Standard Scientific Research and Essays Vol2 (9): 451-463, September 2014 (ISSN: 2310-7502)
http://www.standresjournals.org/journals/SSRE

Research Article

Integrated seismic data with potential fields for Seismotectonic evaluation of great Cairo and its vicinities, Egypt

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Accepted 15 September 2014

Abstract

In spite of the fact that great Cairo region is very important for future development, the scope of this study is to provide a better understanding of seismotectonic set-up in and around Cairo. Therefore, the magnitudes of events during the time period from 1900 to 2012 were statistically treated to evaluate the b-values as a measuring of tectonic parameter. Isoenergy contour maps and 3D representations for these events were computed and constructed. Seismic trends of this area were deduced from isoenergy contour maps and focal mechanism solutions in addition to the tectonic trends from potential field data. The distribution of energy release and b-values indicate that the eastern side of the study area is more active than the western side. Results of tectonic setting, energy release distributions, focal mechanism solution and potential field data were compared to throw a more light on the seismotectonic characterization. It concluded that the major trends affecting the study area are ENE-WSW, WNW-ESE and E-W.

Keywords: Seismic Trends, Focal Mechanism, Energy Release, *b-Value*. Potential Field, Cairo, Egypt

INTRODUCTION

The science of earthquakes is considered alive field study, continually breaking down old fences and taking in new territory. It is usually said that seismology is the science of earthquakes and related phenomena. Seismological interpretations depend partly on geological findings in the field, where faulting or other geological features occur. It is sure that progress in seismology depends mainly on the cooperation between seismologists and geologists.

The seismologists all over the world are trying to do their best to minimize these losses caused by earthquakes. This goal can be achieved if the seismicity of the region is carefully studied and the seismotectonic set-up of the study area is evaluated. To exclude the regions of high seismic risk from the plan of constructing strategic buildings, this is not a solution; the solution is to design engineering buildings.

In Egypt, the population, archaeological sites and sensitive structures are concentrated within a narrow zone around the Nile Valley. Nevertheless, both the population and the newly developed areas in this zone are still growing rapidly. Generally, some buildings in Egypt are designed to resist earthquakes; therefore relatively small events can be the source of huge socio-economic disasters.

Cairo (the capital of Egypt) and the largest city in the Arab World is one of the most densely-populated cities in the world. The area is mainly affected by many seismic sources (e.g. seismicity of the Eastern Mediterranean Region, Northern Red Sea-Gulf of Suez, the Gulf of Aqaba-Dead Sea and the Eastern Desert)

The study area lies in and around Cairo and was bounded by the latitudes 29^o 00^{o}N and 31^o 00^{o}Nand the longitudes 30^o 30^{o}Eand 32^o 30^{o}E. It has been divided into four sectors for detailed seismic study (Figure1).In the present work, several seismic studies have been carried out by the use of the recorded earthquakes during the time period from 1900 to 2012 using moment magnitude values where *b-values*, energy release distributions and focal mechanism solutions for two events were calculated. In addition to potential field data was used to deduce the tectonic trends.

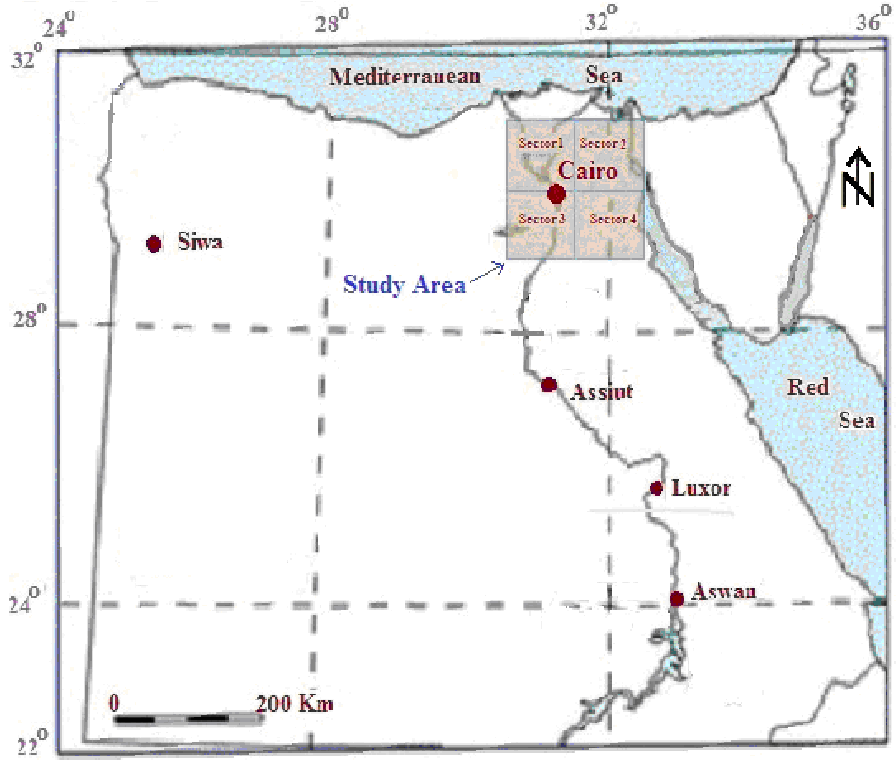

Figure 1. Location map of the study area

Seismicity, Potential Field and Tectonic Setting

Egypt was divided into four main seismic trends using the distributions of historical and recent earthquakes(Maamoun and Ibrahim, 1978;Kebeasy, 1984; Kebeasy, 1990) as follow:

1- Northern Red Sea - Gulf of Suez - Cairo - Alexandria trend.
2- East Mediterranean - Cairo- Fayoum trend.
3- Mediterranean Coastal Dislocation zone trend.
4- Levant - Aqaba trend.

The epicentral area of the 12th October 1992 earthquake has local tectonic activity, but more investigations are needed to discover the ambiguity in its tectonism (Mohamed, 2001). After this earthquake the National Research Institute of Astronomy and Geophysics (NRIAG) took all necessary measurements to carry out different geophysical and geodetic investigations in and around the greater Cairo region. For this purpose, a modern seismic network was installed which will be able to record low energy events and provide a good understanding of the tectonic behavior of the region. Also, a regional GPS network for the same purpose was established. The focal mechanism solutions of the main shock and the largest aftershock show normal faulting with strike-slip components. The trend of the aftershock distribution seems to be NW-SE. The *b-value* in Cairo region was found to fluctuate around an average of (0.524 ± 0.012) which is probably related to the stress-buildup-release conditions of the area. The level of seismic activity is low in Cairo City, but the seismicity was concentrated surrounding Cairo City at Dahshour, Ismailia and Gulf of Suez regions. The period of the field observations of the Cairo GPS network is relatively short. The movements in and around greater Cairo were determined for the different epochs of measurements.

