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Seismicity and Seismotectonics of Jeddah-Makkah Region, West-Central Saudi Arabia

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ABSTRACT: Jeddah-Makkah regionis have been suffering from earthquake crisis where some moderate to destructive earthquakes have been recorded. These earthquake activities are oriented along major faults or clustered in certain spots. Moreover, these earthquake events have annual recurrence periods, so the identification of these seismogenic source zones is of utmost importance for mapping the most hazardous localities which should be avoided in the future urban planning. Historical and instrumental earthquakes have been collected from national and international data centers and unified in catalogue. The existence of microearthquakes inland suggests that there is a significant level of tectonic activity at away from the axial trough of the Red Sea. Then, seismogenic source zones have been defined depending on the major tectonic trends; distribution of earthquake epicenters, seismicity rate (a & b- values) and fault plane solution of major earthquakes. It is concluded that Jeddah-Makkah region is affected by the outlined five seismogenic source zones; three of these zones aligned of the main Red Sea axial trough (southwestern Jeddah, western Jeddah, and northwestern Jeddah zones), while the other two zones are located in the land area of the region (Thewal-Rabegh and Jeddah-Makkah zones). These inland zones correlated well with the main trends of major tectonics which refleet the reactivation of tectonic movements along these fault trends. The Red Sea zones are in agreement with the main path of the axial trough. The range of b-value in these identified zones is 0.65 to 1.03 through these identified zones. The area characterized by higher b-values could be indicative of a relative low stress regime which was a result of resulting from the stress release by the earthquakes. Whereas, the areas of lower b-values can be considered as an evidence of a relatively higher stress regime associated with a dominantly extensional stresses. Based on aforementioned, the region is suffering from different stress level accumulations which, in turn, cause earthquakes with different magnitudes. Accordingly, deployment of local seismograph network through Jeddah-Makkah region is highly recommended. These results will support, to a great extent, seismic hazard assessment and risk mitigation of the region.
KEY WORDS: seismicity, seismotectonic source zones, b-value, Jeddah.

0 INTRODUCTION

Jeddah-Makkah region lies in the west-central part of Saudi Arabia along the eastern coast of the Red Sea (Fig. 1). Jeddah City represents the second major city in the whole Saudi Arabia because: 1) it has one of the most famous marine harbors along the Red Sea coast; 2) it has a lot of strategic industries, multi-national commercial companies and development projects; 3) it has a huge number of population of about 2.5 millions of national citizens and residents and 4) it receives millions of Muslims for the annual pilgrimage at Makkah Al- Mukarramah (about 70 km east of Jeddah City) and throughout the year for the lesser pilgrimage the Umrah. Moreover, Jeddah-Makkah region located close to the Red Sea, is suffering from continuous geodynamic movement that cause of Red Sea floor spreading which is accompanied by earthquake occurrences. Actually, Jeddah-Makkah region experienced some destructive earthquakes in historical and recent times. The maximum recorded earthquake had moment magnitude (M_w) of 7.2 in 1967 and it is located southwest of Jeddah City along the main axial trough of Red Sea. This earthquake affected Jeddah-Makkah region and adjacent zones. Moreover, Makkah was shocked on September 28th, 1993 by an earthquake with magnitude 3.6 from Al-Sharai'a, 30 km northeast of the Holy Mosques. Another earthquake swarm was occurred at Al-Sharai'a in Oct. 3rd, 1993, with the maximum magnitude of 4.1 (Al-Furaih et al., 1994; Swolfs, 1994). Furthermore, another earthquake with magnitude of 3.6 was recorded in June 18th, 1994. These earthquakes have frequently annual recurrences which, in turn, generatehazardous areas through the region.

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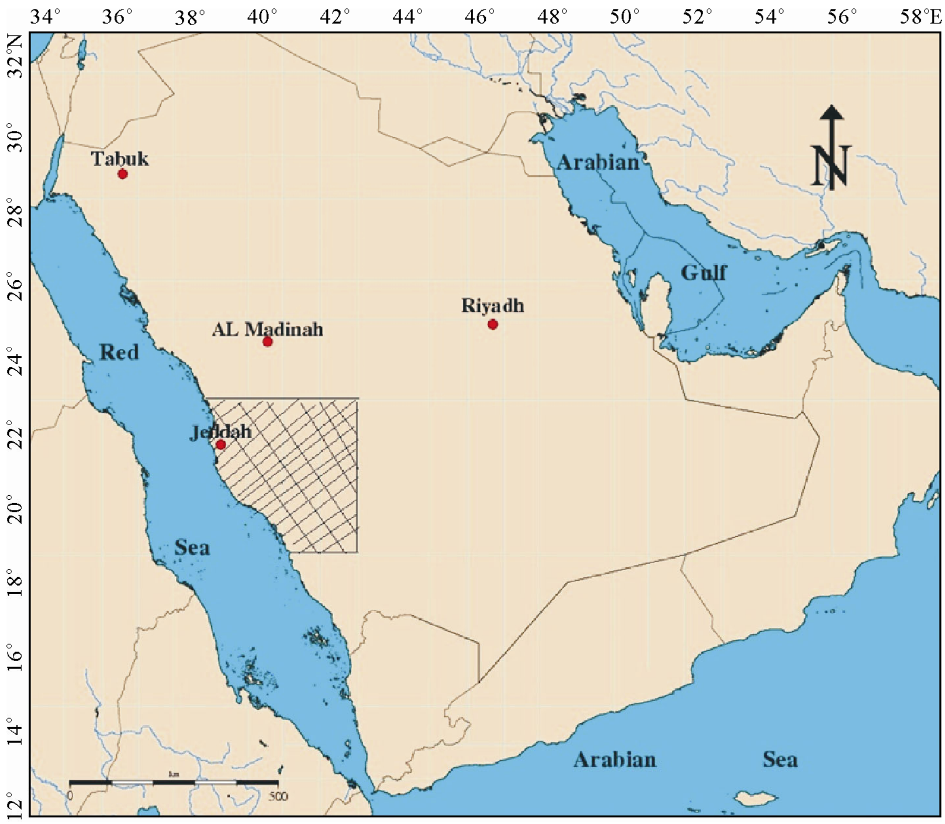

Figure 1. Location map for Jeddah area.

