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A Study on Seismicity and Tectonic Setting in the Northeastern Part of Egypt

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Abstract: Northeastern part of Egypt is considered one of the few regions of the world whereas evidence of historical activities has been documented during the last 48 centuries or more. Instrumental, historical and pre- historical seismicity data indicate that large destructive earthquakes have occurred quite frequently in the investigated area. The main aims in the present study were to redraw attention to the fact that the northeastern part of Egypt is seismically active and this result is associated with earthquake risk in the region. The interaction of the African, Arabian and Eurasian plates and Sinai subplate, is the main factor behind the seismicity of northeastern part of Egypt. All earthquakes occur at shallow depth and are concentrated at four seismic zones, these zones including the Gulfs of Suez and Aqaba, around the entrance of the Gulf of Suez and the fourth one is located at the south- west of great Cairo (Dahshour area). The seismicity map of the previous zones shows that the activity is coincide with the major tectonic trends of the Suez rift, Aqaba rift with their connection with the great rift system of the Red Sea and Gulf of Suez- Cairo- Alexandria trend.

Key words: Seismicity % Gulf of suez % Northern red sea % Gulf of aqaba % Cairo earthquake

INTRODUCTION

Seismicity is the study of the distribution of earthquakes and their characteristics within a particular region. The most important aspects of seismicity are given by the geographic distribution of earthquakes` foci, their magnitude and their occurrence over time, their mechanisms and the damage produced by them. In Egypt, earthquake activity has been observed in various regions. The northeaster part of Egypt plays an important role in both historical and recent seismicity. Most of earthquakes tend to occur along the three main active trends. These are:

- Northern Red Sea- Gulf of Suez- Cairo- Alexandria Clysmic trend.
- East Mediterranean- Cairo- Fayum Pelusiac trend.
- The Levant- Aqaba trend [1].

The area along the northern Red Sea, Gulf of Suez, Gulf of Aqaba and great Cairo is the most seismically active zones in Egypt. The east boundary of northern African plate is characterized by the divergence being accompanying the extension and the north boundary of that is characterized by the convergence being accompanying the compression. The high level of seismic activity in Cairo- Suez district is interpreted to be a result of the interaction among African, Arabian and Eurasian plates [2]. For these reasons, Cairo has long suffered from disastrous earthquakes. However, the largest magnitude of earthquakes which occurred in and around Cairo since B. C. 2200 is less than 6.8. Magnitude of 6 to 7 is usually classified to be a moderate earthquake.

After the occurrence of Cairo earthquake, in 1992, the Egyptian National Seismic Network (ENSN) and the Strong Motion Network have been installed to cover the whole territory Egypt. Due to the intense number of stations and its very well azimuth distribution, monitoring of seismic activities were remarkably increased and new seismic sources have been detected. Nowadays the Egyptian National Seismological Network consists of a main centre located in Cairo and five sub- centers located in Hurghada, Burg EL- Arab, Mersa Alam, Aswan and Kharga. The main centre receives the seismic data from the closer stations by telemetry and from the remote stations and the sub- centers via telephone lines and satellite communications. Data used in the present study were collected and analyzed for determining the earthquakes parameters by using the records of Egyptian National Seismic Network and the National Earthquake Information Service Catalogue.

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GEOLOGIC AND TECTONIC SETTING

Northeastern part of Egypt is dominated by the relative movements of major plates (Africa, Arabia and Eurasia) and relatively aseismic small plates.

The Red Sea, which forms the boundary between the African plate and the Arabian plate, bifurcates into two branches: the Gulf of Suez and the Gulf of Aqaba. The Gulf of Suez follows the main trend of the Red Sea and constitutes the boundary between the African plate and the Sinai sub- plate. The area west of Suez is characterized by high density of faults. All faults west of the Gulf of Suez from latitude 28.5°N to latitude 30.5°N trend northwestward, with the exception of the east-northeast fault bounding Wadi Araba and the east- west faults along the road between Cairo and Suez. The north-westerly fault trend swings westward from the recognized Gulf of Suez trend [3,4]. In Oligocene- Miocene period, during the initial events of the East African rifting, the Gulf of Suez as an area of crustal weakness followed suite and adapted itself to its present shape. The present shape of the Gulf of Suez has been determined by fracture systems which were and possibly still are due to tectonic events caused by movements of the Nubian, Arabian and Sinai plates and also the resulting rift trend, the (NNE- SSW) Aqaba trend and E- W (Tethyan) trend are responsible for the development of the Gulf of Suez. The Eritrean trend controls to a large extent the normal faults flanking and running parallel to the present Gulf of Suez. The age of this trend is still debated.

