

# THE QUANTITATIVE SEISMICITY MAPS OF THE ARABIAN PENINSULA AND ADJOINING AREAS

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## ABSTRACT

Three quantitative seismicity maps, the a-value map, the b-value map and the estimated maximum magnitude map, have been prepared for the Arabian Peninsula and surroundings. For preparation of these maps, the frequency- magnitude relation has been used where the constants a and b were estimated using maximum likelihood method. These maps are superimposed on the modified seismotectonic map of Arabian peninsula. These quantitative seismicity maps reveal that the Arabian peninsula consists of four high seismic activity zones: Zagros high, Dead sea rift system high, southern Red sea high and Gulf of Aden and Arab sea high. The b-values determined by this study are compared with those determined by other workers for various regions in the Arabian peninsula. They show a good agreement. The maximum magnitude map reveals a  $M_{max}$  highs comparable with the a and b highs.

## INTRODUCTION

The seismicity of the region expressed in quantitative terms is always more meaningful than just presenting maps showing the location of epicenters of earthquakes because the former enable one to compare the relative seismicity level of different regions of the earth and their tectonic relations. The seismicity parameters were introduced by Gutenberg and Richter (1954) in their pioneer work in 1954.

Several investigation (e.g., Ritsema, 1954. Ullman and Maaz, Ullman 1966; Karnik, 1971) have tried to express seismicity of a region in terms of energy release or strain release. Other investigators (e.g. Miyamura, 1962; Kaila and Narain, 1971; Kaila et al., 1972; Kaila and Roa, 1975) have tried to express seismicity in term of parameters a and b of the frequency magnitude relation. Hattori (1974) determined the spatial distribution of the b-values at every degree of latitude and longitude of different seismic regions of the world.

Karnik (1969) constructed regional seismic zones in terms of b. Experimental work by Mogi (1962) using rock specimens showed that the parameter b is related to the degree of heterogeneity of material under stress. Scholz (1968) indicated frequency of microshocks is a function of the area of rupture and the applied stress.

The purpose of this paper is to construct three quantitative seismicity maps for the Arabian Peninsula. The a-value map , the b- value map, and the maximum magnitude map. These three maps are studied in relation to tectonics of the region, and then compared with the seismicity data for this region, as published by other workers.

## SEISMOTECTONICS OF THE ARABIAN PENINSULA

The majority of earthquake in the Arabian Peninsula are concentrated along three major belts (Fig.1) the first is Zagros fold belt that extends about 1500 Km in northwesterly direction from Oman

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through west Iran and northeast Iraq to Turkey. The second belt extends from the central Red sea region south to Afar and then east through the Gulf of Aden. The third belt extends from the northern tip of the Red sea in a northeasterly direction through the Gulf of Aqabah, Dead sea, Lebanon, Syria, and terminates in southern Turkey.

The Dead sea transform system connects active spreading centers of the Red sea to the area where the Arabian plate is converging with Eurasia in southern Turkey.

The Gulf of Aqabah in the southern portion of the rift system has experienced left- lateral strike- slip faulting with a 110Km offset since early Tertiary to the present. Earthquakes location provide evidence for continuation of faulting regime from the Gulf north eastward in land beneath thick sediments, suggesting that the northern portion of the Gulf is subjected to more severe seismic hazard compared to southern portion (Al-Amri et.al.,1991).

The majority of earthquakes and tectonic activity in the Red sea region are concentrated along a belt that extends from the central Red sea region south to Afar and then east through the Gulf of Aden . There is little seismic activity in the northern part of the Red sea. Instrumental seismicity of the northern Red sea shows that 68 earthquake ( $3.8 < m_b < 6.0$ ) were reported to have occurred in the period from 1964 to 1993 (Al-Amri, 1995a). Instrumental seismicity of the southern Red sea shows that 170 earthquake ( $3.0 < m_b < 6.6$ ) were reported to have occurred in the period (1965-1994).

The Arabian plate boundary extends east-northeast from the Afar region through the Gulf of Aden and into the Arab sea and Zagros folded belt. The boundary is delineated by teleseismic epicenters, although there are fewer epicenters bounding the

eastern third of the Arabian plate south Oman. Most seismicity occurs in the crustal part of the Arabian plate beneath the Zagros folded belt (Jakson and Fitch, 1981). The Zagros is prolific source of large magnitude earthquakes with numerous magnitudes 7 and above even occurring in the last few decades.