Despite aforementioned,this region has not been studied in terms of earthquake activities and their relation to the prevailing faults through the region. So, this study has been suggested to throw the light on the recent earthquake activities with the major fault trends. Results of the current work will greatly support the seismic hazard assessment and risk mitigation studies of the region.

1 GEOLOGICAL SETTING

The region is constituted by three main physiographic provinces arranged from west to east as follows: 1) Coastal plains of Tihamat-Al Hijaz that consists of Quaternary alluvium and eolian sand and form a seam approximately 50 km wide along the Red Sea coast. 2) Mountainous region of the Hijaz mountains with Precambrian largely eroded and dissected rocks. The region is locally overlain by rather young Tertiary to Quaternary or even historic deposits and basaltic lava flows of HarratRahat, which occupy the northeastern to central parts of the investigation area, and 3) central cratonic plateau that composed of alluvial plains and located at eastern part of the mountainous region. The most prominent geomorphologic feature of the investigation area is the escarpment in the western part of the city of Ta'if. Thus the mountain peaks of the coastal ridges near Jeddah and Makkah have an average elevation of 300–500 m while those around Ta'if are 2 000 m or more.

Geologically, Jeddah-Makkah region occupies a part of the western Arabian Shield, which is covered with Neoproterozoic rocks consisting of various types of volcanics and volcaniclastics, together with several varieties of intrusives (diorites, granodiorites and granites). These rocks are covered with Tertiary and Quaternary lavas and sediments and in some places with recent sediments and sabkhas. Three distinct geologic units could be distinguished in the region, and from the oldest to the youngestare, the Neoproterozoic basement, the Tertiary sediments and lavas, and the Holocene sediments and sabkhas. The Neoproterozoic rocks lie in the eastern part of the region. They consist of volcanic rocks, comprising andesite and dacite, intruded by plutonic rocks including diorite and granite. Shumaysi, Usfan and Hadat Ash-Sham Formations that are covered with basaltic lavas represent the Tertiary rocks recorded in the area east of Jeddah City. The Holocene unit includes the recently emerged marine deposits and corals, the recent basaltic lava flows, the wadi alluvium, sabkha deposits and the Aeolian sands along the coastal plain and pediments (Moore and Al-Rehaili, 1989).

The extention of the Red Sea coastal plain is parallel to Red Sea rift that was formed as a result of the divergence movements between the African and Arabian plates since the Oligo-Miocene time. The sedimentary along the coastal plain ranges in age from Tertiary to Quaternary and rests unconformably on the Precambrian igneous and metamorphic rocks of the Arabian–Nubian Shield. It can be divided into a pre-rift (Pre-Oligo-Miocene) sequence overlain, with a major angular unconformity, by a syn-rift (Oligo-Miocene to Quaternary) succession. The structural architecture of the Red Sea coastal plain has been discussed (Skiba et al., 1977; Greenwood et al., 1976). There are different tectonic trends which are clearly identified through the region (Fig. 2) as follows: N-S and NE-SW tectonic trends prevailing an area of approximately 600 km along the Red Sea coast, extending from Al-Lith to Yanbu and 150 km

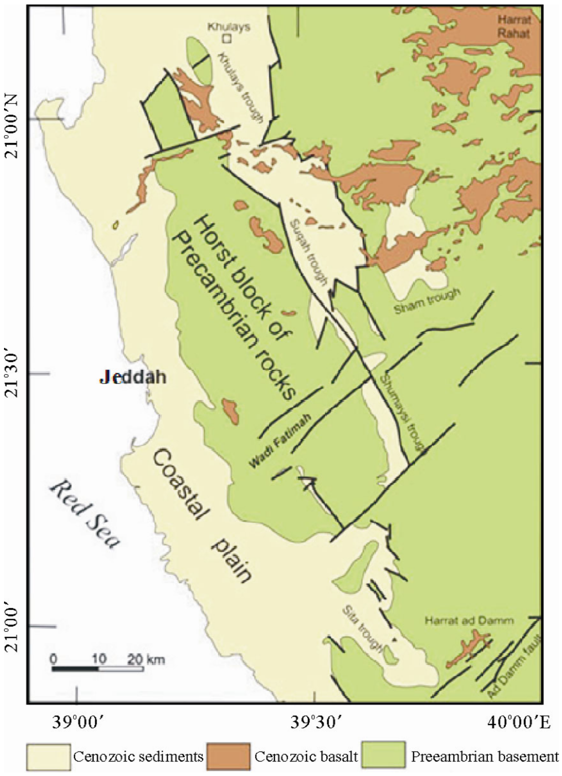

Figure 2. Inland affecting structures of Jeddah area.

inland, the trend of these lineaments as well as the lithostratigraphic belts attain NE direction (El-Isa and Al-Shanti, 1989). There are three of major faults (e.g., Ad Damm and wadi Fatima faults to the south of Jeddah and BirUmq fault to the north) are well documented in the area. These structural trends reflect the major phases of Precambrian deformation and Tertiary faulting. Moreover, SharmUbhur is interpreted by same authors (Moore and Al-Rehaili, 1989; Coleman, 1984; Schmidt et al., 1982) to be an inland extension of the transform faults that compensate the differential movementbetween the different parts of the spreading ocean crust beneath the Red Sea.

