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FULL LENGTH ARTICLE

Seismicity and focal mechanisms of earthquakes in Egypt from 2004 to 2011

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Abstract The earthquake activity and the state of stress in and around Egypt will provide an opportunity to evaluate the seismic hazard. The seismicity data were compiled from the Egyptian National Seismological Network database during the period from 2004 to 2011 in an attempt to identify the different seismic source regions. Thirteen seismic source regions have been identified in this study.

The focal mechanisms for 36 earthquakes in and around Egypt are constructed for the same period using the waveform data recorded by the Egyptian National Seismological Network (ENSN) and the International Data Center (IDC) of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO). These solutions are computed by joining P, S_H, S_V polarities and S_V/**P**, S_H/**P** and S_V/S_H amplitude ratios where the quality of each solution is evaluated. This set of solutions is considered as a completion of the Egyptian focal mechanism catalogue. It will be helpful in understanding the spatial variation in the stress field within Egypt. At northern Egypt, the dominated mechanisms reflect a normal dip-slip, sometimes with strike component except in Dahshour region where strike–slip mechanism dominates. Toward the south, in Aswan source region, the strike–slip mechanism is dominated reflecting that the local tectonics is important characterized by a major strike slip component. The orientations of the T axes appear to be changed from NE-SW in the Gulf of Suez to ENE-WSW in the Gulf of Aqaba and NNE-SSW in the remains of the Egyptian territory. It is clear that Egypt is mainly controlled by extensional stress field.

1. Introduction

Egypt is a region of small to moderate magnitude earthquakes where the activity is distributed within several source regions. The investigated area has a complicated geological structure. The seismic activity is mainly controlled by the relative motions between the African, Arabian and Eurasian plates.

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The earthquakes have great effects on Egypt especially around Nile valley and Delta (e.g. Cairo 1992 earthquake (mb = 5.8) and the 1955 Alexandria earthquake with mb = 6.1) as most of population and the archeological sites are concentrated there. Therefore, understanding the earthquake activity of Egypt is essential for minimizing hazard and risk.

As early as 1899, the start time of the instrumental recording of earthquakes in Egypt, studying of the seismicity of Egypt has been the purpose of many published works (e.g. Sieberg, 1932; Ismail, 1960; Gergawi and El-khashab, 1968; Maamoun et al., 1984; Kebeasy, 1990; Abou Elenean, 1997; Badawy, 2005; Hussein et al., 2008) in an attempt for dividing Egypt into active seismic source zones and evaluation of its seismotectonics. These seismic source zones can be used for constructing the seismic hazard map based on the seismotectonic of the region. The newly dense broadband digital seismographs in Egypt and the surrounding regions produce a high quality waveform data. This has widely made a considerable progress in the study of the physics of local earthquakes in Egypt and the precise determination of their locations. This has enabled to understand the interrelationship between the geological structure and the recent seismicity.

The fault plane solutions of the recorded earthquake are used to determine the actual geometry of the fault, the style of faulting and the stress regime of a particular region. These solutions will also show the stress regime in any source region and its relation to the regional tectonics framework. There are several focal solution studies for earthquakes that have occurred in Egypt, based on the polarity of the first motion of P-wave (e.g. Maamoun, 1976; Megahed and Dessokey, 1988; Hussein, 1989; Abou Elenean, 1997; Abdel-Fattah, 1999; Badawy and Horvath, 1999; Hussein, 1989; Hussein et al., 2001; Hofstetter et al., 2003; Salamon et al., 2003; Abou Elenean et al., 2004; Egyptian National Seismological Network (ENSN, 1998–2004)) and the waveform inversion technique (Abou Elenean et al., 2004; Abdel-Fattah et al., 2006). This study aimed to update the earthquake catalogue of Egypt in the period from 2004 to 2011. The spatial distribution of the earthquakes in the compiled catalogue will help to identify the active sources and hence the mechanisms representing each of them.

2. Data analysis

2.1. Compilation of the catalogue

In this study, the earthquake catalogue is upgraded using data from the Egyptian National Seismological Network (ENSN), International Data Center (IDC) and International Seismological Center (ISC) for the time period from 2004 to 2011 within the region between latitudes 22–34°N and longitudes 25–35.5°E. The EDCAT software of Primakov and Rotwain (2003) is used to correct errors and remove duplicates for all entries within the compiled catalogue. This computer program selects double records with following thresholds for differences between values of parameters of double records: for time 1 min 0 s; for depth 1.00 km; for latitude 0.01°; and for longitude 0.01°. In addition this program creates file with unreasonable and duplicated records. This file is printed, checked manually, and corrected and the duplicated events are removed.