At the north of the Red Sea it splits into the opening of the Gulf of Suez and the Gulf of Aqaba- Dead Sea Rift system predominated by sinistral shear [5]. Also, the Suez Rift is considered to be the plate boundary between the African and Sinai subplates [6, 7]. In general, it is accepted that the Gulf of Suez and Red Sea depressions were formed by the anti-clockwise rotation of Arabian plate away from Africa plate [8].

Several geological and seismological studies show that the area surrounding the Gulf of Suez displayed in the past, extensional tectonics with large deformation rate [9, 12].

Figure 1 shows the Red Sea and the Gulf of Suez Rifts and the overall direction of the opening. The change in tectonic style along the Gulf of Suez is demonstrated by the pattern of faulting with the rift and the increase in the total amount of extension from north to south as noted [11].

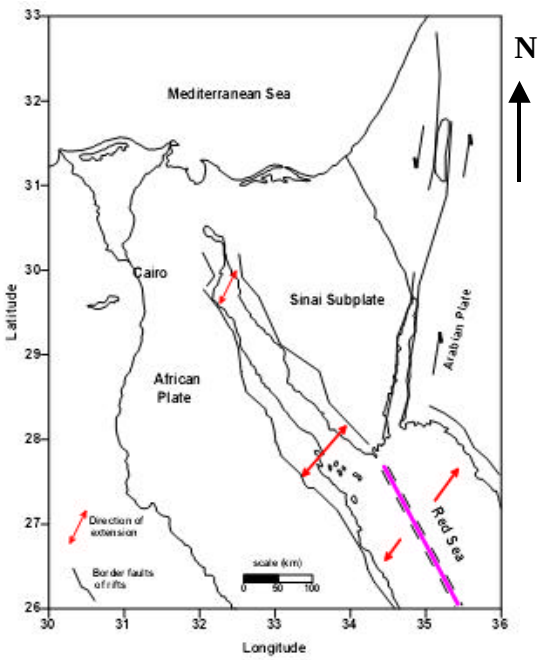

Fig. 1: Topographic map of the northeastern part of Egypt
The rifts are outlined by the heavy black lines with the overall direction of the opening indicated by the arrows (Modified from [11])

The Sinai Peninsula has been recognized as a subplate of the African plate, located at the triple junction among the Gulf of Suez Rift, the Aqaba- Levant transform fault (the southern part of the Dead Sea- Jordan transform) and the Red Sea Rift [5].

The Gulf of Aqaba represents arm of the Red Sea, separating between Saudi Arabia and the Sinia peninsula. The Gulf of Aqaba faulting structure is dominated by a N- S strike- slip system that resulted in the creation of three en- echelon rhomb- shaped grabens, similar to that at the Dead Sea (pull- apart basin), where changes in the trend to NNW and back to N- S occur. These grabens are filled with a few kilometers of sediment.

In the region of the Gulf of Aqaba, the main faults trend N-S to NNE- SSW. They are found on the Sinai and Arabian deformed coastal areas as well as within the gulf [8]. The Gulf of Aqaba- Dead Sea fault system is a left lateral transform linking the Zagros-Taurus area of plate convergence, with the Red Sea opening. *Quennel* [13] *and Freund et al.* [14] argue for a 105 Km left lateral movement between Arabia and Sinai. *Daggett et al.* [15] suggested that the deeps in the Gulf of Aqaba are pull-apart basins that resulted from the shear motion.

The Aqaba- Levant fault zone is a major left lateral strike slip fault that accommodates the relative motion between Africa and Arabia [16]. It connects a region of extension in the Northern Red Sea to the Taurus collision zone to the north. The fault zone extends over 1000 km from the Red Sea rift to the collision zone in Eastern Turkey.