Thehorst-graben and step-faulting nature of Red Sea Rift fracturing is a spectacular feature in the adjacent Wadi Fatima (Nebertet et al., 1974; Al-Shanti, 1966). Strike-slip and oblique movements are occurred along faults of this trend as well. Al-Shanti's (1966) studied the regional and local faults in the Shumaysi area and presented the predominance of NW-NNW-trending, gentle to steep, horst-graben structures. These trends are displaced by N15°E–N40°E trending faults separated from NNW trending Red Sea Rift fractures (Al-Shanti, 1966). However, a few characteristic gabbroic dykes cutting all other mafic and felsic dykes in the area are tentatively interpreted as related to late volcanism. Some of E-W fractures appear to be contemporaneous. They could represent cross joints related to the longitudinal N-S set. South of the catchment area, at AlLith, hot springs occur along N-S fractures (Loupoukhine and Stieltjes, 1974).

2 SEISMICITY OF THE REGION

According to El-Isa and Al-Shanti (1989), there are two historical earthquakes have been occurred on 1 481 and 1 270 in the land around Jeddah-Al-Ta'if area. The instrumental earthquake catalogue for Jeddah-Makkahregion has been collected from 1964 to 2010 from different sources as follows; Saudi Geological Survey (SGS); Seismic Studies Center (SSC) of King Saud University, and King Abdul-Aziz City of Science and Technology (KACST). Microeathquake activities of Jeddah-Makkah region are also included (Merghalani and Gallanthine 1981). Then, these data are merged, precisely reviewed, re-analyzed and refined from the duplicated events. The global sources of earthquake data like the International Seismological Center (ISC); United States Geological Survey (USGS); and the European Mediterranean Seismological Centre (EMSC) have been used in this study for verification of the compiled catalogue. The foreshock and aftershock sequences have been omitted from the catalogue using the windowing procedure proposed by Gardner and Knopoff (1974). Relation of Scordilis (2006) has been used to unify different magnitude scales into moment magnitude. Finally, spatial distribution of the compiled catalogue has been plotted into maps describing the seismicity of the region in terms of magnitude (Figs. 3, 5).

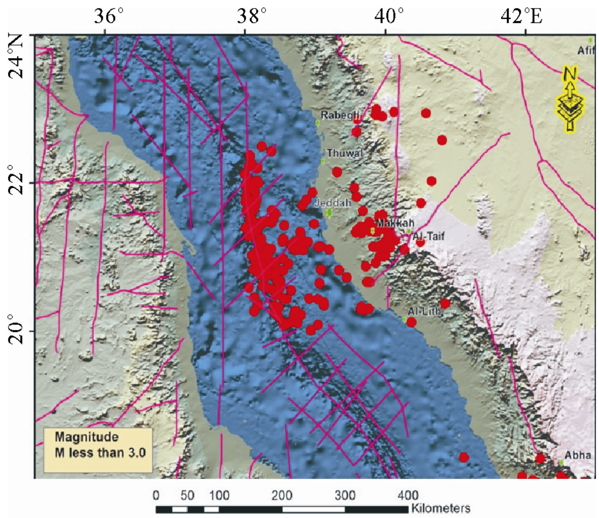

Figure 3. Distribution of earthquakes with M_w<3.0 through Jeddah region.

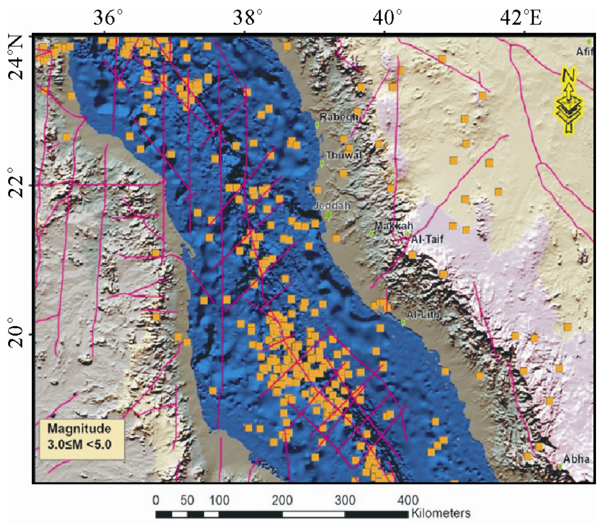

Figure 4. Distribution of earthquakes with 3.0≤M_w<5.0.