B-value is a tectonic parameter describing the relative abundance of large to smaller shocks. It seems to represent properties of the seismic medium in some respect, like stress and/or material conditions in the focal region. Changes in *b-value* may result from the inability of fault dimensions(Kulhanek, 2005). It implies relationships with different tectonic regimes, stress-changes and heterogeneity of the materials. Large heterogeneities correspond to higher *b-values*.

Laboratory tests showed that an increasing of thermal gradients caused an increasing of *b-value* (Warren and Latham, 1970). It has been observed that *b-value* varies laterally and with depth. *b-values* much smaller than 1 were identified. Low *b-value* simply shorter recurrence time.

Many authors pointed out the spatio-temporal *b-value* variability: some of them in seismic hazard assessment analysis (Shanker and Sharma, 1998; McClusky et al., 2000)and others in earthquake forecasting modeling application (Schorlemmer et al., 2005)in correlations between *b-value* and tectonics (López Casado et al., 1995) for a worldwide correlation between *b-value* and focal mechanisms. The state-of-the-art about the different *b-value* estimating in literature was summarized(Bayrak et al., 2002; Olsson, 1999) Different methods to estimate the *b-value* were explained (Marzocchi and Sandri, 2003)while the limits of the Gutenberg and Richter distribution for the application in the engineering of critical structures were highlighted (Krinitzsky, 1993).

The significant of earthquakes must be considered in terms of the energy release. From the point of view of correlation with the seismotectonics, the energy release values appeared to be the most informative as high values of this parameter usually fall predominantly along the boundaries of large structure (Kondorskaya et al., 1985).

Interpretation of focal mechanisms in light of the regional seismic zones showed that many authors have been studied the seismicity of Egypt. The seismicity of Northern Egypt was studied by Ismail (1960) and Gergawi and El Khashab (1968), they concluded the following seismic zones:

1- Abu Roash- North Sinai zone.
2- Northern West Coast of the Red Sea zone.
3- Mediterranean - North Sinai zone.

The focal mechanism solutions demonstrate the mechanism of faulting which occurs during an earthquake. It is needed to determine the seismic fault model by finding the nodal planes of the observed polarity of *P-waves*. In the study area, it was collected all the possible events and selected two events having magnitude >4 to carry out the focal mechanism solutions. The used method and the software package developed by Suetsugu(1995) are used for plotting the data and drawing the nodal lines of the focal mechanism solutions of the selected events.

The most active tectonic parts are the plate boundaries, where the deformation is large. In Egypt, adjacent areas such as the Red Sea Rift and the Mediterranean convergent zone are the present active plate boundaries. Plate motion also controls the deformation within individual plates. Hence the present day tectonic deformation within Egypt is related to regional tectonic forces and the local tectonics of Egypt, accordingly three plate boundaries are bounding Egypt, the African-Eurasian Plate Margin, the Red Sea Plate Margin and the Levant Transform Fault.

The most predominant tectonic features of Egypt were delineated (Youssef, 1968)and grouped them to three main fault directions:

1- The Gulf of Suez-Red Sea fault direction.
2- The Gulf of Aqaba fault direction.
3- A 10°N deviated to the west of both Suez and Aqaba Gulfs fault direction and faults with semi latitudinal direction.

The main structural features controlling the study area are the faults which have a Post Eocene age of deformation (Moustafa et al., 1985). The major faults that affect the study area have the N-W, E-W and N-E directions. The N-W trending faults are the most predominant ones. Analysis of these faults indicated that the main stress regime is the tensile stress (Tawab, 1986). These tensile stresses are created from right lateral divergent strike slip movement on a deep seated of faults. All solutions in Cairo region showed normal faulting mechanism with a strike-slip component.

The main types of macrostructures in the study area are monoclines and faults. Most of these faults have a Post Eocene age of deformation. The major faults that affect the study area have the N–W, E–W and N–E directions(Youssef, 1986). The N–W trending faults are the most predominant ones. Analysis of these faults indicates that the main stress regime is the tensile stress(Abdel Tawab, 1986). These tensile stresses are created from right lateral divergent strike slip movement on a deep seated of faults. The tectonic trends in the Northern part of the Western Desert were studied by Tealeb and Rahman(1986) which is close to the study area, and they concluded that, there are seven tectonic groups trending N60E, E- W, N60W, N40E, N30W, N-S and N20E. These trends are in a good matching with the tectonic setting of the area.

The subsurface major structures from seismic and 3D-gravity modeling were delineated by Abu El-Ata (1990) as:

1. Major faults of top of the basement complex: The most frequent ones are trending NE and NW, and the less frequent are trending WNW and ENE.
2. Major faults of top of the Paleozoic: Major faults of this horizon have a wide pattern of trends and the most pronounced one is the NE trend. The NW trend is moderate frequent.
3. Major faults of base Tertiary: The EW and NW trends are the most major predominant faults and the NE trend is moderately frequent if were compared with the top of the Paleozoic.

4. Surface outcropping major faults: The NW trending faults were much affected the area and are mostly predominant. The EW and NE trends are moderately frequent. Sehim et al. (1992)in his study using seismic profiles and drilled wells concluded that faults crossing the Khalda area, west and close to the study area, exhibited two main directions WNW to E-W and the NW-SE. Abu El-Enean(1997) concluded that the locations of the recorded aftershocks of Dahshour 12th October 1992, show a lineament in the WNW-ESE direction in consistent with the surface lineaments recorded after the main shock.