DISCUSSION

Northeastern part of Egypt has been shaken by several destructive earthquakes in both historical and recent times from regional and local events. The seismicity in this area has increased remarkably in the recent years. The Red Sea earthquake of 31 March 1969 is one of the largest events in the recent history [1]. The 12 October 1992 earthquake which took place at about 25 km southwest of Cairo is an extremely important event. The third significant earthquake in the recent history occurred on November 1995 in the Gulf of Aqaba withmagnitude *Mw 7.3*. This earthquake activity still continues to occur in and around the northeastern part of Egypt (Figure 2). Also the Gulf of Suez and other regions are considered to be seismically active.

Seismic activity has been observed in various regions in Northeast of Cairo. Helwan station observations point out to such activity around Cairo, the Nile Delta and around the Gulf of Suez. Using these observations, *Ismail* [17] located a number of microearthquakes around Cairo in the period from 1903 to 1950. Also *Gergawi and El- Khashab* [18] have located a large number of microearthquakes around Cairo, Gulf of Suez and the Nile Delta region and defined an active trend that runs along the Gulf of Suez and passes through the Nile Delta to the Mediterranean Sea.

The seismicity map of earthquakes in the northeastern part of Egypt shows the presence of four regions of high activity (Figure 2). The first and the second regions are located on the Gulfs of Suez and Aqaba and the third region, the activity is concentrated at the Triple Junction between Red Sea, Gulf of Suez and Gulf of Aqaba and the fourth one located around Dahshour area (South- west Cairo city).

Several studies have been carried out to investigate the seismic activity in the Gulfs of Suez and Aqaba and the triple junction between them and around the entrance of the Gulf of Suez. *Daggett et al.* [15], *Piersanti et al.* [12] and *Dahy et al.* [19], suggested that, the seismic activity in the Gulf of Suez is scattered and does not have any distinct trend. The seismicity in the northern Red Sea is clustered at the entrance of the Gulf of Suez and the activity is continues southward in the medial of the Red Sea [6, 7]. The cluster of the seismic activity at this point may be due to the intersection of Gulf of Suez and the Red Sea faults with the Aqaba trend [11].

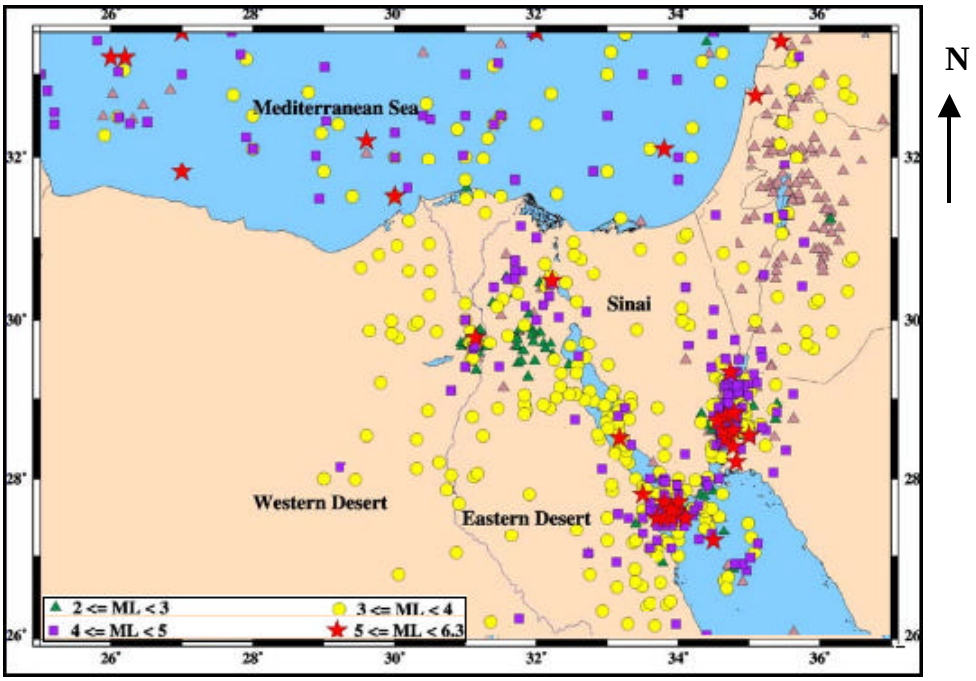

Fig. 2: Seismic activity in the northeastern part of Egypt from the records of ENSN