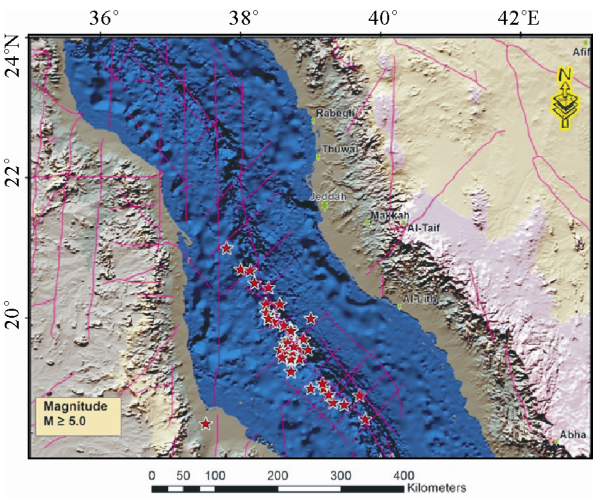

Figure 5. Distribution of earthquakes with $M_w \leq 5.0$ through Jeddah region.

Based on these figures it can be noticed that, 1) all earthquakes with magnitude greater than 5 have been occurred along the Red Sea main axial trough with maximum earthquake magnitude (M_w) of 7.2 in 1967; 2) earthquakes with magnitudes less than 5 have been occurred along the Red Sea axial trough and in land as well. These earthquakes are aligned along major faults and clustered in a certain spots.

3 FOCAL MECHANISM

Fourty-eight earthquake mehanisms have been conducted and compared with the previous investigations (Al-Saud, 2008; Al-Arifi, 2002) and the catalogue of Harvard moment tensor solutions (Tables 1 and 2). Twenty-one of these mechanism solutions are located in the Red Sea for identification of the focal mechanism for the Red Sea axial trough and the transform faults as well while the other mechanism solutions have been used to define the tectonic movements inland through Jeddah-Makkah region (Fig. 6).

4 SEISMOTECTONIC ZONES

Five seismotectonic zones have been identified (Fig. 7), depending on the distribution of earthquakes, fault parameters (strike and dip) of the major structural trend, seismicity parameters (a & b-values, Table 3 and Figs. 8 to 12) and previous geological and geophysical studies (Alwash and Zakir (1992); Al-Garni (2009) and Al-Garni et al. (2012)). Three zones located along the Red Sea axial trough (Northwestern Jeddah, Western Jeddah and Southwestern Jeddah zones), while the other two zones located inland (Thuwal-Rebegh and Jeddah-Makkah zones).

4.1 Jeddah-Makkah Zone (JMZ)

This zone includes the total area of Jeddah-Makkah region and general NE-SW orientation. This zone includes two of major tectonic trends, 1) Wadi Fatima, which is the major fault bounded graben with a length of about 50 km and a width up to 10 km at its southwestern end; and 2) Ad-Dam active fault, which is oneof major fault trendsthrough Jeddah-Makkah region. This zone has a low b-value (0.65) that can be interpreted as an evidence of a relatively higher stress regime associated with an area of dominantly extensional stress (Farrell et al., 2009; Wyss, 1973; Scholz, 1968). The earthquakes of this zone are of crustal origin where the focal depth of earthquakes ranges from 10 to 20 km.

Wadi Fatimah occupies a large area of the southern and eastern parts of Jeddah Governate. The main wadi extends from ENE to WSW along most of its course; however, south of Jeddah City abruptly diverts its orientation towards the north, possibly due to active faulting (Azzedine et al., 1998). The main wadi describes a linear E-W course at its eastern part and a linear N-S course near the industrial city south of Jeddah harbor indicating a subsequent stream (Qari, 2009). The NE-SW major graben has an old faulting trend that is dissected by numerous NW-SE faults, related to the Red Sea tectonics (Al-Garni, 2009). The presence of NNE fractures suggests that the area belongs to the conjugate set Tertiary fractures.

According to Fleck et al. (1980), Ad Damm fault may have originated as an antithetic fault of the prominent Najd Fault system of the central Shield in response to E-W compression during Late Precambrian collision. Davies (1984) suggested that, Ad Damm fault originated as a conjugate fault of the Najd fault. These interpretations were questioned by Stern (1985) who considered the Ad Datum fault was older than the Najd Fault. The Ad Datum fault has remained a zone of crustal weakness until today. Moreover, Alwash and Zakir (1992) stated that, the Precambrian faults were reactivated by movement and volcanism (Harrat Ad Datum) related to the formation of the Red Sea. Sense of late displacement along the Ash Shamiyyah and Na'man-Yarujj shear zones is right-lateral. Fractures of NNW-NNE, ENE-E and WNW-Ware probably somewhat contemporaneousand are tentatively interpreted in terms of asystem with conjugate sets related to an approximately N-S oriented axis of maximum stress.

4.2 Thuwal-Rabegh Zone (TRZ)

This zone covers the area from the north of Jeddah till Rabegh including Wadi Thuwal area and oriented generally NE to NNE. Earthquake activitiesthrough this zone characterized by small to moderate magnitudes ($M_w \leq 5$) that can be considered as an indicator for tectonic activity of fault trends through this zone. The previous geophysical investigations have confirmed the presence of major NE-SW and NNE-SSW fault trends through Wadi Thuwal area. Furthermore, evidences of shear zones are observed close to Harrat Thuwal (Al-Garni et al., 2012). This zone has a higher b-value (1.03) that can be interpreted as an evidence of a relatively lower stress regime associated with an area of dominantly extensional stress (Farrell et al., 2009). The earthquakes in this zone have relatively shallow depth and are of crustal origin.