The overall lack of seismicity in the interior of the Arabian peninsula suggests that little internal deformation of the Arabian plate is presently occurring. There is widespread Quaternary volcanism along the Red sea coast, with at least one documented historical eruption in 1256 A.D (Barazangi. 1981). Some seismicity was associated with that eruption. Seismicity may also be related to transform faults in the Red sea continuing onto land. To date, few on- land epicenters are accurately located and there is little mechanism available.

#### DATA USED

The Arabian peninsula area under study extending between  $10^{\circ}$  N and  $35^{\circ}$  N, and  $30^{\circ}$ E and  $60^{\circ}$ E. Catalogs are prepared for earthquakes (magnitude  $>4$ ) using the epicentral data from the Earthquake Database of the Arabian peninsula issued at (1999) by Seismic Studies Center- King Saud University, Saudi Arabia kingdom. Ambrasey's (1988) catalogue was the main source of seismic data prior to 1965, and from 1965 on wards on the PDE,ISC and Ambraseys (1988). A time period of observation of approximately 100 years (1900-1999) for the seismic data was used in the calculations of the required seismicity parameters. The number of earthquakes falling in each  $2^{\circ}$  by  $2^{\circ}$  grid during this period is determined. Data completeness test in the study area was not conducted since some source areas used in the study do not have sufficient number of events.

**PREPARATION AND ANALYSIS OF SEISMICITY PARAMETERS**

The frequency of occurrence of earthquakes in any area for a fixed interval of time can be expressed as a function of magnitude:

$$\log N_c = a - b M \dots\dots\dots(1)$$

Where  $N_c$  is the cumulative number of earthquake with magnitudes equal to and greater than  $M$ , and  $a$  and  $b$  are constants. The constant  $a$  exhibits significant variations from study to study as it depends on the period of observation, as well as on the area of the region under investigation, while constant  $b$  is characteristic of the region, is correlated to the tectonic structures and to the seismic activity in the given area. Miyamura (1962) re-evaluated the seismicity of the world and found out that parameter  $b$  is related to tectonic structure. Udias (1977) Correlated the low  $b$  - value with heterogeneous physical conditions in the corresponding crustal source region. Wyss (1973) pointed out that the  $b$  - value increases as the degree of symmetry of the applied stress decreases.

The values of the seismicity parameters ( $a$  ,  $b$ ) were determined in space in a given period of time. In this regard, the maximum likelihood method from Utsu (1965) and Aki (1965) was applied as follows:

$$b = \log (e) / (M_a - M_o) \dots\dots\dots ( 2 )$$

$$a = \log (N) + b M_o \dots\dots\dots ( 3 )$$

where:

$M_a$  = average magnitude.

$M_o$  = the minimum magnitude.

( $N$ ) = the number of events equal and larger than  $M_o$  in a set data.

$e$  = the base of natural logarithm.

Owing to data limitation in some source compartment, this method is selected since a minimum number of events can be used (Welkner,

1967). However, for small number of events, the upper and lower limits of confidence for the  $b$  is value becomes larger even for small probability as shown by Aki (1965). In equation (2), the value of  $b$  unbounded without restriction so that the condition imposed in Utsu (1965) equation for total energy of a given group of earthquakes is taken. The minimum magnitude in a given set of data is 4.0.

The maximum magnitude ( $M_m$ ) values were also determined from Pisarenko et al (1996).

$$M_m = M_n + (\exp (B(M_n - M_o) - 1) / NB) \dots\dots\dots(4)$$

Where :

$M_m$  = the maximum magnitude.

$M_n$  = the maximum magnitude in the period of observation.

$M_o$  = the minimum magnitude.

$$B = b \ln (10)$$

The  $a$  ,  $b$   $M_m$  values for each  $2^\circ$  by  $2^\circ$  were contoured by computer to produce three quantitative Seismicity maps. We projected the contoured lines of  $a$  ,  $b$  and  $M_m$  on a modified seismotectonic map of the Arabian Peninsula (Figs. 2,3 and 4).

