Chapter 1

An Updated Seismic Source Model for Egypt

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Additional information is available at the end of the chapter

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1. Introduction

Since the pioneering work of Cornell [1], it is clear that seismic hazard assessment depends on several models, among them perhaps one of the most significant, and usually poorly understood, is the delineation and characterization of the seismic source model for a particular region. Identification and characterization of the potential seismic sources in any region is one of the most important and critical inputs for doing seismic hazard analysis.

In fact, the characterization of seismic source zones depends on the interpretation of the available geological, geophysical and seismological data obtained by many tools such as tectonic studies, seismicity, surface geological investigations and subsurface geophysical techniques [2]. In addition, the characterization depends on the definition of different surface and sub-surface active faults.

Modern investigations on Probabilistic Seismic Hazard Assessment (PSHA) for any region at any scale, requires that the study region should be subdivided into different seismic sources. The issue of seismic source delineation and characterization is often a controversial one in the practice of seismic hazard analyses, both deterministic and probabilistic, as the information available relating to geology and seismotectonics can vary from region to another region.

It has been common practice since the development of PSHA by Cornell [1] and McGuire [3], to utilize areal source zones of seismic homogeneity [4 and 5]. In the classic form, earthquake sources range from clearly understood and well defined faults to less well understood and less well-defined geologic structures to hypothetical seismotectonic provinces extending over many thousands of square kilometers whose specific relationship to the earthquake generating process is not well known [2].

Recent PSHA at a local or a regional scale is usually based on approaches and computer codes (e.g., FRISK: [6]; SEISRISK III: [7]; CRISIS 2014: [8], etc.) that require the study area to be subdivided into seismic source zones which can be generated by delineating a number of polygons over active seismic areas. These polygons, sometimes have a complex shape, which reflects the complexity of the different faults and tectonic trends (e.g., [9]). The delineation will serve for two purposes: i) adequately represents the geological and tectonic setting together with the recorded seismicity, and ii) it allows for expected variations in future seismicity.

2. Seismicity and seismotectonic setting of Egypt

Egypt is situated in the northeastern corner of the African Plate, along the southeastern edge of the Eastern Mediterranean region. It is interacting with the Arabian and Eurasian Plates through divergent and convergent plate boundaries, respectively. Egypt is surrounded by three active tectonic plate boundaries: the African-Eurasian plate boundary, the Gulf of Suez-Red Sea plate boundary, and the Gulf of Aqaba-Dead Sea Transform Fault (Figure 1). The seismic activity of Egypt is due to the interaction and the relative motion between the plates of Eurasia, Africa and Arabia. Within the last decade, some areas in Egypt have been struck by significant earthquakes causing considerable damage. Such events were interpreted as the result of this interaction.

Based on the geophysical studies in the territory of Egypt, Youssef [10] classified the main structural elements of Egypt (Figure 2) into the following fault categories: a) Gulf of Suez-Red Sea, b) Gulf of Aqaba, c) east-west, d) north-south, and e) N45°W trends. However, Meshref [11], from the magnetic tectonic trend analysis, showed the tectonic trends which influenced Egypt throughout its geologic history as: a) NW (Rea Sea-Gulf of Suez), b) NNE (Aqaba), c) east–west (Tethyan or Mediterreanean Sea), d) north–south (Nubian or East African), e) WNW (Drag), f) ENE (Syrian Arc), and g) NE (Aualitic or Tibesti) trends.

The seismicity of Egypt has been studied by many authors [e.g., 12-22]. Although Egypt is an area of relatively low to moderate seismicity, it has experienced some damaging local shocks throughout its history, as well as the effects of larger earthquakes in the Hellenic Arc and the Eastern Mediterranean area. In addition, it has also been affected by earthquakes in Southern Palestine and the Northern Red Sea [18].

In Egypt, mostly population settlements are concentrated along the Nile Valley and Nile Delta, so, the seismic risk is generally related to the occurrence of moderate size earthquakes at short distances (e.g., M_S 5.9, 1992 Cairo earthquake), rather than bigger earthquakes that are known to occur at far distances along the Northern Red Sea, Gulf of Suez, and Gulf of Aqaba (e.g., M_S 6.9, 1969 Shedwan, and M_W 7.2, 1995 Gulf of Aqaba earthquakes), as well as the Mediterranean offshore (e.g., M_S 6.8, 1955 Alexandria earthquake) [23].

Egypt is suffering from both interplate and intraplate earthquakes; intraplate earthquakes are less frequent but still represent an important component of risk in Egypt. Shallow-depth seismicity (Figure 3) is concentrated mainly in the surrounding plate boundaries and on some active seismic zones like Aswan, Abu Dabbab, and Cairo-Suez regions, while the deeper activity is concentrated mainly along the Cyprian and Hellenic Arcs due to the subduction process between Africa and Europe.

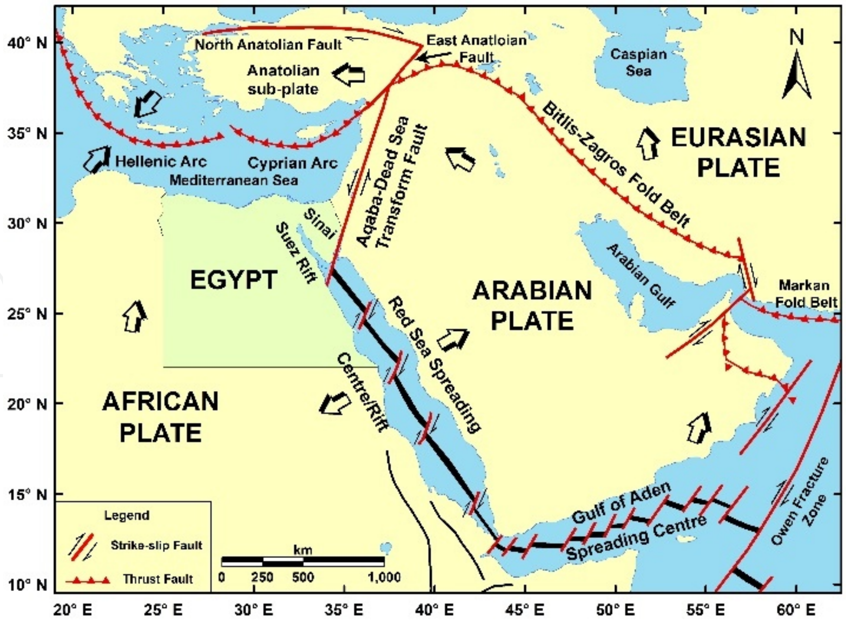

Figure 1. Global tectonic sketch for Egypt and its vicinity (redrawn after Ziegler [24] and Pollastro [25]).

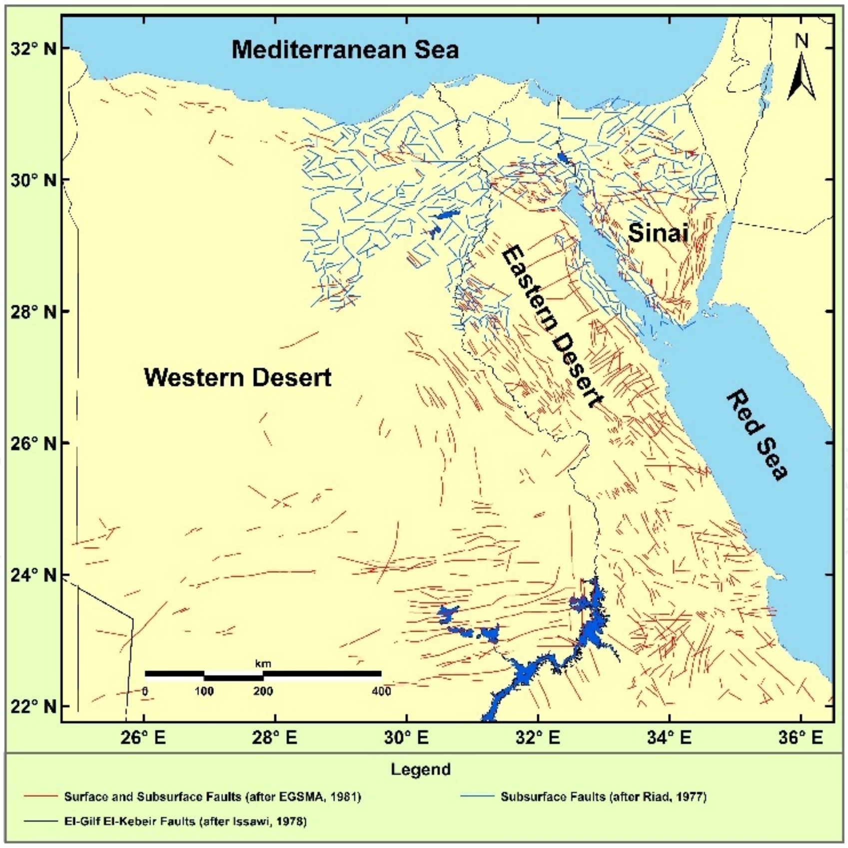

Figure 2. Distribution of major surface and subsurface faults. Compiled and redrawn from EGSMA [26] geologic map, from Riad [27], and from Issawi [28].

3. Review of seismic zoning studies in Egypt

Seismic hazard assessments for Egypt, based on the zoning approach, has been carried out by many authors in the last decades, based upon the main tectonic features prevailed, the dominant tectonic stresses, the history of seismicity in the region, and the distribution of the recorded earthquakes. These authors were used different criteria to obtain seismic source zonation maps.

Among those studies, those carried out by the following authors: Sieberg [12 and 13], Gergawi and El-Khashab [15], Maamoun and Ibrahim [29], Maamoun *et al.* [16], Albert [30 and 31], Kebeasy *et al.* [32], Kebeasy [17 and 33], Marzouk [34], Fat-Helbary [35-37], Reborto *et al.* [38], Mohammed [39], El-Hadidy [40], Fat-Helbary and Ohta [41], El-Sayed and Wahlstörm [42], Abou Elenean [19 and 43], Badawy [44], Deif [45], Riad *et al.* [46], Abou Elenean and Deif [47], El-Sayed *et al.* [48], Fat-Helbary and Tealeb [49], El-Amin [50 and 51], El-Hefnawy *et al.* [52], Abdel-Rahman *et al.* [53], El-Hadidy [54 and 55], Deif *et al.* [56 and 57], Fat-Helbary *et al.* [58] and Mohamed *et al.* [59].

Egypt was divided into different seismic zones by many researchers, using the distribution of historical and instrumental earthquakes. Maamoun and Ibrahim [29] and Kebeasy [33] divided Egypt into four main seismic trends: i) Northern Red Sea-Gulf of Suez-Cairo-Alexandria, ii) Eastern Mediterranean-Cairo-Fayoum, iii) Mediterranean Coastal Dislocation, and iv) Aqaba-Dead Sea Transform. More recently, Maamoun *et al.* [16] added another two trends to the previous four: i) Hellenic and Cyprian Arcs, and ii) Southern Egyptian trend.

In reviewing the seismicity of Egypt, Kebeasy [17] suggested three main seismic zones: i) Aqaba-Dead Sea Transform, ii) Northern Red Sea-Gulf of Suez-Cairo-Alexandria, iii) Eastern Mediterranean-Cairo-Fayoum zones. In addition, he defined other local seismic zones (e.g., El-Gilf El-Kebeir, Aswan and Qena zones).

Fat-Helbary [36] assessed the seismic hazard for Aswan region. He used both of line sources and area source models. Five active faults in the Aswan region (Kalabsha, Seiyal, Gebel El-Barqa, Kurkur, and Khur El-Ramla Faults) were modeled as seismic lines. On the other hand, six area source zones (Old Stream, North Kalabsha, Khur El-Ramla, East Gebel Marawa, Abu Dirwa, and Kalabsha zones) were considered in the assessment. This study was followed by successive assessments by different authors to include other neighbor regions in Upper Egypt (e.g., [37, 41, 49, 50, 51, 57 and 58]).

Using the relation between the paleo-stresses, the present-day stresses and the distribution of earthquake epicenters, El-Hadidy [40] deduced five major trends in Egypt. They are: i) Pelusium megashear, ii) Eastern Mediterranean-Cairo-Fayoum-El-Gilf El-Kebeir, iii) Nubian-Mozambique, iv) Qena-Aqaba-Dead Sea, and v) Northern Red Sea-Gulf of Suez-Cairo-Alexandria seismotectonic trends. Furthermore, he identified some local zones on the Red Sea, Gulf of Suez, Gulf of Aqaba, Nile Delta, and Cairo-Suez regions.

According to the earthquake distribution, focal mechanisms and the structural and tectonic information, Abou Elenean [19] suggested five seismotectonic sources. They are: i) Gulf of

Suez-Northern Eastern Desert, ii) Southwest Cairo (Dahshour), iii) Northern Red Sea, iv) Gulf of Aqaba, and v) Aswan zones. Deif [45], for a seismic hazard assessment study, delineated four additional seismic sources for the southern part of Egypt. They are: i) Abu Dabbab, ii) El-Gilf El-Kebeir, iii) Wadi Halfa, and iv) Northern Nasser's Lake zones.

Riad *et al.* [46] constructed a more detailed seismic zoning map for Egypt and its surroundings. Their regional delineation consists of five main trends: i) the Greek trend, based on the seismic zone regionalization of Papazachos [61], ii) the Dead Sea trend, which mainly based on the earthquake catalogue of Israel and its vicinity [62], iii) Pelusium and Qattara trend, iv) Eastern Mediterranean trend, and v) Aswan area, in Southern Egypt.

El-Hefnawy *et al.* [52], based on the tectonic regime, seismicity, faults location, and focal mechanism solutions, divided the regional seismicity in and around Sinai Peninsula into 25 source zones. His study was succeeded by a certain number of studies that considered a more detailed zonation for the same area (e.g., [53, 54 and 56]).

Recently, Abou Elenean [43] established a detailed zonation map for whole Egypt and its surroundings, considering the recent seismicity distribution and focal mechanism data. He delineated 41 seismic source zones of shallow-depth earthquakes (h < 60 km) in and around Egypt. In addition, he considered 7 seismic sources for intermediate-depth events within the Hellenic Arc (after [63]). More recently, El-Hadidy [55] and Mohamed *et al.* [59] established a new and modified seismic zoning map for Egypt and its surroundings which is based on the compilation of previous studies [53, 57 and 64].

4. Data sources

For the construction of any database of seismic sources, there are two basic steps: first, all of the active faults that affect a specific region need to be recognized, and secondly, each seismogenic structure should be seismotectonically parameterized. In order to recognize the active faults, it is necessary to analyze the seismicity. It is common practice to start analyzing the historical and instrumental seismicity that affects the specific region. Like many other places all over the world, the seismicity in Egypt is not homogeneously distributed, neither in frequency nor in density. Historical information is similarly not uniform all over the region.

4.1. An updated earthquake catalogue

A complete and consistent earthquake catalogue in a region is essential in order to study the distribution of earthquakes in space, time, and magnitude. In the current work, the identification and characterization of regional seismic source zones is based on a unified compiled earthquake catalogue, after Sawires *et al.* [60], for Egypt and its surroundings which covers the area from 21° to 38° N and 22° to 38° E, and extends from 2200 B.C. until 2013 in the time period.

Different earthquake magnitude scaling relations, correlating different scale magnitudes, were used to develop a unified earthquake catalogue for the study region in the moment magnitude

(M_W) scale. The dependent events were removed from the catalogue to ensure a time-independent (Poissonian) distribution of earthquakes (Figure 3).

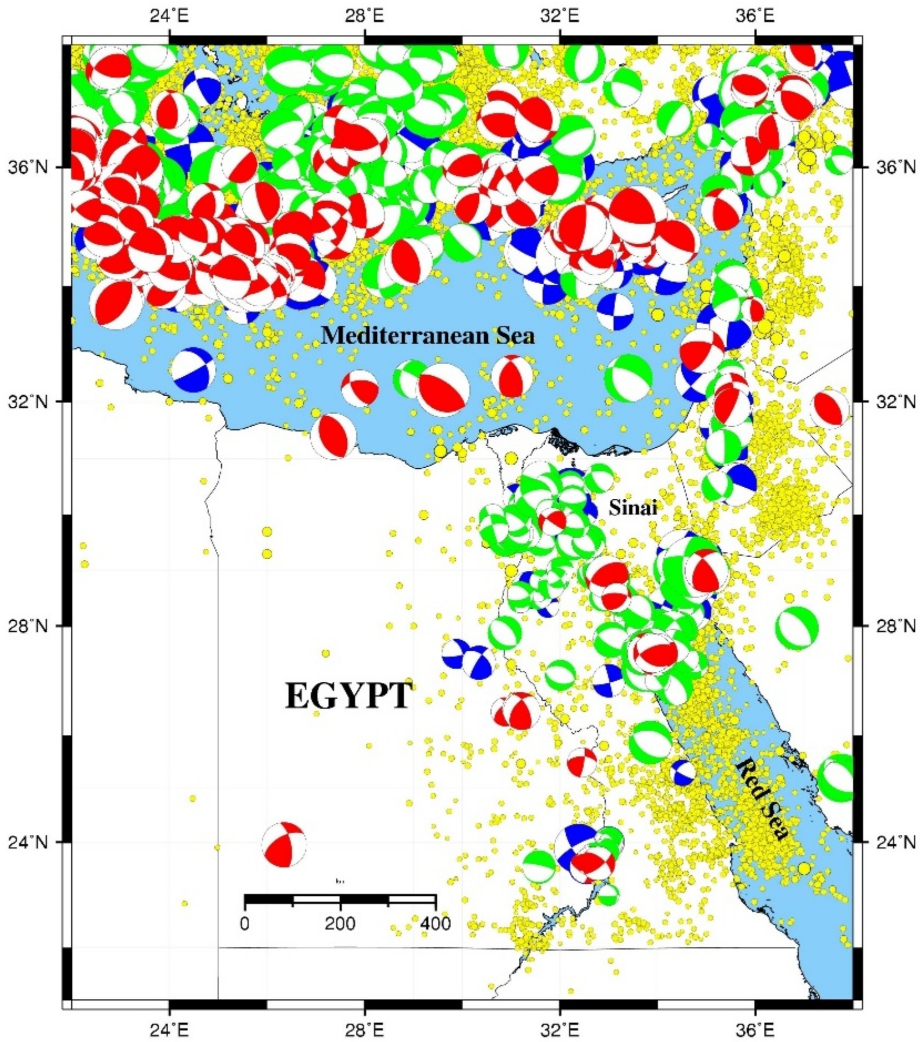

Figure 3. Distribution of the seismicity (2200 B.C. - 2013) and focal mechanism solutions (1940 – 2013) in and around Egypt (after Sawires *et al.* [60]). Symbols and focal sphere sizes are in proportion the moment magnitude. Focal sphere colours refer to different fault types (blue: strike-slip; green: normal; red: reverse).