4.3 Northwestern Jeddah Zone (NJZ)

This N-S zone is parallel to the main Red Sea axial trough in this segment. It has b-value of 0.71 (Fig. 10) which indicates relatively higher stress regime and or lower material heterogeneities (Mogi, 1962). However, there are no earthquakes mechanisms available through this zone, the borders of this zone have been identified upon the main path of the axial

Table 1 Source parameters for the earthquakes

No.	Day	Month	Year	Lat.. (N)	Long.. (E)	Depth (km)	Mag..	Time (GMT)
1	28	11	1981	21.077	39.997	10	2.41	
2	28	11	1981	21.07	39.926	20	1.05	
3	5	12	1981	21.125	40.068	33	1.89	
4	14	12	1981	21.295	40.078	29	2.17	
5	16	12	1981	21.095	39.929	10	1.61	
6	24	12	1981	21.268	39.90	15	2.12	
7	28	12	1981	21.122	40.002	25	1.88	
8	28	12	1981	21.111	40.012	20	1.87	
9	31	12	1981	21.175	39.968	10	2.23	
10	2	1	1982	21.052	39.997	20	1.58	
11	11	1	1982	21.343	40.029	--	2.11	
12	25	1	1982	21.125	40.068	33	1.89	
13	2	2	1982	21.009	39.965	20	1.87	
14	7	2	1982	21.002	39.917	20	1.77	
15	25	11	1982	21.215	40.139	15	1.97	
16	19	12	1982	21.179	40.151	--	2.85	
17	26	12	1982	21.304	40.08	---	2.11	
18	29	12	1982	21.34	40.10	--	2.49	
19	7	3	1983	21.156	40.066	--	2.42	
20	19	3	1994	21.414	39.872	--	1.68	
21	24	3	1994	21.357	39.868	--	1.74	
22	26	3	1994	21.389	39.857	--	1.9	
23	19	11	1995	21.35	39.78 0	3.96	1.62	
24	3	1	1996	21.35	40.02 0	7.67	1.57	
25	5	1	1996	21.4 4	40.0 4	4.08	1.47	
26	7	1	1996	21.35	40.02	7.67	1.57	
27	14	1	1996	21.350	40.01	6.62	1.62	
28	2	7	2006	19.33	38.38	12	4.7	23:45:00
29	12	3	1993	19.63	38.65	15	4.7	23:32:46
30	23	3	1993	19.59	38.69	16	5.2	00:59:33
31	14	3	1993	19.56	38.65	15	4.7	14:49:18
32	22	3	1993	19.52	38.81	10	4.9	20:51:37
33	15	3	1993	19.49	38.74	15	5	1:38:13
34	12	3	1993	19.59	38.66	15	5.1	4:24:20
35	13	3	1993	19.65	38.74	10	4.8	8:12:13
36	11	3	1993	19.55	38.67	15	5	8:19:46
37	16	3	1993	19.5	38.80	15	5.4	11:59:26
38	9	3	1993	19.61	38.662	15	4.8	20:43:31
39	19	3	1993	19.615	38.75	15	4.6	00:20:48
40	2	11	1996	19.23	39.25	15	5	13:50:33
41	14	3	1993	19.5	38.77	15	4.9	8:12:13
42	13	3	1967	19.7	38.70	33	5.8	19:22:19
43	13	3	1993	19.4	38.77	10	4.9	13:59:59
44	23	3	1994	19.523	38.704	10	4.5	4:05:22
45	13	3	1993	19.67	38.75	10	5.7	17:12:26
46	20	2	1993	19.3	39.02	10	5.1	6:05:03
47	5	2	2009	19.03	39.26	12	4.8	21:36:13.3
48	9	8	2010	18.72	39.46	17.5	4.4	9:11:7.7

Table 2 Focal mechanism solutions of the selected earthquakes through the area of interest