**a-value Seismicity map**

Figure 2 represents a seismotectonic map of the Arabian Peninsula comprising  $a$  -value contours. This map brings out a number of  $a$  -value highs, these highs are associated with the seismotectonic belts of the Arabian Peninsula: Zagros Folded zone, Dead Sea system and Gulf of Aden. In Dead Sea rift system, there is a localized high zone centered around Gulf of Aqabah has a maximum  $a$  -value of 7.5 and enclosed by the contour of 6.5 . In Gulf of Aden high zone, there are two localized high, firstly, is centered around (12.8°N, 47.33°E) and enclosed by contour of 5, and secondly, is centered around (15.2°N, 56.73°E) and enclosed by contour of 6.

In Zagros high zone, there are two high localized zone, the first, is centered around (28.0°N, 56.86°E) and enclosed by contour of 6, secondly, is centered around (29.40°N, 51.53°E) and enclosed by contour 6.5 .

There are two low a -value zones, the first is located at the southern end of the Arabian Shield, and enclosed by counter of 2. The second zone is located at the southern tip of Red Sea and enclosed by counter of 3.

#### B-Value Seismicity Map

The b - value map of the Arabian Peninsula (Fig.3) is drawn for equal b -values. This map reveals the same seismic high zones brought out by the a - value map. The regions of high a -value are also regions of high b -values and vice-versa. To bring out a correspondence between high b -values zones and the high density of the epicenters. The b -value map has superimposed on the epicenters locations of earthquakes between 1965 to 1999 as compiled by Seismic Studies Center, King Saud University, Kingdom of Saudi Arabia.

The b -value map shows that the value of b ranges from 0.30 to b =1.2 in the Arabian Peninsula and surrounding areas. There are three seismic zones that high b -value. These zones are in consistent with the main seismic belts of the Arabian plate representing by the plate boundaries, the Zagros high is characterized by two separated zones attaining a high b -value. The first zone shows a maximum b -value counter of 1.0 covers approximately the area located between 28.46°-30.66° N and 50.60°N-52.26°E. The second localized zone is centered around 28.46°N- 56.73°E and enclosed by conotur of 0.9.

In Gulf of Aden high, there are two localized high, the first is centerd around 13.2°N, 47.°E and enclosed by the contour of 0.8. the second localized

zone is centered around 15.0°N, 56.4°E and enclosed by the counter of 1.0. The third high b-value zone is the Dead sea Rift system. In this high, there are two localized high, the first high is centered around Gulf of Aqabah and enclosed by b-value contour of 1.0 the second high is centred around 30.73°N, 32.8°E and enclosed by contour of 1.0.

The b-value decreases toward the interior of Arabian Peninsula. The lowest b -value of 0.3 is obtained in that located in then southern end of the Arabian shield.

#### MAXIMUM MAGNITUDE MAP

The third seismicity map (Fig.4) shows the estimated maximum magnitude value. The range of maximum magnitude from 6 to 7 is seen to be located in the Aden Gulf. The range of maximum magnitude about Gulf of Aqabah and Sueze Gulf is from 5.5 to 6. The maximum magnitude for the southen Red sea is 6.5, the same as in land invicinity of point (13°N, 43°E). The range of maximum magnitude from 6.5 to 7.0 is seen in the Zagros folded Belt.

#### DISCUSSION AND CONCLUSIONS

Our emphasis goes to parameter b, for it is a tectonic factor that is correlated to tectonic structure in a given area and to seismic activity. The constant a which can be considered as an index of seismicity gives the number of events in a given sample with given b and minumum magnitude and therefor, a function of b. Since the parameter a is dependent on parameter b, it is expected that the contour shapes shall be quite similar. Referring to our a and b value maps (Figs.2 and 3), we find that there are similar shapes in most seismic zones such as zagros seismic zone, Gulf of Aden and Arab sea, Red sea and Dead sea transform.