4.2. Focal mechanism data

Different local and international sources were examined and focal mechanism data were compiled into a single database. The solutions of the Global Catalogue of CMT Harvard [65], the International Seismological Centre (ISC) [66], the National Earthquake Information Centre (NEIC) [67], the Regional CMT catalogues (RCMT) in the Mediterranean region [68], as well as ZUR-RMT catalogue of the Institute of Technology (ETH) of Zurich were also included in the catalogue. More than 600 focal mechanism solutions were collected covering different active seismic zones (Figure 3) in Egypt and surroundings, spanning the spatial area from 21°

to 38°N, and from 22° to 38°E. Most of them have a magnitude greater than or equal to M_W 3.0, occurring in the time period 1940 to 2013.

4.3. Geological, tectonic and geophysical data

Several geological, geophysical and tectonic maps were inspected for the purpose of getting more information about the present active faults (e.g., Aswan region) and also for the identification of the prevailed tectonic and structural trends in the study region. Among these studies are those of Said [69-71], Youssef [10], Shata [72], Neev [73], Neev *et al.* [74 and 75], El-Shazly [76], Riad [27], Maamoun [77], Issawi [78], EGSMA [26], Riad *et al.* [47 and 79], Maamoun *et al.* [16], Sestini [80], Schlumberger [81], Woodward-Clyde Consultants [82], Kebeasy [17], Meshref [11], Barazangi *et al.* [83], Guiraud and Bosworth [84], Abdel Aal *et al.* [85], Philobbos *et al.* [86], and Hussein and Abdallah [87].

4.4. Crustal structure data

The crustal structure plays an important role in Seismology. It can be used, as in the current study, for the discrimination between the crustal (shallow-depth) seismicity, the intermediate-depth, and the deeper one.

Several studies have been carried out to evaluate the crustal structure and thickness in Egypt by using different types of datasets coming from seismic reflection surveys, deep seismic sounding, shallow refractions, and gravity (e.g., [34, 40 and 88-108]). In the delimitation of the different seismic zones, the most recent study [108] was taken into our consideration (Figure 4). Their results show that the Moho discontinuity is getting shallow toward the northern and eastern coast of Egypt, and deeper toward Western Desert and Northeastern Sinai. This discontinuity is located at depth of 31-33 km in Greater Cairo and Dahshour, 32-35 km in Sinai, 33–35 km along the Nile River, 30 km near the Red Sea coast, and 39 km towards the Western Desert.

5. Detailed description of the new proposed shallow-depth seismic source model

Seismic sources define areas that share common seismological, tectonic, and geologic attributes, and that can be described by a unique magnitude-frequency relation. In terms of PSHA, a seismic source represents a region of the earth's crust in which future seismicity is assumed to follow specified probability distributions for occurrences in time, earthquake sizes, and locations in space [109].

Araya and Der Kiureghian [109] discriminate between seismogenic and seismicity sources. Seismogenic zones lack the development of a clear history relating the contemporary seismic activity to a geologic structure. For such zones, critical gaps in the Quaternary geologic history preclude direct evidence of active faulting. Seismogenic zones are, by far, the most common type of source zone employed in PSHA. Commonly, seismogenic zones are area sources, but the zone type applies also to inferred associations of seismicity with individual faults. On the other hand, seismicity zones are source zones that are defined with no consideration of their relation to geologic structures. They are defined solely based on the spatial distributions of the seismic history, and their use and reasonableness can only be judged relative to the intended use of the final hazard estimate. This will be the terminology used in this work.

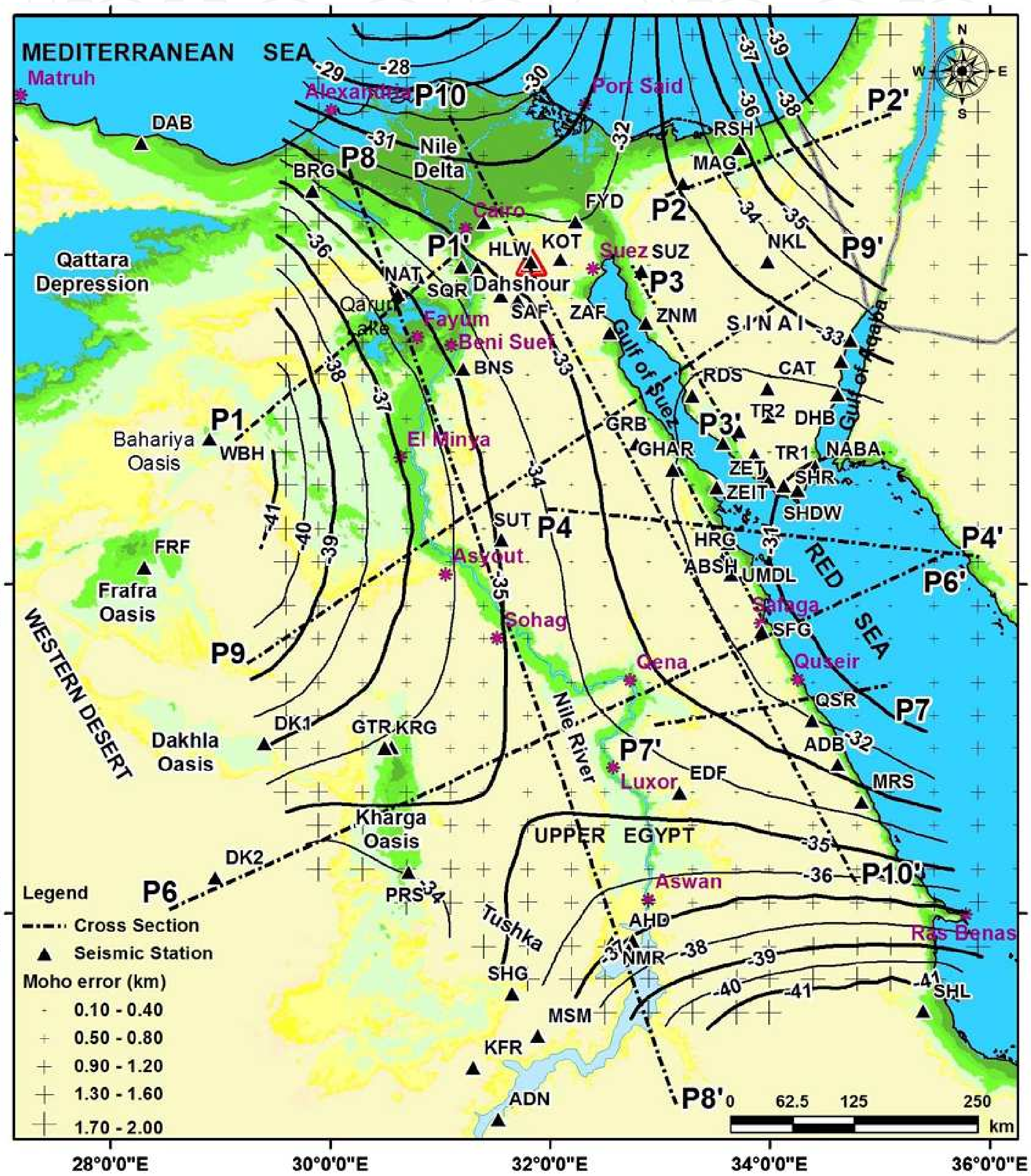

Figure 4. Depth of Moho discontinuity in Egypt (after Abdelwahed *et al.* [108]).

As mentioned previously, the separation of the study area into smaller, seismotectonically homogeneous zones is based on criteria mainly related with the present-day tectonic regime, epicenter distribution, focal mechanism data and the location of known faults. In the present work, we decided to employ simple geometric shapes for the definition of the seismic source model. The regional seismicity of concern to Egypt was divided into 28 seismic sources (Figure 5). These zones was related to the tectonic activity of the previously defined local active belts. Thus, the majority of the proposed sources zones can be considered seismogenic zones, except some sources which can be considered seismicity sources. The delineation of the seismicity sources was based upon the earthquake distribution, this is because there is no enough geologic and tectonic data covering these sources. Both seismogenic and seismicity sources are described below in more details. For each of these source zones, the seismicity parameters (b-value and activity rates) were computed by applying the Gutenberg-Richter [110] relationship and using the least square method considering the entire earthquake events within each zone. Moreover, maximum observed magnitude M_{max} was defined using the earthquake sub-catalogue for each source. Those estimated values will serve as initial inputs for a seismic hazard assessment for Egypt in the near future.

The details of the selection of these seismic sources, together with the estimation of its seismicity parameters and maximum observed magnitude, are given below for each source category, which grouped depending on the similarities of the prevailed tectonic environment.

5.1. Seismic sources along the Gulf of Aqaba–Dead Sea Transform Fault

The Aqaba-Dead Sea Transform Fault (DST) is a 1100 km long left-lateral strike-slip fault (Figure 6) that accommodates the relative motion between Africa and Arabia [111, 112]. It is a seismically active transform boundary, connecting the Red Sea spreading center in the south to the Northern Mediterranean Triple Junction to the north. Its main left-lateral sense of motion is recognized by minor pull-aparts in young sediments [113], cut and offset of drainage lines and man-made structures (e.g., [114-121]).

The Gulf of Aqaba-Dead Sea Transform Fault (Figure 6) is subdivided into three parts; southern, central and northern [122]. The first part, which starts from the Gulf of Aqaba and passing through the Dead Sea and the Jordan Valley, is characterized by the occurrence of N12°E to N20°E left-lateral strike-slip faults. The second part of the DST is characterized by the occurrence of about 200 km long NNE–SSW restraining bend, where the DST branches into different faults. The major one, called the Yammouneh Fault, which connects the first and third parts of the DST, while the other faults connect the DST with the Palmyride Fold Belt (PFB) [122-124]. The last and the northern part of the DST is characterized by the occurrence of two different N–S striking faults surrounding the Ghab Valley and intersecting through a complex braided fault system with the East Anatolian Fault and the Cyprian Arc [125-127]. This intersection corresponds to the Hatay "fault–fault–trench" triple junction that forms the plate boundaries between Arabia, Africa and Anatolia [128].

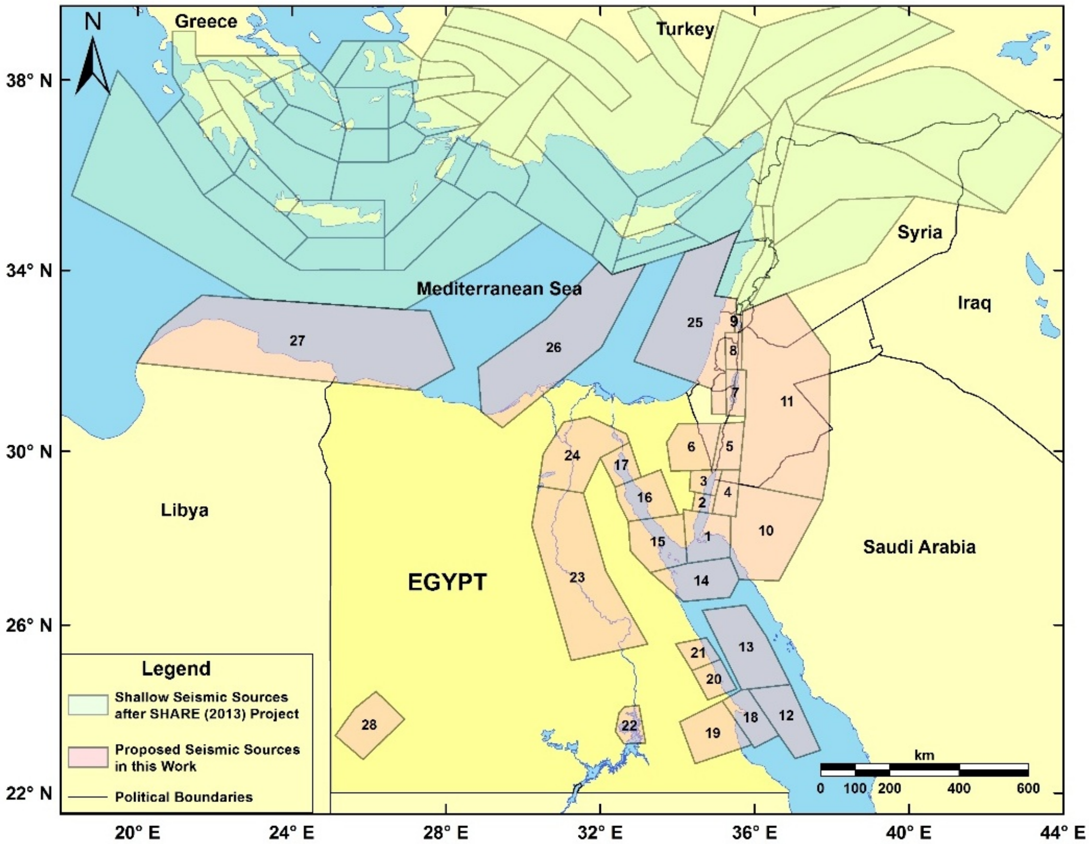

Figure 5. Proposed seismic source zones in Egypt and its surroundings.

5.1.1. Gulf of Aqaba seismogenic sources (EG-01 till EG-04)

The Gulf of Aqaba experienced the largest Egyptian earthquake (M_W 7.2, November 1995) which struck the area and its effects were extending till Cairo. Over than 1000 aftershocks are recorded. The aftershocks area reached a length of about 110 km, striking N 30° E, which in turn parallel to the Gulf of Aqaba trend [129]. Potential damage was observed at Nuweiba city at the western part of the gulf.

The Gulf of Aqaba has been considered to be the most active seismic area over the last few decades, characterized by swarm activity [130-132]. There is no information about the seismicity of the Gulf of Aqaba until the year 1983. However, from January till April 1983, over than 500 events were reported, reaching a maximum recorded magnitude of 4.8. These earthquake events were felt at different places along the gulf area, as well as along the Arava Valley founding a general consideration [133]. From August 1993 up to February 1994, a large earthquake swarm was associated with relatively high magnitudes, reaching a 5.8 value. This swarm included about 1200 events occurred south to the 1983 swarm. Another earthquake swarm has been recorded and located at the central part of the Gulf of Aqaba on November 2002. Over than 10 events with magnitude above 4.0 were recognized, and many other events with magnitudes below this value. Some of these earthquakes were felt, but without damage for buildings at the epicentral area.

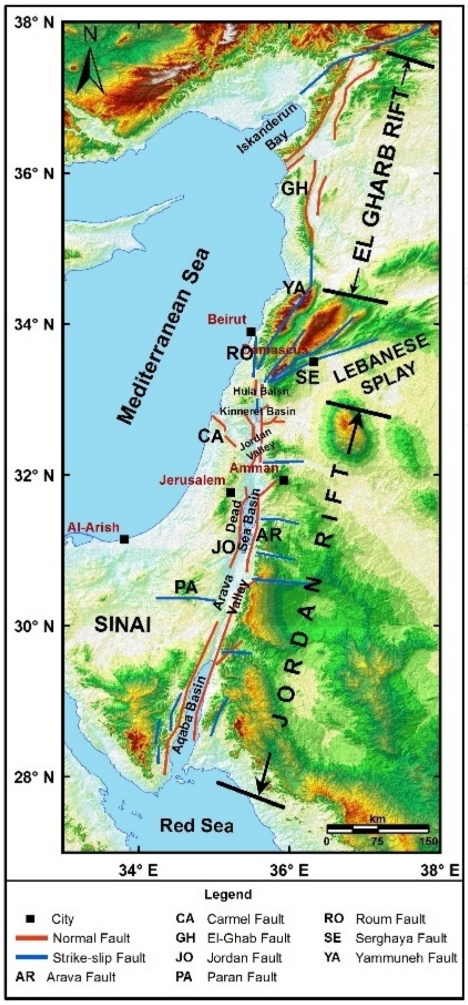

Figure 6. The main structural elements along the DST (redrawn after Heidbach and Ben-Avraham [134]).

The interior of the Gulf of Aqaba is occupied by three elongated en-echelon basins transected by longitudinal faults [131]. This en-echelon system produces several tectonic basins, which are forming rhombic-shaped grabens. Thus, three basins in the Gulf of Aqaba are present. They are, from south to north, Tiran “Arnona”-Dakar, Aragonese and Elat “Aqaba” Basins.

The heterogeneity of the focal mechanism solutions for the earthquake events taken place in the gulf area, indicates its geologic structure complexity. Some fault plane solutions exhibit normal faulting, which are related to the faults that form the boundaries of the major basins in the gulf. Others indicate left-lateral motion of the transform [112]. The focal mechanism of the M_W 7.2, 1995 Aqaba earthquake as well as some aftershocks, show a strike-slip movement with predominant normal components, with the exception of only one solution located on the eastern coast of the Gulf of Aqaba, and exhibits strike-slip movement with a little reverse component in the NNW-SSE and ENE-WNW nodal planes [19].

According to the seismic activity, the epicentral distribution and the local tectonics, different seismogenic sources were delineated in the gulf area (Figure 7).

a. The EG-01 (Tiran – Dakar Basin) seismogenic source lies at the southern part of the Gulf of Aqaba. It includes the M_S 4.4, February 2, 2006 earthquake. There is no historical earthquakes included in this source zone. The majority of the available focal mechanism solutions inside this area source reflects normal faulting mechanism.

b. The EG-02 (Aragonese Basin) seismogenic source lies to the north of the previous EG-01 zone, and is considered the focal area of the M_W 7.2, November 22, 1995 earthquake, which is considered the largest event to occur along the DST in the last century.

c. The EG-03 (Elat Basin) seismogenic source located to the north of the EG-02 seismic zone and considered as the extension area of the M_W 7.2, 1995 Aqaba earthquake rupture. It is characterized by a low seismicity level, if compared with the other two zones of the Gulf of Aqaba. Two historical events have been included in this area source, the I_{max} VIII, March 18, 1068, and the I_{max} VIII-IX, May 2, 1212 earthquakes.

d. In addition to the previous seismogenic sources, a delineation of a separate and fourth zone is taken place. This source lies to the east of the gulf and characterized by dispersed moderate seismicity. This zone is the EG-04 (Eastern Gulf of Aqaba) seismogenic source. The major earthquake included in this area source is the m_b 4.5 December 26, 1995 earthquake.

Previous focal mechanism solution studies for moderate to large earthquakes located in the Gulf of Aqaba region (e.g., [135-138]) assert the dominance of ENE-WSW extension (N60°-80°E). Furthermore, field studies [139, 140] observed two conjugate faults along the Gulf of Aqaba: NNE left-lateral strike-slip faults parallel to the gulf that release the majority of stress, and a nearly ESE-WNW normal faults along the margins of pull-apart basins. On the other hand, body waveform inversion of the M_W 6.1, August 3, 1993, and the M_W 7.2 November 22, 1995 events, support the occurrence of normal faulting take place along the transverse NNW-SSE and ESE-WNW faults, while left-lateral strike-slip movement occurs along NNE major Aqaba trend [135].