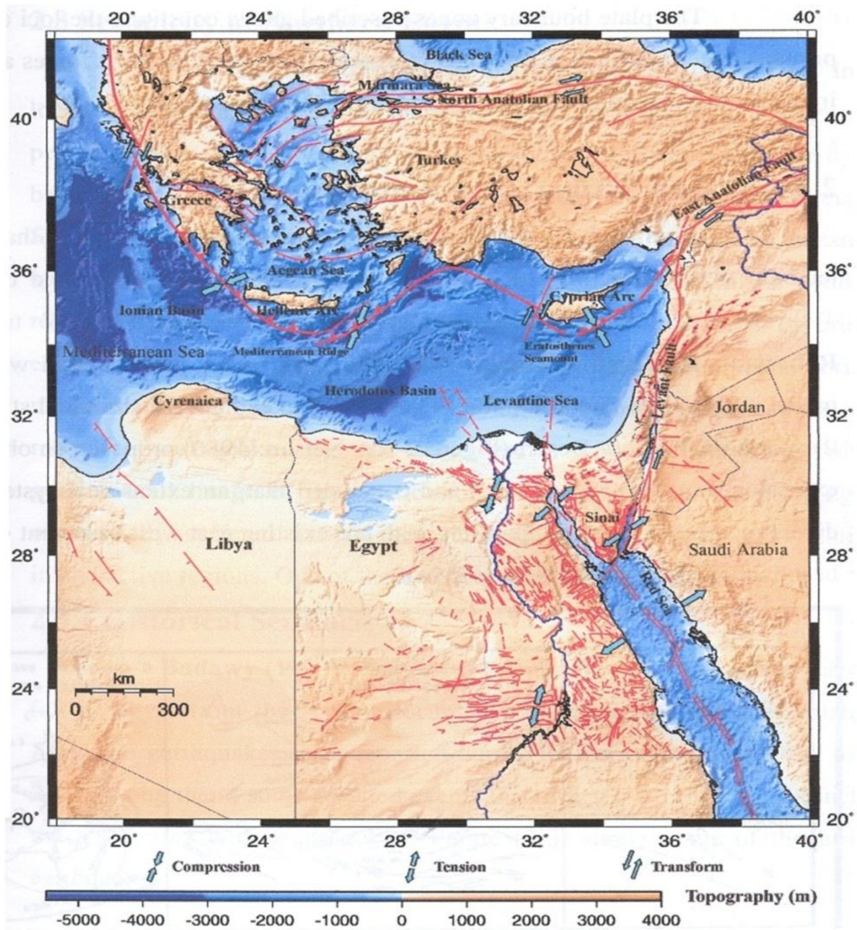

Figure 2. Tectonic map of Egypt and North Africa showing the different plate margins affecting North Egypt region(Abu El-Enean, 1993).

The tectonic regime of Northern Egypt is of considerable seismological and engineering interest. Within this tectonic regime, the seismic activity is considerably related to the relative plate motions occurred between the African, the Arabian and the Eurasian plates. The primary tectonic features of Egypt and its vicinity provided by Abu El-Enean (1993) and Fat-Helbary (1995) are shown in Figure(2). Three major plate boundaries are shown: African-Eurasian plate, Levant transform fault and the Red Sea plate margin. The sub-plate of Sinai block is a piece of the African plate and is partially separated by rifting along the Gulf of Suez (Fat-Helbary, 1995).

RESULTS AND DISCUSSION

The empirical relationship between frequency and magnitude of earthquakes was defined by Gutenberg and Richter (2010) as:

$$\text{Log } N = a - b\,M$$

where: N is the cumulative number of earthquakes of magnitude ≥ M; *a* and *b* are constants. *A* depends on seismic rates; *b-value* is representative of the earthquakes size ratio. The cumulative distribution provides better linear fit since numbers are larger and less degraded by statistics of small numbers (Kulhanek, 2005). The area under investigation has been categorized into four sectors to study the distributions of the *b-values* (Figure 3). The results showed clearly that the b-*values* are lower in the first and the third sectors of the above-mentioned areas, while respectively higher in the second and the fourth sectors. These results were attributed to the tectonic conditions in these sectors as estimated during the present work. Thus, the eastern side of the study area is more tectonically active than the western side.

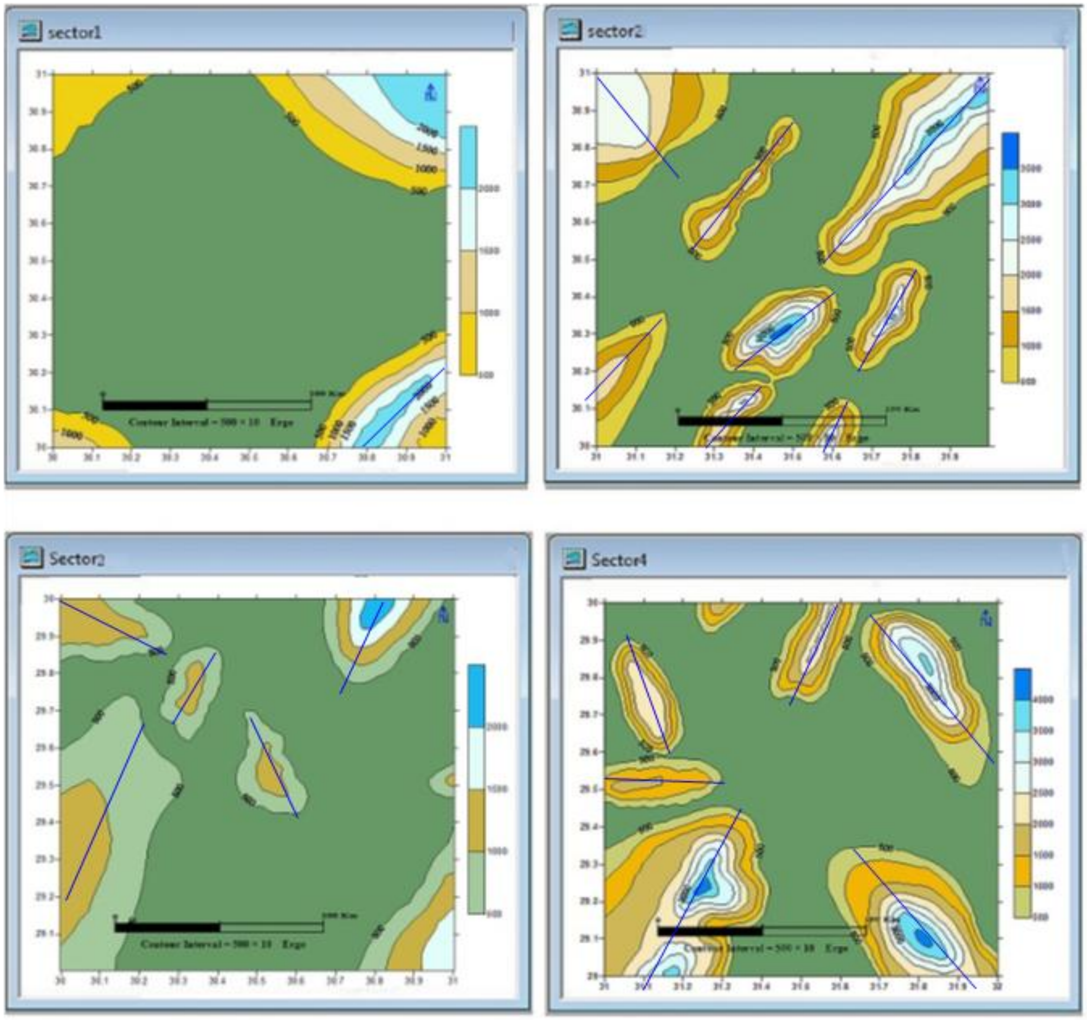

Figure 3. Frequency magnitude plot for the recorded earthquakes of the time period from 1990 to 2012

Energy release map is of interest in relation to faults and structures (Kondorskaya et al., 1985). The area under investigation has been divided into four sectors to study the distributions of the isoenergy contour maps and 3D representations (Figure 4 and 5). The second and the fourth sectors are high active seismic zones whereas the third one is moderately active and the first sector is of low seismic zone. These results are in consistent with the last results of *b-values*. Therefore, the eastern side of the study area is more active than the western side from the point of view of seismicity and tectonic. This is compatible with the findings of the *b-value* calculations in the same sectors. In addition, these isoenergy contour maps reveal that the major seismic trends are in the directions of ENE-WSW, WNW-ESE and E-W as illustrated from the rose diagrams (Figure 6). These trends are also in consistent with the described structural traced trends.

