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Seismicity of the Neom Area, Northwestern Saudi Arabia

Abstract

A new seismic source model has been developed for the north-western part of Saudi Arabia, especially Neom area, which has experienced considerable earthquake activity, both in the historical and in recent times. The data used for the model include an up-to-date earthquake ($M_w \geq 3.0$) catalog, major structures and tectonic trends, aeromagnetic and gravity anomaly maps, geological maps and miscellaneous information on volcanic activity. In this study, ten seismotectonic source zones have been identified. The seismicity parameters a and b vary significantly from zone to another indicating the heterogeneities of tectonic activities affecting the area and consequently, the generation of earthquakes with different magnitudes.[35] The majority of earthquake epicenters along the Red Sea rift are clustered in an axial trough, as well as on or near some active initiated transform faults within the Red Sea basin which are attributed to stresses from magmatic activity and rifting processes.[29] Based on these results, it is indicated that the Gulf of Aqaba seismotectonic source zone is the most hazardous zone for Neom area and consequently damaging earthquakes could affect Neom area in the future, so the seismic hazard assessment of this area in terms of peak ground acceleration and the response spectra is highly recommended for the minimization and mitigation of earthquake losses.

Keywords: Seismicity, structures and tectonics, seismotectonic source, Neom area, Saudi Arabia

1. Introduction

Neom is distinguished by its unique location at the confluence of the continents of Asia and Africa. The region is blessed with a picturesque environment, and biological, topographical and geological diversity, which makes it a destination for tourists, whether from inside or outside the Kingdom. In that context, the government of the Kingdom of Saudi Arabia has initiated a major project to develop a cross-border smart city in Neom, with the project representing a huge cultural, architectural and technological leap towards a bright future for Saudi Arabia. The Neom area has, however, been affected by several earthquakes, historically (before 1900) and/or instrumentally (from 1900 till Dec. 2020). These earthquake activities arise from the complicated tectonic setting with three connected plates (the Arabian, Nubian and Sinai) and associated triple junction tectonics in the northern Red Sea (Fig.1). Understanding this tectonic environment is of utmost importance to enable a robust assessment of the potential for seismic events affecting the northern Red Sea and, especially the Neom area.

Previous earthquake studies for the northern Red Sea have shown high seismicity which is mainly attributed to the presence of the Sinai triple junction (Korrat et al., 2006; Badawy et al., 2008; Al-Amri, 2013; Zahran et al., 2016). Also, rift extensional faults in the southern Gulf of Suez and the juncture with the Gulf of Aqaba have been active from the Quaternary to the present. This is evidenced by continued seismic activity (Daggett et al., 1986; Jackson et al., 1988). Furthermore, the northern Red Sea has been studied through analysis of gravity and magnetic data (Saleh and Păsteka, 2012), revealing both the continental-oceanic crust boundary and several shallow listric normal faults spreading on the Red Sea margins in a NW–SE direction, suggesting a NE–SW extension in these regions.[34]

Based on the above-mentioned, and given also the strategic and economic importance of the Neom region of Saudi Arabia, it is important for scholars to reach a more complete understanding of the tectonic environment so as to be able to assess the potential for seismic events affecting Neom. This paper contributes to that goal by collecting earthquake data from local, regional and global data sources, and processing and auditing these data so as to develop a new seismicity map for the Neom area. It is envisaged that this will greatly support future seismic hazard assessment studies of the area.

2. Geological and tectonic setting

The Red Sea is an NNW–SSE-trending depression about 2,000 km long between the Arabian and African plates (El-Shazly 1982). Morphologically, the floor of the Red Sea consists of an elongated main trough (from 15° to 28 ° N), bisected in the south by a deeper and narrower axial trough (between 15 ° and 20 ° N) where the seafloor spreading process took place (Cochran 1983). North of 20 ° N, the axial trough becomes discontinuous, forming a series of large deeps spaced at about 50 km.[29] The region to the north of 23 ° -30 ° N represents the late stage of continental extension and is characterized by the presence of an axial depression. A Middle Triassic marine transgression from the Tethys appears to be limited to the area of northern Sinai and the Gulf of Suez. Jurassic deposits cover part of the west side of the Gulf of Suez; with Jurassic sediments distributed as far south as Wadi Araba. The sediments include fluvio-marine and marine shallow-water deposits. The maximum extension of the sea seems to have occurred during the Middle Jurassic period.

