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.
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 $S_H/P$, $S_V/P$ and $S_H/S_V$. Therefore, FOC-MEC 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 $S_H$ and $S_V$ 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. FOC-MEC software uses the preliminary solutions obtained from Suetsugu, 1998 software as the initial trial. All these additional
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 1](image_url) Distribution of the earthquake epicenters during the period from 2004 to 2011 and the different seismic source regions in Egypt are represented by numbers.
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).
The 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...
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
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-ENE 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 event on 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 consistent 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 multidirections 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-existing 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.
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 $S_H/P$, $S_V/P$ and $S_V/S_H$. 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-Dabhab 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.
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.

References

Abdel-Fattah, R., 1999. Seismotectonic studies on the Gulf of Suez Region, Egypt. M. Sc. Thesis. Fac. of Sci., Geology Dept., Mansoura Univ..
Abdel-Fattah, A.K., Hussein, H., El-Hady, S., 2006. Another look at the 1993 and 1995 Gulf of Aqaba earthquakes from the analysis of teleseismic waveforms. Acta Geophys. 54 (3), 260–279.
Abou Elenean, K.M., 1997. A study on the seismotectonic of Egypt in relation to the mediterranean and red seas tectonics Ph.D. Thesis. Fac. Sci., Ain Shams Univ., Cairo, Egypt, p. 200.
Abou Elenean, K.M., Hussein, H.M., 2008. The October 11, 1999 and November 08, 2006 Beni Suef Earthquakes, Egypt. Pure Appl. Geophys. 165 (7), 1391–1410.
Abou Elenean, K., Arvidsson, R., Kulhanek, O., 2004. Focal mechanism of smaller earthquakes close to VBB Kottamia station, Egypt. Ann. Geol. Surv. Egypt XXVII, 357–368.
Akawy, A., 2008. Exhumed and neo-formed fault scarps and drainage modification as proxies of present day tectonics at the Abu Dabab area, Eastern Desert, Egypt. Assiut Univ. J. Geol. 37 (2), 25–65.
Badawy, A., 2005. Present-day seismicity, stress field and crustal deformation of Egypt. J. Seismol. 9, 267–276.
Badawy, A., Horvath, F., 1999. Recent stress field of the Sinai subplate region. Tectonophysics 304, 385–403.
Bosworth, W., El-Hawat, A.S., Helgeson, D.E., Burke, K., 2008. Cyrenaican “shock absorber” and associated inversion strain shadow in the collision zone of northeast Africa. Geology 36, 695–698.
EGYPTIAN National Seismic Network (ENSN) Bulletin, (1998–2005).
Earthquakes in and Around Egypt, National Research Institute of Astronomy and Geophysics, Egypt.
El Hadidy, S., 1995. Crustal Structure and its Related Causative Tectonics in Northern Egypt Using Geophysical Data (Ph.D. thesis). Ain Shams Univ.
Gergawi, A., El-Khashab, H.M.A., 1968. Seismicity of Egypt, Helwan Observatory Bull., 76.
Hofstetter, A., Thio, H.K., Shamir, G., 2003. Source mechanism of the 22/11/95 Gulf of Aqaba Earthquake and its aftershock sequence. J. Seismol. 7, 99–114.
Hussein, H.M., 1989. Earthquake activities in Egypt and adjacent regions and its relation to geotectonic features in A.R.E. MSc. Thesis. Fac. of Sci., Geology Dept., Mansoura University, Egypt.
Hussein, H.M., Korrat, I.M., El Sayed, A., 2001. Seismology in the vicinity of Alexandria and its implications to seismic hazard. In: Second International Symposium on Geophysics, 19–20 February 2001. Faculty of Science, Tanta University, Tanta, pp. 57–64.
Hussein, H.M., Hurukawa, N., Al-Arif, N.S., 2008. Relocation of microearthquakes in Abu Dabab region, Egypt using Modified Joint Hypocenter Determination Method. Individual study, International Institute of Seismology and Earthquake Engineering, Tsukuba, Japan.