5.1.2. Arava Valley (EG-05) seismogenic source

The Arava Valley is located to the north of the Gulf of Aqaba. It is an inter-basin zone trending NE-SW. Its faults extend over 160 km from the Gulf of Aqaba to the Dead Sea and provide morphological evidence of essentially strike-slip motion [120]. It is characterized by a low seismicity level compared with the surrounding area, despite clear indications of recent faulting [141]. Klinger *et al.* [120] emphasized the limited earthquake activity in the Arava Valley in the instrumental period. Shapira and Jarradat [133] stated that, from preliminary paleoseismicity studies, the border-faults of Arava Valley generate earthquakes bigger than magnitude 6.0 with an average return period of 1000-3000 years.

There is no historical earthquakes included in this seismogenic source zone. The biggest recorded event is the m_b 5.2, December 18, 1956 earthquake. Two focal mechanism solutions are known in the northern part of this source, both of them exhibiting strike-slip faulting with normal component.

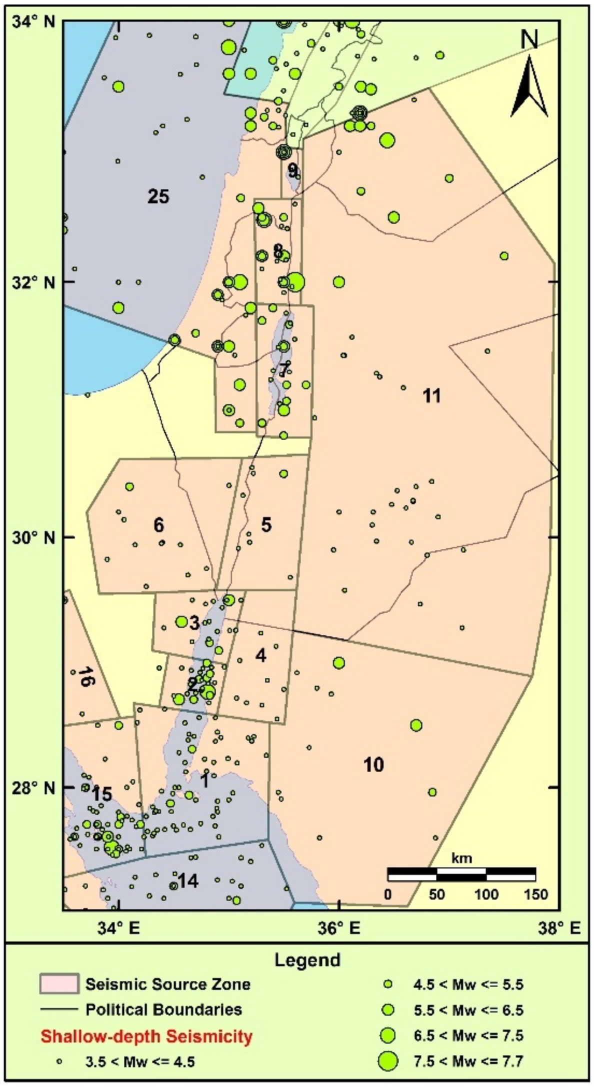

Figure 7. Shallow-depth seismicity (h ≤ 35 km) and delineated seismic sources along the Gulf of Aqaba-Dead Sea Transform Fault.

5.1.3. Eastern Central Sinai (EG-06) seismogenic source

An E-W trending dextral strike-slip faults with up to 2.5 km of displacement has been recognized in central Sinai by Steintz *et al.* [142]. It is called the Themed Fault. The Tih Plateau (in central Sinai) is traversed by the Themed Fault, which extends for about 200 km from the vicinity of eastern margin of the Suez Rift to the DST [71]. The Themed Fault has been reactivated along a pre-existing fault, identifying the southern border of the Early Mesozoic passive continental margin of the Eastern Mediterranean Basin in central Sinai [143].

To the north of the previous fault, the central Sinai-Negav shear zone is located, which is proposed by Shata [72] and Bartov [144]. It is a narrow E to ENE trending fault belt discriminating and separating the North Sinai Fold Belt (tectonically unstable area) from the Tih Plateau (tectonically stable area) in middle and Southern Sinai [145].

The EG-06 seismogenic source lies to the west of the previous EG-05 source and to the east of the Sinai sub-Plate. This seismogenic source includes the low seismic activity related to the Themed Fault, central Sinai-Negav shear zone, Paran Fault and Baraq/Paran Fault junction. This source has a great tectonic effect on Sinai Peninsula and its surrounding areas. There is no historical earthquakes included in this source, and the biggest earthquake located in this zone is the m_b 4.8, September 24, 1927 event.

5.1.4. Dead Sea Basin (EG-07) seismogenic source

The Dead Sea Basin is characterized by a double fault system that is bounded by the Arava Fault from the east, and by the Jordan (Jericho) Fault from the west, hence it occupies a rhomb-shaped graben between two left-lateral slip faults. The average slip rate on the Dead Sea portion of the transform fault is estimated to be 0.7 cm/yr. [114], which is consistent with the average slip of the overall plate boundary of 0.7-1.0 cm/yr.

Earthquake swarms and a mainshock-aftershock type of activity characterize this seismogenic source. Trenching studies across the Jordan Fault indicate that two large earthquake swarms occurred since about 2000 years ago. One of them is between 200 B.C.- 200 A.D., while the other one is between 700 A.D.- 900 A.D. [114]. El-Isa *et al.* [146] attributes these swarms to subsurface magmatic activity and/or to the isostatic adjustments along the Gulf of Aqaba.

Several historical earthquakes are included inside this source zone. They are the 745 B.C., 33 A.D., 1048, 1212, 1293, and 1458 earthquakes. Their intensities range between VII to VIII. Ben-Menahem *et al.* [147] obtained focal mechanism solutions for some recent events (e.g., the M_S 4.9, October 8, 1970 earthquake) which took place in the Dead Sea area. All solutions indicate a left-lateral strike-slip movement on a sub-vertical fault striking with an average trend of N8°-10°E. However, Salamon *et al.* [112] obtained normal focal mechanism solutions for some relatively recent events. These solutions may be describe the earthquake activity of the N-S striking normal faults bordering the Dead Sea Basin. Field observations confirmed this type of activity [113, 148].

5.1.5. Jordan Valley (EG-08) seismogenic source

The Jordan Valley trends in the N-S direction, linking between the Hula Basin to the north and the Dead Sea Basin to the south. The details about its end in the Sea of Galilee are not clear from the surface features [147]. Garfunkel *et al.* [113] noticed a small amount of compression along the valley and near the Jordan Fault trace. Recent earthquake activity along the Jordan Valley is low compared to the Southern Dead Sea Basin. Ten historical events (before 1900) are included in this area source. They are the 1020 B.C., 578 A.D., 580, 746, 854, 1034, 1105, 1160, 1260, and 1287 events. Their intensities range between IV to XI. The most important earthquake included in this source zone is the I_{max} XI, 746 event.

5.1.6. Kineret-Hula Basin (EG-09) seismogenic source

To the north of the previous Jordan Valley source are located the Hula (Shamir-Almagor Fault) and Kineret (Kineret-Sheikh Ali Fault) Basins [149]. Seismic activity in the two mentioned basins was located till the Yammuneh Fault (NE-bend of the Dead Sea Transform). This area source, which surrounded by the Roum Fault from the western side and the Jordan Fault from the eastern side, was considered by Shamir *et al.* [150] as a seismogenic step zone. Three historical events are included in this zone. They are the 19 A.D., 419, and 756 earthquakes. The biggest earthquake is the I_{max} X, 19 A.D. event.

5.1.7. Northwestern Saudi Arabia (EG-10) seismicity source

To the east of the EG-01 and EG-02 seismogenic sources, the Northwestern Saudi Arabia EG-10 source has been considered. This source zone covers disperse, low seismicity in the north-western part of Saudi Arabia. Two historical events are reported to occur inside this area source. They are the March 18, 1068, and January 4, 1588 earthquakes, both of them with intensity VIII.

5.1.8. Lebanon (EG-11) seismicity source

To the north of the previous seismic source and along the eastern boundaries of the EG-04, EG-05, EG-07, EG-08, and EG-09 sources, the Lebanon EG-11 seismicity source has been considered. This area source covers a dense disperse low-magnitude seismicity in Lebanon and Southern Syria. Nine historical earthquakes are located inside this area source. The most important among them are the 972, 1159, and 1182 events. Their felt intensities are I_{max} IX, IX-X, and IX, respectively.

The computed b-value, the annual rate of earthquakes, and the observed recorded maximum magnitude for the delineated seismic sources along the Gulf of Aqaba-Dead Sea Transform Fault are displayed in Table 1.

Source Zone	b-value	Yearly Number of Earthquakes		Observed M_{max}
		Above M_W 4.0	Above M_W 5.0	
EG-01	1.13	0.9799	0.0732	m_b 4.4 on 2006/02/02
EG-02	0.98	0.4952	0.0521	M_W 7.2 on 1995/11/22
EG-03	0.97	0.2763	0.0296	I_{max} VIII-IX on 1212/05/02
EG-04	1.01	0.1961	0.0191	m_b 4.5 on 1995/12/26
EG-05	0.88	0.1882	0.0251	m_b 5.2 on 1956/12/18
EG-06	1.12	0.1853	0.0140	m_b 4.8 on 1927/09/24
EG-07	0.87	0.3232	0.0438	I_{max} VIII on 1458/11/12*
EG-08	0.71	0.1865	0.0366	I_{max} XI on 0746/--/--
EG-09	0.91	0.0651	0.0080	I_{max} X on 0019/--/--
EG-10	1.03	0.1934	0.0180	I_{max} VIII on 1588/01/04*
EG-11	0.97	0.3645	0.0388	I_{max} IX-X on 1159/06/06

(*) the most recent event.

Table 1. b-value, annual rate of earthquakes, and maximum observed magnitude for the delineated seismic source zones along the Gulf of Aqaba-Dead Sea Transform Fault.

5.2. Seismic sources along the Red Sea Rift

The Arabian Plate is continuing to rotate away from the African Plate along the Red Sea Rift spreading center. The Red Sea occupies a long and slightly sinuous NW-trending escarpment-bound basin, 250-450 km wide and 1900 km long, between the uplifted shoulders of the African and Arabian shields. It is part of a rift system extending from the Gulf of Aden to the northern end of the Gulf of Suez. The overall trend of the rift is N30˚W, although a few kinks occur at around 15˚N, 18˚N, and 22˚N.

Depending on the structural setting and morphology of the Red Sea, it can be subdivided into four different zones (Figure 8). Each zone are representing distinct stage in the development of the continental margin and the generation of the mid-ocean ridge spreading system [151, 152]. These zones are:

i. *Active sea-floor spreading (Southern Red Sea):* It is located between 15°N and 20°N and characterized by a well-developed axial trough which has developed through normal sea-floor spreading during the last 5 Ma [153-155] or even older, at about 9–12 Ma [156].

ii. *Transition zone (central Red Sea):* It is located between 20°N to about 23°20′N, where the axial trough becomes discontinuous, in which the central Red Sea consists of a series of 'deeps' alternating with shallow 'inter-trough zones' [157]. An identical zone may flanks the deep axial trough between the side walls of the shallow main trough on both sides of other zones [151, 152].

iii. *Late stage continental rifting (Northern Red Sea):* This zone composed of a wide trough without a distinct spreading center, in spite of a number of small isolated "deeps" is occurred [152].

iv. *Active rifting:* This zone representing the expected line along which the Southern Red Sea may be propagate through the Danakil Depression Afar. This zone may be considered separately or it can be added to the first mentioned zone.

Based on the morphological and structural features of the Red Sea, the Egyptian part (northern latitude 22°N) can be divided into three distinct seismogenic source zones (EG-12, EG-13, and EG-14) (Figure 9). Each zone represents different stage of development [159]. The delineation is made, based upon the occurrence of the transverse structures, change of the fault trend along the axial rift and the variety of the seismic activity along the rift axis.

5.2.1. Southern Red Sea (EG-12) seismogenic source

The EG-12 Southern Egyptian Red Sea seismogenic source represents the northern part of the transition zone. It is characterized by NW-SE trending faults. The boundary proposed by Bonati [160], north latitude 25ºN, is found herein to coincide with the NE-trending transform faults and the associated seismicity. Only one historical event is included in this seismic source, the I_{max} VI-VII, 1121 earthquake.

Figure 8. Tectonic framework of the Red Sea region (redrawn after Ghebreab [158]).

5.2.2. Central Red Sea (EG-13) seismogenic source

The EG-13 Central Egyptian Red Sea seismogenic source is located to the northwest of the previous zone. It corresponds to the region north of latitude 24º30´N, which consists of a broad main trough without a recognizable spreading center [152]. Recent recorded seismicity could indicate the expected location of the axial rift. In this zone, the degree of seismicity is relatively low and scattered, compared to the previous zone. Like the previous zone, there is only one historical event included here. It is the I_{max} V, 1899 earthquake. The maximum observed magnitude along this source corresponds to the m_b 4.7 (M_S 5.1), July 30, 2006 earthquake.

5.2.3. Northern Red Sea (EG-14) seismogenic source

The EG-14 Northern Egyptian Red Sea seismogenic source is characterized by higher seismic activity than the previous two sources. This activity may be due to the juncture between the two gulfs. Daggett *et al.* [161] studies of the low-magnitude seismicity shows that, the high seismic activity of the northern Red Sea is different from the activity at the southern part of the Gulf of Suez. There is no earthquakes related to this area source before the year 1900. In addition, the m_b 5.0 (M_S 5.0) March 22, 1952 event represents the biggest recorded earthquake till now.

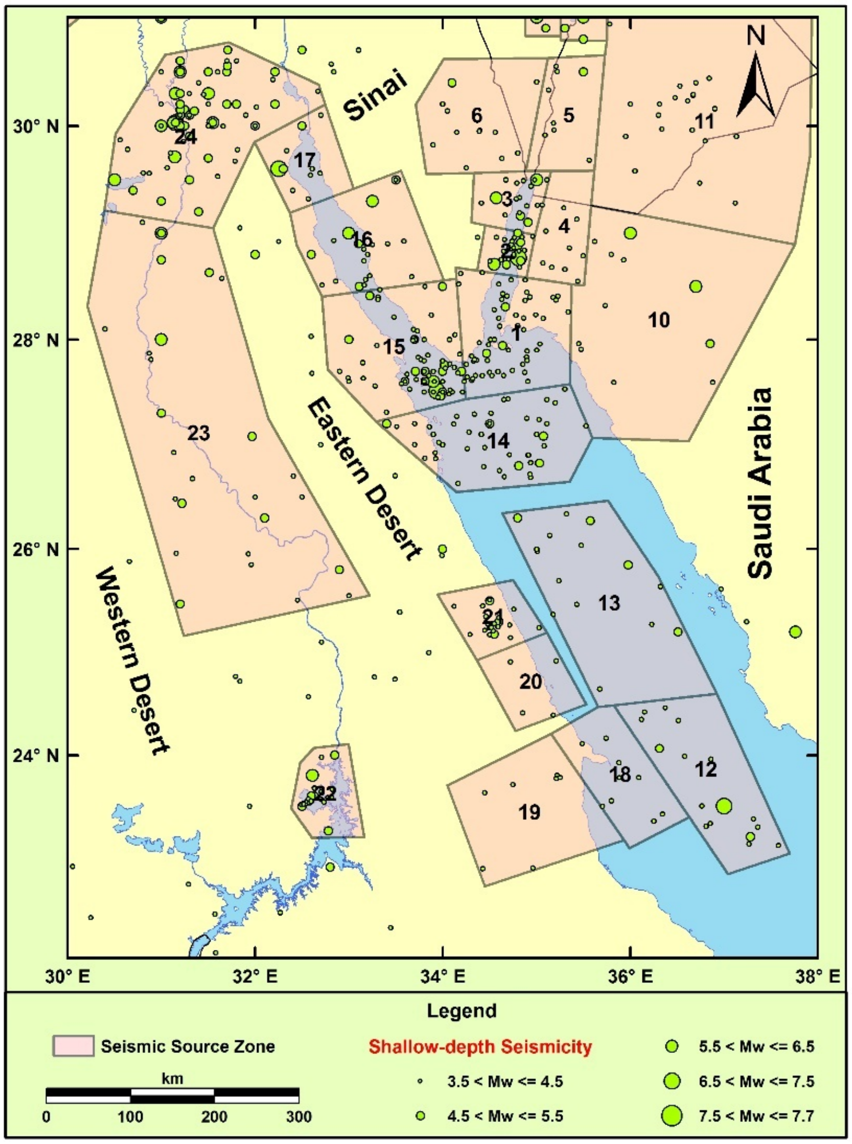

Figure 9. Shallow-depth seismicity (h ≤ 35 km) and delineated seismic sources along the Red Sea-Gulf of Suez and the Nile River.

Seismicity parameters for the delineated seismic sources along the Red Sea Rift are displayed in Table 2.

Source Zone	b-value	Yearly Number of Earthquakes		Observed M_{max}
		Above M_W 4.0	Above M_W 5.0	
EG-12	1.00	0.4359	0.0434	I_{max} VI-VII on 1121/--/--
EG-13	0.91	0.3029	0.0376	m_b 4.7 on 2006/07/30
EG-14	1.13	0.6425	0.0472	m_b 5.0 on 1952/03/22

Table 2. b-value, annual rate of earthquakes, and maximum observed magnitude for the delineated seismic source zones along the Red Sea Rift.

5.3. Seismic sources along the Gulf of Suez

The Gulf of Suez is considered to be the plate boundary between the African Plate and Sinai sub-Plate [162]. It extends along a NW trend from latitude 27°30′ N to 30°N. The Gulf of Suez constitutes the northern part of the Red Sea Rift System. It was developed, together with the Red Sea and the Gulf of Aqaba, as one of the three arms of the Sinai Triple Junction [69, 81 and 163-166].

The Gulf of Suez has been interpreted as being a complex half-graben system [139], or an asymmetric graben [167]. It is composed of three successive half-grabens, as mentioned by Moustafa [168], with opposite tilt directions: northern, central, and southern. These distinct half-grabens include several rift blocks of a uniform dip direction. The dip direction, along the Gulf of Suez Rift, changes from the north to the south as: SW to NE and again to SW defining the three half-grabens, respectively.