An axial trough varying from 30 km in width near 20° N and narrowing southward where it may be 5 to 14 km wide cuts the main trough. Selected topographic cross-sections reveal steep-sided walls in the axial trough and a very irregular bottom topography. A line connecting the deepest parts of the axial trough reveals sharp changes in direction, with apparent offsets.[33] The northern end of the Red Sea bifurcates into the Gulf of Suez and the Gulf of Aqaba. The Gulf of Suez is controlled primarily by normal faulting, but the Gulf of Aqaba is controlled by wrench faults. The narrow coastal plains here climb directly into fault-bounded blocks of basement rocks less than 5 to 10 km from the shoreline.

Structurally, the Red Sea is a graben along the crest of an anticline, which formed in the Arabian-African Shield. A zone of 1–2 km wide that is composed of high and tensional faults concealed by coastal sediments lies at the foot of the escarpments.[27] On the seaward side of this zone, the basement has been step-faulted downward in blocks and lies beneath the shelf area at depths of 2–3 km below sea level (Chapman 1978).[27] Two sets of faults seem to have controlled the development of the Red Sea.[27] These were the NW–SE trending main line of faults, which are associated with step faulting and the WNW–ESE major fault trend in the Precambrian basement, which caused many irregularities in the coastline.[28] The occurrence of earthquakes and active volcanisms with the axial trough indicates the present-day rifting (El-Isa and Shanti 1989; Fairhead and Girdler 1970; Al-Amri 1995).[33] Depending on the tectonics of the Red Sea–western Arabia region, there are many NE trending transform faults along the Red Sea rift system (Whiteman 1970). This is confirmed by marine and land magnetic studies, which show that some of these transform faults extend inland and displace prominent upper Cenozoic structural features (Blank 1977).

Two major Tertiary tectonic trends prevail in the region of the Red Sea and western Arabia; NW and NE faults. The NE trending faults in the Red Sea region can be placed into two categories:[31] faults controlled by older Precambrian ones and reactivated during the Tertiary, or newly formed transverse faults related to the opening of the Red Sea and ocean floor spreading. The clustering of NE trending faults in the central Red Sea and west-central Saudi Arabia is most probably related to reactivation movements along the pre-existing Precambrian faults. NW faults are responsible for the rifting and opening of the Red Sea. They form the structural basins along the coastal zones, where shallow marine Tertiary clastics were deposited (Almadani et al. 2015).

[41] At the northern end of the Red Sea, the active extensional features produced the strike-slip motion along the Gulf of Suez in addition to the sinistral shear along the Gulf of Aqaba–Dead Sea rift system (Ben-Menahem et al. 1976). It is postulated that the depressions were formed by the anticlockwise rotation of Saudi Arabia away from Africa about a pole of rotation in the central or south-central Mediterranean Sea (36.5N, 18.0E) (Le Pichon and Gaulier 1988), and that the Sinai sub-plate has moved relative to both Africa and Arabia. The Suez rift is a slightly arcuate depression extending generally NW (30-40 NW), parallel to the major normal faults. It is 69–80 km wide, and about 500 km long (Steckler et al. 1988).

3. Seismicity Assessment

[45] 3.1 Earthquake dataset collection

Earthquake dataset in and around the Neom area has been collected from local, regional and international sources; the Saudi National Seismic Network of the Saudi Geological Survey (SGS); the Seismic Studies Center (SSC) of King Saud University and King Abdul-Aziz City of Science and Technology (KACST); the International Seismological Center (ISC) and the European Mediterranean Seismological Center (EMSC). In addition, regional catalogue of Ambraseys et al., (1988) and (1994) has been integrated in this study. The collated seismological catalog of earthquake datasets covered the period from January 1900 until December 2020 and served to give an overview of earthquake activities in the study area between longitude 34° to 38° East and latitude 25° to 29° North. These data were then merged and the duplicated events were removed and then carefully reviewed and analyzed.