The fault plane solutions were determined where the lower magnitude events are not considered in this study as their focal mechanism solutions will be generally not reliable, but reliable solutions exist only for the largest earthquakes. Seismograms of the National Seismic Network in Egypt (ENSN) in NRIAG are recorded in digital format data. From this large data base, there are only two earthquakes of available data for the focal mechanism study having magnitude (>4) are selected at the investigated area. Using the software package of Suetsugu (1995), the take off angles are calculated using the local crustal model adopted by El Hadidy (1995).Projection of the P-wave polarities is carried out on the lower hemisphere net. Figures (7 and 8) show the focal mechanism of the studied events. The source parameters of these two events and the deduced fault plane parameters of the present analysis are listed in Tables (1 and 2).

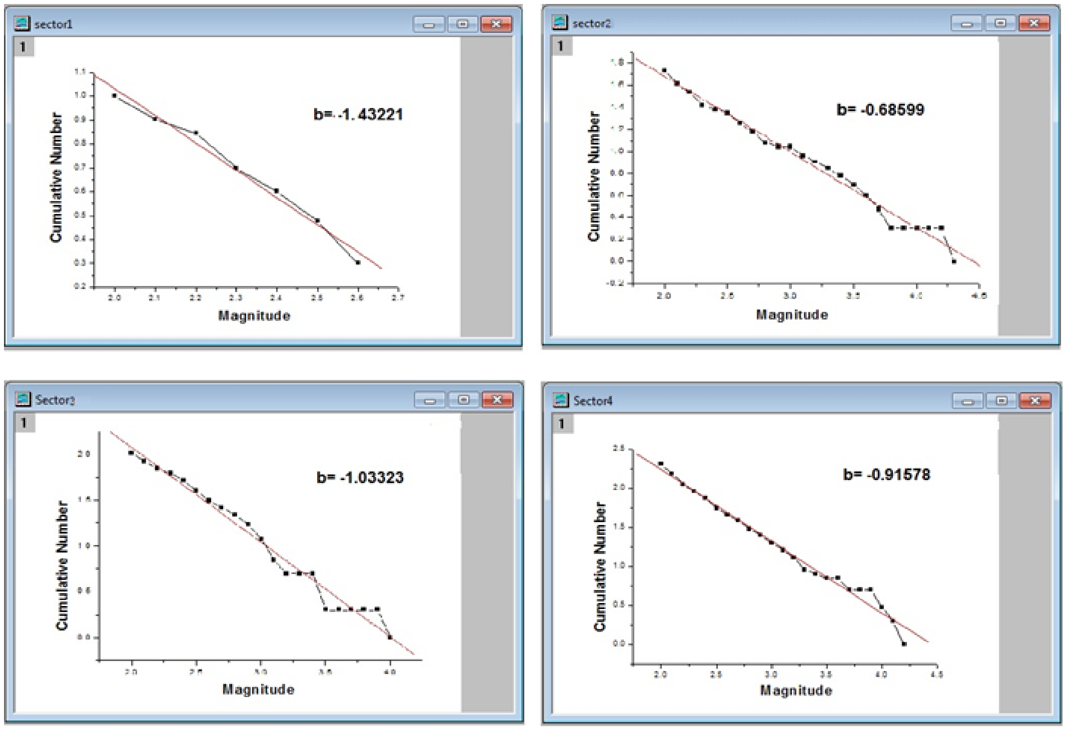

Figure 4. Isoenergy contour maps for the study of four sectors

In addition to the geological methods for determining the orientation of fault planes and fault displacements, there is a powerful seismological method that yields similar information. The procedure is called focal mechanism solutions and its input data are the first-motion records of earthquakes. The final results of these solutions can be interpreted in terms of fault movements. The solution shows two possible planes of faulting. It is also useful in determining the stress orientations; tectonics around the earthquake source region; plate motion and orientation of the tectonic stress which causes the earthquake. The main purpose of the focal mechanism study is to identify seismic fault from seismological observation.

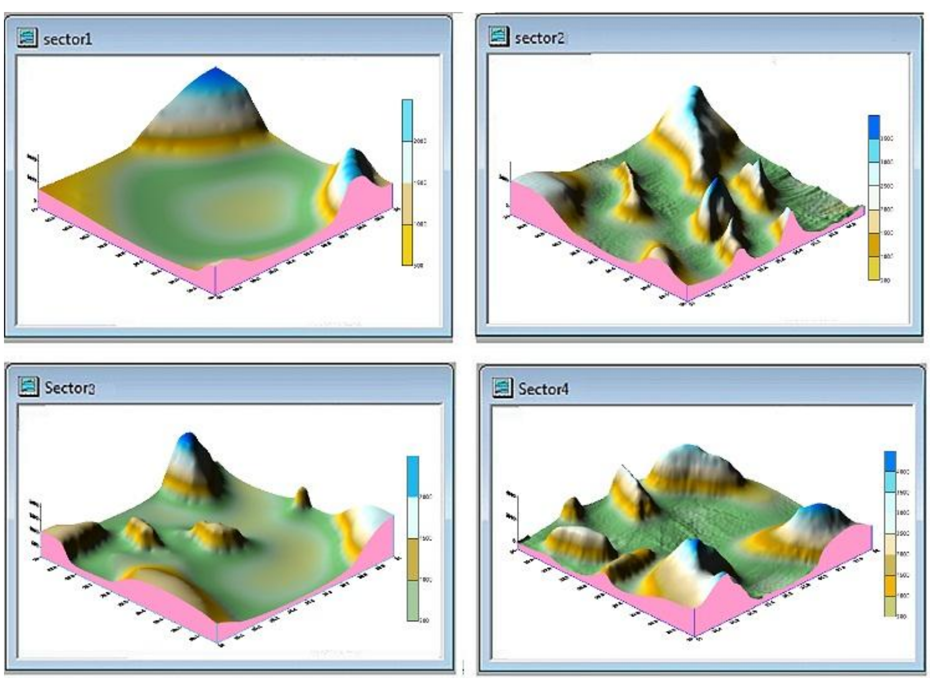

Figure 5. 3D representations for the distributions of energy release values in the four sectors