Two-accommodation zones [169] coexist among these half-grabens which extend transversely across the rift (Figure 10). These are the Galala-Zenima [168] or Gharandal [167] accommodation zone, of broad extension (about 60 km wide) in the north, and the Morgan [168] or Sufr El Dara [170] accommodation zone (20 km wide) in the south. Both zones exhibit a broad range of deformation, including distinct normal, oblique, or strike-slip faults [171], or wide complex zones of normal faulting, trans-tension [172-174] or broad warping [175].

The Gulf of Suez is considered to be an aseismic area during the first half of the last century and this consideration let some researchers (e.g., [176, 177]) to conclude that all the present motion taking place in the Red Sea Rift is transferred into shearing along the DST. Ben-Menahem [178] and Salamon *et al.* [111] studied the seismic activity of the Suez Rift. Fault plane solutions of the m_b 6.1, March 31, 1969 earthquake and other low-magnitude events show that the Gulf of Suez Rift is active which agree with Ben-Menahem and Aboodi [179] results. Considering the tectonic setting, seismicity and earthquake faulting mechanisms, the Gulf of Suez can be divided into three seismogenic sources (Figure 9) as follow.

5.3.1. Southern Gulf of Suez (EG-15) seismogenic source

The EG-15 Southern Gulf of Suez seismogenic source is distinguished by intensive structural deformation. It is characterized by its relatively high seismic activity. The higher seismicity rate at the southern part of the Gulf of Suez is related to the crustal movements among the three surrounding plates: Arabian Plate, African Plate, and Sinai sub-Plate. Six historical events are included in this zone. Those are 28 B.C., 955, 1091, 1195, 1778, and 1839 events. Their intensities range from VI-VII to VIII. The most important event occurred inside this area source is the M_W 6.8, March 31, 1969 Shedwan earthquake [16, 181]. Three foreshocks and 17 aftershocks (m_b 4.5-5.2) located in the Shedwan Island district are related to this big event. However, Maamoun and El-Khashab [182] mentioned that 35 foreshocks, taken place during the last half of March 1969, were preceding the main earthquake. The focal mechanism solutions of the largest two earthquakes (M_W 6.8, March 31, 1969 and M_W 5.5, June 28, 1972 earthquakes) show a normal faulting mechanisms with negligible shear component along the NW-trending fault plane that it is in agreement with the main axis of the Gulf of Suez [183]. This is also consistent

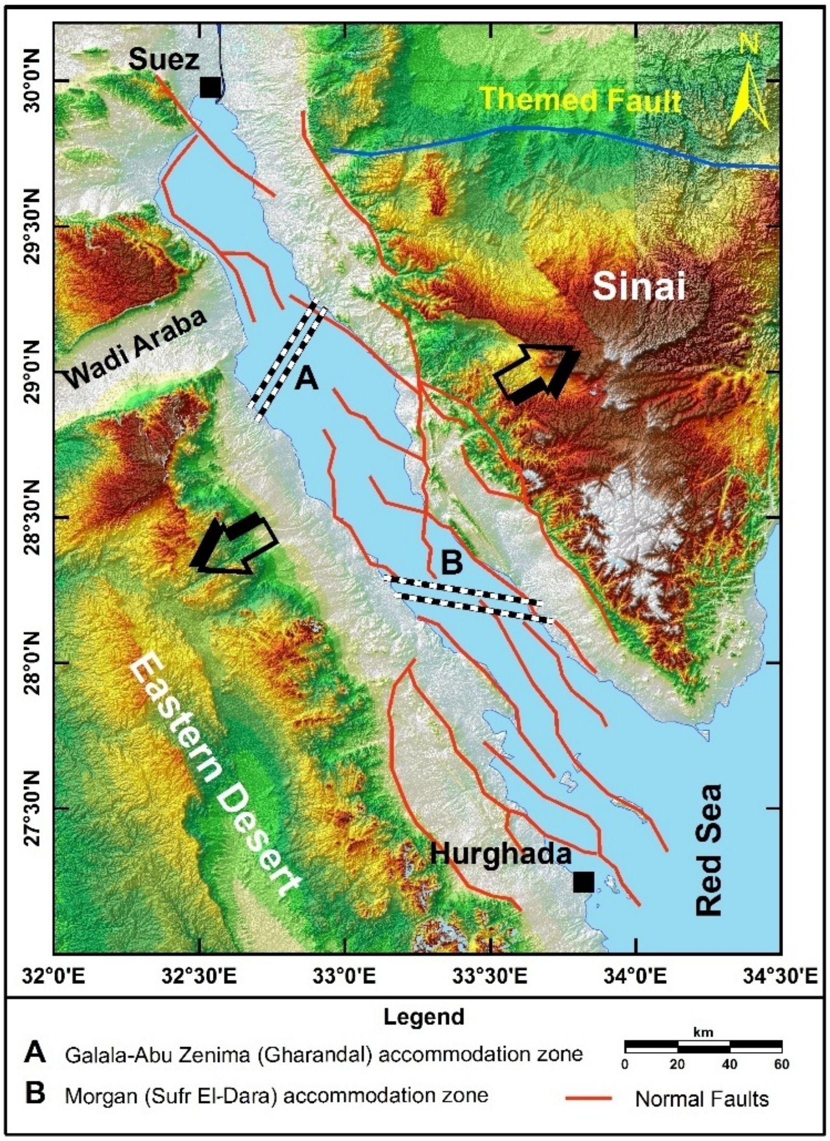

Figure 10. Tectonic setting of the Gulf of Suez. Red lines refer to normal faults (redrawn after Meshref [11]; and Younes and McClay [180]).

with the results obtained using the waveform inversion techniques proposed by Huang and Solomon [184].

5.3.2. Central Gulf of Suez (EG-16) seismogenic source

The seismic activity in the EG-16 Central Gulf of Suez seismogenic source is relatively low when compared with the previous source. Five historical events are included in this source zone: the 1220 B.C., 1425, 1710, 1814, and 1879 earthquakes. Its intensities range from IV to VII. The most important earthquake inside this area was the M_S 6.2 March 6, 1900 event.

Abou Elenean [20] computed some focal mechanism solutions for earthquakes which taken place in the central part of the gulf, showing generally normal faulting, following the main gulf trend. A few of these events show slight strike-slip component, especially for those events closer to the transfer zones of the three gulf dip provinces [11]. This change, from a purely normal faulting in the southern part to a mixed (strike-slip and normal) movement, supports the separation between the southern and middle seismogenic zones in the Gulf of Suez.

5.3.3. Northern Gulf of Suez (EG-17) seismogenic source

Finally, the EG-17 Northern Gulf of Suez seismogenic source is characterized by its low seismic activity. Two large earthquakes occurred before the year 1900. They are the I_{max} VI, 742, and I_{max} V, 1754 earthquakes. Focal mechanism analyses for this seismogenic zone indicate normal faulting mechanism. Fault plane solutions by Abou Elenean [20] showed that the events located at the gulf apex show normal faults, generally trending NW-SE to WNW-ESE, and reflect a good agreement with the surface faults crossing the Eastern Desert from the gulf apex towards Cairo.

Abou Elenean [20] concluded that the focal mechanisms of small to moderate size earthquakes based on the P-wave polarities by Badway and Horváth [185-187], Badawy [188] and Salamon *et al.* [112], show the existence of few thrust faulting mechanisms along the Gulf of Suez trend. The author argues that these unexpected mechanisms could be due to the lack of local stations with clear polarities at that time. On the other hand, borehole breakouts analyses performed by Badawy [188] show a different stress direction, inconsistent with the NE-SW tension direction estimated from earthquake focal mechanisms.

Seismicity parameters for the delineated seismic sources along the Gulf of Suez are displayed in Table 3.

Source Zone	b-value	Yearly Number of Earthquakes		Observed M_{max}
		Above M_W 4.0	Above M_W 5.0	
EG-15	1.06	0.8347	0.0721	M_W 6.8 on 1969/03/31
EG-16	0.80	0.3085	0.0488	M_S 6.2 on 1900/03/06
EG-17	0.86	0.1381	0.0190	M_S 6.6 on 1754/--/--

Table 3. b-value, annual rate of earthquakes, and maximum observed magnitude for the delineated seismic source zones along the Gulf of Suez.

5.4. Seismic sources of the Egyptian Eastern Desert

The Eastern Desert of Egypt, structurally, is a part of the Arabian-Nubian Shield. It lies within the fold and thrust belt of the Pan-African continental margin [189]. It is underlain mainly by the Pre-Cambrian basement of igneous and metamorphic rocks, which constitutes the Nubian Shield that had been formed before the Red Sea opening. It is believed that Nubian Shield basement was stabilized during the Pan-African Orogeny (about 570 Ma ago) [190].

Stern and Hedge [191] divided the Eastern Desert belt into three structural domains (Figure 2): northern, central and southern. These domains are separated by two major faults: i) the first is the Safaga-Qena zone, extending from Safaga to Qena, and ii) the second one is the Marsa Alam-Aswan fault zone. The Eastern Desert is characterized by E-W trending faults in the southern part, which changes to ENE-WSW in the middle one, near to Hurghada city. Further to the north, towards the Cairo-Suez District, the main fault trend becomes in the E-W direction.

However, Youssef [10] classified the main tectonic structures developed in the Eastern Desert into three main groups: i) NW-SE trending normal faults parallel to the Gulf of Suez-Red Sea Rift, ii) NE-SW trending faults parallel to the Gulf of Aqaba, and iii) a set of fault system trending nearly in the E-W direction. In addition, there are many simple and open folds with a NW-SE trend and low plunges.

Deif *et al.* [57] quote that the relationship between the earthquake activity in the Eastern Desert and the causal structures is not fully understood, due to the lack of geological and geophysical studies in this region. Furthermore, no historical earthquakes have been reported in the current seismogenic sources [17, 21]. The following seismogenic sources are identified (Figure 9).

5.4.1. Western Red Sea Coast (EG-18) seismicity source

In addition to the Red Sea seismogenic sources mentioned above, there are some earthquakes located in the region which extends to the west, from the EG-12 Southern Egyptian Red Sea source till the western coast of the Red Sea. This activity may be related to the block adjustment in this region or to some ocean floor spreading. This source is characterized by a low seismic activity. The biggest observed earthquake is the M_L 4.5, May 23, 1990 earthquake.

5.4.2. Southern Eastern Desert (EG-19) seismicity source

This seismicity source exhibit a low seismic activity rate in comparison to the adjacent Red Sea seismic sources. There are no focal mechanism solutions for earthquake events inside this area source. The M_L 4.4, July 15, 1991 earthquake is the biggest recorded event in this zone.

5.4.3. Southern Abu Dabbab (EG-20) seismicity source

Depending on both the changes in the seismicity rate and distribution, another seismicity source (EG-20) has been considered to the north of the previous zone. The same as the previous, there is no focal mechanism solutions in this source. The biggest recorded event is the M_L 4.7, January 21, 1982 earthquake.

5.4.4. Abu Dabbab (EG-21) seismicity source

The Abu Dabbab region is located in the central part of the Eastern Desert of Egypt. The moderate level of seismic activity and extremely tight clustering of low-magnitude earthquakes at Abu Dabbab suggests that the seismicity in this area is not directly related to regional tectonics. One possible explanation is that the activity is related to magmatic intrusions into the Pre-Cambrian crust, but there is no direct evidence to support this hypothesis [161].

The most important event included inside this area source is the M_S 5.3, November 12, 1955 earthquake. This event is felt in the Upper Egypt in Aswan and Qena cities, and as far as Cairo, but no damage was reported. Its focal mechanism solution has normal and strike-slip faulting components produced by a NNW minimum compressive stress and a NE maximum compressive stress. Fault planes strike roughly E-W or N-S to NE-SW. Another important event related to this area is the M_W 5.1, July 2, 1984 earthquake, which is felt strongly in Aswan, Qena and Quseir cities. A large number of foreshocks and a huge sequence of aftershocks are recorded. The focal depth of the whole sequence was less than 12 km.

Seismicity parameters for the delineated seismic sources of the Eastern Desert of Egypt are displayed in Table 4.

Source Zone	b-value	Yearly Number of Earthquakes		Observed M_{max}
		Above M_W 4.0	Above M_W 5.0	
EG-18	1.29	0.1566	0.0080	M_L 4.5 on 1990/05/23
EG-19	1.15	0.1182	0.0085	M_L 3.9 on 1991/07/15
EG-20	1.20	0.0625	0.0039	M_L 4.7 on 1982/01/21
EG-21	0.87	0.3714	0.0496	m_b 6.2 on 1955/11/12

Table 4. b-value, annual rate of earthquakes, and maximum observed magnitude for the delineated seismic source zones of the Eastern Desert.

5.5. Seismic sources along Nasser's Lake, Nile Valley and Cairo-Suez region

5.5.1. Southern Aswan (EG-22) seismogenic source

The geological structural pattern of the Nasser's Lake and Aswan region is characterized by a regional basement rock uplift and regional faulting [192-197]. Faults around the Aswan region, according to their behavior, are grouped into three categories [82]:

i. E-W trending faults (Figure 11), as the Kalabsha and Seiyal Faults, which lay to the west of Nasser's Lake. The Kalabsha Fault is about 185 km long right-lateral strike-slip fault. Its slip rate was estimated to be 0.028 mm/yr., and the Seiyal Fault is considered to be similar to that of the Kalabsha Fault [82].

ii. N-S trending faults (Figure 11), which can be subdivided into two main sets: *The first set* lies to the NW of Nasser's Lake and consists of three faults: the Gebel El-Barqa Fault, the Kurkur Fault and the Khur El-Ramla Fault. The Gebel El-Barqa is a left-lateral strike-slip fault, with a total length of 110 km. The Kurkur Fault is also a left-lateral strike-slip fault, and it is characterized by its low seismic activity if compared with the neighbor faults. The Khur El-Ramla Fault is about 36 km in length, and it has no direct indication of its sense of movement. *The second set* of faults are lying to the SW of Nasser's Lake, and consists mainly of two faults: the Abu Dirwa and the Ghazala Faults. Abu Dirwa Fault is a 20 km long left-lateral strike-slip fault and it has a very low degree of seismic activity. In addition, for the Gazelle Fault, the analysis of its geomorphic expression shows no active features, and that there is no ground cracks observed along the fault trace. Likely this fault is inactive [192]. The fault planes of this system are nearly vertical (80-85°).

iii. The third one is a fault system trending NNE-SSW (Figure 11) and lies to the east of Nasser's Lake. The Dabud Fault, which represents the main fault of this group, is about 36 km length. Geological evidences indicate reverse-slip, opposed to the tectonic setting of the area.

In addition to the previous fault systems, Deif [57] has mentioned three faults located at the High Dam area. They are the Powerhouse, the Spillway and the Channel Faults. Deif [57] provided that the evidence of the occurrence of these faults is hidden below the Aswan High Dam and Nasser's Lake. These three faults show no evidence of being active in the Quaternary, and are considered as inactive with no significant hazard to the Aswan region [82].

No historical earthquakes were reported by Ambraseys *et al.* [18] inside this area source. However, two historical events (epicentral intensity VII) were reported by Maamoun *et al.* [16] to be located at the same place of the M_W 5.8, November 14, 1981 earthquake. These two events occurred in 1210 B.C. and in 1854.

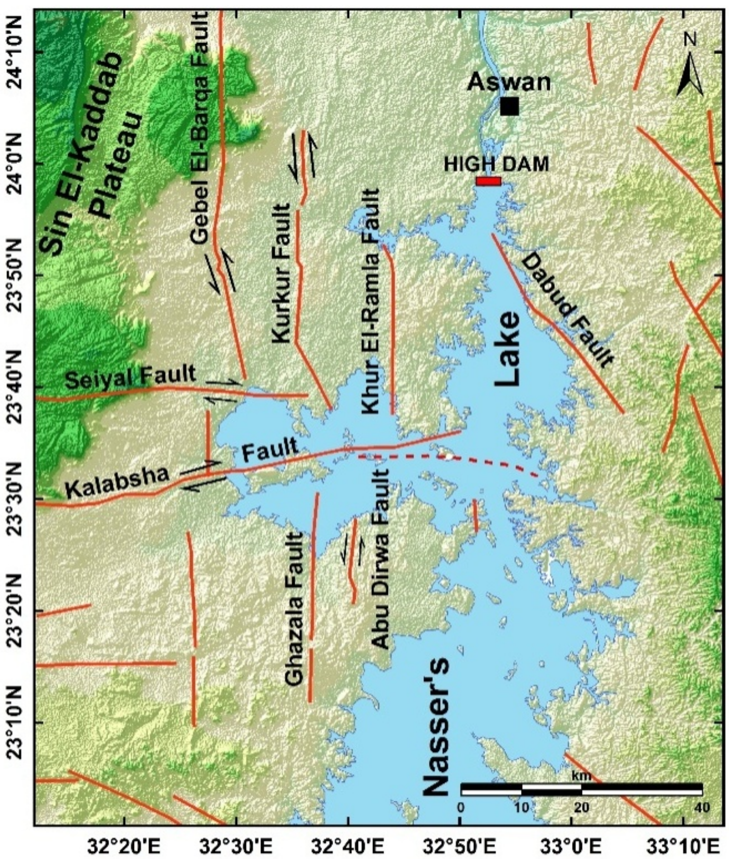

Figure 11. Geological and tectonic features around Nasser's Lake (redrawn after Woodward-Clyde Consultants [82]).

Woodward-Clyde Consultants [82] evaluated the fault system in the Kalabsha area and reported that the Western Desert Fault System consists of a set of E-W faults that exhibit dextral-slip displacement, and a set of N-S faults that exhibit sinistral-slip displacement. The E-W faults are longer, and have greater degree of activity in the Quaternary, having larger total slip rates (about 0.03 mm/yr.) than the N-S faults (0.01–0.02 mm/yr.).

Many seismic hazard studies have been carried out in the Aswan area and its surroundings due to its importance and neighborhood to the High Dam (e.g., [51, 57 and 58]). Three alternative seismotectonic models for Aswan area have been considered in these studies. The first model consider the Aswan Area as one seismotectonic model, while in the second one is subdivided into six seismotectonic provinces. The third model is mainly depending on the fault seismic sources. The latter one is based mainly on the well-known defined active faults and its associated seismic activities.

However, this work, the Aswan region and its surroundings is considered as one source zone (Figure 9). The main earthquake that took place inside this area was the M_W 5.8, November 14, 1981 event. This earthquake occurred in the Nubian Desert of Aswan. It is of great significance because of its possible association with Nasser's Lake. Its effects were strongly felt up to Assiut city (440 km to the north from Kalabsha Fault), as well as to Khartoum city (870 km to the south). Several cracks on the western bank of the Nasser's Lake, and several rock-falls and minor cracks on the eastern bank, are reported. The largest of these cracks is about one meter in width and 20 km in length. This earthquake was preceded by three foreshocks and followed by a large number of aftershocks. The focal depth of this earthquake is estimated to be 25 km. The composite fault plane solution of this event indicates a nearly pure strike-slip faulting with a normal-fault component [49, 195].