3.2 Earthquake data analysis and results

The catalog analysis was the principal step after collecting all the data from the different seismic networks. A number of programs, including Excel, Grapher, Spread Sheet Compare and ArcGIS, were used to analyze the raw datasets. The initial stage of analysis involved unifying the different magnitudes (M_S, M_B, M_L, M_D) into moment magnitude (M_W). The trend line fitting approach was used to calculate the inter-relationships and the following conversion equations proposed by Scordilis (2006) were used to modify the different magnitude scales into M_W:

$$M_w = 0.85\ Mb + 1.03,\quad 3.5\_mb\ \_6.2 \qquad \sigma = 0{:}29$$

$$M_w = 0.67\ Ms + 2.07,\ 3.0\_Ms\ \_6.1 \qquad \sigma = 0{:}17$$

$$M_w = 0.99\ Ms + 0.08,\ 6.2\_Ms\ \_8.2 \qquad \sigma = 0{:}20$$

Where local magnitude (M_L) and duration magnitude (M_D) were reported, the following conversion equations by Al Kathery (2010) were adopted:

$$Mw = 0.742\ M_L + 0.754,\ \sigma = 0.042$$

$$Mw = 0.843\ M_D + 0.281,\ \sigma = 0.092$$ [30]

Finally, the spatial distribution of the compiled seismicity catalogue was plotted into seismicity maps for the study area (Figs. 3 – 7).

4. Seismotectonic source zones

Seismic hazard analysis depends on the ability to identify and characterize seismic source zones. Seismotectonic zones (Fig.8) can give good idea about the association between the faults in a specific area and the locations of earthquakes. The earthquakes identified from the datasets collated in this research were therefore plotted against the structural trends using GIS. This allowed the identification of ten seismic source zones in the northern Red Sea area related to recognizable faults and seismically active geologic structures. The Gutenberg-Richter (G-R) relationship was used to describe the regional seismicity for each identified zone. The general G-R relationship between earthquake magnitude and frequency is as follows:

[55] $$Log\ N(M) = a - bM$$

or

$$N = 10^{a-bM}$$

Where N is the number of earthquakes of magnitude ≥ M, a and b are constants, and the logarithms are taken to the base 10; "a" represents the total seismicity rate, while "b" represents the magnitude-frequency distribution. The value of "a" depends on the period of observation, the size of the region considered and the level of seismic activity. Whereas that of "b"[76] depends on the ratio of the number of earthquakes in low – to high magnitude groups. The values of "b" have been reported to range from approximately 0.5 to 1.5, but mostly between 0.7 and 1.0 (Isacks and Oliver, 1964). Nevertheless, many researchers believe that "b" varies from region to region according to the focal depth. In addition, its value depends on the stress conditions and on the heterogeneity of the rock volume generating the earthquakes, (Mogi, 1962; Karnik, 1969).

The relationship between reputed surface length and magnitude was used to calculate the expected magnitude.[30] (L) can be used to estimate the most likely magnitude for a given maximum rupture, but it must be stressed that such an estimate is not maximum magnitude, but rather the magnitude that could be expected to be exceeded in 50% of the earthquakes associated with that rupture length.

$$M = 5.08 + 1.16 \cdot \log (L)$$

It is possible to use the regression models to estimate the expected magnitude. Wells and Coppersmith (1994) obtained relationships of average surface displacement and rupture length to magnitude from published reports of documented historical and recent surface ruptures. They found magnitude M and surface rupture length L using data from all types of faults. The maximum magnitude was obtained by adding 0.5 units to the maximum observed magnitude (Kijko 2004). The resulting seismotectonic zones that affect the Neom area, and their parameters, are tabulated in figure (9) and Table (1). These zones are described below:

4.1 Northwestern Saudi Arabia

On May 19th, 2009 earthquake swarm struck the area near Al-Ays City in the northwestern Saudi Arabia with 19 earthquakes of magnitude higher than M4.0 including the main M5.4 event.[29] More than 34,000 earthquakes were recorded in the northern part of the volcanic sheets of Harrat Lunayyir between April 18th and July 10th, 2009. Some of these earthquakes were felt in areas located more than 200 km away from Harrat Lunayyir. The earthquake swarm has resulted in an 8 km-long surface fault rupture trending NNW-SSE. The origin of these swarm was caused by magma rising and emplacement of a shallow subsurface dyke (Pallister et al., 2010). In this study, the datasets of Al-Ays zone revealed 45 earthquakes in this source zone with a magnitude $3.3 \leq 5.8$ in the fault zone. After applying G-R relationship to deduce the link between earthquake magnitude and frequency, the value of a was found to be 3.8539 while that of b was 0.5971.[28]

