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Seismic Active Zones and Mechanism of Earthquakes in Northern Egypt

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Abstract: Northern Egypt is known to be seismically active from the past several thousand years, based on the historical records and documents of eyewitnesses on one- hand and instrumental records on the other hand. Instrumental, historical and pre- historical seismicity data indicated that large destructive earthquakes have occurred quite frequently in the investigated area. The interaction of the African, Arabian, Eurasian plates and Sinai sub-plate is the main factor behind the seismicity of northern 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. On the other hand, the focal mechanisms of some earthquakes occurred inside the studied area and having small to moderate size show a variety of patterns. The most predominant type is normal faulting.

Key words: Northern Egypt % Seismic Active Zone % Seismicity % Focal Mechanism

INTRODUCTION

Seismic activity is the study of the distribution of earthquakes and their characteristics within a particular region. The most important aspects of seismic activity 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 northern 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 between 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. The 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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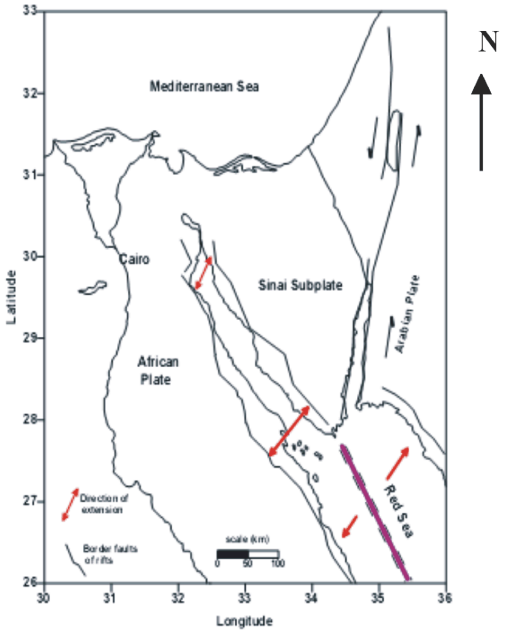

Fig. 1: Topographic map of the northeastern part of Egypt. The rifts are outlined by the heavy black lines with the overall direction of the opening indicated by the arrows (Modified from Stickler *et al*., [3])

Geological Setting: Northern part of Egypt is dominated by the relative movements of major plates (Africa, Arabia and Eurasia) and relatively aseismic small plates. The Red Sea and its two branches, the Gulf of Suez and Gulf of Aqaba, form the northern extension of the great East African Rift (Fig. 1).

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 [3].

The Suez Rift is the north termination of the Red Sea Rift. It is considered the only well- defined part of the western boundary of the Sinai subplate. This structure was considered to be a tectonic boundary between the African plate and Sinai subplate by McKenzie *et al*., [4]. They also noted that, the Dead Sea shear did not correspond to a small circle centered on the Red Sea opening pole. The Gulf of Suez originated as a depositional realm that dates back to the Early Paleozoic time. Contrary to the Red Sea and the Gulf of Aqaba, which were formed by upwarping of Nubian- Arabian shield with its subsequent rifting, transform faulting and final break – apart, the Gulf of Suez had formed as a result of tensional movement and subsidence along the NW- SE trending normal faults, probably prior to Devonian time [5]. 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 [6]. Also, the Suez Rift is considered to be the plate boundary between the African and Sinai subplates [4,7]. 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].

Seismic Active Zones of the Studied Area: Northern 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. 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 with magnitude *M*w 7.3. This earthquake activity still continues to occur in and around the northern part of Egypt (Fig. 2). Also the Gulf of Suez and other regions are considered to be seismically active.

DISCUSSION

Seismic activity has been observed in various regions in Northern of Egypt. Helwan station observations point out to such activity around Cairo, the Nile Delta and around the Gulf of Suez. Using these observations, Ismail [9] located a number of microearthquakes around Cairo in the period from 1903 to 1950. Also Gergawi and El- Khashab [10] 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 northern part of Egypt shows the presence of four regions of high activity (Fig. 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).

