology of the Sinai Peninsula ranges from Precambrian basement rocks to Quaternary deposits. According to the surface geologic map (Fig. 1) after Khalil, 1998; McClay et al., 1998, Egyptian Geological Survey (1993), the Quaternary deposits cover the northern part and along the Gulf of Sinai and the Mediterranean Sea coasts. The Mesozoic limestone covers a wide area from the central part of Sinai Peninsula, while the Pre-Cambrian rocks outcrop and covers a wide areas in the southern part of the Peninsula.

The regional stratigraphy of the southern part of the peninsula (Darwish and El Azaby, 1993) shows that the sedimentary sequences overlying the basement comprise rocks from Cambrian to Quaternary. Post-rift sediments include the erosional surface that marks the base of the strata deposited during thermal or post-rift subsidence phases (Purser and Bosence, 1998). The syn-rift strata were deposited in active fault-controlled depocenters of the evolving rift, and the pre-rift strata were deposited prior to rifting according to the paleoenvironment. The upper surface of the pre-rift strata is the syn-rift unconformity or a superimposed post-rift unconformity, according to the geotectonic evolution of the basin.

The Gulf of Aqaba transform apparently lessened extension in the southern part of the gulf, and restricted active rifting to the central area (Steckler et al., 1988; Bosworth et al., 1998). The northern end is comprised of Precambrian basement rocks, Paleozoic sediments of the Carboniferous and Permian, and Mesozoic, Tertiary, and Quaternary deposits. According to Barakat (1982) the geologic sequence can be described from bottom to top as sandstone intercalated with shale and claystone, with dolomitic limestone of the Jurassic occurring at the top. Its maximum thickness reaches about 2200 m. The Cretaceous sediments are divided into Lower and Upper Cretaceous, the former consisting of sandstone with intercalations of clay and limestone, and the latter of thick limestone. This sequence is about 520 m thick. The Tertiary sediments consist of thick limestone with claystone (465 m thick), while the Quaternary is represented by sand and gravels with a maximum thickness of about 100 m.

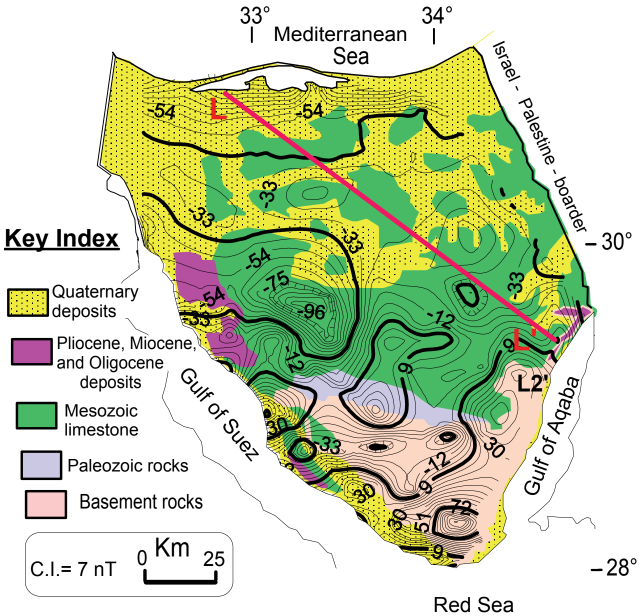

Fig. 1. Compiled geologic map after Khalil, 1998; McClay et al., 1998 and Egyptian Geological Survey (1993), and RTP land magnetic map after Rabeh (2008).