Duba seismotectonic zone includes the northeastern coastal strip of the Red Sea, where a number of earthquakes occurred parallel to the coast of the Red Sea, which confirms the presence of faults extending along the coastal strip of the Red Sea. Despite the low-moderate magnitudes of these earthquakes, it should be considered during seismicity evaluation of the northwestern Saudi Arabia and especially Neom area. Duba seismogenic zone includes 12 earthquakes with a magnitude $3.1 \leq 4.7$ in the fault zone. After applying G-R and deducing the earthquake relationship which join cumulative earthquake with the magnitude, the value of a was found to be 2.3611 while that of b was 0.4119.

4.2 Northern Red Sea axial trough

The seismic activity in the northern Red Sea tends to follow the two different structural trends and the shear zones of the Aqaba-Levant trend and the Gulf of Suez zone (Maamoun et al. 1984). The historical earthquakes that have been felt in the northern Red Sea (2200 BC to 1899 AD) were compiled by Badawy and Horvath (1999) from the Arabic documents and earlier catalogue.[31] The seismicity of Red Sea axial trough clustered on or near the transform faults of the deep axial trough in consistent with Al-Amri (1994) and supports the interpretation of the magnetic anomalies in terms of seafloor spreading.

[30] In this study, the data for northern Red Sea axial trough zone (1) included 120 earthquakes with a magnitude $3 \leq 5.7$ in the fault zone. After applying G-R and deducing the earthquake relationship which join cumulative earthquake with the magnitude, the value of a was found to be 3.9681 while that of b was 0.6487. Besides, the northern zone (2) comprises 25 earthquakes with a magnitude $3 \leq 5.1$ in the fault zone. After applying G-R and deducing the earthquake relationship which join cumulative earthquake with the magnitude, the value of a was found to be 3.8353 while that of b was 0.4993.

4.3 Southern Safaga zone

Structurally, Safaga area was subjected to different tectonic movements, leading to a complex series of normal faults with different trends, half-grabens, and folds. Khalil and McClay (2001) described extensional fault-related folding in the northwestern Red Sea. The main faults and folds are trending NNW-SSE and NW-SE. Younes and McClay (2001) indicated that the study area is characterized by Precambrian structural features of the Arabo-Nubian shield, which is a system of linear, deep-seated shear zones which were considered left lateral northwest oriented faults and shear zones (Abuzeid 1988). In this study, total of 116 earthquakes with a magnitude $3.1 \leq 5.4$ are distributed within southern Safaga zone along the northwestern coast of the Red Sea. After applying G-R and deducing the earthquake relationship which connect cumulative earthquake with the magnitude, the value of a was found to be 4.7208 while that of b was 0.9349.

4.4 Gulf of Aqaba

The Aqaba Gulf is considered as an active seismic trend where many destructive earthquakes have been occurred (Maamoun et al., 1984; Salamon et al., 1996 and Al-Arifi et al., 2013). This zone encompasses the Gulf of Aqaba and Southern end of Gulf of Aqaba where it extends between 28 and 30.9N. The earthquakes sequences of this zone mainly characterized by left-lateral strike-slip faulting mechanism along the main axis of the gulf and normal slip along transverse faults. In May 1212, the largest historical earthquake (Mw = 6.7) occurred while the largest instrumental one happened on the November 22, 1995 (Mw = 7.2). Earthquake larger than 6 is predictable with an average return period 1,000–3,000 years according to the paleoseismicity (Shapira and Jarradat, 1995). In this study, the earthquake dataset for Gulf of Aqaba zone comprised 477 earthquakes with a magnitude $3 \leq 6.2$ in the fault zone. After applying G-R and deducing the earthquake relationship which link cumulative earthquake number with the magnitude, the value of a was found to be 5.6487 while that of b was 0.866. While the southern end of Gulf of Aqaba zone has 112 earthquakes with a magnitude $3 \leq 5.3$ in the fault zone. After applying G-R and deducing the earthquake relationship which intersect the cumulative earthquakes with the magnitude, the value of a was found to be 4.1499 while that of b was 0.7022.