It may be worth while to compare the  $b$  -value obtained by this study with that obtained by other workers. Everndon (1970) has obtained a  $b$  -value of 1.46 within 1000 Km of Shiraz City in Zagros Folded Belt (29.38°N, 52.31°E) and Kaila et al. (1971) found the  $b$  -value contour of 1.1 passes through that region. This value is equal to that obtained by our study for the first localized zone that includes Shiraz City. The  $b$  -value of 1.3 is obtained at Lar- Bander Abbas region (Kaila et al., 1974). Our study shows that this region enclosed by contour of 0.9. This difference may be attributed to the observation period (14 year in Kaila's study and 100 year in our study), to the range of magnitude and due to the techniques of treating magnitude interval size. Since the frequency – magnitude relation is not linear, the  $b$  -value by 15% or more, even for Individual catalogues, depending on the exact range of magnitude used for its determination (Al- Amri, 1994).

Ben- Menahem and Vered (1982) indicate that  $b$  is of 0.86 for whole Jordan- Dead Sea transform. El- Isa and Hasweh (1986) found the  $b$  -value for the whole southern Dead Sea transform to be 0.65.

From comparison of our results with the previous studies mentioned above, we find a good consistent in the  $b$  - value Dead Sea transform region.

Thenhaus et al. (1986) estimated  $b$  -values for the Red Sea and western Saudi Arabia, to be between 0.89 to 1.1. El- Isa and Al-shanti (1989) and Al-haddad et al. (1994) found that the  $b$  -value for the whole southern Red Sea in the range from 0.5 to 0.8. Al-Amri (1994-1995) has found that the  $b$ -value for the whole southern Red is 0.91 Al-Amri et. al (1998) Studied the spatial distribution of seismicity parameter in the Red Sea region (between 12°-22°N and 37°-46°E). They divided the study area to four zones, which correspond to respective  $b$  - value range. Zone

(0)- areas covered by the oceanic portion has the  $b$ -value greater than. 1.0. Zone( I ) the coastal area on both flanks of the Red Sea basin and the southern tip of the Red Sea has the  $b$ -value range from 0.8 to 1.0. Zone( II ) has the  $b$  -value range from 0.61 to 0.8 Zone( III ), whose  $b$  -value is less than 0.61, covers the stable and mobile continental areas.

If we compare the  $b$  - value obtained by this study with the results of the investigation mentioned above, we find that the  $b$  - value (0.5 - 0.8) for the southern Red Sea obtained by our study are equal to those obtained by El-Isa and Al- shanto (1989) and Alhaddad et al. (1994). Our  $b$  - value are also in a good agreement with those less than 0.61 to greater than 1.0 obtained by Al- Amri et al. (1998).

The  $b$  -value highs (Fig.3) are associated with the high seismic activity belts in the Arabian Peninsula. These seismic belts are associated with the Arabian plate boundaries.

The  $b$  – value decreases toward the interior of Arabian peninsula. The lowest  $b$  -value of 0.3 is obtained in an area that located in the southern end of the Arabian

The estimated magnitude map reveals a  $M_{max}$  highs associated with the  $a$  and  $b$  -value highs. The unreasonable values of  $M_{max}$  in interior of Arabian peninsula may be attributed to the fact that contouring has been done by computer.

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#### REFERENCES

- [1] Aki, k, (1965) Maximum likelihood estimate of  $b$  value in the formula  $\log N=a-bm$  and its