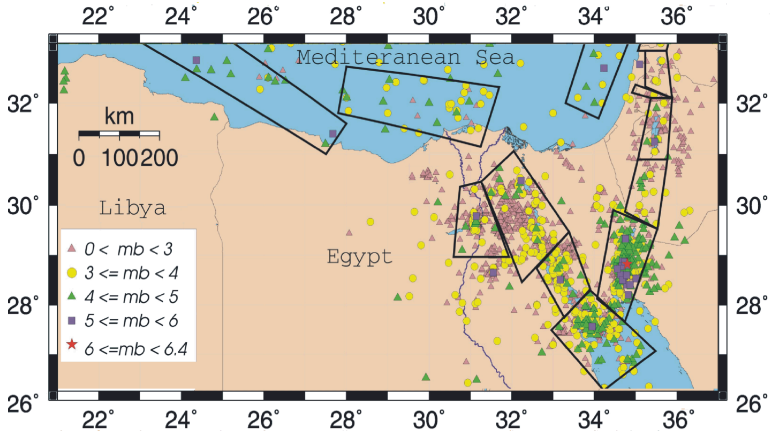

Fig. 2: Seismic activity in the northern part of Egypt from the records of ENSN

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*. [11], Piersanti *et al*. [12] and Dahy *et al*. [13], 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. 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.

Frequency of shallow earthquake occurrences in the Gulf of Suez region during a period of the years from 1969 to the early 2010 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 this area, which occurred in June 28, 1972 at latitude 27.6° N and longitude 33.7° E with focal depth is equal 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 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 (Fig. 3).

The Gulf of Aqaba, created by seismic activity along the Afro- Syrian Rift, is a deep narrow body of water. This gulf is located to the east of the Sinai Peninsula and to the west of the Kingdom of Saudi Arabia. It is one of the hinges connecting the Asian and African continents. In the recent history, 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. 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 (Fig. 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.

On 12 October 1992, a damaging earthquake of magnitude mb= 5.6, hit the Capital of Egypt. This event took place in Dahshour area 25 km to the southwest of

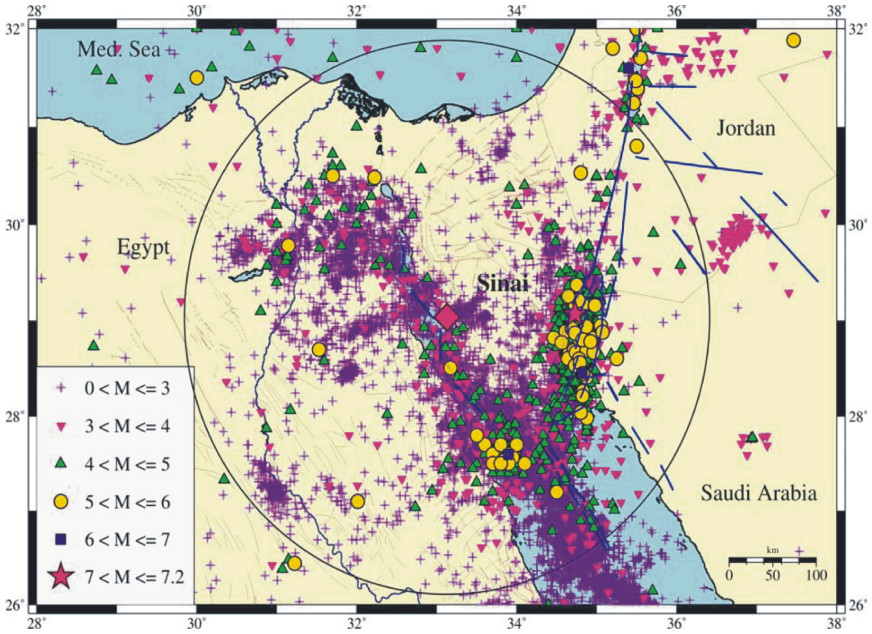

Fig. 3: Seismicity map of the studied area from 1900 t0 late 2009 [14].

Cairo City (Fig. 3). 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. 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 surroundings are lower than for the other regions in northern part of Egypt. Generally, the majority of the earthquakes reported in 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.