Hussein, H.M., Moustafa, S.S.R., Elawadi, E., Al-Arif, N.S., Hurukawa, N., 2011. Seismological aspects of the Abu Dabbab Region, Eastern Desert, Egypt. Seismol. Res. Lett. 82 (1).
Hussein, H.M., Abou Elenean, K.M., Marzouk, I.A., Korrat, I.M., Abu El-Nader, I.F., Ghazala, H., ElGabry, M.N., 2013. Present-day tectonic stress regime in Egypt and surrounding area based on inversion of earthquake focal mechanisms. J. Afr. Earth Sci. 81, 1–15.
IDC: International Data Center CTRTO, Vienna, Austria.
ISC (2004–2011). Bulletins of the International Seismological Centre, Edinburgh. <http://www.isc.ac.uk>.
Ismail, A., 1960. Near and local earthquakes at Helwan from 1903–1950, Helwan Observatory Bull. No. 49.
Kebeasy, R.M., 1990. Seismicity. In: Said, R. (Ed.), Geology of Egypt. A.A. Balkema, Rotterdam, pp. 51–59.
Maamoun, M., 1976. La seismicite du Moyen et du proche-orient dans le cadre de la seismotectonique mondiale These-Doct. Es Science. Univ. Louis Pasteur de Strasbourg, France.
Maamoun, M., Megahed, A., Allam, A., 1984. Seismicity of Egypt. HAG Bull. IV (B), 109–160.
Makris, J., Stofen, B., Vees, R., Allam, A., Maamoun, M., Shehata, W., 1979. Deep Seismic Sounding in Egypt. Part I: The Mediterranean Sea between Crete-Sidi Barani and the Coastal Area of Egypt. Unpublished report, NRIAG, Egypt.
Marzouk, I., 1988. Study of Crustal Structure of Egypt Deduced from Deep Seismic and Gravity Data (Ph.D. thesis). Hamburg Univ., Germany.
Megahed, A., 2004. Seismic deformation studies on the northeastern part of Egypt Ph. D. Thesis. Fac. of Sci., Geology Dept. Mansoura Univ., Egypt.
Megahed, A., Dessokey, M., 1988. The Ismailiya (Egypt) earthquake of January 2nd, 1987, location, macroseismic survey, radiation pattern of the first motion and its tectonic implications. Bull. ISEEE 23, 143–153.
Mohamed, Emad K., Hassoup, A., Elenean, K.M. Abou, Othman, Adel A.A., Hamed, Diaa-Eldin M.K., 2015. Earthquakes focal mechanism and stress field pattern in the northeastern part of Egypt. NRIAG J. Astron. Geophys. 4 (2), 205–221.
Moustafa, A., Abd-Allah, A., 1992. Transfer zones with en echelon faulting at the northern end of the Suez rift. Tectonics 11, 499–509.
Persan, A., Rotwain, I.M., 2004. Analysis and definition of magnitude selection criteria for NEIC (PDE) data, oriented to the compilation of a homogeneous updated catalogue for CN monitoring in Italy (personal communications).
Primakov, I., Rotwain, I., 2003. Seventh Workshop on Non-Linear Dynamics and Earthquakes Prediction (EDCAT, CATAL and AFT).
Salamon, A., Hofstetter, A., Garfunkel, Z., Ron, H., 2003. Seismotectonics of the Sinai subplate—the eastern Mediterranean region. Geophys. J. Int. 155, 149–173.
Sieberg, A., 1932. Untersuchungen ueber Erdbeben und Bruchschollenbau im Oestlichen Mittelmeergebiet, Denkschriften der med. naturw. Ges. Zu Jena, 18-band, 2.Lief.
Simpson, D., 1984. Crustal model around Aswan Lake, Aswan seismological center, unpublished.
Snoke, J.A., Munsay, J.W., Teague, A.G., Bollinger, G.A., 1984. A program for focal mechanism determination by combined use of polarity and SV-P amplitude ratio data. Earth Notes 55 (3), 15.
Suetsugu, D., 1998. Practice on source mechanism. IISEE Lecture Notes, 104 pp.