The present study is considered as the complement and extension of the previous works in particular the studies of Maamoun et al. (1984) and Hussein et al. (2008) respectively. They did their best to compile more reliable and homogenous earthquakes catalogue during the time periods 1900–1984 and 1985–2004 respectively. Their results indicated that the total number of events in both catalogues is 15,875 (82; 289; 5785 and 9719) corresponding to four stages through the whole time span of 105 years. The first stage includes time period before the World Wide Seismic Station Network (WWSSN) Helwan station (i.e., before 1962) and only 82 events are reported. The second stage (1962–1984) reflects only 289 events while the third and fourth stages correspond to pre ENSN (1985–1997) and post ENSN (1998–2004). The number of events during these stages increased abruptly to be 5785 and 9719 respectively. This is due to the installation of Aswan network (i.e. during the third stage) and the installation of ENSN in 1997 and the continuous increase of seismic stations installation in Egypt and the surrounding regions. The number of earthquakes data in this study is counted of nearly twice (1.8 times) higher than that recorded in 105 years, during the periods 1900–1984 and 1985–2004 (Hussein et al., 2008) respectively. This of course returns to the continuous installation of stations. The maximum magnitude (Mmax) is chosen among all available reported magnitude scales to have a catalogue of unified magnitude scale for further analysis (Persan and Rotwain, 2004). Fig. 1 shows the spatial distribution of the earthquake epicenters of the compiled catalogue and the different seismic source regions of Egypt.

2.2. Focal mechanism solutions

In this study, a new focal mechanism solution is constructed for 36 local earthquakes (Mmax = 3.5) within the Egyptian territory occurring between 2004 and 2011. The digital waveform data for these events are extracted from the database of the Egyptian National Seismological Network (ENSN). Additional information from the regional surrounding stations is also extracted as digital waveform from database of International Data Center (IDC) (Fig. 2). The chosen events have been reanalyzed to have great location accuracy. The first motion polarities of P wave were picked from the digital waveform data. PMAN software (Suetsugu, 1998) is used to obtain an initial focal mechanism solution. This software depends on the azimuth, incidence angle and polarities of P-phase only. The different crustal models upon which we calculated the parameters required for the focal mechanism analysis is summarized in Table 2.

To make the obtained solutions more reliable, an additional information is needed such as polarities of S_H, S_V and spectral amplitude ratios of S_V/P, S_H/P and S_V/S_H. Therefore, FOCMEC software (Snoke et al., 1984) is used for constructing more reliable focal mechanism solutions. The polarities and amplitudes of P-phase were picked from vertical component seismograms while S_V and S_H were picked from the radial and transverse components that obtained from rotation of N-S and E-W horizontal components using the seismic analysis code (SAC). We used stations which equipped with three components and epicentral distance less than 90 km. FOCMEC software uses the preliminary solutions obtained from Suetsugu, 1998 software as the initial trial. All these additional