4.5 Gulf of Suez

The central Gulf of Suez zone includes 62 earthquakes with a magnitude $3 \leq 5.3$ along the fault zone. After applying G-R and deducing the earthquake relationship which join cumulative earthquake with the magnitude, the value of a was found to be 4.1797 while that of b was 0.7437. Recent seismic activity has been proved along the Gulf of Suez Ben-Menahem (1979) and Salamon et al. (1996). The epicentral distribution of the micro-earthquakes shows clustering beneath Gobal Island, southern Gulf of Suez, while the scattering events existed beneath the southern borders of the gulf Daggett et al. (1986). The focal mechanism solutions of March 31, 1969 earthquake revealed the continuous activity. In addition, the data for southern end Gulf of Suez zone represented by 143 earthquakes with a magnitude $3 \leq 6.2$ in the fault zone. After applying G-R and deducing the earthquake relationship which join cumulative earthquake with the magnitude, the value of a was found to be 4.2003 while that of b was 0.6315. High rate of seismicity at the southern end of the Gulf of Suez is attributed to the crustal movements among the Arabian plate, African plate, and the Sinai sub-plate (Al-Arifi et al., 2013). The activity along the Suez Gulf is supported by the recent seismic activity observed by the National Research Institute of Astronomy and Geophysics (NRIAG-Bulletins 1994–2012, Helwan Egypt).

4.6 Tabuk zone

Number of earthquakes took place in June 2004 approximately 60 km southeast of Tabuk, Saudi Arabia (Aldamegh et al., 2009). The first felt event (M_W = 3.9)[88] occurred on

June 9 and caused minor damage in the epicentral area according to the National Earthquake Information Center (NEIC, USGS) and the local reports. Another moderate size event occurred on June 22 ($M_W = 5.1$) and was followed by a few felt aftershocks without any reported damage. This earthquake sequence caused considerable alarm at Tabuk and highlights the fact that damaging earthquakes can occur in this region away from the major plate boundary in the Red Sea. Focal mechanisms indicate normal faulting mechanisms with two nodal planes-oriented NW–SE in parallel to the faults bounding the Tabuk graben and the Red Sea rift axis (Aldamegh et al., 2009; Xu et al., 2015). These events originated at shallow focal depths of 4–5 km, possibly contributing to the widely felt ground motions.

In this study, the dataset of Tabuk zone includes 27 earthquakes with a magnitude $3.1 \leq 5.1$ After applying G-R and deducing the earthquake relationship which join cumulative earthquake with the magnitude, the value of a was found to be 3.5919 while that of b was 0.6454. This zone follows NW-trending faults that represent the northern extension of the Najd Fault System. The seismicity of the zone is attributed to the reactivation movement of the preexisting faults. It is characterized by low seismic activity concentrated along Tabuk Graben.

5. Discussion and Conclusion

The study area covered the northern part of the Red Sea between longitudes 34° to 38° and latitudes 25° to 29°.[40] The level of seismic activity in the study area is high indicating complex tectonic setting that could affect the stability of this region (Merghelani, 1979). [40] The earthquakes may be related to transform faults detected in the Red Sea magnetic anomalies or they might be related to the continuing uplift of the continental crust (Fnais et al., 2014). It is also possible that the earthquakes are caused by the relative movement of Arabian, African plates and Sinai sub-plate.[35] Moreover, they demonstrate a significant rate of tectonic deformation far from the Red Sea spreading center in the center of the Red Sea, as Tabuk inland sesimogenic source zone, and along the Red Sea coastal strip, as Duba source. These results indicate the need for a more careful analysis of earthquake risk along the coast particularly at sites where major new construction is proposed.

Neom area could be affected by earthquakes from ten seismotectonic zones (Al-Ays Zone, Duba Zone, Axial trough (1), Axial trough (2), Southern Safaga, Gulf of Aqaba, Southern Gulf of Aqaba, Central Gulf of Suez, Southern Gulf of Suez and Tabuk zone). The expected magnitudes of seismic events were estimated for each zone related to the faulting activity in that zone. Overall, Neom area affected by earthquakes ranging in magnitudes between $3 \leq M_w \leq 7.2$.[29] According to above-mention results, it is revealed that the Gulf of Aqaba and southern end of the Gulf of Suez are the most hazardous seismotectonic source zones affecting Neom strategic area. Consequently, the seismic hazard of the Neom area must be assessed urgently for earthquake risk mitigation. This will help the decision and policy makers to improve land-use planning and designing earthquake-resistant structures throughout this very important and promising area in Saudi Arabia.