Focal Mechanism: Earthquake focal mechanisms are both a blessing and a curse. The focal mechanism connects an earthquake to its tectonic setting, permitting systematic study of plate motions and local stress conditions from a distant seismic observatory. Archetypic focal mechanisms characterize each type of plate boundary. Dynamical information concerning intraplate and deep earthquakes is obtained from focal mechanisms as well [15]. Most of the earthquakes occur due to a sudden rupture taking place along faults in the Earth. There are three main types of fault that may cause an earthquake: normal, reverse (thrust) and strike- slip. Normal and reverse faulting are examples of dip- slip, where the displacement along the fault is in the direction of dip and movement on them involves a vertical component. Normal faults occur mainly in areas where the crust is being extended such as a divergent boundary. Reverse faults occur in areas where being extended such as a divergent boundary. Reverse faults occur in areas where the crust is being shortened such as at a convergent boundary. Strike- slip faults are steep structures where the two sides of the fault slip horizontally past each other; transform boundaries are a

Table 1: Focal mechanism parameters for the selected earthquakes

No.	Location		Depth	Mag.	Nodal Planes		Stress Axes	
	Lat.	Long.	(km)	ML	NP1 St. Dip	NP2 St. Dip	P- axis St. Dip	T- axis St. Dip
1	30.34	31.67	13.2	3.5	167 39	348 51	264 84	77 06
2	29.83	32.33	16.6	3.1	243 21	126 80	57 51	201 33
3	30.54	31.74	24.7	3.7	315 48	101 47	296 72	28 01
4	28.04	34.51	14.5	3.0	182 60	283 72	146 35	50 08
5	28.94	32.78	03.1	3.2	78 84	348 87	303 06	33 02
6	27.68	34.29	12.1	4.2	216 50	337 58	192 55	95 05
7	27.57	33.50	05.0	2.7	346 84	249 45	219 36	109 25
8	27.40	34.56	09.8	3.6	147 56	251 70	114 40	16 09

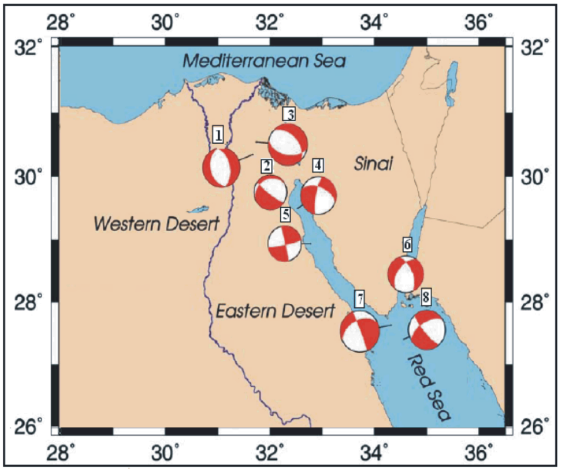

Fig. 4: Focal mechanisms of some selected natural earthquakes recorded by ENSN in the northeastern part of Egypt. Earthquake parameters are listed in table 1 and the red quadrant denotes compression.