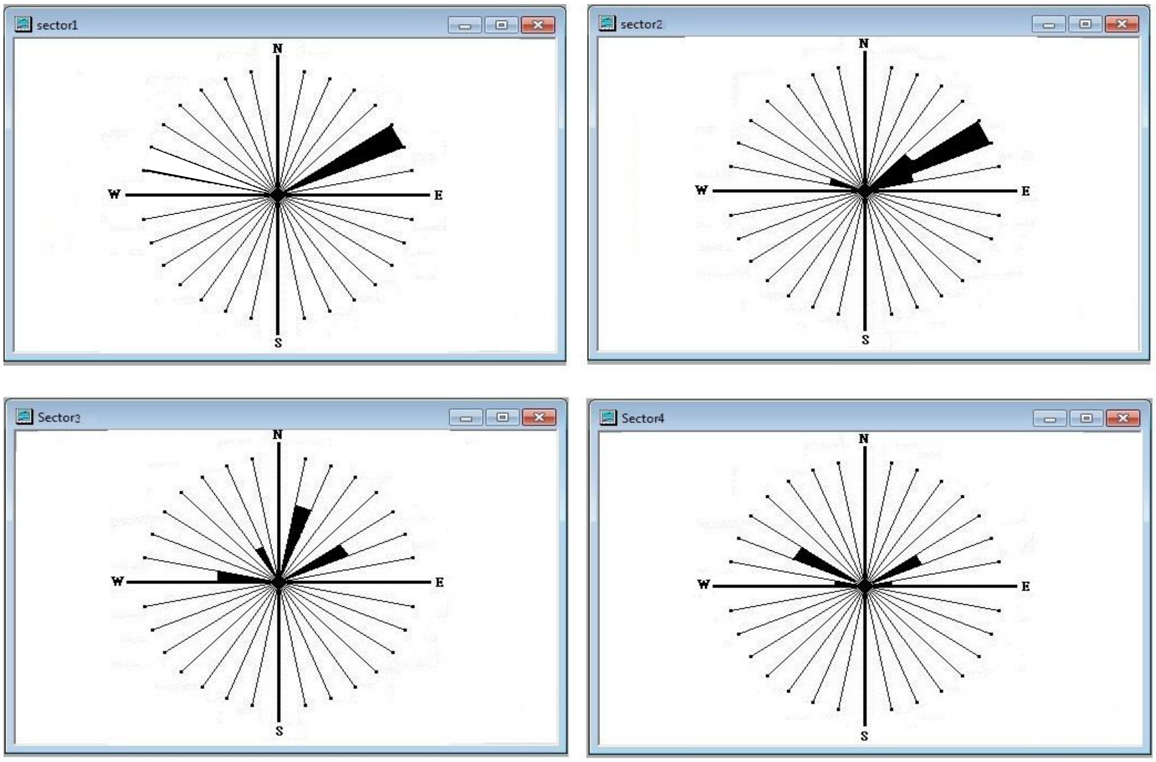

Figure 6. Rose diagrams showing the major seismic trends (deduced from the isoenergy contour maps).

The present analysis indicates that the mechanism of the studied events represents normal fault movements with slightly strike-slip component. The two nodal planes are trending in the WNW-ESE and ENE-WSW directions. The dominant stress is the tension stress of the NNE-SSW trend. In the present study, the shear component demonstration is unclear. So, more data are needed to know the exact sense of the shear motion along both planes. The trend of the present solution is consistent with trends of the major faults crossing the study area. Parameters of the second nodal plane are agreed well with trends of the Syrian arc system faults. These two nodal planes are in consistent with these tectonic trends (Northern Red Sea - Gulf of Suez - Cairo - Alexandria and Abu Roash- North Sinai belt) which were suggested by many authors (Ismail, 1960;Gergawi and El Khashab, 1968; (Maamoun and Ibrahim, 1978;Kebeasy, 1984).

The trends deduced from the analysis of the focal mechanism solutions and isoenergy contour maps are used to determine the main seismic trends affecting the study area. It is clear that the isoenergy trends are relatively in consistent with the results of the focal mechanism solutions. These solutions deal with the mechanism of faulting that occurs during an earthquake. The result obtained for the events (August 24, 2002 east Cairo and July 31, 2005 south Cairo earthquakes) demonstrates normal fault movements with slight strike slip component. The trends of the two nodal planes are WNW-ESE and ENE-WSW.

Table (1): Source parameters of the selected events

No		Event 1	Event 2
Date	D	24	31
	M	8	7
	Y	2002	2005
Origin Time	S	21.2	36.4
	M	1	16
	H	20	16
Latitude °N		30.14	29.67
Longitude °E		31.35	31.12
Depth (km)		18.8	20.4
Magnitude		4.3	4.3

Table (2): Focal mechanism solution parameters

No		Event 1	Event 2
Plane (1)	Strike	71°	63°
	Dip	57°	41°
	Rake	-124°	-146°
Plane (2)	Strike	302°	306°
	Dip	46°	69°
	Rake	-49°	-55°
P-axis	Azimuth	285°	258°
	Plunge	61°	53°
T-axis	Azimuth	-176°	11°
	Plunge	6°	16°