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References

Abuzeid HI (1988) The youngest Precambrian volcanic succession of Wadi Hamrawein, Eastern desert, Egypt, PhD. Thesis., Earth Sc. And Res. Inst.[31] South Carolina, Columbia, USA

Al-Amri AM (1994) Seismicity of the south-western region of the Arabian Shield and southern Red Sea. J Afr Earth Sci 19:17–25

Al-Amri, A. (1995): Recent seismic activity in the northern Red Sea. J. Geodynamics Vol. 20, No. 3, pp. 243-253.

Al-Arifi N. S., R. E. Fat-Helbary, Ahmad R. Khalil, Lashin A. A. (2013):[96] A new evaluation of seismic hazard for the northwestern part of Saudi Arabia. Nat Hazards DOI 10.1007/s11069-013-0756-1

Al-Amri, A. (2013): Seismotectonics and seismogenic source zones of the Arabian Platform in K. Al Hosani et al. (eds.), Lithosphere Dynamics and Sedimentary Basins: The Arabian Plate and Analogues, Frontiers in Earth Sciences, DOI: 10.1007/978-3-642-30609-9_15,

Al-Ahmadi, M.E. (2008): Hydrogeology of the Saq Aquifer Northwest of Tabuk, Northern Saudi Arabia JKAU: Earth Sci., Vol. 20 No. 1, 51-66 (2009 A.D. / 1430 A.H.).

Al-Dabbagh, M. E. (2013):[46] Effect of tectonic prominence and growth of the Arabian shield on Paleozoic sandstone successions in Saudi Arabia. Arab J Geosci (2013) 6:835–843.DOI 10.1007/s12517-011-0368-6.

Aldamegh, K. S.; Abou Elenean, K. M.; Hussein, H. M.; Rodgers, A. J. (2009): Source mechanisms of the June 2004 Tabuk earthquake sequence, Eastern Red Sea margin, Kingdom of Saudi Arabia. J Seismol. DOI 10.1007/s10950-008-9148-5

AlKathery AM (2010) Short-term and long-term seismic hazard assessment, NW Arabian Peninsula. MSc thesis, Geology Department, College of science, King Saud University, p 179

Almadani, S., A. Al-Amri, M. Fnais, K. Abdelrahman, E. Ibrahim, and E. Abdelmoneim. 2015. "Seismic Hazard Assessment for Yanbu Metropolitan Area, Western Saudi Arabia." Arabian Journal of Geosciences 8 (11):9945–58. https://doi.org/10.1007/s12517-015-1930-4.

Badawy A., Horvath F.[32] (1999) The Sinai subplate and tectonic evolution of the northern Red Sea region. Geodynamics 27:433–450

Badawy A., Mohamed A. M. S, Abu-Ali N., 2008: Seismological and GPS constraints on Sinai sub-plate motion along the Suez rift. Studia Geod. Geophys., 52, 3, 397‐412.

Baker, B., Mohr, P.A., Williams, L.A.J., 1972. Geology of the Eastern Rift System of Africa. Geol. Soc. Am. Spec. Pap. 136, 67 p.

Bayer, H.J., El-Isa, Z., Hotzl, H., Mechie, J., Prodehl, C., Saffarini,G., 1989. Large tectonic and lithospheric structures of the Red Sea Region. J. Afr. Earth Sci. 8, 565–587.

Ben-Avraham Z, Garfunkel Z, Lazar M (2008) Geology and evolution of the southern Dead Sea Fault with emphasis on subsurface structure. Ann Rev Earth Planet Sci 36:357–387.

Ben-Avraham Z, Garfunkel Z, Almagor G, Hall JH (1979) Continental breakup by a leaky transform: The Gulf of Elat (Aqaba). Science 206:214–216.[42]

Ben-Menahem A, Nur A, Vered M (1976) Tectonics, seismicity and structure of the Afro-Eurasian junction and the breaking of an incoherent plate. Phys Earth Planet Inter 12:1–50.[42]

Ben-Menahem A, Nur A, Vered M (1976) Tectonics, seismicity and structure of the Afro-Eurasian junction and the breaking of an incoherent plate. Phys Earth Planet Inter 12:1–50

Chapman, R. W. 1978. “Geomorphology.” In Quaternary Period in Saudi Arabia, 19–30. Springer.