No.	Date			Lat.. (N)	Long.. (E)	S1 D1	S2 D2	Slip vector	Stress axes
						Strik1 Dip1 Rak1	Strik2 Dip2 Rak2	SV1/SV2	*P*-axis *T*-axis
	Day	Month	Year						az. pl. az. pl.
1	28	11	1981	21.077	39.997	243 46	033 49	283 166	74 233 02 137
2	28	11	1981	21.07	39.926	037 89	127 89	317 151	01 82 01 352
3	5	12	1981	21.125	40.068	243 46	033 49	319 156	74 233 02 137
4	14	12	1981	21.295	40.078	011 51	141 77	284 167	03 311 57 217
5	16	12	1981	21.095	39.929	141 77	047 74	316 235	04 21 -86 02
6	24	12	1981	21.268	39.9	037 89	127 89	037 129	01 82 01 352
7	28	12	1981	21.122	40.002	037 89	127 89	032 130	01 82 01 352
8	28	12	1981	21.111	40.012	037 89	127 89	031 127	01 82 01 352
9	31	12	1981	21.175	39.968	243 46	033 49	313 153	74 233 02 137
10	2	1	1982	21.052	39.997	243 46	033 49	321 156	74 233 02 137
11	11	1	1982	21.343	40.029	037 89	127 89	033 128	01 82 01 352
12	25	1	1982	21.125	40.068	037 89	127 89	037 125	01 82 01 352
13	2	2	1982	21.009	39.965	037 89	127 89	031 131	01 82 01 352
14	7	2	1982	21.002	39.917	037 89	127 89	032 131	01 82 01 352
15	25	11	1982	21.215	40.139	243 46	033 49	318 155	74 233 02 137
16	19	12	1982	21.179	40.151	037 89	127 89	037 131	01 82 01 352
17	26	12	1982	21.304	40.08	243 46	033 49	317 158	74 233 02 137
18	29	12	1982	21.34	40.1	278 68	162 42	063 188	144 52 34 15
19	7	3	1983	21.156	40.066	037 89	127 89	038 130	01 82 01 352
20	19	3	1994	21.414	39.872	141 77	047 74	314 233	04 21 -86 02
21	24	3	1994	21.357	39.868	141 77	047 74	317 231	04 21 -86 02
22	26	3	1994	21.389	39.857	141 77	047 74	315 234	04 21 -86 02
23	19	11	1995	21.35	39.78 0	355 81	111 22	331 238	67 35 282 50
24	3	1	1996	21.35	40.02 0	135 77	263 25	327 264	-142 26 72 53
25	5	1	1996	21.4 4	40.0 4	345 83	248 36	321 241	103 32 228 44
26	7	1	1996	21.35	40.02	316 61	179 40	328 252	61 17 179 69
27	14	1	1996	21.350	40.01	349 81	245 32	321 246	105 30 226 47
28	2	7	2006	19.33	38.38	22 45 -86	196 45 -94		
29	12	3	1993	19.63	38.65	325.2 65.9 -155	224.4 67.3 -26.2		184.5 34.1 275.1 0.9
30	23	3	1993	19.59	38.69	51.7 71.9 167.7	145.5 78.3 18.5		277.8 4.4 9.5 21.3
31	14	3	1993	19.56	38.65	357.9 47.4 -139.8	238.1 61.6 -50.3		199.3 54.5 300.9 8.2
32	22	3	1993	19.52	38.81	326.5 74 -39	69.3 52.4 -159.6		281 38.8 22.3 13.6
33	15	3	1993	19.49	38.74	311 67.8 -171.2	217.5 81.9 22.5		172.1 21.6 266 9.7
34	12	3	1993	19.59	38.66	320 59 -94	148 31 -83		218 75 53 14
35	13	3	1993	19.65	38.74	301 45 -90	121 45 -90		121 90 211 00
36	11	3	1993	19.55	38.67	336.6 76 -149.3	238.3 60.3 -16.5		202.4 31.3 106 10.3
37	16	3	1993	19.5	38.8	346.1 72 -149.5	245.8 61.2 -20.7		206 10.6 112 22
38	9	3	1993	19.61	38.662	336.6 78.6 -35.2	74.6 55.6 -166.1		290 32.6 29.9 15
39	19	3	1993	19.615	38.75	306.3 64 -50.4	64.2 46.2 -142.6		264.9 53 9 10.3
40	2	11	1996	19.23	39.25	310 72 -98	153 20 -68		208 63 46 26
41	14	3	1993	19.5	38.77	333.9 76 -150.7	236.2 61.6 -15.9		198.7 32.6 103.7 7.7
42	13	3	1967	19.7	38.7	334 70 -11	68 80 -160		292 22 200 7
43	13	3	1993	19.4	38.77	322.4 49.2 -164.1	221.9 78 -42		167.7 28.7 266.5 15.6
44	23	3	1994	19.523	38.704	305.9 63.2 -270	125.9 26.8 -90		216 72 36 18.2
45	13	3	1993	19.67	38.75	173.2 80.2 159.9	266.8 70.2 10.4		193 84 50 5
46	20	2	1993	19.3	39.02	313 45 -90	133 45 -90		133 90 223 00
47	5	2	2009	19.03	39.26	106 49 -127	335 53 -55		
48	9	8	2010	18.72	39.46	329 29 -59	114 66 -106		

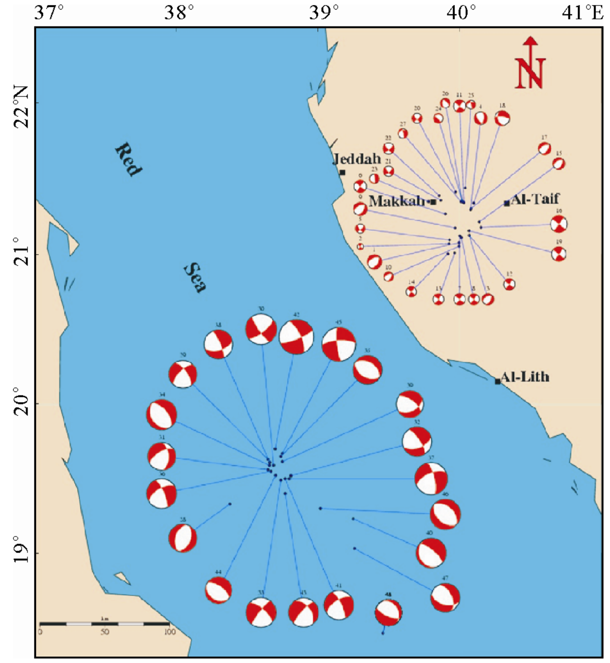

Figure 6. Focal mechanism solutions for some earthquakes through the region.