5.5.2. Luxor- Southern Beni Suef (EG-23) seismogenic source

Several geophysical studies have been carried out by many authors using different approaches in individual localities lying along the Nile Valley. The most interesting geological studies in the Nile Valley are those carried out by Said [69-71], Issawi [78], Philobbos *et al.* [86], and El-Younsy *et al.* [196]. All these works were conducted independently and aimed to obtain information about the drainage system, the stratigraphy and structural geology in this part of Egypt.

The Nile Valley is a large elongated Oligo-Miocene rift, trending N-S as an echo of the Red Sea rifting. There is no agreement among scientists, till now, about the origin of the Nile Valley. Some authors [197, 198] supported the opinion of the erosional origin of the Nile Valley, while many others (e.g., [11, 12, 13, 17, 70 and 199]) consider the tectonic origin. This is supported by the fault scarps bordering the cliffs of the Nile Valley, the numerous faults recognized on its sides [70, 71 and 199] and the most recent focal mechanism solutions. Furthermore, geological studies of the Nile Valley show that, it occupies the marginal area between two main tectonic blocks (the Eastern Desert and the Neogene-Quaternary platform), which in turn behaves as a barrier that prevents the further extension of the East African Orogenic Belt activity to the west [71].

From the structural point of view, the faults and joints are the most deformational features observed at the cliffs bordering the Nile stream [69 and 70]. These faults have different directions (Figure 2). The most abundant present the NW-SE and NNW-SSE trends, while others (less abundant) exhibit the WNW-ESE, ENE-WSW and NE-SW directions. Most of the major valleys, at the east of the Nile River, are generated and controlled in a more or less degree by these faults.

To the north of Aswan area, in the region between Luxor and Southern Beni Suef, along the Nile River, there is a low seismicity level, which coincides with the main trend of the Nile River. This active area has been considered as a separate seismogenic source. Several historical earthquakes are reported to occur along the Nile River in this area source that may be due to the high population density along the Nile River in the ancient times. These earthquakes are the 600 B.C., 27 B.C., 857, 967, 997, 1264, 1299, 1694, 1778, and 1850 events. Their intensities range from V to VIII. Focal mechanism solutions exhibit reverse faulting mechanism to the west of the Nile River, in the area between Luxor and Assiut. However, normal faulting mechanism with strike-slip component appears to the north of Assiut till Beni Suef city.

5.5.3. Beni Suef – Cairo – Suez District (EG-24) seismogenic source

To the north of the previous zone and to the west of the Gulf of Suez, there is a moderate seismic activity between Beni Suef and Cairo, on the River Nile, till Suez, on the apex of the Gulf of Suez (Figure 9). Three fault trends are affecting the Cairo-Suez district: the first one is trending E-W, which aligned by latitude 30°N, and it is very dominant, while the other two (ENE and NW) are spatially more abundant [200]. The faults are predominantly normal, and have produced a series of fault blocks with a large strike-slip component [200].

Field observations, satellite images, aerial photographs and seismic profiles confirm that the region between Cairo and Suez is active from a tectonic point of view. Seismic activity are noticed along this belt at Wadi Hagul and Abu Hammad. However, the earthquake distribution in this area is very scattered, and cannot be attributed to a specific known fault. This disperse seismicity yields a difficulty in delineating seismic zones. It is assumed that the seismic potential is uniform throughout the zone, although this is not entirely clear.

Sixty one historical earthquakes are related to this area source. The most important among them are the 935, 1111, 1259, 1262, 1303, and 1588 events. Moreover, the most important instrumental earthquake taken place in this source is the M_W 5.8, October 12, 1992 event. Its epicenter was located about 40 km south of Cairo, in Dahshour. It caused a disproportional damage (estimated at more than L.E. 500 million) and the loss of many lives. The shock was strongly felt, and caused sporadic damage and life loss in the Nile Delta, around Zagazig. Damage was extended to reach Fayoum, Beni Suef and Minia cities. The mostly affected area was Cairo, especially its old sections, Bulaq and the southern region, along the western bank of the Nile to Gerza (Jirza) and El-Rouda. In all, 350 buildings collapsed completely and 9000 were irreparably damaged, killing 545 persons and injuring 6512. Most causalities in Cairo were victims of the horrible stampedes of students rushing out from schools. Approximately, 350 schools and 216 mosques were destroyed and there was about 50000 homeless.

Abdel Tawab *et al.* [201] studied the surface tectonic features of the area around Dahshour and Kom El-Hawa, and found a major N55°E trending normal fault at Kom El-Hawa (800 m length of surface trace with a vertical displacement of 40 cm) and a major E-W trending open fracture at Dahshour area (1200 m in length). Maamoun *et al.* [202] concluded that, most of the surface lineaments recorded after the occurrence of the main shocks are trending E-W to NW-SE. Abou Elenean [19] studied the focal mechanism solutions for some earthquakes in Dahshour area, and found normal faulting with a large strike-slip component. The first nodal plane is trending nearly E-W, showing coincidence with the surface lineaments that appeared directly after the occurrence of the M_S 5.9, 1992 earthquake.

In addition to the previous earthquake, there were three important earthquakes located inside this source zone. One of them located to the southwest of Suez, is the m_b 4.9 (M_S 4.8), March 29, 1984 Wadi Hagul earthquake. It was strongly felt in Suez, Ismailia and Cairo. A large number of aftershocks were recorded by nearby temporary stations. The second earthquake was located Northeast Cairo; it is the m_b 4.8, April 29, 1974 Abu Hammad earthquake. It was strongly felt in Lower Egypt (Nile Delta) and Southwest Israel. The last earthquake was the m_b 5.0, January 2, 1987 Ismailia event.

Mousa [203] and Hassib [204] computed two nodal planes trending ENE-WSW and NNW-SSE, with left-lateral strike-slip motion along the second plane, for the Abu Hammad event. They computed the same strike-slip with reverse component for the Wadi-Hagul earthquake. In addition, the mechanism of the Ismailia earthquake shows also strike-slip movement with two nodal planes trending N68° E and S24°E, with steep dip angles (each of them is 80°) [205].

The seismicity parameters for the delineated seismic sources along the Nile River are displayed in Table 5.

Source Zone	b-value	Yearly Number of Earthquakes		Observed M_{max}
		Above M_W 4.0	Above M_W 5.0	
EG-22	0.79	0.5860	0.0946	M_W 5.8 on 1981/11/14
EG-23	0.73	0.2948	0.0549	I_{max} VIII on 0857/04/--
EG-24	0.99	0.5964	0.0608	I_{max} IX-X on 1262/--/--

Table 5. b-value, annual rate of earthquakes, and maximum observed magnitude for the delineated seismic source zones along the Nile River.

5.6. Seismic sources along the Mediterranean Coastal Line

The Mediterranean Coastal area is characterized by small to moderate seismicity. This area is located at the southeastern part of the Mediterranean Sea. It separates between the high seismic activities along the Gulf of Aqaba-Dead Sea Transform Fault and the seismicity of the Mediterranean Sea (Hellenic and Cyprian Arcs). Moreover, it separates the Southern Cyprus seismic activity from the Northern Egypt activity. Hence, this area has been divided into three seismic sources (Figure 12), based mainly on the available focal mechanism data and the seismic activity.

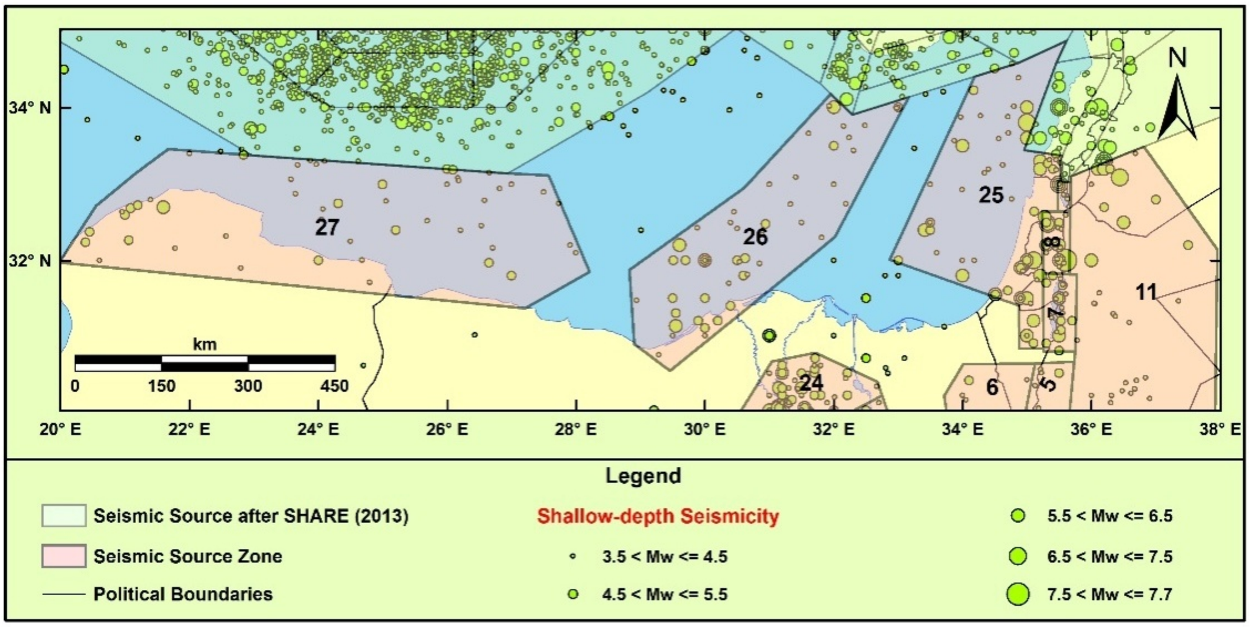

Figure 12. Shallow-depth seismicity (h ≤ 35 km) and seismic source zones delineated for the Mediterranean coastal line.

5.6.1. Eastern Mediterranean Coast (EG-25) seismicity source

This area source is parallel to the eastern coastal line of the Mediterranean Sea. It is located to the west of the previous quoted sources EG-07, EG-08, and EG-09, and to the southeast of Cyprus. It includes all the seismicity located to the west of the DST, and those earthquakes are not related with the Cyprian Arc. 29 historical events are included inside this area source. The most important among them are the 590 B.C., 525 B.C., 12 B.C., 306, 332, 551, 1269, and 1546 earthquakes.

5.6.2. Northern Delta (EG-26) seismicity source

This source is located to the northwest of the Nile Delta region. It extends from Alexandria towards the Mediterranean Sea in NE direction. 23 historical events are included inside this large area source, among them the 796, 951, 955, 956, 1303, 1341, and 1375 earthquakes. Moreover, the m_b 6.5 (M_S 6.8), September 12, 1955 Alexandria earthquake, represents the most important recorded event inside this source. This earthquake was felt in the entire Eastern Mediterranean Basin. In Egypt, it was strongly felt, and led to the loss of 22 lives and damage in the Nile Delta, between Alexandria and Cairo [17]. The destruction of more than 300 buildings of old brick construction was reported in Rosetta, Idku, Damanhour, Mohmoudya and Abu-Hommos. A maximum intensity of VII was assigned to a limited area in Behira province, where 5 people killed and 41 were injured.

Mostly of the focal mechanism data inside this area source reflects reverse faulting mechanism with, sometimes, strike-slip component, except one event, showing a strike-slip motion with a notable normal component (the M_W 4.5, April 9, 1987 event).

5.6.3. Western Mediterranean Coast (EG-27) seismicity source

The Western Egyptian Mediterranean Coastal zone is located to the north of the Egyptian-Libyan boundary. Only two historical events are reported inside this source: the I_{max} VIII, 262, and I_{max} VI, 1537 earthquakes. However, the most important recorded earthquake is the M_W 5.5, May 28, 1998 Ras El-Hekma event. This earthquake is widely felt in Northern Egypt. Intensity of VII is assigned at Ras El- Hekma village (~300 km west of Alexandria), and an intensity of V–VI at Alexandria city [206]. Ground fissures trending NW–SE were observed along the beach. Some cracks were also observed in concrete buildings. Furthermore, some people left their houses. The windows rattled and hanging objects swung, but the direction of the ground motion was poorly identified [206].

Recent studies concerning the crustal structure and focal mechanism of the M_W 5.5, May 28, 1998 Ras El-Hekma earthquake suggested that this source is an extension of the compressional stress from the Hellenic Arc. This compressional stress reactivated the old Triassic normal faults as reverse faults, or reverse faults with strike-slip component. This activity coincides with the hinge zone geometry proposed by Kebeasy [17]. Mostly of the focal mechanism analyses data indicate reverse faulting with some strike-slip component.

Seismicity parameters for the delineated seismic sources along the Mediterranean coastal line are displayed in Table 6.

Source Zone	b-value	Yearly Number of Earthquakes		Observed M_{max}
		Above M_W 4.0	Above M_W 5.0	
EG-25	0.97	0.5204	0.0554	I_{max} X on 1546/01/14
EG-26	0.94	0.5975	0.0688	m_b 6.5 on 1955/09/12
EG-27	0.60	0.7134	0.1793	I_{max} VIII on 0262/--/--

Table 6. b-value, annual rate of earthquakes, and maximum observed magnitude for the delineated seismic source zones along the Mediterranean coastal line.

5.7. Seismic sources of the Western Desert

5.7.1. El-Gilf El-Kebeir (EG-28) Seismogenic Source

Issawi [28] studied the geology of El-Gilf El-Kebeir region, and concluded that the area is affected by three main faults (Figure 2). The first one is the Gilf Fault, which strikes N-S for a distance of 150 km inside Egypt. Its extension in Sudan is unknown. Its northward extension is not traced. He interpreted this fault as a normal, gravity, strike and hinge type of structure. The second one is Kemal Fault, which limits the northwestern side of the Gilf Plateau. It is normal, strike fault which trends NW-SE. The Kemal Fault intersects the Gilf Fault at its northern end. The third one is the Tarfawi Fault, which has the same trend similar to the Gilf Fault. Its length, in Egypt, is 220 km but it extends in Sudan. He interpreted this fault as a normal, gravity and hinge fault.

The only recorded earthquake in this area source is the m_b 5.3 (M_L 5.7), December 9, 1978 El-Gilf El-Kebeir earthquake. It had a reverse faulting mechanism. Riad and Hosney [207] studied its focal mechanism and concluded that, a shear direction did exist in the basement rocks of the southern part of the Western Desert and has been explained as due to compressional stress resulting from the spreading of the Red Sea. Their fault planes solution shows that the P-axis is almost perpendicular to the Red Sea spreading axis. They concluded that the Gilf Plateau is probably divided into two parts by a fault striking nearly E-W. Some authors [e.g., 208 and 209] pointed out that this activity is linked to the pre-existing weak zones, while, Abou Elenean [19] linked such an intraplate activity to the intersection of more than one local fault.

In the current work, the Gilf El-Kebeir (EG-28) seismogenic source covers the seismic activity in this area, as well as the above mentioned faults.

6. Eastern Mediterranean region seismic sources

The Mediterranean region is characterized by a very complex tectonics that can be generally described in the frame of the collision between the Eurasian and African Plates [183, 210-219]. It can be divided into western, central, and eastern basins.

The Eastern Mediterranean region, which defines the region lying between the Caspian Sea and the Adriatic Sea through Caucasus, Anatolia, Aegean Sea and Greece, is one of the world's most seismically active regions. Recent tectonics of the Eastern Mediterranean region has been studied intensely in the last four decades. The Eastern Mediterranean region is known to be seismically active over a period of more than 2000 years based on historical and instrumental records. The tectonic and seismotectonic studies reflect a highly complicated tectonic setting.

It is characterized by two main seismic regions: the Hellenic and Cyprian Arcs (Figure 13). The Cyprian Arc has a similar geometry to the Hellenic Arc and the two are often compared (e.g., [220]). However, the observed seismic activity and the well-known plate movement in the Eastern Mediterranean area, suggest that the previously mentioned arcs are affected by a very distinct tectonic activity. The convergence across the first one (Hellenic Arc) is 20–40 mm/yr. (two to three times faster across the Cyprian Arc). Thus, this biggest displacement level yields in higher seismicity rate at much deeper levels (up to 300 km) [220].

The Cyprian Arc represents a tectonic plate margin separating the Anatolian sub-Plate (to the north) from the Nubian and Sinai sub-Plates (to the south) (Figure 13). It is connected from the west by the Hellenic Arc, and from the east by the Dead Sea and the East Anatolian Faults. In addition, it extends from the Gulf of Antalia, to the west to the Gulf of Iskenderun, to the east. On the other hand, the Hellenic Arc is considered to be the most active seismic region in Europe. It is represents the convergent plate boundary between the African Plate and the Eurasian Plate (Aegean sub-Plate) in the Mediterranean area (Figure 13).

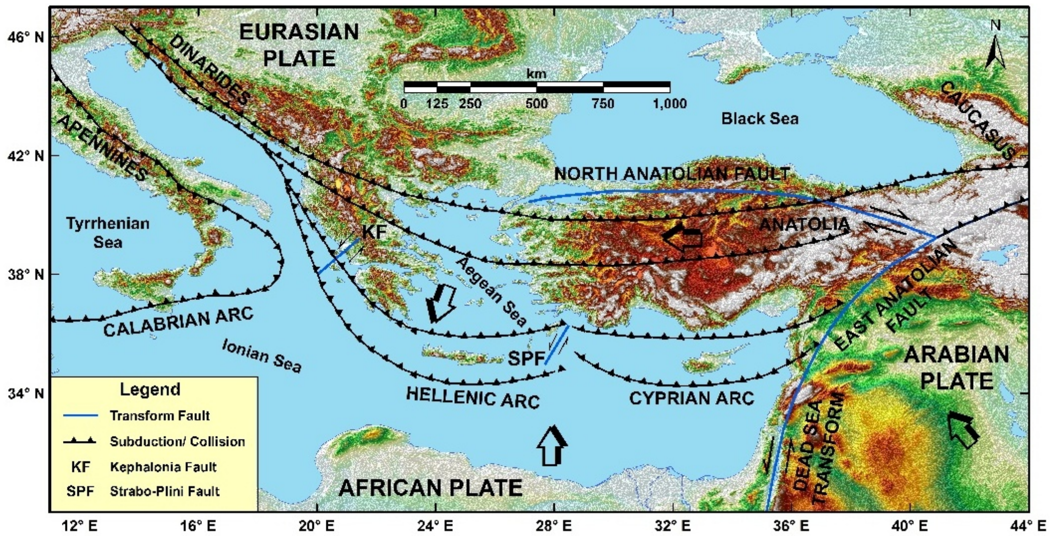

Figure 13. Tectonic map of the Eastern Mediterranean region (after Ziegler [221]; Meulenkamp *et al.* [222]; and Dewey *et al.* [223]).