Many studies were performed to understand the subsurface geo-structure of the area. It is considered as a part of a Tertiary cratonic rift between the north-eastern Africa and the Arabian Peninsula. The rifting phase essentially ceased during the early-Middle Miocene (18-14 Ma) when continental separation became more oblique due to the dominant movements on the left-lateral transform fault, that extends through the Gulf of Aqaba north-eastward till the Dead Sea (Patton, et al., 1994, USGS, 1998). The Gulf of the Suez region has long been recognized as one of the best examples of long-axis segmentation with different dip polarities (Colleta et al., 1988; Moustafa, 1993; Bothworth, 1994; Patton et al., 1994; McClay et al., 1994 & 1998). It displays examples of interaction between extensional tectonics and sedimentations (Gawthorpe et al., 1997; Gupta et al., 1999; Sharp et al., 2000). It is remarkably non-volcanic with only a few late pre-rift to early syn-rift basic dykes and isolated basaltic features (Bosworth and McClay, 2001). Four distinct depocenters (sub-basins) separated by complex accommodation zones occur within the Gulf of Suez and Northwestern Red Sea (Bosworth and McClay, 2001). Each sub-basin is a symmetric, bounded on one side by NW trending border fault system with large throws 3-6 Km in general (Gupta et al., 1999). This is providing a good idea about the tectonic position of the Peninsula. The Pre-Cambrian Basement rocks appear in the southern part of the peninsula while the depositional depocenter is dipping towards the northern part (*cf.* Fig. 2). This is due to the compression forces due to Suez rifting that we show it in that Chapter.

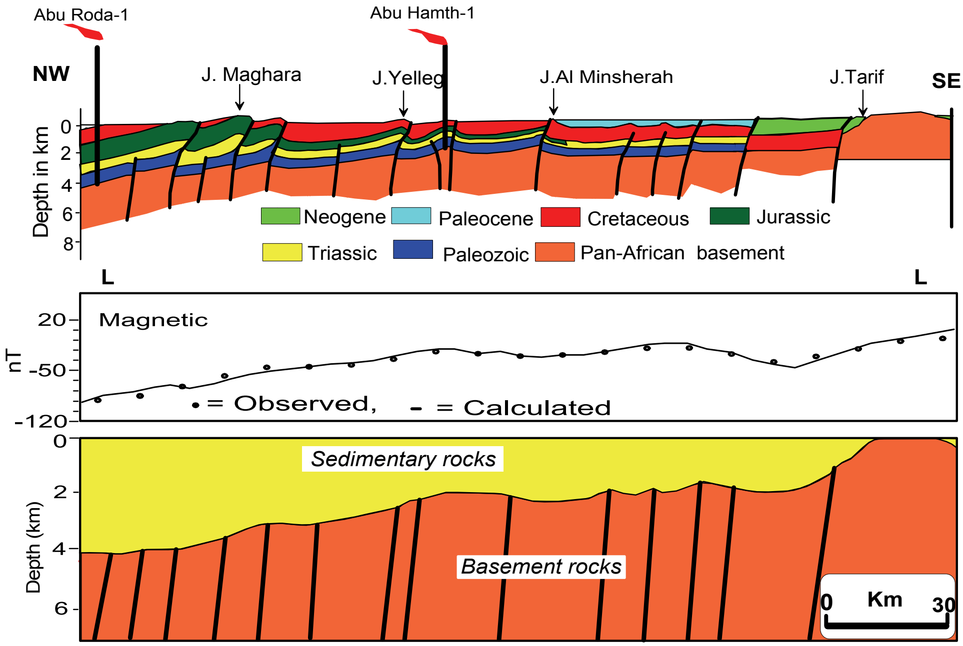

Fig. 2. Schematic geological cross-section along northern Sinai, after Guiraud and Bosworth (1999).

3. Geophysical evaluation

Using the integrated interpretation of seismological, GPS, potential potential-field, geological and well logging data, and several non-outcropping fault zones have been recognized and tentatively mapped in the study area (Rabeh and Miranda, 2008).

Based on Grant & West (1965), Linsser technique (1967) and horizontal gradient method we were able to delineate the subsurface fault trends from the RTP land magnetic map (*cf.* Fig. 3). The Euler deconvolution method, published by Reid et al. (1990) serves to determine source positions and the depths of the geomagnetic inhomogeneities. This method confirmed the existence of the deduced structures whereas the Euler solutions were clustering along these structures. The different directions were then grouped into segments of 10° of azimuth each. These groups are represented according to the tectonic movements/forces prevailed in the studied area by rose diagrams (*cf.* Fig. 3).