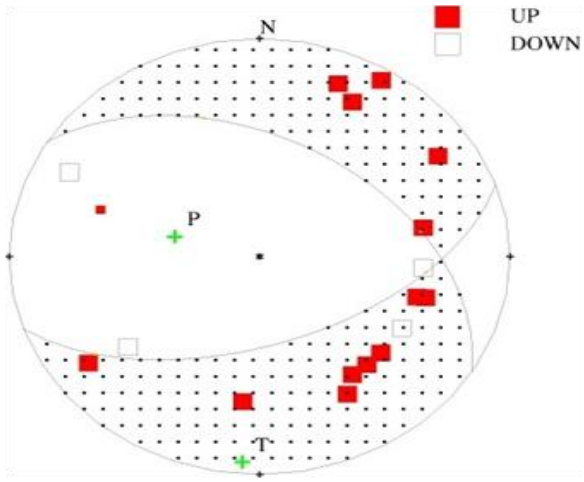

Figure 7. The focal mechanism solution of the August 24, 2002 earthquake

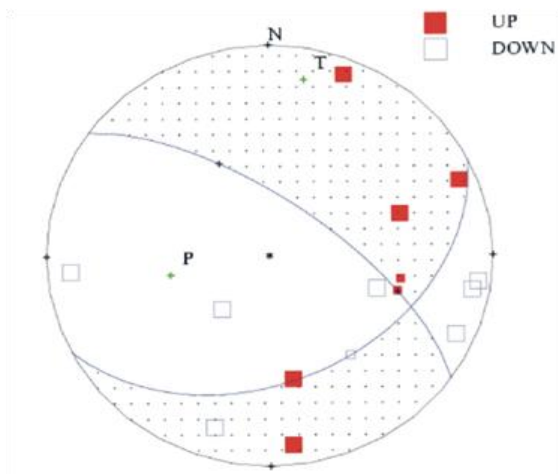

Figure 8. The focal mechanism solution of the July 31, 2005 earthquake

The Bouguer gravity anomaly map of the study area (Figure 9) (Scale1: 100,000) (Egyptian Petroleum Company, 1984) comprises alternating parallel positive and negative gravity anomalies zones trending in the E-W, ENE-WSW and NE-SW directions. The northern zones are positive anomalies (50mGal) and occupy the coastal area of/or Mediterranean. The pronounced negative anomaly is extended in the E-W direction crossing the Nile Delta. Its minimum amplitudes are in the central part (-40mGal). The Bouguer anomaly in the central part may reflect the presence of very thick sedimentary cover. Another important observation is that most of the steep gradients gravity anomalies have alternative negative and positive anomalies in the central part of the map. This may indicate that the area is structurally controlled by many major fault zones trending NE-SW and NW-SE directions. Moreover, the negative anomaly amplitude in the central part of the area becomes smaller at its both ends in the western and eastern terminations. Towards the south, there is a negative gravity anomaly zones trending NNE-SSW and N-S and occupying most the area east Cairo, as well as the eastern corner of the study area. The southern part has anomalies of well-defined polarities, characterized by irregular contouring patterns, positive values, different sizes and shapes and ranging from moderate to high gradients. The source of these anomalies may be due to very shallow of high density basement and or basaltic rocks in that region.

Magnetic map contains signals with a wide range of amplitudes, reflecting the varying basement depths, geometry and susceptibility contrast of sources. Such map is often dominated by large amplitude anomalies which can obscure more suitable anomalies. In the last view years there have been a number of methods proposed to help normalize the signatures in images of magnetic data so that weak, small amplitude anomalies can be amplified relative to stronger, large amplitude anomalies. The resultant RTP aeromagnetic map (Figure10) is represented by geomagnetic anomalous negative closures, their elongated shape, low gradient, high relief and negative polarities reflect a deep sedimentary basin. The central part of the area has anomalies of different polarities, characterized by irregular shape, high sharpness and high gradient. This illustrates a continuous tectonic activity in that area. In the southern part of the area, the anomalies have an elongated shape, negative polarity and low gradient. These observations explain the presence of sedimentary basin having thick sedimentary deposits; spherical shape anomalies of different closures, high gradient and high sharpness are also appearing in the southwest part of the RTP maps. This indicates the uplifting of the basement rock surface in the area. These anomalies with the intervening magnetic gradients reflect basement of different lithologic natures dissecting by structural elements of circular and linear features(Grant and West, 1965). The tectonic trend analyses deduced from potential field data (Figure 11) are:

- *Northern trending structures*: This trend has a mean strike of about N40° E.
- *West-northwest trending structures*: The peak of this trend has a mean strike of about N45ºW. This trend is considered as one of the most profound fault systems which affected the Precambrian basement (Said, 1962). It has a good agreement with the tectonic structural works of Youssef (1968) and Orwig (1982).
- *East-west trending structures*: This trend refers to the Tethyan trend. East-West structural trend is prominent features in of the Precambrian basement of Southeastern Mediterranean Sea (El Shazly, 1977; Ross and Uchupi, 1977).
- *East-northeast trending structures*: ENE trend has a mean strike of N60ºE. This trend is known as a Syrian Arc.
- *North 35º west*: Red Sea trend has a peak on the Nubian Shield ranging in direction between N25º-55ºW

All the tectonic trends deduced from potential field data and those that were deduced from seismic together with the trends obtained by Meshref (1990) and Abd El-Nabi et al. (1993) are used to interpret the seismotectonic situation of study area.