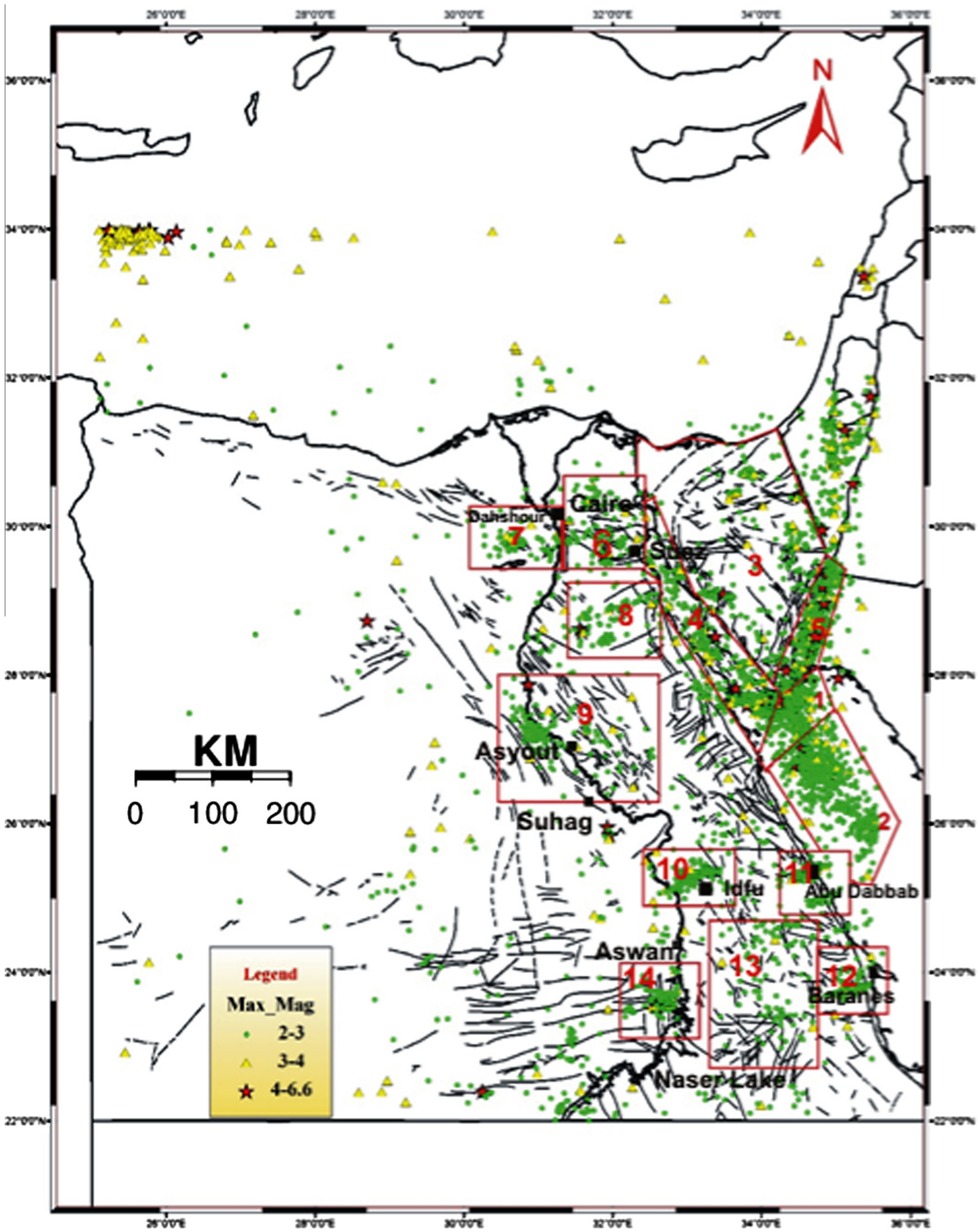

Figure 1 Distribution of the earthquake epicenters during the period from 2004 to 2011 and the different seismic source regions in Egypt are represented by numbers.

information enforce the solutions and make them more reliable.

3. Results

In this work, we find that the territory of Egypt can be divided into 13 seismic source regions as observed from the spatial distribution and mechanisms of earthquakes of the compiled catalogue during the period from 2004 to 2011. These are Gulf of Suez, Gulf of Aqaba, Red Sea, Cairo-Suez District, Abu-Dabbab, Dahshour, Aswan, Sinai Peninsula, Suhag-Assiut, the zone to the south of Cairo-Suez District and the zone between Barnes and Nasser Lake in the Eastern Desert and Idfu zone. It is important to note, the well coverage of ENSN has played the essential role in detection of small events and

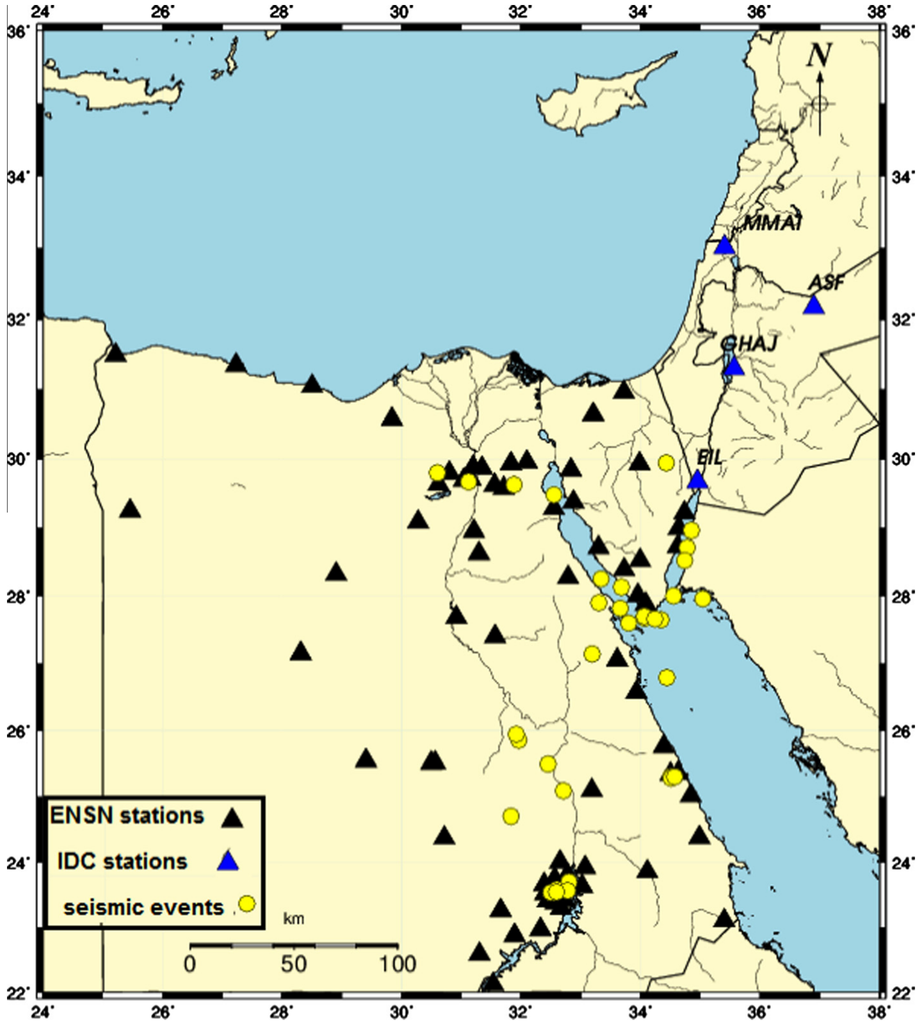

Figure 2 Geographic distribution of the Egyptian National Seismic Network (ENSN), the International Data Center (IDC) and the locations of the 36 seismic events.

identification of new seismically active source regions. These source regions include the zone to the South of Cairo-Suez source region, the zone between Barnes and Nasser Lake in addition to some sources regions which are distributed along Nile Valley such as Suhag-Assiut source region and Idfu source region. The seismicity in Abu-Dabbab and Branes source regions which are located along the Red Sea coast is mainly related to the movement along one of the Red Sea transverse transform faults. These faults are linked to these source regions.