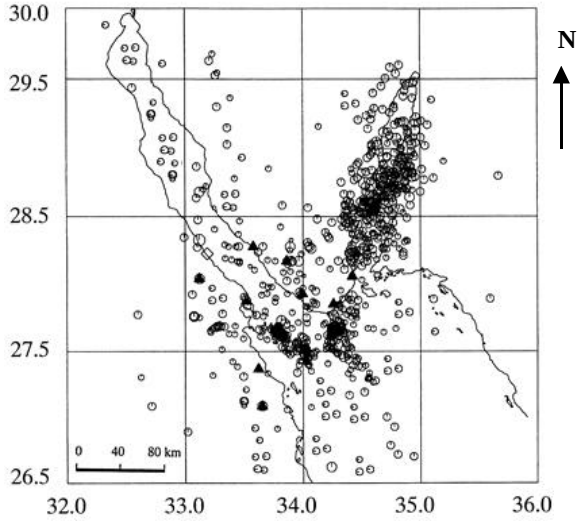

Fig. 3: Distribution of recent earthquakes in the Gulfs of Suez and Aqaba and the entrance of the Gulf of Suez with the northern Red Sea

Frequency of shallow earthquake occurrences in the Gulf of Suez region during a period of the years from 1969 to the early 2009 was studied and found that, the Gulf of Suez could be divided into two zones. The first one which extends from the mouth of the gulf Suez to the center is seismically active zone; it is characterized by the occurrences of shallow, micro, small, moderate and large earthquakes. Magnitude 5.4 was the largest earthquake reported from the study area, which occurred in June 28, 1972 at latitude 27.6°N and longitude 33.7°E with focal depth between 12 to 15 km. Many of aftershocks were recorded in the months following the main shock. At the entrance of the Gulf of Suez a 5.0 magnitude earthquake occurred on 12 June 1983.

The second area lies between the central of the Gulf of Suez to the end of it and this area is characterized by less crowded earthquakes of different magnitude ranges. The Egyptian National Seismic Network (ENSN) recorded a thousand of events having different magnitudes ranging from 2.5 to 4.8 and few numbers of events between" 4.9 to 5.2" in this area. This study indicates that, in general, the level of seismicity is moderate in the southern part of the Gulf of Suez and low in the northern part (Figure 3).

The Gulf of Aqaba earthquake occurred on November 22,1995 with *Mw= 7.3* and was the largest event to occur along the Dead Sea Transform in the end of the last century. The aftershock sequence was recorded by the seismic stations in Egypt and other countries. In this investigation, we analyzed the aftershock sequence of the Gulf of Aqaba earthquake recorded by the Egyptian Seismic Network through the period from November 1995 to the end of December 1997. The mainshock was followed by an intense aftershocks swarm, including several relatively strong aftershocks with a peak of *Mw= 5.7*. Most of the aftershock activity is concentrated around the northern part of the main earthquake. In the center of the Gulf of Aqaba, the earthquake activity is diffused south of the main earthquake in the Tiran basin. Most of the moderate to strong aftershocks of the whole aftershock sequence occurred in the first four months following the main shock (Figure 3). The focal depths of almost all earthquakes observed in the national network range mainly from 5 to 20 km.

The northern Red Sea is not aseismic through a microearthquake reconnaissance. The recorded events define an active zone extending south- southeast from the Gulf of Suez into the axial region of the Red Sea down to 27.0°N, with additional microseismicity between 26.5°and 27.5°N, suggesting active median spreading in the northern Red Sea. A cluster of the seismic activity is shown on the northern part of the Red Sea at the triple junction area. The seismicity around the entrance of the Gulf of Suez is attributed to the Red Sea rifting as well as to several active faults, which have trends NNW parallel to the Red Sea- Gulf of Suez direction and its continuation toward East Mediterranean.

Historical documents illustrate that the north-western part of Egypt and its vicinity of the south eastern Mediterranean basin had experienced major damages during some large historical earthquakes.