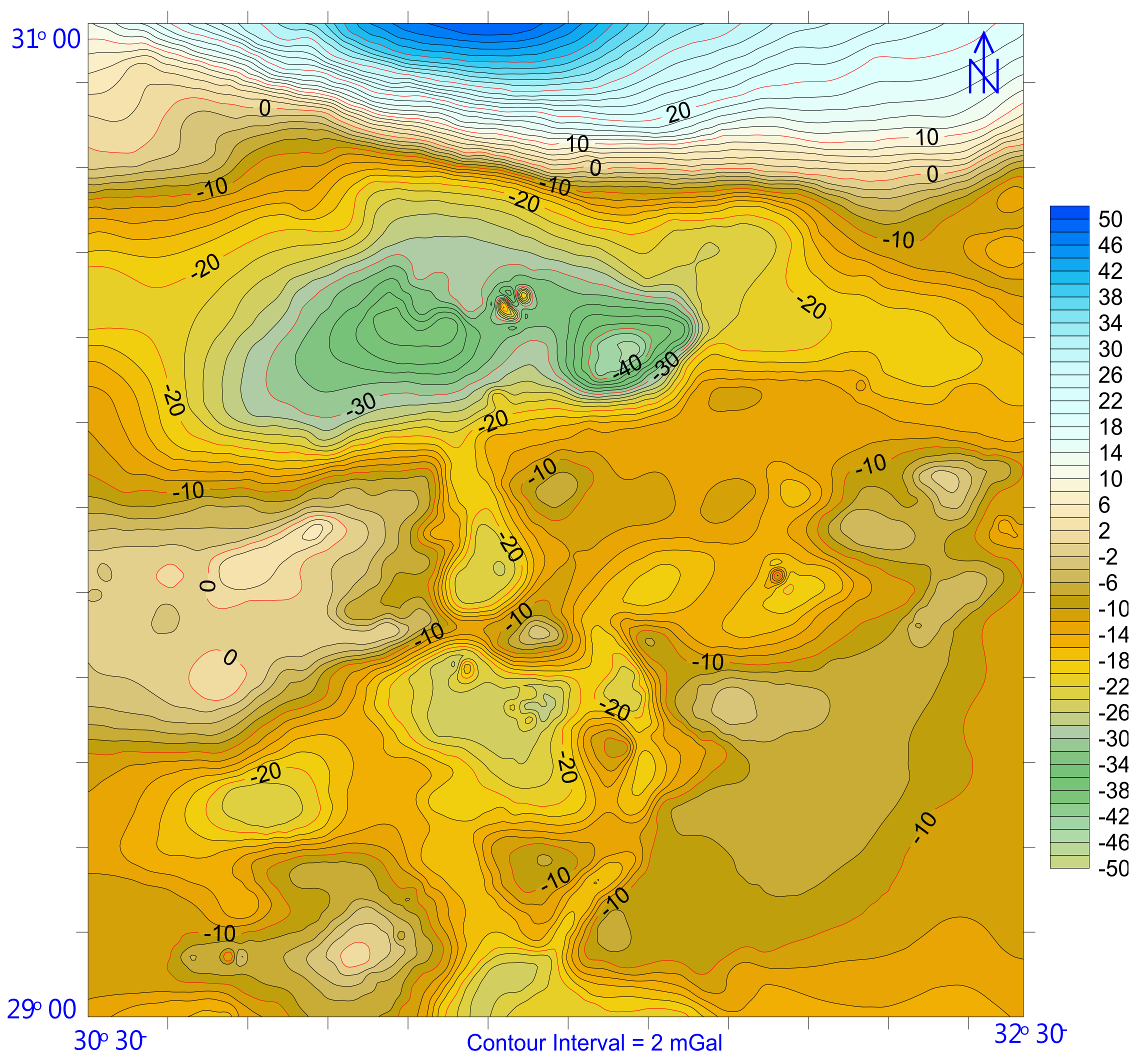

Figure 9. Bouguer gravity anomaly map of the study area (Egyptian Petroleum Company, 1984).

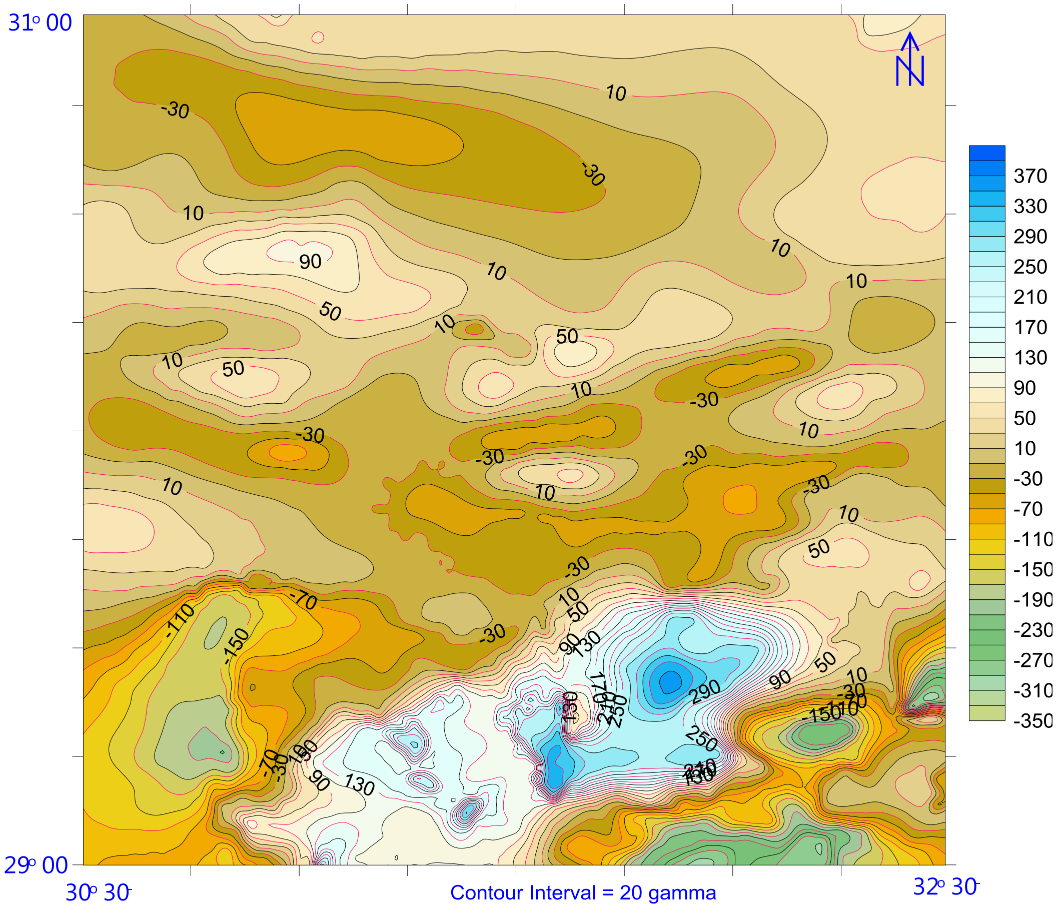

Figure 10. RTP aeromagnetic anomaly map of the studied area (Egyptian Petroleum Company, 1984)