A detailed description of the fault plane solution of earthquakes for each seismic zone will be discussed. The hypocentral information and the parameters of the focal mechanism solutions for these events are listed in Table 1 and the geographical distribution of the solutions for these events is shown in Fig. 3.

4. Gulf of Suez region

The Gulf of Suez region is the location of two significant events; the 1969, March 31, Shadwan earthquakes with magnitude Ms = 6.8, Mb = 6.3 and the Jun 28, 1972 earthquake (mb = 5.6 and Ms = 5.5). There are new 8 earthquakes (see Table 1, Fig. 3, and Appendix) which have occurred along it. The focal mechanism solutions of these events indicate the present day tectonic activity in this area. Their fault plane solutions indicate three types of mechanisms. The first group (4 events; Nos. 17, 19, 28, 34) gives pure normal faults; with the two planes trending from NNW-SSE to NW-SE and dipping either to NE or to SW. These events occurred at the northern and southern parts of the gulf with fault planes in consistence with the main trend of the Gulf of Suez. The second group (event Nos. 03, 35) is characterized by normal fault mechanism with minor strike-slip component (i.e., oblique mechanism); with two nodal planes trending NNW-SSE and ESE-WNW, while the last group (event Nos. 20, 29) shows normal faults with major strike -slip component. The nodal planes are trending in the NNW-SSE and ENE-WSW directions in agreement with the transfer faults within the two accommodation zones of the Gulf of Suez. The 8 solutions yield *T*-axes in N33°–59°E directions which represent the dominant trend of extension in the Gulf of Suez (Megahed, 2004; Hussein et al., 2013).

Table 1 The location and fault plane solutions parameters of earthquakes used in this study.

No.	Date			Time			Location		Depth (km)	Mmax	*P* axis		*T* axis		Source area
	Y	M	D	H	Mn	S	Lat. E°	Long N°			Az	Pl	Az	Pl	
01	2004	02	03	08	28	46	25.3	34.5	9.7	3.8	95	54	200	11	Abu Dabbab
02	2004	06	03	09	32	36	26.79	34.44	16	4.2	123	66	24	04	Northern Red Sea
03	2004	07	06	12	13	52	29.48	32.55	24.8	3.5	109	65	223	10	Gulf of Suez
04	2004	09	27	13	30	49	23.59	32.60	3.4	3.7	164	72	29	13	Aswan
05	2004	10	28	07	10	31	29.94	34.43	15.7	3.8	265	60	18	12	Sinai
06	2004	11	06	14	16	21	25.28	34.51	10.71	3.8	102	55	227	22	Abu Dabbab
07	2005	04	16	19	55	13	29.63	31.88	6.4	4.2	271	58	36	20	Cairo Suez district
08	2005	07	31	16	16	36	29.67	31.12	21.1	4.3	263	56	19	16	Dahshour
09	2006	01	13	03	28	46	25.30	34.57	13.64	3.9	94	64	213	13	Abu Dabbab
10	2006	02	25	01	50	08	27.9	33.3	9.7	4.0	116	58	23	02	South Cairo-Suez
11	2006	03	03	20	59	17	27.14	33.19	19.52	3.5	286	47	31	14	South Cairo-Suez
12	2006	06	08	04	24	09	24.70	31.83	1.96	3.8	105	69	204	03	Nile Valley
13	2006	12	13	12	21	44	25.09	32.71	17.6	3.8	299	52	204	04	Nile Valley
14	2007	04	01	16	20	46	23.54	32.50	14.54	3.8	291	21	21	02	Aswan
15	2007	04	12	14	19	22	23.59	32.71	13.8	3.8	332	63	198	19	Aswan
16	2007	04	13	22	02	18	28.00	34.55	11.8	4.1	151	54	54	05	Northern Red Sea
17	2007	05	20	22	01	51	27.6	33.8	6.1	4.2	59	80	237	10	Gulf of Suez
18	2008	06	21	17	59	47	29.8	30.6	6.2	4.0	258	23	352	09	Dahshour
19	2008	06	26	23	25	26	27.82	33.66	7.6	4.2	43	83	226	07	Gulf of Suez
20	2008	09	10	01	58	33	28.25	33.34	13.96	3.7	123	34	27	09	Gulf of Suez
21	2009	02	10	23	43	05	23.7	32.8	3.8	4.0	300	42	202	09	Aswan
22	2009	12	29	06	28	44	28.71	34.78	10.90	3.6	169	69	65	05	Gulf of Aqaba
23	2010	02	24	16	43	12	25.49	32.45	1.36	3.5	180	89	36	01	Nile Valley
24	2010	03	09	19	58	09	28.13	33.68	8.38	3.9	267	81	47	07	Sinai
25	2010	03	13	02	22	16	23.57	32.78	3.57	3.9	91	36	183	04	Aswan
26	2010	07	15	11	25	54	28.96	34.85	22.3	4.4	167	66	64	06	Gulf of Aqaba
27	2010	10	28	09	02	31	25.85	31.96	14.1	4.2	93	77	200	04	Nile Valley
28	2011	02	20	01	27	04	27.69	34.06	18.2	4.9	121	76	228	04	Gulf of Suez
29	2011	02	20	04	52	36	27.67	34.07	17.8	4.4	318	48	57	07	Gulf of Suez
30	2011	06	30	10	50	36	27.65	34.34	10.26	3.7	285	53	33	13	Northern Red Sea
31	2011	07	29	16	19	23	25.94	31.92	19.6	4.0	325	64	215	10	Nile Valley
32	2011	10	21	16	36	41	28.52	34.74	8.2	4.2	311	75	71	08	Gulf of Aqaba
33	2011	11	03	11	23	12	27.96	35.04	0.0	4.3	143	52	51	01	Northern Red Sea
34	2011	11	19	07	12	15	27.70	34.06	15	4.6	103	74	221	08	Gulf of Suez
35	2011	11	20	05	16	04	27.66	34.24	15.9	4.2	117	68	227	08	Gulf of Suez
36	2011	12	26	17	01	26	23.55	32.59	10.1	4.0	307	41	209	10	Aswan