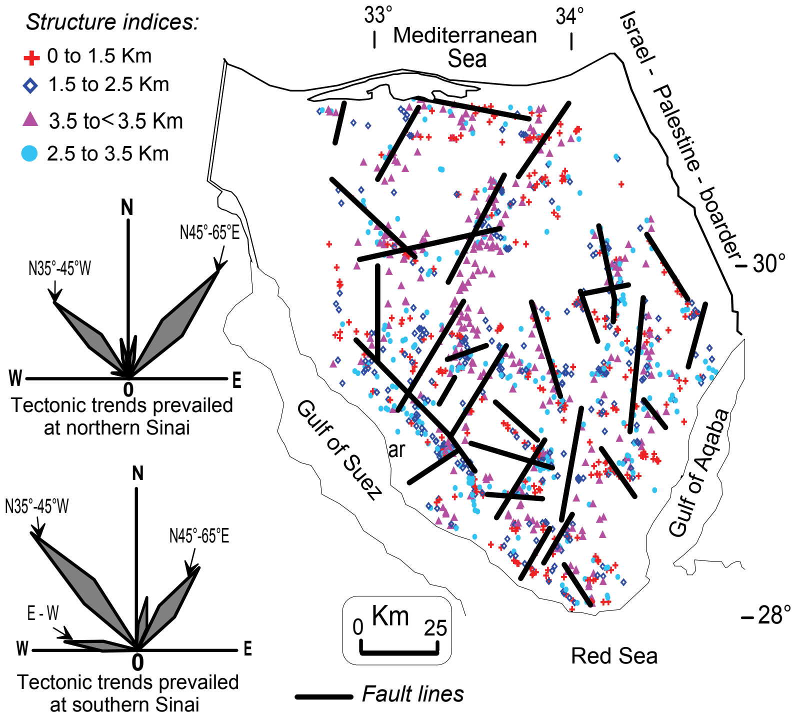

Fig. 3. A deduced structures map shows clustering the Euler solutions along the fault lines and a Rose diagrams show the prevailed tectonic trends at both northern and southern parts.

The results indicate that the N35º-45ºW tectonic trend (related to Gulf of Suez and Red Sea tectonics) is more predominant at the southern part of Sinai Peninsula than N35º-65ºE tectonic trend (related to Syrian trend) while this arrange is reversed at the northern part. Aqaba trend (N15º-25º E) comes at the third order of predominance is prevailed at the southern part while the E-W trend is predominant at the northern part (related to the Mediterranean tectonics).

The Stress – tension axis prevailed in the studied area derived from the focal mechanism solutions of the events located in the southern Gulf of Suez suggest pure normal faulting mechanism, with a NE-SW trending tension axis. Whereas the mechanism of this event along the Gulf of Aqaba reflects strike slip mechanism with left lateral motion along NW-SE plane (*cf.* Fig. 4). The stress fields based on the deduced focal mechanism of the different seismic zones according to our study have been selected and the average direction of pressure axis (P-axis) and tension axis (T-axis) are calculated for each zone Abu El Enean, (1997). The distribution of the P and T axis along the studied area (*cf.* Fig. 4) shows a dominant T-axis trending N 45º E. The surface faults illustrate that there is an extension stresses act in the region. These results were confirmed from recent analysis of GPS data (Rabeh and Miranda, 200).

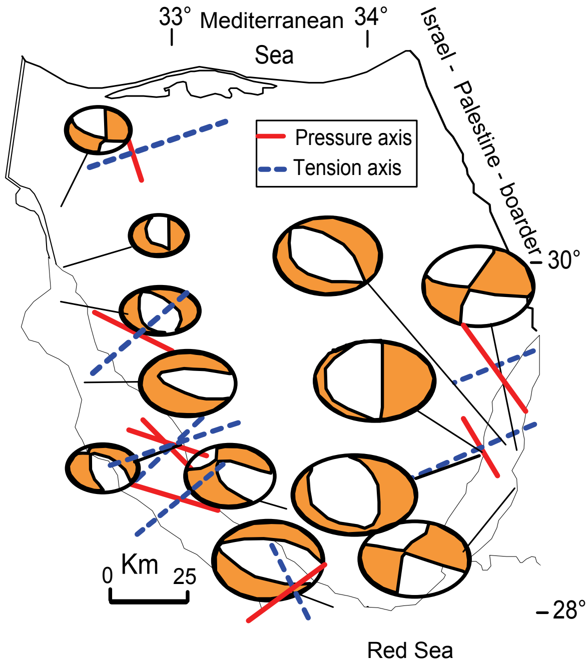

Fig. 4. Map showing focal mechanism solutions and stress – tension axis prevailed in the studied area.