Cochran JR (1983) A model for the development of the Red Sea. Am As Pet Geol Bull 67:40–69.

Daggett P., Morgan H., Boulos P., Hennin F. K., El-Sherif S. F., El-Sayed A. A., Basta N. Z., Melek Y. S., 1986: Seismicity and active tectonics of the Egyptian Red Sea margin and the northern Red Sea. Tectonophysics, 125, 313‑324.

Egyptian National Research Institute of Astronomy and Geophysics (NRIAG) (1994–2012) Seismological Bulletins.

El-Isa, Z. H., and A. Al Shanti. 1989. “Seismicity and Tectonics of the Red Sea and Western Arabia.” Geophysical Journal International 97 (3):449–457.

Fairhead, J. D., and R. W. Girdler. 1970. “[31]The Seismicity of the Red Sea, Gulf of Aden and Afar Triangle.” Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 267 (1181):49–74.

Fnais M. S., K. Abdelrahman, Sh. E-Hady & E. Abdel-monem (2014): Seismicity and seismotectonics of the Jeddah area, Saudi Arabia. WIT Transactions on State of the Art in Science and Engineering, Vol 79. doi:10.2495/978-1-84564-978-4/01

Garfunkel Z, Zak Y, Freund R (1981) Active faulting in the Dead Sea rift. Tectonophysics, 80:1–26.

Girdler, R.W., 1991. The Afro-Arabian Rift System, an overview. Tectonophysics 197, 139–153.

Haggag H. Mohamed (2007) Seismicity and seismotectonics of area, northern Aswan, Egypt. Exploration Geophysics, Remote Sensing and Environment, X IV. 1-2

Heaton, R.C., Jackson, M.P.A., Bamahmoud, M., Nani, A.S.O., 1995.[41] Superposed Neogene extension, contraction and salt canopy emplacement in the Yemeni Red Sea. In: Jackson, M.P.A., Roberts, D.G., W. Bosworth et al. / Journal of African Earth Sciences 43 (2005) 334–378 373Snelson, S. (Eds.), Salt Tectonics: A Global Perspective, vol. 65. American Association of Petroleum Geologists Memoir, 333–351.

Hume, W.F., 1920. Preliminary general report of the occurrences of petroleum in western Sinai. Petr. Res. Bull., 2, Ministry of Finance, Egypt, 15 p.

Jackson J. A., White N. J., Garfunkel Z., Anderson H., 1988: Relations between normal fault geometry, tilting and vertical motions in extensional terrains: an example from the southern Gulf of Suez. Journal of Structural Geology, 10, 155‐170.

Johnson, P. R. (1998).[32] Tectonic map of Saudi Arabia and adjacent areas, Technical Report USGS-TR-98-3 (IR948), Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

Khalil SM, McClay KR (2002) Extensional fault-related folding, northwestern Red Sea, Egypt. J Struct Geol 24(4):743–762

Kijko A (2004) Estimation of the maximum earthquake magnitude, Mmax. Pure Appl Geophys161:1655–1681

Korrat I. M., Hussein H. M., Marzouk I., Ibrahim E. M., Abdel-Fattah R., Hurukawa N., 2006: Seismicity of the northernmost part of the Red Sea (1995-1999) Acta Geophysica, 54, 1, 33‑49, doi: 10.2478/s11600-006-0004-0.

Laughton, A. S., 1970. A new bathymetric chart of the Red Sea: Phil. Trans. Roy. Soc. Lond., A., v. 267, 21-22.

Le Pichon X, Gaulier JM (1988) the rotation of Arabia and the Levant fault system. Tectonophysics153:271–294.

Maamoun M, Allam A, Megahed A (1984) Seismicity of Egypt. Bull HIAG, Vol. IV, Ser B:109–160.

Merghelani H. M. (1979): Seismicity of the Tihamat-Asir Region, Kingdom of Saudi Arabia. Saudi Arabian project report 261, directorate general of mineral resources ministry of petroleum and mineral resources, Jeddah, Saudi Arabia, 28p.