Table 2 Crustal structure models used in this study.

Layer no.	First layer			Second layer			Third layer			Fourth layer			Site
Layer parameters	H	VP	VS	H	VP	VS	H	VP	VS	H	VP	VS	
Makris et al. (1979)	3.5	3.55	1.99	18.5	6.0	3.37	11	6.35	3.56	–	8.0	4.49	WD
Simpson (1984)	0.5	4.00	2.30	05	6.0	3.40	15	6.80	3.90	–	8.0	4.49	ASL
Marzouk (1988)	4.0	4.00	2.32	8.0	6.3	3.66	10	6.6	3.83	–	8.0	4.47	NRS
El Hadidy (1995)	3.5	4.50	2.52	12.5	6.0	3.37	15	6.50	3.65	–	8.0	4.49	ED

Abbreviations: H, layer thickness; VP, P-wave velocity; VS, shear wave velocity; WD, Western Desert; ASL, Aswan Lake; NRS, Northern Red Sea; ED, Eastern Desert.

5. Gulf of Aqaba region

The Gulf of Aqaba is a source region of intense activity which is located along a main tectonic plate boundary. The movement along this transform boundary caused some significant earthquakes. The largest recorded earthquake (Mw = 7.2) in this region is that of November 22, 1995. It is the strongest earthquake occurred in this region. Three earthquakes (event Nos. 22, 26, 32 with Mmax = 3.6–4.4) occurred within the central part of the Gulf of Aqaba (i.e., the epicentral area of the 1995 event), are used for focal mechanism solutions. The fault plane solutions give pure normal fault mechanism with

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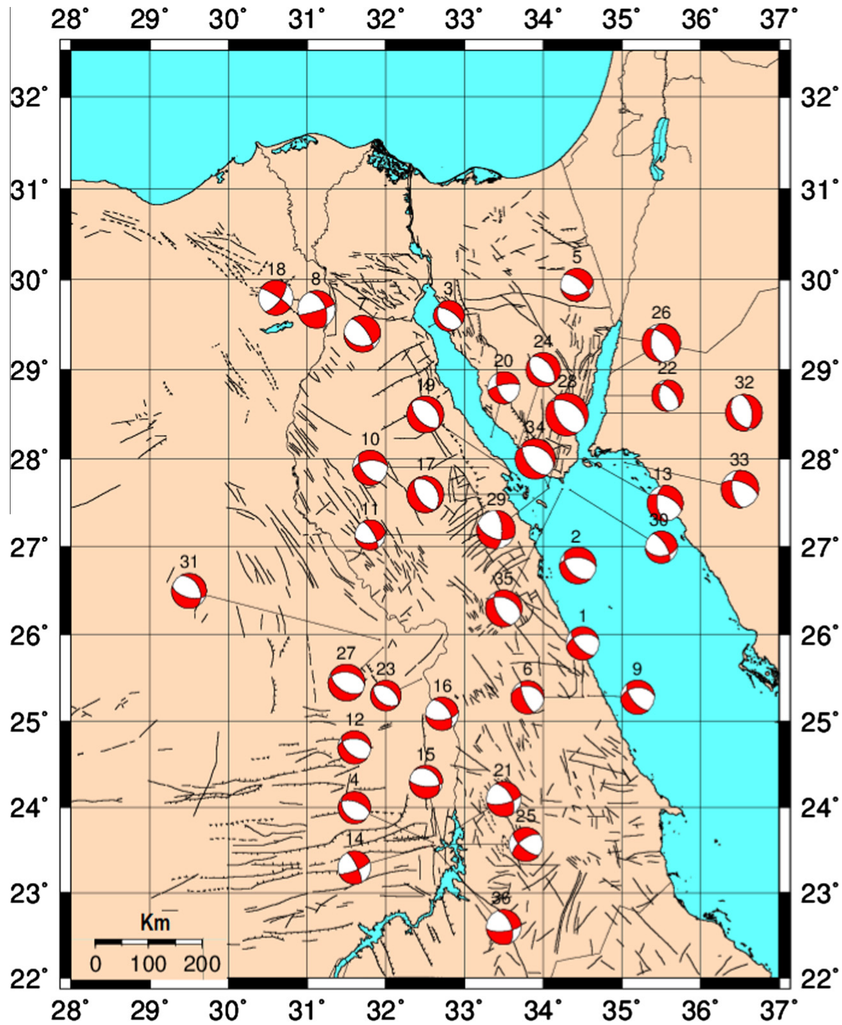