The kinematic model that explains the implications of deformation, stress and tectonic activities in the Sinai Peninsula were interpreted through an integrated study using land magnetic surveys, seismology and geodynamics as well as geological analysis. The most predominant tectonic trends is N35° - 45°W direction. This trend originated due to opening process of the Gulf of Suez and is normal to the NE - SW tension axis (Said 1990). It comes in the first order of predominance while N45° - 65°E (connected to Syrian Arc tectonics) comes in the second order at the southern part of the Peninsula. This order is reversed at the northern part. The N25° - 35°E which is related to Gulf of Aqaba tectonics can be detected at the southern part whereas the E-W (related to the Mediterranean tectonics) tectonic trend is prevailed at the northern part. They are considered as a third order of their predominance.
These forces were confirmed by stress-tension relation derived from focal mechanism solutions of seismological data. Moreover, the results obtained by magnetic and seismological interpretations has been confirmed by GPS data analysis. It indicates that the velocity of Sinai Peninsula ranges from 1.8 to 2.3± 0.5 mm/yr in the NE direction
Finally, the integrated analysis for the magnetic, seismic and GPS interpretations can produce a kinematic model for Sinai Peninsula (*cf.* Fig. 5).

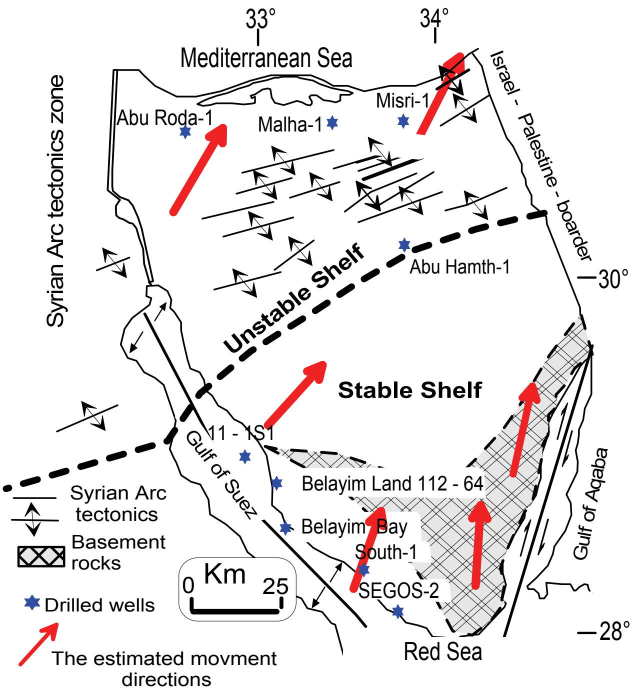

Fig. 5. The deduced kinematic model of the Sinai Peninsula.

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The term tectonics refers to the study dealing with the forces and displacements that have operated to create structures within the lithosphere. The deformations affecting the Earth's crust are result of the release and the redistribution of energy from Earth's core. The concept of plate tectonics is the chief working principle. Tectonics has application to lunar and planetary studies, whether or not those bodies have active tectonic plate systems. Petroleum and mineral prospecting uses this branch of knowledge as guide. The present book is restricted to the structure and evolution of the terrestrial lithosphere with dominant emphasis on the continents. Thirteen original scientific contributions highlight most recent developments in seven relevant domains: Gondwana history, the tectonics of Europe and the Near East; the tectonics of Siberia; the tectonics of China and its neighbourhood; advanced concepts on plate tectonics are discussed in two articles; in the frame of neotectonics, two investigation techniques are examined; finally, the relation between tectonics and petroleum researches is illustrated in one chapter.