6.1. SHARE shallow-depth seismic sources (h ≤ 20 km)

The Seismic Hazard Harmonization in Europe (SHARE) project [224], since the year 2009 till 2013, worked in establishing an appropriate seismic hazard model for Europe and Turkey. This project delivered a seismic hazard reference model for the current use of the European building design and seismic regulations, Eurocode 8 (EC8), that came into force in 2010.

The EU-FP7 European Commission Project (SHARE), aiming at providing an updated state-of-the art time-independent seismic hazard model, envisioned to serve as a reference model for the revision of the EC8 building code. SHARE, in addition, contributes its results to the Global Earthquake Model (GEM, www.globalquakemodel.org), a public/private partnership initiated and approved by the Global Science Forum of the OECD- GSF, aiming to provide a uniform hazard and risk model around the globe.

The Euro-Mediterranean area is complex from a seismotectonic point of view. The plate boundary between Africa and Europe runs roughly west to east from the Mid-Atlantic Ridge to Eastern Turkey with different mechanisms including continental collision, subduction, and transcurrent movement. Moving away from the plate boundary, the stable continental region is also locally rather active.

SHARE inherits knowledge from national, regional and site-specific PSHAs, assessed new data, assembled the data in a homogeneous fashion, and built comprehensive hazard relevant databases. In the frame of this project, the establishment of a seismic source model for Europe and the surrounding areas was considered. This model is built upon the available local and regional models as well as newly defined source zones. It has been developed during eight separate workshops by the SHARE consortium. Almost 80 experts from 28 countries from the informed European-Mediterranean seismological community have participated in building the zonation model.

The principle for seismic source zones is that they represent enclosed areas within which, a uniform seismicity distribution and maximum magnitude is expected. Background sources have been avoided in the sense that all areas have been covered by seismic sources, i.e., even very low seismicity areas are covered with areal source zones. The principles along which seismic source zones in the current model have been constructed are based on information from geological structures on different scales, tectonics and seismicity.

Seismicity also follows these structures well, e.g., as can be seen along the North Anatolian Fault, the Gulf of Corinth and the Hellenic Arc. The use of fault source information has also been done in the delineation of the source zones, especially in the case of the foundation of the sources for Balkans, Greece and Turkey, Italy and Portugal. b-value, annual activity rates, and maximum expected magnitude were computed using different approaches and methods and included in the SHARE project database (www.share-eu.org) [225].

In the current work, 53 shallow-depth seismic sources ($h \leq 20$ km) from the SHARE source model (Figure 5), were considered to the north of Egypt, till latitude 38° N, and covering the Greece and Turkey regions. Some of the events located at this region were felt and caused few damages in the northern part of Egypt (e.g., the I_{max} VIII, August 8, 1303 offshore Mediterranean earthquake, the I_{max} VI, February 13, 1756 and the M_S 7.4, June 26, 1926 Hellenic Arc earthquakes, the M_W 6.8, October 9, 1996 Cyprus earthquake, and the M_S 6.4, October 12, 2013 Crete earthquake). Thus, these source zones have a certain contribution to the seismic hazard in Northern Egypt.

The model in the Greek and Cyprian area build to a large extent upon the previous works of Papiouannou and Papazachos [64] and Papiouannou [226]. The Turkish model [227, 228] is provided as a cooperation between the EMME project and SHARE. The Turkish model is further a hybrid model, in the sense that the area sources have been delineated with respect to the integrated fault line sources from the main faults, like the North and East Anatolian Faults.

6.2. Intermediate-depth seismic sources ($20 \leq h \leq 100$ km)

Intermediate focal depth earthquakes occur in the Eastern Mediterranean region (Southern Greece and Turkey) define a Benioff zone of stair shape which dips from the convex side of the Cyprian and the Hellenic Arcs to its concave side (from the Eastern Mediterranean to the Greek and Turkish lands) [229-231]. Some of these earthquakes are moderate to large earthquakes, and constitute a seismic threat for the whole Mediterranean area, including Northern Egypt. Since, because of their magnitudes and focal depths, these earthquakes produce seismic waves of large amplitude and period which travel large distances with low attenuation [232]. Therefore, these earthquakes can contribute to the seismic hazard of Northern Egypt.

In this work, intermediate-depth sources for earthquakes having focal depths ranging from 20 km to 100 km have been delineated. Below this depth (100 km) and considering the large distance from Egypt, deep events have no contribution to the seismic hazard. Thus, 7 intermediate-depth source zones have been considered in the Hellenic and Cyprian subduction zones to cover the intermediate-depth seismicity ($20 \leq h \leq 100$ km) (Figure 14). The zoning was based on the seismicity distribution and the tectonic setting of the region. Seismicity parameters for these intermediate-depth seismic sources are displayed in Table 7.

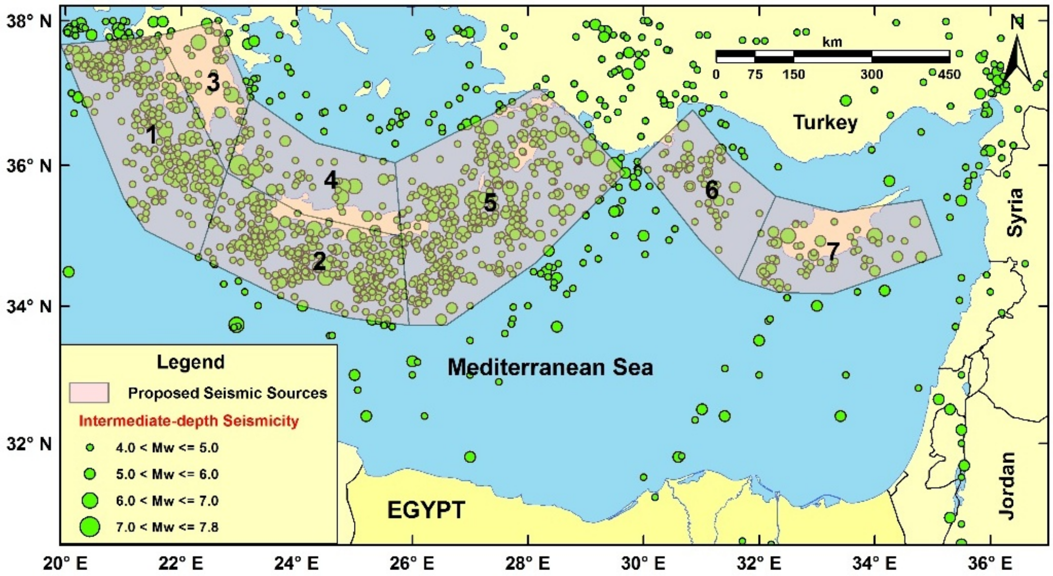

Figure 14. Intermediate-depth seismicity (20 ≤ h ≤ 100 km) and delineated intermediate-depth seismogenic source zones for the Eastern Mediterranean region.

Source Zone	b-value	Yearly Number of Earthquakes		Observed M_{max}
		Above M_W 4.0	Above M_W 5.0	
MD-01	0.88	12.2091	1.6212	M_W 6.9 on 2008/02/14
MD-02	0.97	14.1395	1.5283	m_b 6.4 on 2013/10/12
MD-03	0.78	1.9892	0.3324	m_b 6.9 on 1962/08/28
MD-04	0.83	2.8908	0.4316	m_b 7.2 on 1903/08/11
MD-05	0.88	14.8782	1.9434	m_b 7.1 on 1984/02/09
MD-06	0.93	2.2986	0.2727	M_S 5.8 on 1984/04/30
MD-07	0.82	2.9083	0.4409	m_b 6.5 on 1941/01/20

Table 7. b-value, annual rate of earthquakes, and maximum observed magnitude for the delineated seismic source zones of the Eastern Mediterranean region.

7. Conclusion

To reach a more realistic seismic hazard quantification in Egypt, it is necessary to recognize the seismic source zones, including the seismic activity that can affect different regions all over the country. In the current work, a new seismic source model for Egypt and its surroundings is proposed, using all available geological, geophysical, tectonic and earthquake data, aimed at carrying out seismic hazard studies.

This work presents a detailed review on major tectonic features and the correlation of seismicity with them, to demarcate seismic sources in Egypt and neighborhood. The Gulf of Aqaba-Dead Sea Transform, the Red Sea-Gulf of Suez Rift, and the Cyprian and Hellenic Arcs are the three most active seismotectonic belts in the region, which have produced several large earthquakes in the recent past. On the basis of a comprehensive and critical analysis of the seismotectonic characteristics, different seismic sources are defined to model the seismicity for the assessment of seismic hazard in Egypt.

Focal mechanism solutions data, active faults data, as well as an updated earthquake catalogue for the period 2200 B.C.–2013 are taken into account. Potential seismic sources are modeled as area sources, in which configuration of each seismic source is controlled, mainly, by the fault extension and seismicity distribution.

The proposed seismic source model consists of 28 shallow-depth seismic zones ($h \leq 35$ km) for the Egyptian territory and its surroundings, specified on the basis of mainly seismotectonic and seismicity criteria. In addition, the authors have considered 53 shallow-depth seismic sources ($h \leq 20$ km) for the Eastern Mediterranean region after SHARE (2013). Furthermore, the current model involves 7 delineated intermediate-depth seismic sources ($20 \leq h \leq 100$ km) covering the intermediate-depth seismicity in the Eastern Mediterranean region.

Seismicity parameters (b-value and activity rates) of the Gutenberg–Richter magnitude–frequency relationship have been estimated for each one of the seismic sources. In addition, the maximum observed magnitude for each seismic source zone was reported from the sources sub-catalogues. The coordinates of these seismic source zones and the estimated seismicity parameters can be directly inserted into PSHA after the estimation of the maximum expected magnitude for each source. The computation of seismic hazard for Egypt using these data will form the subject matter of a future paper.

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References

[1] Cornell CA. Engineering Seismic Risk Analysis. Bulletin of Seismological Society of America 1968; 18: 1583-1606.

[2] Reiter L. Earthquake Hazard Analysis. Columbia University Press, 1990.

[3] McGuire RK. FORTRAN Computer Programs for Seismic Risk Analysis. United States Geological Survey. Open-File Report No. 76-67, 1976.

[4] Kramer SL. Geotechnical Earthquake Engineering. Prentice-Hall Editor. Upper Saddle River, New Jersey, 07458; 1996.

[5] Abrahamson N. Seismic Hazard Assessment: Problems with Current Practice and Future Development. First European Conference on Earthquake Engineering and Seismology, 3-8 September 2006, Geneva, Switzerland.

[6] McGuire RK. Computer Program for Seismic Risk Analysis Using Faults as Earthquake Sources (FRISK) 1978. US. Department of Interior Geological Survey. Open-File Report 78-1007, 71 pp., Denever, Colorado.

[7] Bender BK. and Perkins DM. SEISRISK III: A Computer Program for Seismic Hazard Estimation. USGS Bulletin 1987: 1772.

[8] Ordaz M., Faccioli E., Martinelli F., Aguilar A., Arboleda J., Meletti C., and D'Amico V. CRISIS 2014. Institute of Engineering, UNAM, Mexico City, Mexico.

[9] Woo G. NPRISK Seismic Hazard Computation Algorithm Based on Cornell-McGuire Principles. Code developed at NORSAR; 1994.

[10] Youssef MI. Structural Pattern of Egypt and its Interpretation. The American Association of Petrolum Geologists Bulletin 1968; 53: 601-614.

[11] Meshref W. Tectonic Framework. In: Said R. (ed.). The Geology of Egypt. A.A. Balkema, Rotterdam, Netherlands; 1990. p113-155.

[12] Sieberg A. Handbuch der Geophysik. Band IV, Erdbeben-geographie. Borntraeger, Berlin, 1932a. p527-1005.

[13] Sieberg A. Erdbeben und Bruchschollenbau in Östlichen Mittelmeergebiet. Denkschriften der Medizinisch-Naturwissenschaftlichen Gesellschaft zu Jena 18, No. 2; 1932b.

[14] Ismail A. Near and Local Earthquakes at Helwan from 1903-1950. Helwan Observatory Bulletin No. 49, 1960.

[15] Gergawi A. and Khashab A. Seismicity of U.A.R. Helwan Observatory Bulletin No. 76, 1968.

[16] Maamoun M., Allam A. and Megahed A. Seismicity of Egypt. Bulletin of Helwan Institute of Astronomy and Geophysics, 109-160, 1984.

[17] Kebeasy RM. Seismicity. In: Said R. (ed.) The Geology of Egypt. A.A. Balkerma, Rotterdam, Netherlands; 1990. p51-59.

[18] Ambraseys NN., Melville CP., and Adams RD. The seismicity of Egypt, Arabia and Red Sea. Cambridge University Press; 1994.

[19] Abou Elenean K. Seismotectonics of Egypt in relation to the Mediterranean and Red Sea tectonics. PhD. thesis. Ain Shams University, Egypt; 1997.

[20] Abou Elenean K. Focal Mechanism of Small and Moderate Size Earthquakes Recorded by the Egyptian National Seismic Network (ENSN), Egypt. NRIAG Journal of Geophysics 2007; 6 (1) 119-153.

[21] Badawy A. Historical Seismicity of Egypt. Acta Geodaetica et Geophysica Hungarica 1999; 34 (1-2) 119-135.

[22] Badawy A. Seismicity of Egypt. Seismological Research Letters 2005; 76 (2) 149-160.

[23] Abou Elenean KM., Mohamed AME., and Hussein HM. Source Parameters and Ground Motion of the Suez-Cairo Shear Zone Earthquakes, Eastern Desert, Egypt. Natural Hazards 2010; 52: 431-451.

[24] Ziegler MA. Late Permian to Holocene Paleofacies Evolution of the Arabian Plate and its Hydrocarbon Occurrences. GeoArabia 2001; 6 (3) 445-504.

[25] Pollastro RM. Total Petroleum Systems of the Paleozoic and Jurassic, Greater Ghawar Uplift and Adjoining Provinces of Central Saudi Arabia and Northern Arabian-Persian Gulf. US. Geological Survey Bulletin 2202-H; 2003.

[26] Egyptian Geological Survey and Mining Authority “EGSMA”. Geologic Map of Egypt 1:2000000; 1981.

[27] Riad S. Shaer Zones in North Egypt Interpreted from Gravity Data. Geophsyics 1977; 24 (6) 1207-1214.

[28] Issawi B. New Findings on the Geology of Uweinat, Gilf Kebir, Western Desert, Egypt. Annals of the Geological Survey of Egypt 1978; 8: 275-293.

[29] Maamoun M. and Ibrahim EM. Tectonic Activity in Egypt as Indicated by Earthquake. Helwan Institute of Astronomy and Geophysics. No. 170, 1978.

[30] Albert RNH. Seismicity and Earthquake Hazard at the Proposed Site for a Nuclear Power Plant in the El-Dabaa Area, North Western Desert, Egypt. Acta Geophysica Polonica 1986; 34 (3) 263-281.

[31] Albert RNH. Seismicity and Earthquake Hazard at the Proposed Site for a Nuclear Power Plant in the Anshas Area, Nile Delta, Egypt. Acta Geophysica Polonica 1987; 35 (4) 343-363.

[32] Kebeasy RM., Maamoun M., and Albert RNH. Earthquake Activity and Earthquake Risk around the Alexandria Area in Egypt. Acta Geophysica Polonica 1981; 29 (1) 37-48.

[33] Kebeasy R. Seismicity of Egypt. Personal Communication; 1984.

[34] Marzouk I. Study of the Crustal Structure of Egypt Deduced from Deep Seismic and Gravity Data. PhD. thesis. Institute of Geophysics, University of Hamburg; 1988.

[35] Fat-Helbary RE. Investigation and Assessment of Seismic Hazard in Egypt. Unpublished Report Submitted to MAPFRE, Spain; 1999.

[36] Fat-Helbary RE. Assessment of Seismic Hazard and Risk in Aswan Area, Egypt. PhD. thesis. Tokyo University, Japan; 1994.

[37] Fat-Helbary RE. Probablistic Analysis of Potential Ground Motion Levels at the Principal Cities in Upper Egypt. Journal of Applied Geophysics 2003; 2: 279-286.

[38] Reborto P., Paolo L., and Dimitris D. Seismotectonic Regionalization of the Red Sea Area and its Application to Seismic Risk Analysis. Natural Hazard 1992; 5: 233-247.

[39] Mohammed A. Seismic Microzoning Study and its Applications in Egypt. PhD. thesis. Ain Shams University, Egypt; 1993.

[40] EL-Hadidy S. Crustal Structure and its Related Causative Tectonics in Northern Egypt using Geophysical Data. PhD. thesis. Ain Shams University, Egypt, 1995.

[41] Fat-Helbary RE., and Ohta Y. Assessment of Seismic Hazard in Aswan Area, Egypt. 11th World Conference on Earthquake Engineering. Paper No. 136 Published by Elsevier Science Ltd 1996.

[42] El-Sayed A. and Wahlström R. Distribution of the Energy Release, b-values and Seismic Hazard in Egypt. Natural Hazards1996; 13: 133-150.

[43] Abou Elenean K. Seismotectonics Studies of El-Dabaa and its surroundings. Unpublished Report 2010. NRIAG, Egypt.

[44] Badawy A. Earthquake Hazard Analysis in Northern Egypt. Acta Geodaetica et Geophysica Hungarica 1998; 33 (2-4) 341-357.

[45] Deif A. Seismic Hazard Assessment in and around Egypt in Relation to Plate Tectonics. PhD. thesis. Ain Shams University, Egypt, 1998.

[46] Riad S., Ghalib M., El-Difrawy MA., Gamal M. Probabilistic Seismic Hazard Assessment in Egypt. Annals of the Geological Survey of Egypt 2000; 23: 851-881.

[47] Abou ELenean K. and Deif A. Seismic Zoning of Egypt. Unpublished Work 2001. NRIAG, Egypt.

[48] El-Sayed A., Vaccari V. and Panza GF. Deterministic Seismic Hazard in Egypt. Geophysical Journal International 2001; 144: 555-567.

[49] Fat-Helbary RE., and Tealeb AA. A Study of Seismicity and Earthqauake Hazard at the Proposed Kalabsha Dam Site, Aswan, Egypt. Natural Hazards 2002; 25: 117-133.

[50] El-Amin EM. Study of Seismic Activity and its Hazard in Southern Egypt. MSc. thesis. Assiut University, Egypt; 2004

[51] El-Amin EM. Study of Seismic Hazard Analysis Using Fault Parameter Solutions in Aswan Region, Upper Egypt. PhD. thesis. Assiut University, Egypt; 2011.