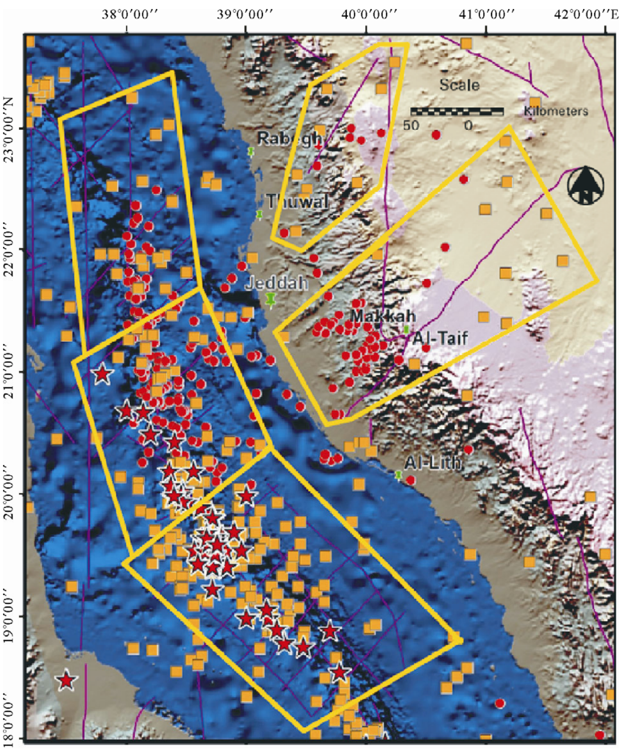

Figure 7. Seismotectonic source zones affecting Jeddah-Makkah region.

trough of the Red Sea. The focal depth of earthquakes through this zone lies in the range of less than 3 to 5 Vnit.

4.4 Western Jeddah Zone (WJZ)

Thegeneral trend of this zone has been shifted slightly to-the west and gains the NNW-SSE direction. The main b-value of this zone is 0.77 (Fig. 11) indicatingthe relatively higher

Table 3 Seismicity parameters for the identified source zones

Zone No.	Zone Name	a	b	M_{max} (observed)
1	Jeddah-Makkah	1.77	0.65	4.2
2	Thuwal-Rabegh	2.58	1.03	3.8
3	Northwestern Jeddah	2.31	0.71	4.5
4	Western Jeddah	2.98	0.77	5.4
5	Southwestern Jeddah	4.42	0.91	7.2

a & b are seismicity parameters; $M_{max\ (observed)}$ is the maximum observed magnitude.

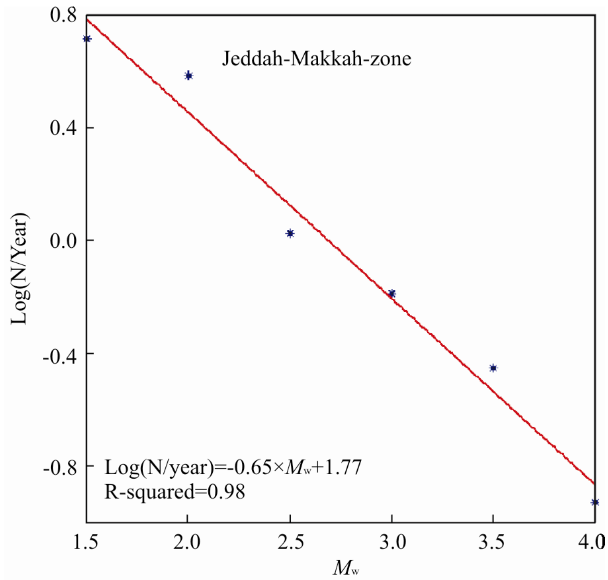

Figure 8. Gutenberg-Richter Relation for Jeddah- Makkah zone.

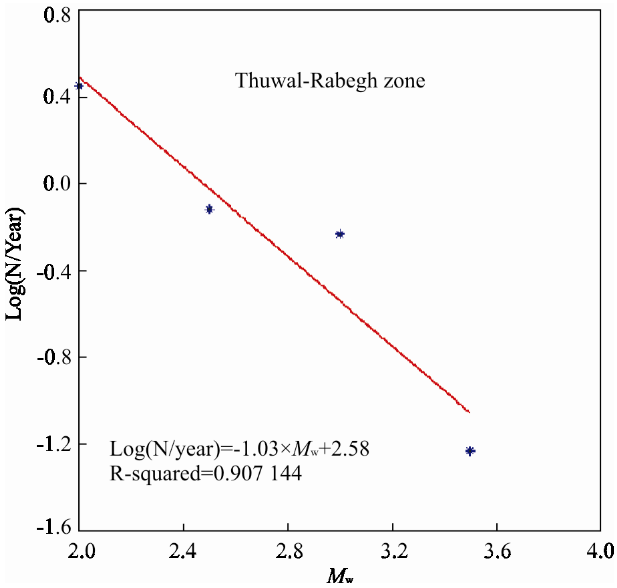

Figure 9. Gutenberg-Richter Relation for Thuwal-Rabegh zone.

stress regime. This zone has been outlined according to the main axial trough of the Red Sea. There are no focal mechanisms for earthquakes through this segment of the Red Sea. The depth of earthquakes in this zone ranges from less than 3 to greater than 5.

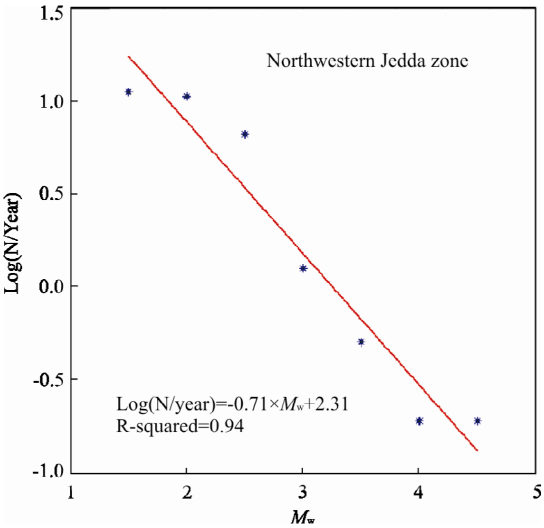

Figure 10. Gutenberg-Richter Relation for Northwestern Jeddah zone.