- confidence limits. *Bull. Earthq. Res. Inst.* 43, 23 - 240.
- [2] AL -Haddad, M., Siddiqi, G., AL – Zaid, R., Arafah, A., Neciogly, A., Tukelli, N.(1994) A basis for evaluation of seismic hazard and design criteria for the Kingdom of Saudi Arabia. *Spectra* 10,223-258 .
- [3] AL – Amri, A., Schult, F., Bufe, C. (1991). Seismicity and aeromagnetic features of the Gulf of Aqabah ( Elat ) region. *Journal Geophysical Research* 96, 20179 – 20185 .
- [4] AL – Amri, A. (1994) Seismicity of south – western region of the Arabian shield and southern Red Sea. *Journal of African Earth Sciences* 19,17 – 25 .
- [5] AL – Amri, A. (1995a) Recent seismic activity in the northern Red Sea. *Journal of Geodynamics* 20, 243 – 253 .
- [6] AL – Amri, A. (1995b) Preliminary seismic hazard assessment of the southern Red Sea region. *European Earthquake Engineering* 3, 33 – 38 .
- [7] AL – Amri, A., Punsalan, B., Uy, E.(1998) Spatial distribution of the seismicity parameters in the Red sea region. *Journal of Asian Earth Sciences* 16, 557 – 563 .
- [8] Ambraseys, A.(1988) Seismicity of Saudi Arabia and adjacent areas. Imperial College of Science and Technology, London , U. K.
- [9] Barazangi, M.(1981) Evaluation of seismic risk along the western part the Arabian plate: Discussion and Recommendation Bulletin Faculty of Earth Sciences . King Abdulaziz University 4, 77 – 78 .
- [10] Ben-Menahem, A.,Vered, D.(1982) Earthquake risk in the Holy Land. *Bolletin Geofisica Teorica ed Applicata* 24,175-203.
- [11] El-Isa , Z., Hasweh,N.(1988)Seismicity of the southern Jordan-Dead sea transform: Proceedings of the 3rd Arab symposium on Earthquake seismology, 8-10 March 1986, pp: 47-85 King Saud University , Riyadh, Saudi Arabia.
- [12] El-Isa , Z.,Al-shanti, A.(1989) Seismicity and tectonics of the Red Sea and western Arabia. *Geophysical Journal Royal Astronomical Society* 97,449-457.
- [13] Evernden, J.(1970) Study of regional seismicity and associated problems. [14] *Bulletin Seismological Society of America* 60,393-446.
- [15] Gutenberg, B., Richter, C.(1954) Seismicity of earth and associated phenomena. Princeton University press.
- [16] Hattori, S.(1974)Regional distribution of b - value in the world. *Bulletin International Institute Seismology Earthquake Engineering* 12,39-57.
- [17] Jackson, J., Fitch, T.(1981) Basement faulting and the focal depths of the larger earthquakes in the Zagros mountains (Iran). *Geophysical Journal Royal Astronomical Society* 64,561-586.
- [18] Kaila, K., Narain, H.(1971) A new approach for preparation of seismicity maps as applied to Alpide belt-Sunda arc and adjoining areas. *Bulletin Seismological Society of America* 61,1275-1291.
- [19] Kaila, K., Gaur, V., Narain, H.(1972) Quantitative seismicity map of India .*Bulletin Seismological Society of America* 62,1119-1132.
- [20] Kaila, K., Rao, N., Narain, H.(1974) Seismotectonic map of southwest Asia region comprising eastern Turkey, Caucasus, Persian

plateau, Afghanistan and Hindukusk. Bulletin Seismological Society of America 64,657-669.

- [23] Kalia, K., Rao,N.(1975) Seismotectonic maps of the European area. Bulletin Seismological Society of America 65,1721-1732.
- [24] Karnik, V.(1969 ) Seismicity of the European area, Geophysical Monograph, the earth's crust and upper mantle. American Geophysical Union. Washington D.C.,Seismicity of the European area, part 2. Academia publishing house of the Czechoslovak. Academy of sciences Praha, Czechoslovakia, 123-169.
- [25] Karnik, V.(1971) Seismicity of European area part II. Reidel Publishing Company, Dordercht, Holland.
- [26] Miyamura, S.(1962) Magnitude-frequency relation of earthquakes and its bearing to geotectonics. Proc Japan Academy 38,27pp.
- [27] Mogi, K.(1962) Magnitude-frequency relation for elastic shocks accompanying fractures of various materials and some related problems earthquakes. Bulletin Earthquake Research institute 46,831.
- [28] Pisarenko, V.,Lyubushin, A., Lysenko,V. and Golubeba, T.(1996) Statistical estimation of seismic hazard parameters :maximum possible magnitude and related parameters. Bulletin Seismological Society of America 86,691-700.
- [29] Ritsema, A (1954) The seismicity of the Sunda arc in space and time. Indonesia Madjalah Ilmu Alam 110,41-49.
- [30] Thenhaus , P.,Algermissen, S., Perkins , D., Hansen ,S.,Diment , W.(1986) Probabilistic estimates of the seismic ground motion hazard in western Saudi Arabia,U.S.Geological survey Bulletin 1968 , 40p.
- [31] Scholz, C.,(1968) Microfractures, aftershocks and seismicity. Bulletin Seismological Society of America 58 , 1117-1130.
- [32] Udias ,A.(1977) Time and magnitude relation for three microaftershock series near Hollister California. Bulletin Seismological Society of America 67,173-185.
- [33] Ullmann ,W., Maaz, r.(1966) A new method for computation of seismicity. Pure and Applied Geophysics 63, 15-22.
- [34] Utsu , T.(1965) A method for determining the value of b in a formula  $\log n = a - b M$  showing the magnitude- frequency relation for earthquakes. Geophys. Bull. Hokkaido Univ. 13,99-103
- [35] Welkner, P. ( 1967) On space distribution of some seismic parameters in Japan., Bull. Inter. Inst. Seism .Engineering 4, 1-18.
- [36] Wyss, M.(1973) Towards a physical understanding of the earthquake frequency distribution. Geophysical Journal Royal Astronomical Society 31, 341-359.