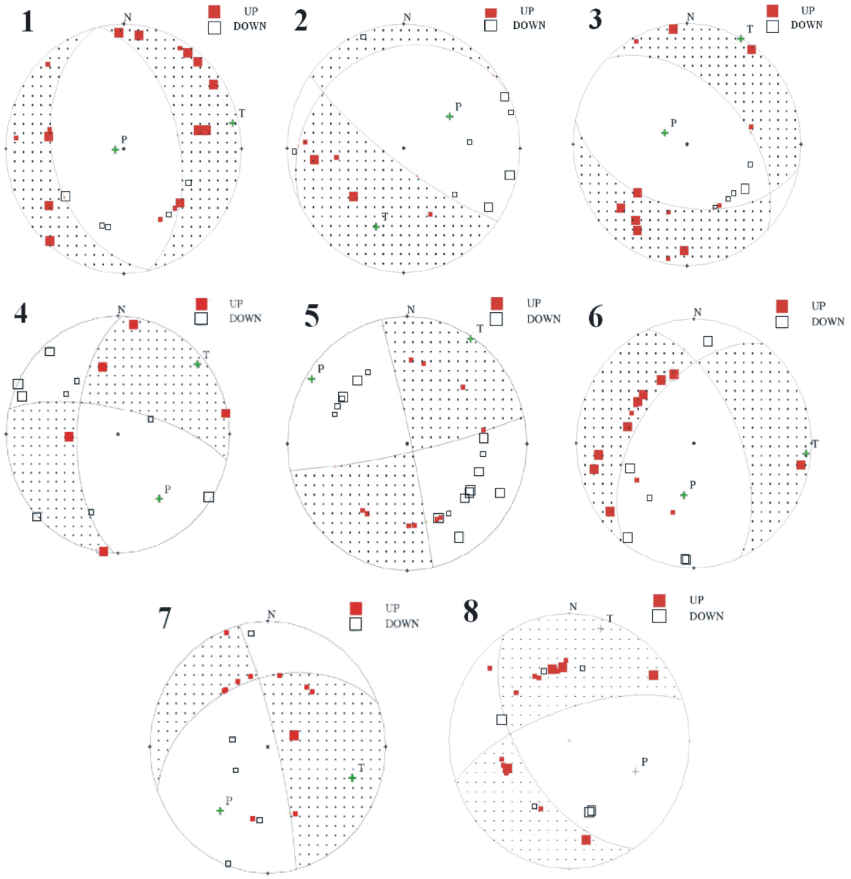

Fig. 5: Focal mechanisms of the selected earthquakes (The numbers from 1 to 8 refer to the selected earthquakes illustrated in fig.4)

particular type of strike- slip fault [16]. Earthquake focal mechanisms are of prime importance in monitoring of local, regional and global seismicity. They reflect the stress pattern acting in the area under study and help to map its tectonic structure, which causes the earthquake. Previous studies for different areas in the northern part of Egypt were made to determination of fault plane solution.

Daggett *et al*. [11], Jackson *et al*. [17], Mechine and El- Isa [18], Abou Elenean *et al*. [19] and Hussein *et al*., [20] indicated that, the extension of the northern province of the Red Sea and Gulf of Suez appears to have been achieved by northeast slip vectors rather than north-northeast ones. Most of these events involved predominantly, normal faulting along the NE- SW tensional axes, with nodal planes oblique to the strike of the Gulf of Aqaba. In the present study, the fault plane solutions available for eight events have small to moderate size in the northern part of Egypt are analyzed and determined according to their first onset quality and locations (Table 1) using a lower hemisphere projection (Figs, 4 and 5).

These events were recorded by the Egyptian National Seismic Network (ENSN). The polarities of ENSN stations are picked from the digital waveform. The focal mechanism of four events no. 1, 2, 3 and 4 located at the apex of Suez gulf show normal faulting mechanisms. The majority of the fault planes are consistent with the Gulf trend (NW- SE). The dominant stress is tension and directed NE- SW. The event no. 5 on the western part from the Suez gulf shows strike slip fault with two nodal planes; the first is parallel to the gulf while the second is perpendicular to it. The T- axis for this solution is deviated from the rifting trend. The focal mechanism solution of event no. 6 located along the Gulf of Aqaba reflects normal faulting with small left lateral shear component. Both nodal planes are parallel to the Aqaba fault trend. The solution of event no. 7 located at the northern Red Sea show normal faulting with one plane parallel to the Red Sea trend and another perpendicular to it. The tension axis for this solution is deviated from the rifting trend which may be related to the complex tectonics at that site due to the crossing of different tectonic trends. The focal mechanism of event no. 8 lies at the central part of the northern Red Sea reflect normal faulting with one plane parallel to Red Sea trend and the another perpendicular to it. The solution contain small shear component and has dominant T- axis trends NE- SW in agreement with the rifting direction.

CONCLUSIONS

Earthquake activities in the northern part of Egypt are 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. The following conclusions are obtained.

- 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. Also, the northern 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 recognized as an active seismic zone, where many destructive earthquakes have occurred. The distribution of recent earthquakes indicates that, most activities are concentrated at the center of the Gulf of Aqaba while, the areas at the northern and southern ends of the gulf are considered low active seismic zones. These earthquake activities are mainly attributed to the relative motion between African, Sinai and Arabian plates.
- The earthquake activity in the northern Egypt is concentrated at the southwestern of Cairo and around Dahshour area. Some of these events are observed clearly using Egyptian seismic network 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 focal mechanism of eight events in the northern part of Egypt shows that, the most predominant type is normal faulting parallel to or coincides with the main rift direction. The high angle reverse mechanism may be interpreted due to the accretion of sediments or low density continental layers of the African plate during its subduction beneath Eurasian plate.

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