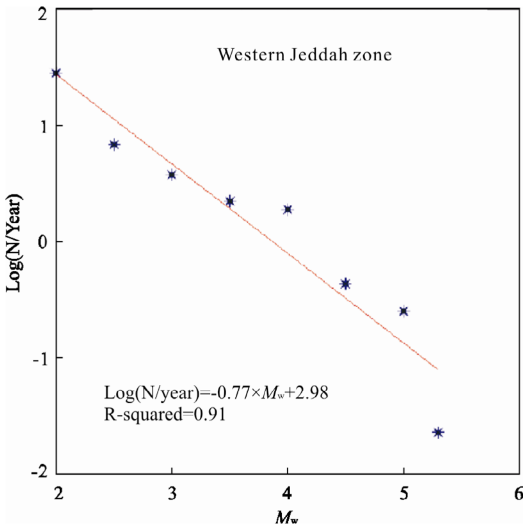

Figure 11. Gutenberg-Richter Relation for Western Jeddah zone.

4.5 Southwestern Jeddah Zone (SJZ)

This NW-SE zone is parallel to the main axial Red Sea trough in this segment. Figure 12 presents a higher b-value (0.91) illustrating the relatively higher stress regime and/or the material heterogeneities. This is confirmed by strike-slip and normal focal mechanisms that have been clarified through this zone. The earthquakes are of relatively deeper depth where the maximum depth reached 65 km. However, this great depth has been recorded in 1967, but the depth has been controlled recently by adding more and well azimuthally coverage of Saudi Geological Survey stations.

5 DISCUSSION AND CONCLUSIONS

It is noticed that the distribution of earthquakes are aligned through main trends either in the Red Sea or in land. This phenomenon clearly indicates the prevailing tectonic activity along these trends. Makkah Al-Mokaramah is bounded by two of these tectonic trends and oriented northeast.

Based on the analysis of earthquake catalogue it can be

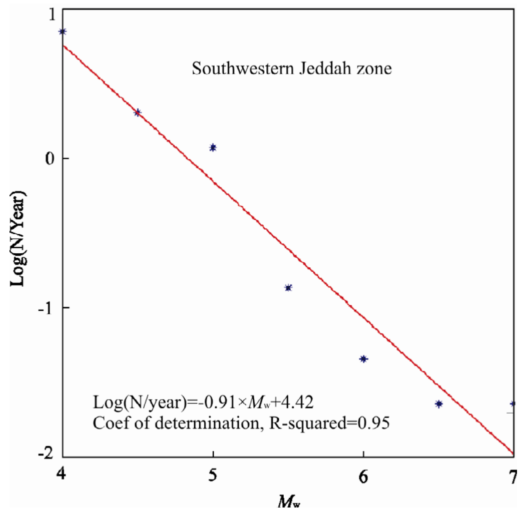

Figure 12. Gutenberg-Richter Relation for Southwestern Jeddah zone.

noticed that, the area has been affected by wide range of magnitudes with 7.2 M_{max} that occurred in 1967. Accordingly, the earthquake data has been classified into three main categories according to their magnitudes (M_w≤3.0; 3≤ M_w<5.0 and M_w≥5.0). It is noticed that all earthquakes with magnitudes greater than 5.0 have been occurred along the Red Sea main trough, while earthquakes with magnitudes less than 5.0 have recorded inland. According to earthquake epicenteral pattern, directions of the fault trends from the geological and geophysical studies and the seismicity parameters (a & b-value); the main seismotectonic source zones that affecting Jeddah area have been identified; northwestern Jeddah; western Jeddah; southwestern Jeddah; Thuwal-Rabegh and Jeddah-Makkah zones.

The seismotectonic zones of Thuwal-Rabegh and Jeddah-Makkah are closely related and then they are very important for the area of study due to their recent tectonic activities and earthquake occurrences. Thuwal-Rabegh zone has major NE fault trends as well as the presence of shear zone close to HarratThuwal. On the other hand, Jeddah-Makkah earthquake source is one of the recent earthquake prone sources, due to the presence of major tectonic fault trends of Wadi Fatima and Ad Dam and other fault trends through this zone. Among the three zones of the Red Sea, the main axial trough of the Red Sea is changed, reflecting sever tectonic movements the Red Sea. As well as the general trend of the coastline changes parallel to that occurs in the Red Sea which indicates the correlatio between the coastline and the main axial trough of the Red Sea. This change of axial direction of the Red Sea shows the presence of transform faults (NE-SW) dissected the main axial trough of the Red Sea and extends towards the coast line and disappears underneath the Arabian Shield rocks.

Al-Saud (2008) studied the seismic characteristics and kinematic models of the area and divided Jeddah area into four seismotectonic zones, some of these zones are intersected and it indicates the complicated tectonics of Jeddah area. Other observation is that two of these suggested zones are extended from the Red Sea axial trough into land, even this is cannot be accepted because these are two different tectonic environments, which represents the extension of earthquake activities from the Red Sea into land along the transform faults. Moreover, the deep seismic profiling that carried out through Jeddah (Hansen et al., 2007) indicates mantel upwelling through the area which exerts the stresses along the pre-existing faults and then generate earthquakes.

According to the aforementioned, the area is suffering from earthquake activities and owing to the great urbanization and industrial development plans of Jeddah area, it is highly recommended that, the detailed earthquake monitoring must be applied through deployment of seismic network especially in the area of the active tectonic trends before new construction operations.

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