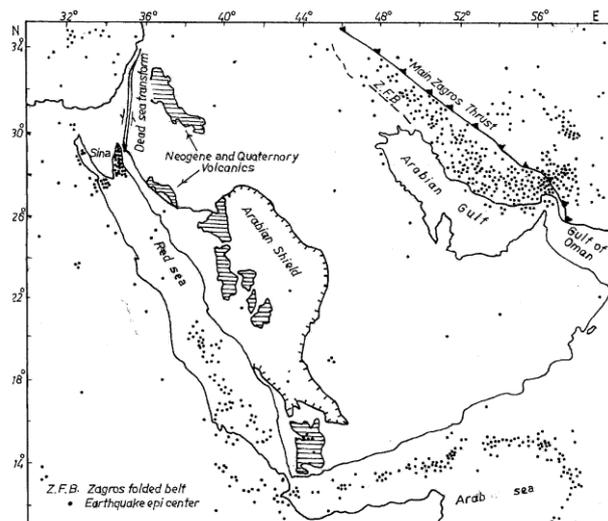
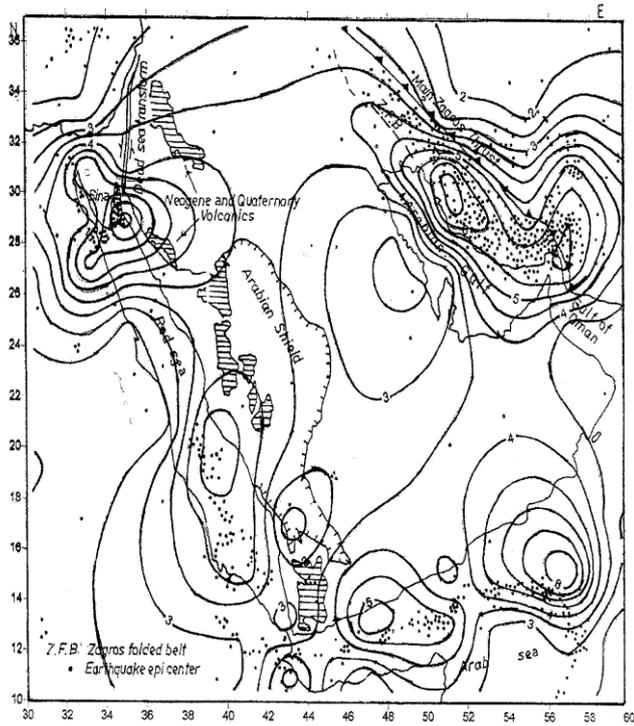