[52] El-Hefnawy M., Deif A., El-Hemamy ST., and Gomaa NM. Probablistic Assessment of Earthquake Hazard in Sinai in Relation to the Seismicity in the Eastern Mediterranean Region. Bulletin of Engineering Geology and the Environment 2006; 65: 309-319.

[53] Abdel-Rahman K., Al-Amri AMS. and Abdel-Moneim E. Seismicity of Sinai Peninsula, Egypt. Arabian Journal of Geosciences 2009; 2 (2) 103-118.

[54] El-Hadidy M. Seismotectonics and Seismic Hazard Studies for Sinai Peninsula, Egypt. MSc. thesis. Ain Shams University, Egypt; 2008.

[55] El-Hadidy M. Seismotectonics and Seismic Hazard Studies in and around Egypt. PhD. thesis. Ain Shams University, Egypt; 2012.

[56] Deif A., Abou Elenean K., El-Hadidy M., Tealeb A. and Mohamed A. Probabilistic Seismic Hazard Maps for Sinai Peninsula, Egypt. Journal of Geophysics and Engineering 2009; 6: 288-297.

[57] Deif A., Hamed H., Igrahim HA., Abou Elenean K., and El-Amin EM. Seismic Hazard Assessment in Aswan, Egypt. Journal of Geophysics and Engineering 2011; 8: 531-548.

[58] Fat-Helbary RE., El Khashab HM., Dojcinovski D., El Faragawy KO., and Abdel-Motaal AM. Seismicity and Seismic Hazard Analysis in and around the Proposed Tushka New City Site, South Egypt. Acta Geodynamica et Geomaterialia 2008; 5 (4) 389-398.

[59] Mohamed AA., El-Hadidy M., Deif A., and Abou Elenean K. Seismic Hazard Studies in Egypt. NRIAG Journal of Astronomy and Geophysics 2012; 1: 119-140.

[60] Sawires R., Ibrahim HA., Fat-Helbary RE., and Peláez JA. A Seismological Database for Egypt Including Updated Seismic and Focal Mechanism Catalogues. 8th Spanish-

Portuguese Assembly of Geodesy and Geophysics. 29-31 January 2014, Évora, Portugal.

[61] Papazachos BC. Seismicity of the Aegean and Surrounding Area. Tectonophysics 1990; 178: 287-308.

[62] Shapira A., and Shamir G. Seismicity Parameters of Seismogenic Zones in and around Israel. The Institute of Petroleum Research and Geophysics 1994. Report No. Z1/567/79 (109).

[63] Papazachos BC. and Papaioannou ChA. Long–term Earthquake Prediction in the Aegean area Based on A Time and Magnitude Predicate Model. Pure Applied Geophysics 1993; 140: 595-612.

[64] Papioannou ChA. and Papazachos BC. Time–independent and Time–dependent Seismic Hazard in Greece Based on Seismogenic Sources. Bulletin of the Seismological Society of America 2000; 90: 22-33.

[65] CMT, Global Centroid Moment Tensor Catalogue: http://www.globalcmt.org/

[66] International Seismological Centre, On-line Bulletin, http://www.isc.ac.uk, International Seismological Centre, Thatcham, United Kingdom, 2011.

[67] PDE, Preliminary Determination of Epicentre: USGS National Earthquake Information Center (NEIC), http://earthquake.usgs.gov/earthquakes/.

[68] RCMT, European-Mediterranean RCMT Catalogue: http://www.bo.ingv.it/RCMT/.

[69] Said R. The Geology of Egypt. Elservier, Amsterdam; 1962.

[70] Said R. The Geological Evolution of the River Nile. Springer-Verlag, New York Inc., USA; 1981.

[71] Said R. The Geology of Egypt. A.A. Balkema, Ralkema, Rptterdam, Brookfield; 1990.

[72] Shata A. Structural Development of the Sinai Peninsula (Egypt). Conference Proceedings. 20th International Geological Congress, 1956, Mexico, 1959. p225-249.

[73] Neev D. Tectonic Evolution of the Middle East and the Levantine Basin (Easternmost Mediterranean). Geology 1975; 3: 683-686.

[74] Neev D., Almagor G., Arad A., Ginzburg A., and Hall J. The Geology of the Southern Mediterranean Sea. GSI, 68. 1976

[75] Neev D., and Hall JK. A Global System of Spiraling Geosutures. Journal of Geophysical Research 1982; 87:589-708.

[76] El-Shazly EM. The Geology of the Egyptian Region. In: The Ocean Basin and Margins. Volume 4A: The Eastern Mediterranean. Plenum Press. New York-London 1977.

[77] Maamoun M. Macroseismic Observation of Principal Earthquakes in Egypt. Bulletin of Helwan Institute of Astronomy and Geophysics. No. 183, 1979.

[78] Issawi B. Geology of the South Western Desert of Egypt. Annals of the Geological Survey of Egypt 1981; 2: 57-66.

[79] Riad S., EL-Etr HA., and Mokhles A. Basement Tectonics of Northern Egypt as Interpreted from Gravity Data. International Basement Tectonics Association Publication 1983; 4, 209-231.

[80] Sestini G. Tectonic and Sedimentary History of NE African Margin (Egypt/Libya). In: JE. Dixon and AHF. Robertson (eds.). The Geological Evolution of the Eastern Mediterranean. Blackwell Scientific Publications, Oxford, 1984. p161-175.

[81] Schlumberger. Geology of Egypt. Paper Presented at the Well Evaluation Conference, Schlumberger, Cairo; 1984.

[82] Woodward-Clyde Consultants. Earthquake Activity and Stability Evaluation for the Aswan High Dam. Unpublished report. High and Aswan Dam Authority, Ministry of Irrigation, Egypt; 1985.

[83] Barazangi M., Seber D., Chaimov T., Best J., Litak R., Al-Saad A and Sawaf T. Tectonic Evolution of the Northern Arabian Plate in Western Syria. In: Boschi E, Mantovani E and Morelli A. (ed.) Recent Evolution and Seismicity of the Mediterranean Region. Kluwer Academic Publishers, the Netherlands; 1993. p117–140.

[84] Guiraud RA. and Bosworth W. Phanerozoic Geodynamic Evolution of Northeastern Africa and the Northwestern Arabian Platform. Tectonophysics1999; 315: 73-108.

[85] Abdel Aal A., El Barkooky A., Gerrites M., Meyer H., Schwander M., and Zaki H. Tectonic Evolution of the Eastern Mediterranean Basin and its Significance for Hydrocarbon Prospectivity in the Ultradeep Water of the Nile Delta. The Mediterranean Offshore Conference. Alexandria, Egypt; 2000.

[86] Philobbos ER., Riad S., Omran AA. and Othman AB. Stages of Fracture Development Controlling the Evolution of the Nile Valley in Egypt. Egyptian Journal of Geology 2000; 44 (2) 503-532.

[87] Hussein IM. and Abd-Allah AM. Tectonic Evolution of the Northeastern Part of the African Continental Margin, Egypt. Journal of African Earth Sciences 2001; 33: 49-68.

[88] Drake CL., Girdler RW. A Geophysical Study of the Red Sea. Geophysical Journal of the Royal Astronomical Society 1964; 8: 473-495.

[89] Tramontini C. and Davies D. A Seismic Refraction Survey in the Red Sea. Geophysical Journal of the Royal Astronomical Society 1969; 17: 2225–2241.

[90] Tealeb A. Depth Determination of Density Contrasts in the Earth's Crust using Autocorrelation Analysis. Bulletin of Academy of Scientific Research, Helwan Institute of Astronomy and Geophysics, Cairo, No. 2008; 1979.

[91] Makris J., Stofen B., Maamoun M., Shehata W. Deep Seismic Sounding in Egypt, Part I: The Mediterranean Sea between Crete-Sidi Barani and the Coastal Area of Egypt. Unpublished Report, University of Hamburg ERG, 1979.

[92] Makris J., Allam A., Mokhtar T., Basahel A., Dehghani GA. and Bazari M. Crustal Structure in the Northwestern Region of the Arabian Shield and its Transition to the Red Sea. Bulletin of Faculty of Earth Sciences, King Abdulaziz University 1983; 6: 435-447.

[93] Makris J., Rihm R. and Allam A. Some Geophysical Aspects of the Evolution and Structure of the Crust in Egypt. In: Greiling SE.-G.a. R.O. (ed.) The Pan-African Belt of Northeast Africa and Adjacent Areas,Tectonic Evolution and Economic Aspects of a Late Proterozoic Orogen: Braunschweig, Friedr. Vieweg and Sohn; 1988. p345–369.

[94] Makris J., Henke CH., Egloff F. and Akamaluk T. The Gravity Field of the Red Sea and East Africa. Tectonophysics 1991; 198: 369–381.

[95] Rihm R. Seismische Messungen in Roten Meer und ihre interpretation. Diplom Arbeit, Institute fur Geophysik der Univeristat Hamburg, 1984.

[96] Gaulier JM., Le Pichon X., Lyberis N., Avedik F., Geli L., Moretti I., Deschamps A. and Hafez S. Seismic Study of the Crust of the Northern Red Sea and Gulf of Suez. Tectonophysics 1988; 153: 55–88.

[97] Rihm R., Makris J., Moller L. Seismic Surveys in the Northern Red Sea: Asymmetric Crustal Structure. Tectonophysics 1991; 198: 279–295.

[98] Shaaban MA., El Eraqi MA., Mamdouh EM. Deep Tectonics of Northern Eastern Desert of Egypt as Integrated from Gravity and Seismic Data. Journal of King Abdulaziz University: Earth Sciences 1994; 7: 75–88.

[99] Abd El-Hafiez H. The Role of Earthquake Analysis for Modeling the Dahshour Area Egypt. MSc. thesis. Ain Shams University, Egypt; 1996.

[100] Dorre AS., Carrara E., Cella F., Grimaldi M., Hady YA., Hassan H., Rapolla A. and Roberti N. Journal of African Earth Sciences 1997; 25: 425-434.

[101] Seber D., Steer D., Sandvol E., Sandvol C., Brindisi C., and Barazangi M. Design and Development of Information Systems for the Geosciences: An Application to the Middle East. GeoArabia 2000; 5 (2) 269-296.

[102] Mohamed H. and Miyashita K. One-dimensional Velocity Structure in the Northern Red Sea Area, Deduced from Travel Time Data. Earth's Planet Spaces 2001; 53: 695–702.

[103] El-Khrepy S. Tomographic Modeling of Dahshour Area Local Earthquakes, Northern Egypt. MSc. thesis. Ain Shams University, Egypt, 2001.

[104] El-Khrepy S. Detailed Study of the Seismic Waves Velocity and Attenuation Models Using Local Earthquakes in the Northeastern Part of Egypt. PhD. thesis. Mansoura University, Egypt, 2008.

[105] Koulakov I. and Sobolev SV. Moho Depth and Three-dimensional P and S Structure of the Crust and Uppermost Mantle in the Eastern Mediterranean and Middle East Derived from Tomographic Inversion of Local ISC Data. Geophysical Journal International 2006; 164: 218-235.

[106] Gharib A. Crustal Structure of Tushka Region, Abu-Simbel, Egypt, Inferred from Spectral Ratios of P-waves of Local Earthquakes. Acta Geophysica 2006; 54: 361- 377.

[107] Salah MK. Crustal Structure Beneath Kottamiya Broadband Station, Northern Egypt from Analysis of Teleseismic Receiver Functions. Journal of African Earth Sciences 2011; 60: 353–362.

[108] Abdelwahed MF., El-Khrepy S., and Qaddah A. Three-dimensional Structure of Conrad and Moho Discontinuities in Egypt. Journal of African Earth Sciences 2013; 85: 87-102.

[109] Araya R., and Der Kiureghian A. Seismic Hazard Analysis: Improved Models, Uncertanities and Sensitivities. Report to the National Science Foundation, Earthquake Enginnering Research Center 1988. Report No. UCB/EERC-90/11.

[110] Gutenberg B. and Richter CF. Frequency of Earthquakes in California. Bulletin of the Seismological Society of America1944; 34: 185-188.

[111] Salamon A., Hofstetter A., Garfunkel Z. and Ron H. Seismicity of the Eastern Mediterranean Region: Perspective from the Sinai Subplate. Tectonophysics 1996; 263: 293-305.

[112] Salamon A., Hofstetter A., Garfunkel Z. and Ron H. Seismotectonics of the Sinai Subplate-the Eastern Mediterranean Region. Geophysical Journal International 2003; 155: 149-173.

[113] Garfunkel Z., Zak I. and Freund R. Active Faulting in the Dead Sea Rift. Tectonophysics 1981; 80: 1–26.

[114] Reches Z. and Hoexter DF. Holocene Seismic Activity in the Dead Sea Area. Tectonophysics 1981; 80: 235-254.

[115] Marco S., Agnon A., Ellenblum R., Eidekman A., Basson U. and Boas A. 817-year-old Walls Offset Sinistrally 2.1 m by the Dead Sea Transform, Israel. Journal of Geodynamics 1997; 24:11–20.

[116] Marco S., Heimann A., Rockwell KT. and Agnon A. Late Holocene Earthquake Deformations in the Jordan Gorge Fault, Dead Sea Transform. In Abstracts of Israel Geological Society Annual Meeting. Ma’alot, 2000, p85.

[117] Zilberman E., Amit R., Heimann A. and Porat N. Changes in Holocene Paleoseismic Activity in the Hula Pull-apart Basin, Dead Sea Rift, Northern Israel. Tectonophysics 2000; 321: 237–252.

[118] Amit R., Zilberman E., Porat N., Enzel Y. Relief Inversion in the Avrona Playa as Evidence of Large-magnitude Historical Earthquakes, Southern Arava Valley, Dead Sea Rift. Quaternary Research 1999; 52 (1) 76 – 91.

[119] Zhang H. and Niemi TM. Slip Rate of the Northern Wadi Araba Fault, Dead Sea Transform, Jordan. GSA Abstracts with Programs 1999; 31, A-114.

[120] Klinger Y., Avouac J., Abou Karaki N., Dorbath L., Bourles and Reyss J. Slip Rate on the Dead Sea Transform Fault in Northern Araba Valley, Jordan. Geophysical Journal International 2000; 142: 755-768.

[121] Gomez F., Meghraoui M., Darkal AN., Sbeinati R., Darawcheh R., Tabet C., Knawlie M., Charabe M., Khair K. and Barazangi M. Coseismic Displacements along the Serghaya Fault: An Active Branch of the Dead Sea Fault System in Syria and Lebanon. Journal of the Geological Society of London 2001; 158: 405-408.

[122] Garfunkel Z. Internal Structure of the Dead Sea Leaky Transform (Rift) in Relation to Plate Kinematics. Tectonophysics 1981; 80, 81-108.

[123] Walley CD. A Braided Strike-slip Model for the Northern Continuation of the Dead Sea Fault, and its Implications to Levantine Tectonics. Tectonophysics 1988; 145: 63–72.

[124] Girdler RW. The Dead Sea Transform Fault System. Tectonophysics 1990; 180: 1–13.

[125] Gomez F., Meghraoui M., Darkal AN., Hijazi F., Mouty M., Suleiman Y., Sbeinati R., Darawcheh R., Al-Ghazzi R., Barazangi M. Holocene Faulting and Earthquake Recurrence along the Serghaya Branch of the Dead Sea Fault System in Syria and Lebanon. Geophysical Journal International 2003; 153: 1–17.

[126] Meghraoui M., Cakir Z., Masson F., Mahmoud Y., Ergintav S., Alchalbi A., Inan S., Daoud M., Yonlu O., Altunel E. Kinematic Modelling at the Triple Junction between the Anatolian, Arabian, African Plates (NW Syria and in SE Turkey). Geophysical Research Abstracts 2011; 13, EGU2011-12599, EGU General Assembly, Vienna.

[127] Karabacak V., and Altunel E. Evolution of the Northern Dead Sea Fault Zone in Southern Turkey. Journal of Geodynamics 2013; 65: 282–291.

[128] Mahmoud Y., Masson F., Meghraoui M., Cakir Z., Alchalbi A., Yavasoglu H., Yönlü O., Daoud M., Ergintav S., Inan S. Kinematic Study at the Junction of the East Anatolian Fault and the Dead Sea Fault from GPS Measurements. Journal of Geodynamics 2013; 67: 30–39.

[129] Dziewonski AM., Ekstrom G., Salganik MP. Centroid Moment Tensor Solutions for October – December 1995. Physics of the Earth and Planetary Interiors 1997; 101: 1 – 12.

[130] Garfunkel Z. The Tectonics of the Western Margins of the South Arava. PhD. thesis. The Hebrew University of Jerusalem, Israel, 1974.

[131] Ben-Avraham Z., Almagor G. and Garfunkel Z. Sediments and Structure of the Gulf of Elat (Aqaba) Northern Red Sea. Sedimentary Geology 1979; 23: 239-267.

[132] Eyal M, Eyal Y., Bartov Y. and Steinitz G. The Tectonic Development of the Western Margin of the Gulf of Eilat (Aqaba) Rift. Tectonophysics 1981, 80: 39-66.

[133] Shapira A., Jarradat M. Earthquake Risk and Loss Assessment in Aqaba and Eilat Regions. Submitted to the US Aid-Merc Program 1995.

[134] Heidbach O., and Ben-Avraham Z. Stress Evolution and Seismic Hazard of the Dead Sea Fault System. Earth and Planetary Science Letters 2007; 257: (1-2) 299-312.

[135] Pinar A. and Türkelli N. Source Inversion of the 1993 and 1995 Gulf of Aqaba Earthquakes. Tectonophysics 1997; 283: 279–288.

[136] Klinger Y., Rivera L., Haessler H. and Maurin JC. Active Faulting in the Gulf of Aqaba: New Knowledge from the M_W 7.3 Earthquake of 22 November 1995. Bulletin of Seismological Society of America 1999; 89: 1025–1036.

[137] Hofstetter A., Thio HK. and Shamir G. Source Mechanism of the 22/11/1995 Gulf of Aqaba Earthquake and its Aftershock Sequence. Journal of Seismology 2003; 7: 99-114.

[138] Abdel Fattah AK., Hussein HM. and El Hady S. Another Look at the 1993 and 1995 Gulf of Aqaba Earthquake from the Analysis of Teleseismic Waveforms. Acta Geophysica 2006; 54 (3) 260-279.

[139] Lyberis N. Tectonic Evolution of the Gulf of Suez and the Gulf of Aqaba. Tectonophyics 1988; 153: 209-220.

[140] Bayer H., Hötzl H., Jado A., Bocher B. and Voggenreiter W. Sedimentary and Structural Evolution of the Northwest Arabian Red Sea Margin. Tectonophysics 1988; 153: 137-151.