Figure 3 Spatial distribution of focal mechanism diagrams for earthquakes in Egypt during the period from 2004 to 2011.

slight strike-slip component along the nodal planes of trend NNW to N-S and NW. The NNW to N-S nodal plane shows slight left lateral component in accordance with the strike of the NNW-SSE transverse faults (see Table 1, Fig. 3 and Appendix) and appears to be consistent with the mechanisms of the two sub-events of August 1993 (i.e., the main shock and the largest aftershock). These mechanisms are consistent with the extensional regime of rhomb-shape grabens within the Gulf, and with the NNW-SSE trend of the aftershocks of August 1993 earthquake (Abdel-Fattah et al., 2006).

6. Northern Red Sea source region

Two events (Nos. 16, 33) among the 4 earthquakes (Table 1, Fig. 3 and Appendix) which occurred at the northern end of the Red Sea near Ras Mohamed with magnitude 3.7–4.3 Mmax, show normal fault mechanisms with large strike-slip component. The nodal plane trending in the NNW-SSE direction has steep dip and shows left lateral motion compatible with the strike of the transverse NNW-SSE faults. The other two events (Nos. 02, 30) reflect normal mechanism with considerable strike slip component along the two nodal planes of orientation E-W and NW-SE to NNW-SSE. The dip direction of two planes is in opposite directions with two mechanisms. The four events reflect ENE-WSW to NNE-SSW extensional direction.

7. Cairo-Suez district source region

Only one earthquake (no. 07, see Table 1, Fig. 3 and Appendix) of 4.2 Mmax has occurred in this source area during the study period. Its fault plane solution suggests normal fault mechanism with slight horizontal component, along nodal planes trending nearly NW-SE and E-W (Fig. 3). The E-W nodal plane shows right lateral movement in accordance with the general strike directions of the faults in this zone (i.e., NW-SE and the E-W transverse normal faults). The T-axis trend of this solution is different from that inferred from stress tensor inversion in the same area by Hussein et al. (2013). This confirms the suggestion that one fault plane solution only cannot represent well the stress pattern in any source region.

8. The Nile valley region

Five earthquakes (Nos. 12, 13, 23, 27, 31; Table 1, Fig. 2 and Appendix) of 3.5–4.2 Mmax magnitude range which occurred along the Nile valley source region are used for constructing

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focal mechanism solutions. The results of fault plane solutions for these events show that there are two groups of solutions as shown in Fig. 3; the first group (Nos. 12, 27) gives normal fault with slight horizontal component which has two nodal planes trending WNW-ESE to NW-SE with opposite dip directions. The second group (three events; Nos. 13, 23, 31) gives normal faults with slight to large strike slip components. They have the nodal planes varying in trends; one plane trends between WSW-ENE and WNW-ESE and the other from NW-SE to ESE. All events yield NNE direction of *T*-axes as the dominant trend of extension which is in well agreement with the results of Bosworth et al. (2008) and Hussein et al. (2013) in this area.

9. Aswan seismic zone

Six earthquakes occurred in Aswan source region (Mmax = 3.7–4) during the study period and are used for calculating the focal mechanism solutions. The results show that these solutions can be divided into three groups (Fig. 3 and Appendix). The first one (Nos. 14, 21, 36) gives mainly strike slip fault with small normal component with the two nodal planes trending NNW-SSE and ENE-WSW. The two planes reflect left and right lateral sense of motion respectively. The second group (Nos. 04, 15) gives normal faults with small strike slip component with the two nodal planes of trend WNW-ESE and NW-SE. The third group (no. 25) is mainly strike slip mechanism with large normal component with the two planes trending in the NW-SE and NE-SW. It also shows two types of motion, right lateral along NE-SW, and left lateral along NW-SE plane. The *T*-axis has a NNW trend. This solution is not consistent with the main structural trends in this area, but it reflects the same mechanism of the Abu Dabbab earthquake of 2nd June, 1984 mb 5.1 (Hussein et al., 2011). While the rest solutions mostly reveal right lateral motion and/or normal along ENE-WSW to E-W trending plane and left lateral and/or normal along NNW-SSE and NE-SW. In fact both the two planes fit well the strike of the traced faults in the area. All these groups are greatly affected by local structures in this area. The ENE-WSW to E-W trending plane is consistence with right lateral strike slip faulting along the Kalabsha trend. Whereas, the NNW-SSE to N-S oriented plane is consistent with the N-S faults for events located near Kurkur and Khor El-Ramla faults.