On 12 October 1992, a damaging earthquake of magnitude mb= 5.8, hit the Capital of Egypt. This event took place in Dahshour area 25 km to the southwest of Cairo City. Many aftershocks followed the main shock. The similarity between the mechanisms as well as the spatial distribution of the geological faults around Cairo suggest seismic activity along the extension of the stress field of the Red Sea rift system to the area around the City of Cairo. This situation affects the level of seismic hazard in the Cairo area. The hypocenters of major aftershocks are located by using the records of a temporary local network installed directly after the mainshock beside the permanent stations in Egypt (Figure 4). Many of major aftershocks seem to be active on the east side of the main shock and the depth of those aftershocks is determined to be around 15- 25 km, which is shallower than that of main shock.

Earthquake activity in Cairo and its vicinity are lower than for the other regions in northeastern part of Egypt. Generally, the majority of the earthquakes reported in

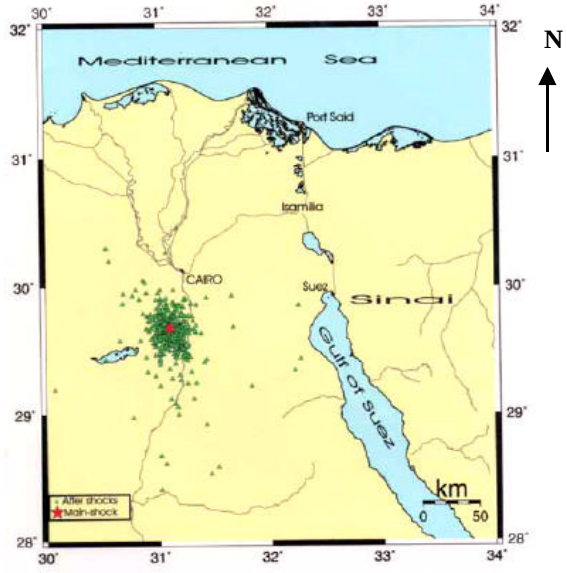

Fig. 4: The epicentral distribution map of the mainshock (Red circle) and aftershocks (Green points) of October 12, 1992 earthquake

Egypt are concentrated in and around the Nile Delta and the Nile valley. Most of these events have magnitudes less than 5. A few earthquakes occurred southeast of Cairo and two of them were observed beside Beni Suef City on October 11, 1999 and November 8, 2006, with many events having local magnitude ranging from 1.8 to 3.8.

CONCLUSIONS

In the present investigation, the seismicity in the northeastern part of Egypt is concentrated in four major zones. These are known as northern Red Sea including the Gulfs of Suez and Aqaba and the southwestern of Cairo around Dahshour area. Instrumental, historical and pre- historical seismicity data indicate that large destructive earthquakes have occurred quite frequently in this region with magnitudes as high as 7.3. A general correlation between seismicity and the tectonic setting is observed clearly in these regions. The following conclusions from this study can be summarized as:

- Most of the earthquake activities are concentrated at the center of the Gulf of Suez and at the southern end of the Gulf where the triple junction of Africa, Arabia and Sinai is situated.
- The seismic activity in the Gulf of Suez takes a NW trend coinciding with the main trend of the opening of the rift and the activity markedly decreases from south to north.
- The focal depths of almost all events observed in the Gulf of Suez by the records of ENSN range mainly from 4 to 25 km.
- The northern part of the Red Sea appears to have more seismic activity. The largest recorded earthquake in this area occurred on 31 March 1969 at Shadwan Island.
- The Gulf of Aqaba is characterized by very high seismic activity and most of this activity is intense around the center of the Gulf and characterized by intermediate to shallow focus earthquakes. The seismicity of the region indicates that the Gulf of Aqaba has been the more active segment of the plate boundary between Arabian and Sinai plates.
- The distribution of earthquakes in the Nile Delta and eastern Nile River are concentrated at the southwestern of Cairo and around Dahshour area. Some of these events are observed clearly using Egyptian seismic stations at different places in Eastern desert and most of them have magnitudes less than 5 with focal depths ranging from 5 to 30 km.
- The degree of the seismic activity in and around of Dahshour area was estimated to be low and it can be considered as a direct seismotectonics consequence of the Sinai subplate kinematics.

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