[141] Gerson R., Grossman S., Amit R. and Greenbaum N. Indicators of Faulting Events and Periods of Quiescence in Desert Alluvial Fans. Earth Surface Processes and Landforms 1993; 18: 181-202.

[142] Steinitz G., Bartov Y., and Hunziker JC. K-Ar Age Determinations of Some Miocene-Pliocene Basalts in Israel: Their Significance to the Tectonics of the Rift Valley. Geological Magazine 1978; 115: 329–340.

[143] Moustafa AR. and Khalil MH. Superposed Deformation in the Northern Suez Rift, Egypt: Relevance to Hydrocarbon Exploration. Journal of Petroleum Geology 1995; 18: 245–266.

[144] Bartov Y. A Structural and Paleographic Study of the Central Sinai Faults and Domes. PhD. thesis (in Hebrew with an English Abstract). The Hebrew University of Jerusalem, Israel; 1974.

[145] Moustafa AR. and Khalil MH. Rejuvenation of the Eastern Mediterranean Passive Continental Margin in Northern and Central Sinai: New Data from the Themed Fault. Geological Magazine 1994; 131: 435-448.

[146] El-Isa Z., Merghelani H. and Bazari M. The Gulf of Aqaba Earthquake Swarm of 1983. Geophysical Journal of the Royal Astronomical Society 1984; 76: 711-722.

[147] Ben-Menahem A., Nur A., and Vered M. Tectonics, Seismicity and Structure of the Afro-Eurasian Junction--The Breaking of an Incoherent Plate. Physics of the Earth and Planetary Interiors 1976; 12: 1-50.

[148] Gardosh M., Reches Z. and Garfunkel Z. Holocene Tectonic Deformation along the Western Margins of the Dead Sea. Tectonophysics 1990; 180: 132-137.

[149] Heimann A. The Development of the Dead Sea Rift and its Margins in Northern Israel in the Pliocene and Pleistocene. PhD. thesis. The Hebrew University of Jerusalem, Israel; 1990.

[150] Shamir G., Bartov A., Fleischer L., Arad V., Rosensaft M. Preliminary Seismic Zonation. Geological Survey of Israel. Report No. GSI/12/2001, Geophysical Institute of Israel Report No. GII 550/ 95/01/ (1); 2001.

[151] Cochran JR. A Model for the Development of the Red Sea. American Association of Petroleum Geologists Bulletin 1983; 67: 41-69.

[152] Cochran JR., Martinez F., Steckler and Hobart MA. Conrad Deep, a New Northern Red Sea Deep, Origin and Implications for Continental Rifting. Earth and Planetary Science Letters 1986; 78: 18-32.

[153] Girdler RW and Styles P. Two Stage Sea-floor Spreading. Nature1974; 247: 7-11.

[154] Roeser HA. A Detailed Magnetic Survey of the Southern Red Sea. Geologie Jahrbuch 1975; 13: 131–153.

[155] LaBrecque JL., and Zitellini N. Continuous Sea Floor Spreading in the Red Sea: An Alternative Interpretation of Magnetic Anomaly Pattern. The American Association of Petroleum Geologists Bulletin 1985; 4: 513-524.

[156] Makris J. and Rihm R. Shear-controlled Evolution of the Red Sea: Pull-Apart Model. Tectonophysics 1991; 198: 441–466.

[157] Searle RC. and Ross DA. A Geophysical Study of the Red Sea Axial Trough Between 20.58 and 22.8N. Geophysical Journal of the Royal Astronomical Society 1975; 43: 555–572.

[158] Ghebreab W. Tectonics of the Red Sea Region: Reassessed. Earth-Science Reviews 1998; 45: 1-44.

[159] Cochran JR. and Martinez F. Evidence from the Northern Red Sea on the Transition from Continental to Oceanic Rifting. Tectonophysics 1988; 153: 25-53.

[160] Bonati E. Punctiform Initiation of Seafloor Spreading in the Red Sea during Transition from a Continental to an Oceanic Rift. Nature 1985; 316: 7-33.

[161] Daggett P., Morgan P., Boulous F., Hennin S., El-Sherif A., El-Sayed A., Basta N. and Melek Y. Seismicity and Active Tectonics of the Egyptian Red Sea Margin and the Northern Red Sea. Tectonophysics 1986; 125: 313-324.

[162] McKenzie DP., Davies D. and Molnar P. Plate Tectonics of the Red Sea and East Africa. Nature 1970; 226: 243–248.

[163] Robson D. The Structure of the Gulf of Suez (Clysmic) Rift with Special Reference to the Eastern Side. Geological Society of London 1971; 115: 247-276.

[164] Garfunkel Z. and Bartov Y. The Tectonics of the Suez Rift. Geological Survey of Israel Bulletin 1977.

[165] Jackson J., White N., Garfunkel Z. and Anderson H. Relation between Normal-fault Geometry, Tilting and Vertical Motions in Extensional Terrains: An Example from the Southern Gulf of Suez. Journal of Structural Geology 1988; 10 (2) 155-170.

[166] Bosworth W. and Taviani M. Late Quaternary Reorientation of Stress Field and the Extension Direction in the Southern Gulf of Suez, Egypt: Evidence from Uplifted Coral Terraces, Mesoscopic Fault Arrays and Borehole Breakouts. Tectonics 1996; 15: 791-802.

[167] Moustafa AR. Internal Structure and Deformation of an Accommodation Zone in the Northern Part of the Suez Rift. Journal of Structural Geology 1996; 18: 93-107.

[168] Moustafa AM. Block Faulting in the Gulf of Suez. Conference Proceedings, 1976, Cairo, Egypt. 5th Egyptian General Petroleum Corporation Exploration Seminar, 35 p.

[169] Bosworth W. A High-strain Rift Model for the Southern Gulf of Suez, Egypt. In: Lambiase L L (ed.) Hydrocarbon Habitat in Rift Basins. Geological Society of London 1985. Special Publication 80, p75–102.

[170] Moustafa AR. and Fouda HG. Gebel Sufr El Dara Accommodation Zone, Southwestern Part of the Suez rift. Middle East Research Center, Ain Shams University, Earth Science Series 1988; 2: 227–239.

[171] Chorowicz J. and Sorlien C. Oblique Extensional Tectonics in the Malawi Rift, Africa. Geological Society of America Bulletin 1992; 104: 1015–1023.

[172] Maler MO. Dead Horse Graben: A West Texas Accommodation Zone. Tectonics 1990; 9: 1257–1268.

[173] Boccaletti M., Getaneh A., and Tortoorici L. The Main Ethiopian Rift: An Example of Oblique Rifting. Annales Tectonicae 1992; 6: 20–25.

[174] Lacombe O., Angelier J., Byrne D., and Dupin JM. Eocene-Oligocene Tectonics and Kinematics of the Rhine-Saone Continental Transform Zone (Eastern France). Tectonics 1993; 12: 874-888.

[175] Colletta B., Le Quellec P., Letouzey J., and Moretti I. Longitudinal Evolution of the Suez Rift Structure, Egypt. Tectonophysics 1988; 153: 221–233.

[176] Le Pichon X. and Gaulier J. The Rotation of the Arabia and Levant Fault System. Tectonophysics 1988; 153: 271-294.

[177] Mart Y. The Dead Sea Rift: From Continental Rift to Incipient Ocean. Tectonophysics 1991; 197:155–179.

[178] Ben-Menahem A. Earthquake Catalogue for the Middle East (92 BC-1980 AD). Bollettino di Geofisica Teorica e Applicata 1979; 21: 245-310.

[179] Ben-Menahem A. and Aboodi E. Tectonic Pattern in the Northern Red Sea Region. Journal of Geophysical Research 1971; 76: 2674-2689.

[180] Younes AI., and McClay K. Development of Accommodation Zones in the Gulf of Suez-Red Sea Rift, Egypt. The American Association of Petroleum Geologists Bulletin 2002; 86: 1003-1026.

[181] Fairhead JD. and Girdler RW. The Seismicity of the Red Sea, Gulf of Aden and Afar Triangle. Philosophical Transactions of the Royal Society of London 1970; 267: 49-74.

[182] Maamoun M. and El Khashab HM. Seismic Studies of the Shedwan (Red Sea) Earthquake. Helwan Institute of Astronomy and Geophysics. No. 171, 1978.

[183] Jackson JA. and McKenzei DP. Active Tectonics of the Alpine Himalayan Belt between Western Turkey and Pakistan. Geophysical Journal of the Royal Astronomical Society 1984; 77: 185-264.

[184] Huang P. and Soloman S. Centroid Depth and Mechanisms of Mid-ocean Ridge. Journal of Geological Research 1987; 92: 1361-1383.

[185] Badawy A., and Horváth F. Sinai Subplate and Kinematic Evolution of the Northern Red Sea. Journal of Geodynamics 1999a; 27: 433-450.

[186] Badawy A., and Horváth F. Seismicity of the Sinai Subplate Region: Kinematic Implications. Journal of Geodynamics 1999b; 27: 451-468.

[187] Badawy A., and Horváth F. Recent Stress Field of the Sinai Subplate Region. Tectonophysics 1999c; 304: 385-403.

[188] Badawy A. Status of the Crustal Stress as Inferred from Earthquake Focal Mechanisms and Borehole Breakouts in Egypt. Tectonophysics 2001; 343 (1-2) 49-61.

[189] El-Gaby S. Architecture of the Egyptian Basement Complex. 5th International Conference on Basement Tectonics, Egypt; 1983.

[190] El-Gaby S., List FK., and Tehrani R. Geology, Evolution and Metallogenesis of the Pan-African Belt in Egypt. In: S.El-Gaby and R. O. Greiling (eds), The Pan-African Belt of Northeast African and Adjacent Areas, Fried. Vieweg and Shon, Braun Schweig, Wiesbaden 1988, p17-68.

[191] Stern RJ., and Hedge CE. Geochronologic and Isotopic Constraints on Late Precambrian Crustal Evolution in the Eastern Desert of Egypt. American Journal of Science 1985; 285: 97-127.

[192] Issawi B. The Geology of Kurkur-Dungul Area. General Egyptian Organization for Geological Research and Mining; Cairo, Egypt. Geological Survey. No. 46, 101 pp; 1969.

[193] Issawi B. Geology of the Southwestern Desert of Egypt. Annals of the Geological Survey of Egypt 1982, 215 p.

[194] Issawi B. Geology of the Aswan Desert. Annals of the Geological Survey of Egypt; 1987.

[195] Fat-Helbary RE. A Study of the Local Earthquake Magnitude Determination Recorded by Aswan Seismic Network. MSc. thesis. Assiut University, Sohag Branch, Egypt; 1989.

[196] El-Younsy ARM., Ibrahim HA., Senosy MM. and Galal WF. Structural Characteristics and Tectonic Evolution of the Area around the Qena Bend, Middle Egypt. 6th International Conference on the Geology of Africa, 2010, Assiut, Egypt.

[197] Beadnell HJL. Dakhla Oasis, Its Topography and Geology: Egypt. Survey Department 1901; 104 Pages, 9 Maps, 7 Figures.

[198] Sandford KS. Paleolithic Man and the Nile Valley in Upper and Middle Egypt. Chicago University Oriental Institute Publications 1934; 18: 1-131.

[199] El-Gamili M. A Geophysical Interpretation of A part of the Nile Valley, Egypt Based on Gravity Data. Journal of Geology 1982. Special Volume, Part 2: 101-120.

[200] Abdel-Rahman MA., and El-Etr HA. The Orientational Characteristics of the Structure Grain of the Eastern Desert of Egypt. In: Symposium of the Evolution and Mineralization of the Arabian-Nubian Shield. Institute of Applied Geology, Jeddah, Saudi Arabia; 1978.

[201] Abdel Tawab S., Helal A., Deweidar H. and El-Sayed A. Surface Tectonic Features of 12 Oct., 1992 Earthquake, Egypt, at the Epicentral area. Ain Shams Scientific Bulletin 1993; Special Issue, p124-136.

[202] Maamoun M., Megahed A., Hussein A. and Marzouk I. Preliminary Studies on Dahashour Earthquake. National Research Institute of Astronomy and Geophysics, Cairo, Egypt. (Abstract), 1993.

[203] Mousa HH. Earthquake Activity in Egypt and Adjacent Regions and its Relation to the Geotectonic Features. MSc. thesis. Mansoura University, Egypt, 1989.

[204] Hassib GH. A Study of Focal Mechanism for Recent Earthquakes in Egypt and their Tectonic Implication. MSc thesis. Assiut University, Egypt, 1990.

[205] Megahed A. and Dessoky MM. The Ismailia (Egypt) Earthquake of January 2nd, 1987 (Location, Macroseismic Survey, Radiation Pattern of First Motion and its Tectonic Implications), 1988.

[206] Hassoup A. and Tealab A. Attenuation of Intensity in the Northern Part of Egypt Associated with the May 28, 1998 Mediterranean Earthquake. Acta Geophysica Polonica 2000; 48: 79-92.

[207] Riad S. and Hosney H. Fault Plane Solution for the Gilf Kebir Earthquake and the Tectonics of the Southern Part of the Western Desert of Egypt. Annals of the Geological Survey of Egypt 1992; 18: 239-248.

[208] Sykes LR. Intraplate Seismicity, Reactivation of Preexisting Zones of Weakness, Alkaine Magmatism and Other Tectonic Postdating Continental Fragmentation. Reviews of Geophysics and Space Physics 1987; 16: 621-688.

[209] Talwani P. and Rajendrank. Some Seismological and Geometric Features of Intraplate Earthquakes. Seismological Research Letters 1991; 59, 305-310.

[210] McKenzie D. Plate Tectonics of the Mediterranean Region. Nature1970; 326: 239-243.

[211] McKenzie D. Active Tectonics in the Mediterranean Region. Geophysical Journal of the Royal Astronomical Society 1972; 30: 109-185.

[212] Dewey JF., Pitman WC., Ryan WBF. and Bonnin J. Plate Tectonics and the Evolution of the Alpine System. Bulletin of the Geological Society of America 1973; 84: 3137-3180.

[213] Westaway R. Present-day Kinematics of the Middle East and Eastern Mediterranean. Journal of Geophysical Research 1994; 99 (6) 12071-12090.

[214] Kiratzi A. and Papazachos C. Active Crustal Deformation from the Azores Triple Junction to the Middle East. Tectonophysics 1995; 243: l-24.

[215] Ambraseys N. and Jackson J. Faulting Associated with Historical and Recent Earthquakes in the Eastern Mediterranean Region. Geophysical Journal International 1998; 133: 390-406.

[216] McClusky S., Balassanian S., Barka A., Demir C., Ergintav S., Georgiev I., Gurkan O., Hamburger M., Hurst K., Kahle H., Kastens K., Kekelidze G., King R., Kotzev V., Lenk O., Mahmoud S., Mishin A., Nadariya M., Ouzounis A., Paradissis D., Peter Y., Prilepin M., Reilinger R., Sanli I., Seeger H., Tealeb A., Toksoz MN. and Veis G. Global Positioning System Constraints on Plate Kinematics and Dynamics in the Eastern Mediterranean and Caucasus. Journal of Geophysical Research 2000; 105 (3) 5695–5719.

[217] Vidal N., Alvarez-Marron J. and Klaeschen D. Internal Configuration of the Levantine from Seismic Reflection Data (Eastern Mediterranean). Earth and Planetary Science Letters 2000a; 180: 77–89.

[218] Vidal N., Alvarez-Marron J. and Klaeschen D. The Structure of the Africa–Anatolia Plate Boundary in the Eastern Mediterranean. Tectonics 2000b, 19: 723–739.

[219] Vidal N., Klaeschen D., Kopf A., Docherty C., Von-Huene R. and Krasheninnikov VA. Seismic Images at the Convergence Zone from South of Cyprus to the Syrian Coast, Eastern Mediterranean. Tectonophysics 2000c; 329: 157–170.

[220] Papazachos BC. and Papaioannou ChA. Lithospheric Boundaries and Plate Motions in the Cyprus Area. Tectonophysics 1999; 308: 193–204.

[221] Ziegler PA. Evolution of the Arctic-North Atlantic and Western Tethys. The American Association of Petroleum Geologists Memoir 1988; 43, 198p.

[222] Meulenkamp JE., Wortel MJR., van Wamel WA., Spakman W. and Hoogerduyn Strating E. On the Hellenic Subduction Zone and the Geodynamic Evolution of Crete since the Late Middle Miocene. Tectonophysics 1988; 146: 203–215.

[223] Dewey JF., Helman ML., Turco E., Hutton DHW., and Knott SD. Kinematics of the Western Mediterranean. In: Alpine Tectonics, edited by M.P. Coward, D. Detrich and R.G. Park, Geological Society of London, Special Publication 1989, 45: 265-283.

[224] SHARE "Seismic Hazard Harmonization in Europe", 2013. http://www.share-eu.org/.

[225] Woessner J., Giardini D., and the SHARE consortium. Seismic Hazard Estimates for the Euro-Mediterranean Region: A Community-based Probabilistic Seismic Hazard Assessment. Proceedings of the 15th World Conference of Earthquake Engineering, Lisbon, Portugal, 2012.

[226] Papioannou ChA. A Model for the Shallow and Intermediate-depth Seismic Sources in the Eastern Mediterranean Region. Bollettino di Geofisica 2001; 42: 57-73.

[227] Demircioglu MB., Sesetyan K., Durukal E. and Erdik M. Assessement of Earthquake Hazard in Turkey. Conference Proceedings, 4th International Conference on Earth-

http://dx.doi.org/10.5772/58971

quake Geotechnical Engineering, 25-28 June 2007, Thessaloniki, Greece. Springer, New York.

[228] Demircioglu MB. The Earthquake Hazard and Risk Assessment for Turkey. PhD. thesis. Bogazici University, Turkey, 2010.

[229] Papazachos BC., and Comninakis PE. Geophysical Features of the Greek Island Arc and Eastern Mediterranean Ridge. Final Proceedings. Seances de la Conference Reunie a Madrid, 1969/1970. Madrid, Spain. 16: 74-75.

[230] Papazachos BC., and Comninakis PE. Geophysical and Tectonic Features of the Aegean Arc. Journal of Geophysical Research 1971; 76: 8517-8533.

[231] Comninakis PE., and Papazachos BC. Space and Time Distribution of the Intermediate Depth Earthquakes in the Hellenic Arc. Tectonophysics 1980; 70: 35-47.

[232] Papazachos BC., Papadimitriou EE., Karakostas BG. and Karakaisis GF. Long-term Prediction of Great Intermediate-Depth Earthquakes in Greece. Proceedings of the 12th Regional Seminar on Earthquake Engineering, EAEE-EPPO, Halkidiki, 1985, 1-12.