Saleh, S. and Paˇsteka R. (2012): [62] Applying the regularized derivatives approach in Euler deconvolution and modeling geophysical data to estimate the deep active structures for the northern Red Sea Rift region, Egypt. Contributions to Geophysics and Geodesy, Vol. 42/1, 2012 (25‑61)

Salamon A, Hofstetter A, Garfunkel Z, Ron H (1996) Seismicity of the eastern Mediterranean region: Perspective from the Sinai subplate. Tectonophysics 263:293–305.

Sandra J. Lindquist1 (1998) the Red Sea Basin Province: Sudr-Nubia and Maqna Petroleum Systems, Page 1 of 21.

Schlumberger 1995. Well evaluation conference – Egypt; Houston, Texas, U.S.A, 87p Abd El-Naby, A., M. Abd El-Aal, J. Kuss, M. Boukhary and A. Lashin (2009)

Scordilis EM (2006) Empirical global relations converting Ms and mb to moment magnitude. J Seismol. 10:225–236.

Shapira A, Jarradat M (1995): Earthquake risk and loss assessment in Aqaba and Eilat regions. Submitted to the US Aid-Merc Program

Smith, W.H.F., Sandwell, D.T., 1997.[32] Global sea floor topography from satellite altimetry and ship depth soundings. Science Magazine, 277, 1956–1962.

Stampfli, G.M., Mosar, J., Favre, P., Pillevuit, A., Vannay, J.-C., 2001.Permo-Mesozoic evolution of the western Tethys realm: The Neo-Tethys East Mediterranean Basin connection. In: Ziegler, P.A., Cavazza, W., Robertson, A.H.F., Crasquin-Soleau, S. (Eds.), Peri- Tethys Memoir 6: Peri-Tethyan Rift/Wrench Basins and Passive Margins, Me´moires du Muse´um National d!Histoire Naturelle de Paris, vol. 186,51–108.

Steckler MS, Berthelot F, Lyberis N, Le Pichon X (1988) Subsidence in the Gulf of Suez: implications for rifting and plate kinematics. Tectonophysics 153:249–270.

MacFadyen, W. A., 1930.[35] The geology of the Farsan Islands, Gizan, and Kamaran Island, Red Sea, Part I -General geology: Geol. Mag., v. 67, 310-315.

Makris, J., and C.H. Henke, 1992, Pull-apar evolution of the Red Sea, J. Petrol. Geol. 15, 2, 127-134.

McKenzie, D.P., Davies, D., Molnar, P., 1970. Plate tectonics of The Red Sea and East Africa. Nature 226, 242–248.

Mitchell, D.J.W., Allen, R.B., Salama, W., and Abouzakm, A., 1992, Tectonostratigraphic framework and hydrocarbon potential of the Red Sea: Journal of Petroleum Geology, v. 15, no. 2, 187-210.

Mohr, P. A., 1962. The geology of Ethiopia: Univ. College of Addis Ababa Press.

Moore's, E.M., and R.J. Twiss, 1995, Tectonics, W.H. Freeman and Co., New York, 415 pp.

Pallister, J., McCausland, W., Jónsson, S., Lu, Z., Zahran, H., El Hadidy, S., Aburukbah, A., Stewart, I., Lundgren, P., White, R., Moufti, M., 2010. Broad accommodation of riftrelated extension recorded by dyke intrusion in Saudi Arabia. Nature Geoscience, 3, 705-712. DOI: 10.1038/NGEO966

Whiteman, A. J. 1971. The geology of the Sudan Republic: Oxford (Clarendon Press).

Wells, D. L., and K. J. Coppersmith (1994).[81] New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, Bull. Seism. Soc. Am. 84, 974-1002.

Younes A, McClay K (2002) Development of accommodation zones in the Gulf of Suez-Red Sea Rift, Egypt. AAPG Bull 86(6):1003–1026

Xu, W., Dutta, R., and Jónsson, S. (2015): Identifying Active Faults by Improving Earthquake Locations with InSAR Data and Bayesian Estimation: The 2004 Tabuk (Saudi Arabia) Earthquake Sequence. Bulletin of the Seismological Society of America, Vol. 105, No. 2a, pp. 765–775, April 2015, doi: 10.1785/0120140289

Zahran HM, Sokolov V, Roobol MJ, Stewart ICF, El-Hadidy SY, El- Hadidy M (2016) On the development of a seismic source zonation model for seismic hazard assessment in western Saudi Arabia. J. Seismol 20(3):747–769. https://doi.org/10.1007/s10950-016-9555-y