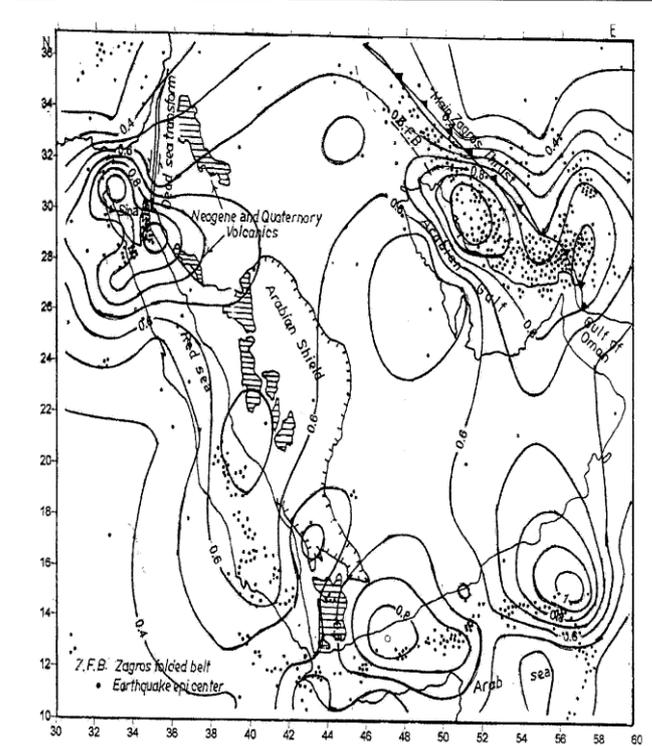
Fig.1

**Fig.1. Recent seismicity map ( $4.0 \leq m \leq 5.9$ ) of Arabian peninsula and adjoining regions from 1965 to 1999 (modified from the map compiled by Seismic studies center, King Saud University, Kingdom, of Saudi Arabia.**



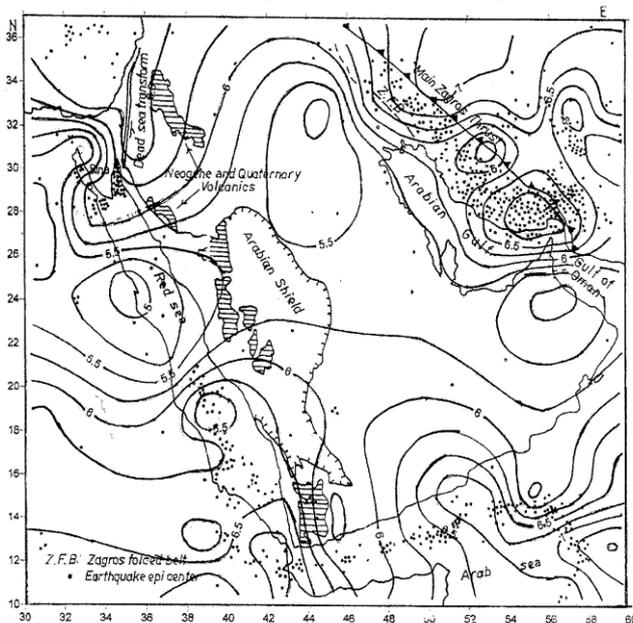
C.I = 0.5  
 Fig.2

**Fig.2. Quantitative seismicity map of Arabian peninsula based on a values contour values represent a corresponding to a 20 X 20 area and 100-year earthquake observation period.**



C.I= 0.2  
 Fig. 3

**Fig.4. Quantitative seismicity map of Arabian peninsula based on estimated maximum magnitude.**



C.I= 0.25  
 Fig. 4

**Fig.3. Quantitative seismicity map of Arabian peninsula based on b -values. magnitude.**

## الخرائط الزلزالية الكمية لشبه الجزيرة العربية وما يجاورها

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### الخلاصة

تم بناء ثلاثة خرائط زلزالية كمية لشبه الجزيرة العربية وما يجاورها، الأولى هي خارطة الثابت (a) والثانية خارطة الثابت (b) والثالثة خارطة المقدار الزلزالي الأقصى. لبناء هذه الخرائط استخدمت علاقة التردد - المقدار الزلزالي والتي خمنت ثوابتها (a) و (b) باستخدام طريقة الاحتمالية القصوى.

أسقطت الخرائط الثلاثة على خارطة زلزالية تكتونية معدلة لشبه الجزيرة العربية. أظهرت الخرائط الزلزالية الكمية الثلاثة وجود ثلاثة أنطقة زلزالية نشطة في شبه الجزيرة العربية وما يجاورها وهي: نطاق زاكروس، نطاق البحر الميت وأخيرا نطاق جنوب البحر الأحمر وخليج عدن وبحر العرب. قورنت قيم الثابت (b) المستنتجة في هذه الدراسة مع تلك المقدمة من قبل باحثين آخرين لمناطق في الجزيرة العربية وأظهرت المقارنة توافق جيد. أظهرت خارطة المقدار الزلزالي الأقصى قيم مرتفعة تتوافق مع القيم المرتفعة للثابت (a) والثابت (b) .