10. Abu-Dabbab source region

This source area is marked by two moderate magnitude earthquakes, 12 Nov. 1955 mb = 6.1 and 2 July, 1984, mb = 5.1. The fault plane solution of both events is nearly consistent. It shows strike slip mechanism with normal slip component along NW-SE and NE-SW planes. Seismic activity in this source region occurs in the form of repeated micro-earthquake swarms. In Abu-Dabbab source region, 3 earthquakes (Mmax = 3.8–3.9) are used for constructing focal mechanism solutions. The fault plane solutions show normal faulting with slight to considerable strike slip component (Table 1, Fig. 3 and Appendix). The three events have one plane trending NW-SE and the other varies between WSW-ENE and WNW-ESE. We notice that the three solutions are nearly consistent with the mechanism solutions of 12 Nov. 1955 and 2 July, 1984, except their *T*-axes rotated in clockwise direction. This confirms that the inferred present day stress field from recent structural features, recent drainage modification and seismic data shows N-S compression and multi-directions of extension (Akawy, 2008).

11. Dahshour source region

Dahshour source region is one of the most significant intraplate sources region in which a damaging earthquake of magnitude mb 5.8 & Ms 5.3 occurred in 12 October 1992. In this study, 2 new earthquakes occurred in this region are used for constructing the focal mechanism solutions. One event (No. 18, see Table 1) shows strike–slip mechanism with considerable normal component, and the other (No. 8) gives normal faulting with considerable strike-slip component. The nodal planes trend between NW-SE and NE-SW/WNW-ESE respectively as shown in Fig. 3 and Appendix. The two events exhibit *T*-axes in the NNE direction (Table 1) which is similar to the stress regime of intraplate source regions inferred from inversion of focal mechanism data set (Hussein et al., 2013).

12. The source region to south of Cairo-Suez district

In this new source region, two earthquakes (Nos. 10, 11) which occurred within it are used for constructing the fault plane solutions. The fault plane solutions could be constructed to show normal faulting with considerable strike slip component as shown in Fig. 3 and Appendix. The two nodal planes are trending on the NNW-SSE and ENE-WSW directions. Generally, both solutions confirm a suggestion of a reactivation of the pre-exiting E-W and NW-SE faults due to a partly transfer of rifting deformation from the Red Sea-Gulf of Suez along these trends Moustafa and Abd-Allah (1992).

13. Focal mechanism in Sinai source region

In this study, 2 earthquakes (Nos. 05, 24) which occurred in Sinai source region are used for constructing the focal mechanism solutions (Table 1). The results show normal faulting with slight horizontal component. The nodal planes; one trending NNW-SSE and the other varies from trending WNW-ESE to ENE-WSW are shown in Fig. 3 and Appendix.

14. Discussion and conclusions

In this study, we construct more comprehensive and more reliable catalogue for seismicity and focal mechanism solutions in Egypt during the period from 2004 to 2011. This catalogue contains more accurate information which will be useful for seismotectonic interpretation and seismic hazard evaluation. The data used in this study are collected from different agencies such as the Egyptian National Seismological Network (ENSN), International Seismological Center (ISC) and International Data Center (IDC). These data are filtered to remove duplicate events from the catalogue. Unification of the magnitudes reported by the different agencies is performed in order to obtain the homogenous data of earthquakes. The types of faulting and the stress pattern obtained from the focal solutions are interpreted to discuss the present-day tectonic framework of Egypt.

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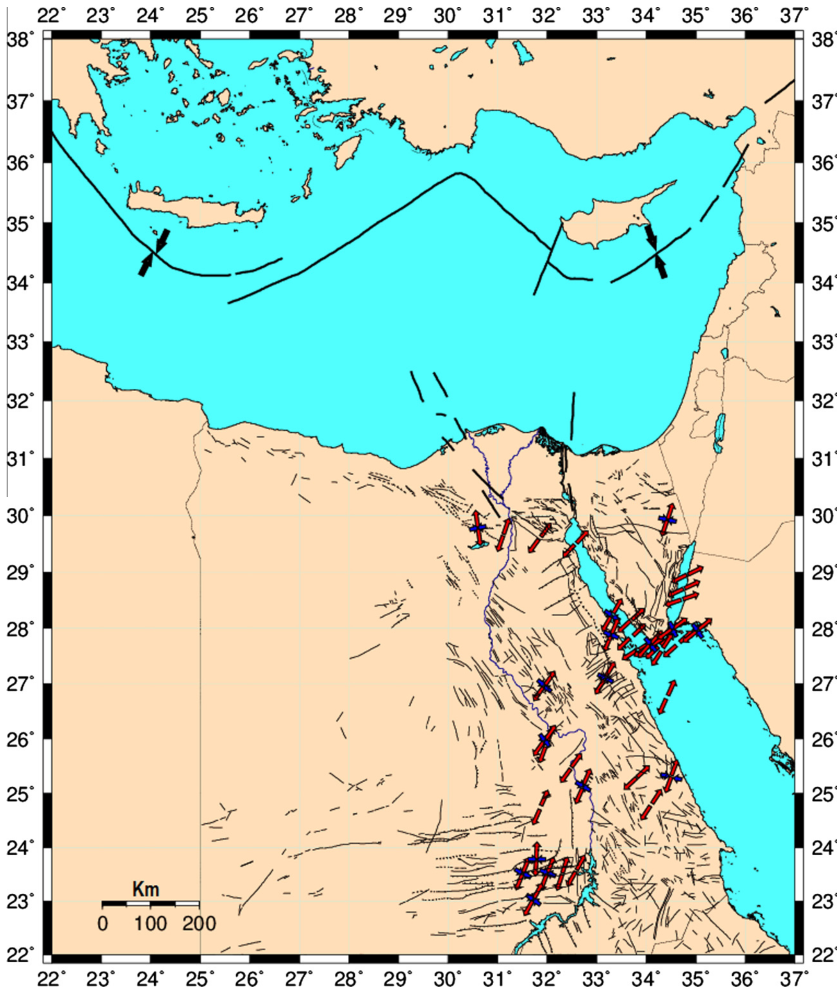