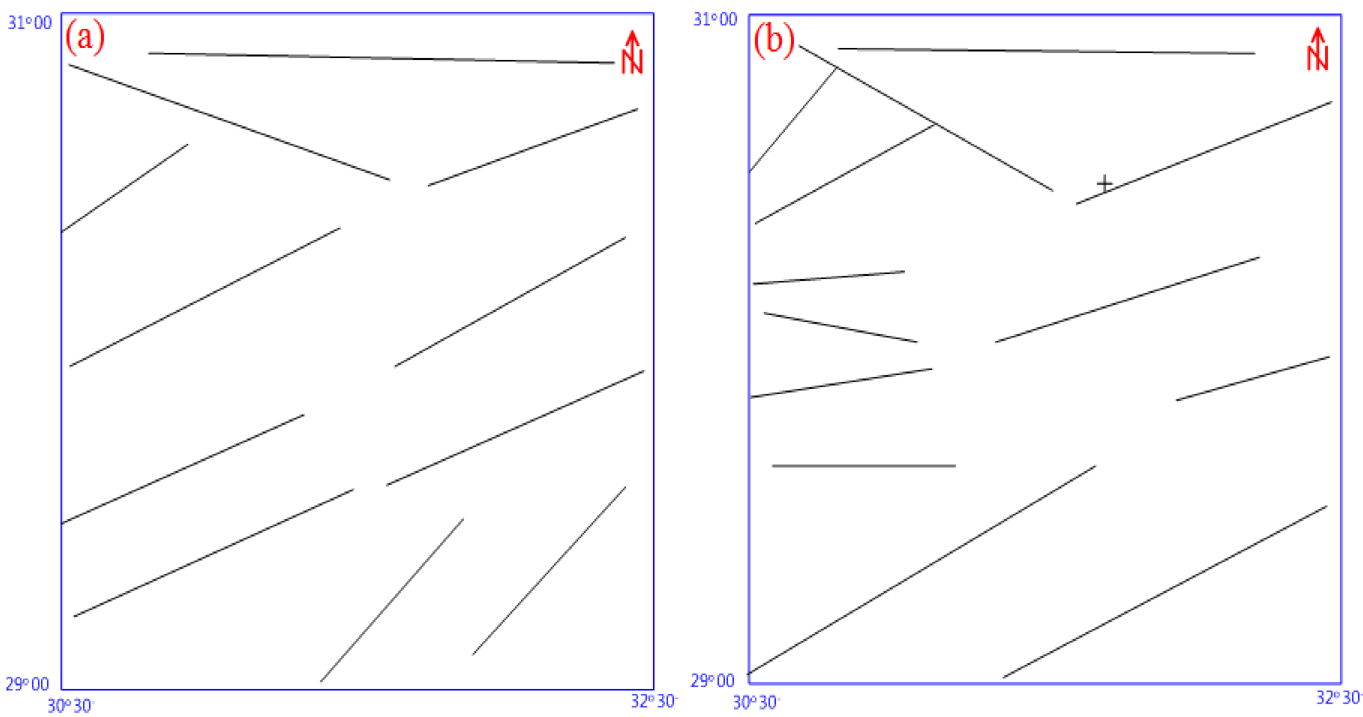

Figure 11. Tectonic lineaments deduced from Bouguer gravity anomaly map (a) and total magnetic intensity anomaly map reduced to the pole (b)

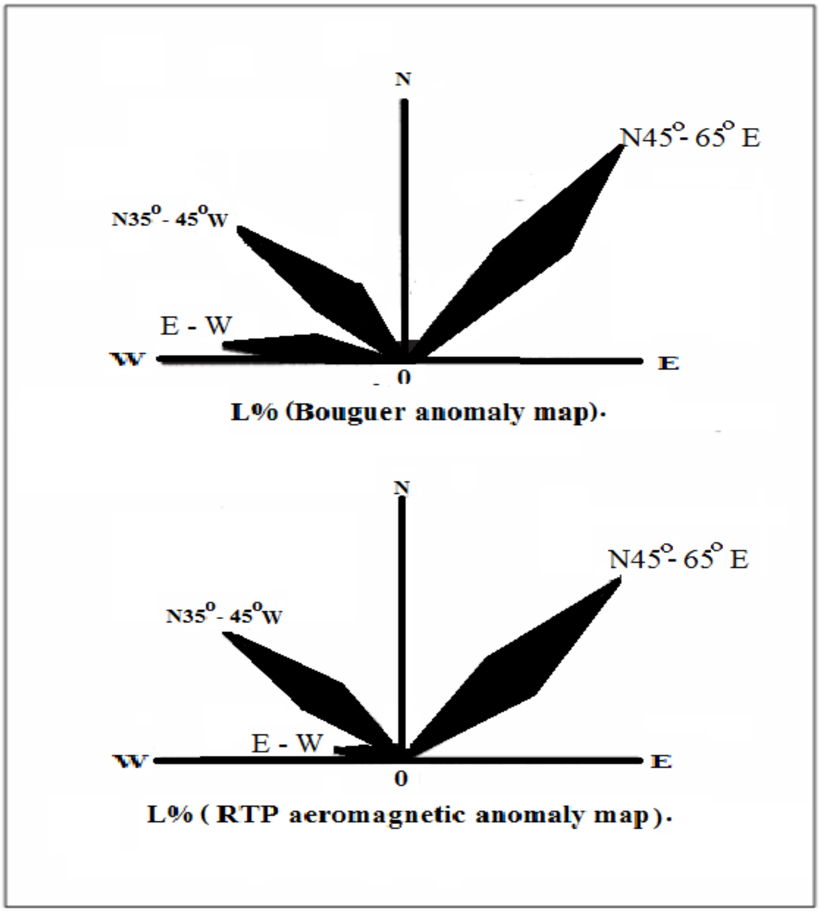

Figure 12. Rose diagrams illustrate the distribution of the lengths percentage (L %) of faults against

CONCLUSIONS

Seismotectonic set-up in and around Cairo is deduced by seismic and potential field data. Seismic data was represented by the *b-values*, the energy release distributions and focal mechanism solutions. The potential field data was represented by gravity and magnetic studies. The detailed study of these seismic and potential field data in and around Cairo provides a great help to understand the seismotectonic set-up of the study area. Therefore, the magnitudes of the instrumental recorded earthquakes are statistically treated to evaluate the *b-values* as a measuring parameter of tectonics and for estimating the energy release distributions in the study area.

The results of the *b-value* calculations show that the eastern side at the study area is more tectonically active than the western side. The energy release values were estimated by the use of magnitudes of the earthquakes at the time period from 1900 to 2012. It can be seen that high values of this parameter fall predominantly along the boundaries of large structures. The energy release contour maps and their 3D representations show that the eastern side is more active than the western side. These energy release distributions are compatible with the results of *b-values*.

The isoenergy contour maps are also used to determine the seismic trends within the study area. The trends are in the direction of ENE-WSW,WNW-ESE and E-W. The focal mechanism solutions deal with the mechanism of faulting that occurs during an earthquake. The result obtained for the events (August 24, 2002 east Cairo and July 31, 2005 south Cairo earthquakes) demonstrates normal fault movements with slight strike slip component. The trends of the two nodal planes are WNW-ESE and ENE-WSW.

Qualitative interpretations of the Bouguer and RTP magnetic data in relation to the structure and tectonic of the area were accomplished through the integration of seismic interpretation. Close examination of the interpreted magnetic structural map and rose diagrams show that, the study area has been overstated by two major sets of fault structures of the first order magnitude, mainly trending in NW to WNW and NE to ENE directions. Moreover, several second order minor fault systems, mainly in N-S direction have been prevailed. Tectonic lineaments map (Figure11) were obtained that give a significant detail about the tectonic activity in the study area. They can be arranged according to their magnitudes and importance as NW, NE, E-W and ENE respectively.

Matching the collected tectonic trends in the study area with the seismic trends (deduced from isoenergy contour maps and fault plane solutions) with the trends deduced from potential field data reveals presence of many major trends within the study area trending in the ENE-WSW, WNW-ESE and E-W directions.

ACKNOWLEDGMENT

We are greatly indebted to Prof. H.M.A. El-Khashab, professor of seismology, faculty of science, Sohag University for his absolute criticism of the manuscript that improved the paper considerably.

The authors express their sincere appreciation to all staff members of Seismology Department, National Research Institute of Astronomy and Geophysics (NRIAG) for their kind assistance and providing the possible facilities to carry out this work .

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