Figure 4 The distribution of *P* and *T* axes orientations correspond to the 36 earthquake focal mechanisms between 2004 and 2011.

The source mechanisms for 36 earthquakes were also calculated using the waveform data extracted from ENSN stations in addition to waveform data extracted from IDC stations of the CTBTO. In this study, focal mechanism solutions are constructed for 36 earthquakes which occurred across Egypt during the period from 2004 to 2011. These solutions are not considered only by polarities of first onset (P-phase) but also polarities of S_H, and spectral amplitude ratios of $\mathbf{S_H/P}$, S_V/P and $\mathbf{S_V/S_H}$. The results of these solutions show that Egypt is characterized by pure normal faults, normal faults with strike slip component and strike-slip faults. The relatively pure normal faults exist in the Gulf of Suez and Nile Valley source regions. The combination between normal faults and strike slip components is observed when moving westward. Strike slip faulting mechanism dominates in Aswan and Dahshour source regions.

For the Gulf of Suez region, the nodal planes for the majority of the solutions reflect the main NW-SE trend of faults in this source region. For the Gulf of Aqaba region, the nodal planes for the majority of the solutions are in NNW-SSE direction. This trend is in a good agreement with the major Gulf of Aqaba trend. For the Northern Red Sea source region, the nodal planes reflect a movement along NW-SE, NNW-SSE and NNW-SSE to E-W trending planes. For the Cairo-Suez district source region, the nodal planes reflect a movement either along NNW-SSE or along E-W direction. These two trends of the nodal planes match the structural elements in this source region. For the Nile Valley region, the majority of the solutions show mainly both pure normal mode of motion and oblique sense of dominant normal component combined with more or less subordinate right shear component on E-W to NWN-SES and NW-SE striking planes in accordance with the general strike direction of the exposed faults (i.e., NW-SE and the E-W transverse normal faults). The other directions seem to reflect the auxiliary planes. For Aswan region, the majority of the solutions reflect a movement along NNW-SSE to ENE-WSW, WNW-ESE to NW-SE, NNW-SSE to ENE-WSW and NW-SE to NE-SW trending planes. The ENE-WSW and NNW-SSE trending planes show good agreement with the structural system in this region. For Abu-Dabbab region, the nodal planes for the majority of the solutions reflect a movement along either NNW-SSE to WNW-ESE or NW-SE to ENE-WSW trend. For Dahshour source region, the nodal planes reflect a movement along either WNW-ESE to ENE-WSW or NNE-SSW to WNW-ESE trending planes. The directions of these fault planes agree well

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with the faults observed in this region. For the source region to the South of Cairo-Suez district, the nodal planes reflect a movement along either the NNW-SSE or ENE-WSW trend. For Sinai region, the nodal planes for the solutions reflect a movement along either NNW-SSE or WNW-ESE to ENE-WSW trends. The first trend agrees with the dominant NW-SE striking faults existing very close to the Gulf of Suez. The second trend agrees well with the strike of the major fault existing in central Sinai.

The stress map which is constructed from the focal mechanism results shows that Egypt is affected by both extensional and transtensional stress regimes with the tension axes trending NE-SW along the Gulf of Aqaba and Gulf of Suez-Red Sea source regions (Fig. 4). The tension axes in the in-plate region appeared rotate slightly toward the north. These results agree well with the previous studies (Abou Elenean and Hussein, 2008; Mohamed et al., 2015).

The orientation of the T axes in the on-land differs from the directions of stress field in the Gulf of Suez-Red Sea divergent plate boundary, while the P axes appeared to be oriented parallel to the direction of the compressional stress along the Hellenic Arc convergent plate boundary. The interaction between these two stress regimes modifies the stress field in the onland of Egypt. Analysis in this study, shows that the stress pattern in Egypt can be preliminary divided into two main types: first and second order stresses. The first order stress pattern appears to be related to the divergent plate boundary force between the African and Arabian plates which significantly controls this type of stress pattern. The Gulf of Suez source region represents a first order stress source. The second order stress field appears in the inland of Egypt, causing a slight rotation of the tensional stress axes. This type of stress is mainly related to localized deformation associated with rotation of the plates.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.nrjag.2016.08.002.

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