Pergamon

Journal of Asian Earth Sciences, Vol. 16, Nos. 5-6, pp. 557-563, 1998

1367-9720/98 $ - see front matter

P11: 50743-9547(98)00046-4

Spatial distribution of the seismicity parameters in the Red Sea regions

A. M. S. Al-Amri*, B. T. Punsalan and E. A. LJy Seismic Studies Center, Box 2455, King Saud University, Riyadh 11451, Saudi Arabia

(Accepted 17 September 1998)

Abstract The spatial distribution of the seismicity parameters of the magnitude-frequency relation has provided preliminary quantitative basis for establishing different zones of seismic activities in the southern Red Sea regions. Four zones were constructed from application of proposed models that yielded approximate *b* value range for each zone, thus, providing relative bases for preliminary classification as follows: zone III has *b* value <_0.6; zone II has *b* value <_0.8; zone I has *b* value _<1.0; and zone 0 has *b* value > 1.0. The zones were characterized through correlation to seismotectonic and some geophysical configuration in the study area. Narrow contour spacing among zones is observed to occur along intersections of areas of probably different seismic source zones, while wider spacing occurs seemingly for a prominently dominating source of seismic activity. Corresponding spatial distribution of estimated maximum magnitude and expected magnitude at 90% non-exceedance in 50 years was prepared. Likely occurrence of a major earthquake is spread over a wider area of coverage characterized by presence of rift zones, structural discontinuities, and dislocations in the study area. Broad confidence limits for the parameter values are encountered, but correlation to primary tectonic structures is seen to be possible. Comparison of the present results to previous relevant studies indicates general agreement with regards to tectonics and related phenomena. The spatial distribution of the parameters seemed to provide appropriate basis of analysis to the observed complexities of seismic occurrences in the Red Sea and adjacent shield areas. © 1998 Elsevier Science Ltd. All rights reserved

Introduction

The seismicity parameters were introduced by Gutenberg and Richter in their monumental work in 1954. Utilizing an augmented database gathered by sets of modern and standardized seismographs, Miyamura (1962) re-evaluated the seismicity of the world and found out that the parameter b of the magnitude-frequency equation is related to tectonic structures. A more detailed analysis was undertaken by Hattori (1974), wherein the spatial distribution of the b-values was determined 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 materials under stress. Scholz (1968) indicated that the frequency of microshocks is a function of the area of rupture and the applied stress.

The gradual perception of the significance of parameter b as characteristic of seismogenic zone and recognition of its role in the magnitude-frequency relation in the assessment of seismic hazard could have prompted some authors (Aki, 1965; Utsu, 1965; Karnik, 1969; Bender, 1983) in developing different methods for its determination. The applications of some methods in seismic hazard assessment for Saudi Arabia and adjacent regions can be seen in the work of Thenhaus *et al.* (1988); Al-Amri (1994); Al-Haddad *et al.* (1994) and El-Isa and AI-Shanti (1989). The essential knowledge and information obtained in their respective study areas cannot be over-emphasized. In their studies, the usual process of delineating seismic source zones has been applied. The arbitrariness of drawing the boundaries of the delineated zones is recognizable and depended on the point of view of the investigators. Justifiably, this may be due to randomness of earthquake events in space-time. However, non-uniform occurrence of seismic events is an observed phenomenon even in seemingly considerable one geological unit (Ritsema, 1969).

Hence, it is deemed appropriate that this observation be given essential and detailed treatment in space-time for proper evaluation of the characteristics and tendencies from the viewpoint of seismotectonics and related geophysical phenomena in the study area. Further, the vital role of parameter b in assessment of seismic hazard requires detailed analysis of its spatialtemporal distribution, subsequently for the other parameters of the magnitude-frequency relation. These considerations prompted this present study to initiate application of established and proposed methods and models for the spatial distribution of the parameters of the magnitude-frequency relation that respond in establishing preliminary basis for evaluation and comparison to other related results.

The study area is located between 12-22°N and 37-46°E (Fig. 1). It can generally be considered to be composed of two portions. These are the oceanic

*Corresponding author. Tel.: 00966 1 468 3012; Fax: 00966 1 467 3662.

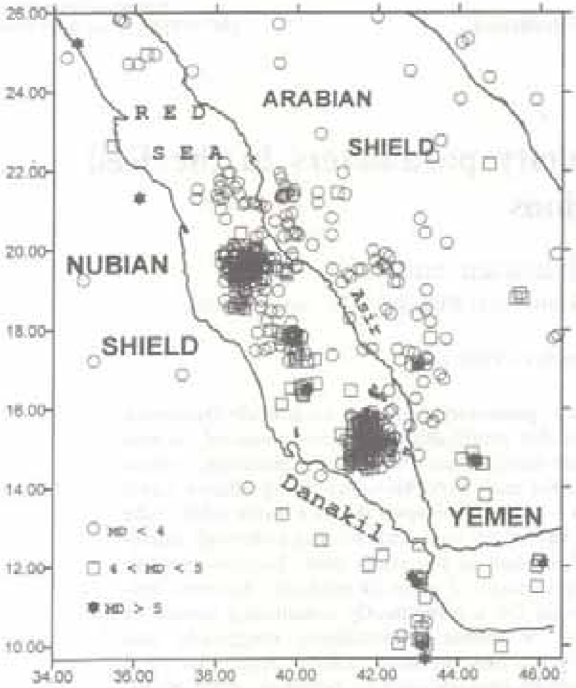

Fig. 1. Recent seismicity map ($3.0 \leqslant M_D \leqslant 7.0$) of the Arabian Shield, central and southern Red Sea for the period from 1980 to 1997.

portion which is covered by the central and southern Red Sea and the continental portion on both flanks of the Red Sea. The continental portion is further subdivided into stable and active regions.

Analytical method

The paper of Ambrasey (1988) and the preliminary determination of epicenters from the United States Geological Survey (1965–1997) were used as the main sources of seismic data for this study. Comprehensive and exhaustive efforts were conducted in this paper, performing some relocation of epicenters, magnitude conversion, computation of macroseismic magnitude and verification of doubtful entries. It is probable that errors of about 20–30 km for continental events, 50–100 km for oceanic, and value of 0.6 unit for the magnitude are attainable in the paper. Likewise, there may still be some events of magnitude 4.5 which could only be noted, but could not be defined properly especially in the Red Sea.

Ambrasey's (1988) catalogue was the main source of seismic data prior to 1965 due the processes that were used, and the USGS after, 1965. A time period of observation of approximately 98 years (1900–1997) for the seismic data was used in the calculations of the required seismic parameters.

Magnitudes from the main sources of data were composed of different types due to availability and quality of instrumental and observational means of gathering and compiling of seismic data in the study region. These were the surface, body, local, and duration magnitudes. Preference is given to the utilization of the body-wave magnitude (mb) for consistency of results. These are due to the establishment of the World Wide Standard Seismograph Network (WWSSN) of USGS in 1965 which published magnitude of seismic events in its seismic bulletin mostly in mb. Notably, the bulk of the data starts after this year (1965) which contributes significantly to some degree of sufficiency of data in the study. Secondly, most authors observe consistency of results for the seismicity parameters when mb is used below the saturation level of mb = 6.5. Thirdly, the most observed magnitude ranges in the study area are below 6.5, only few are above this value. Local and duration magnitudes were assumed to be equal to mb from 4.0–6.5 since within this range, formulas obtained for each of these two types are thought to be statistically based on mb as the standard value.

Data completeness test for each data source in the study area was not conducted since some source areas used in the study do not have sufficient number of events. However, the procedure applied in the calculation of the seismicity parameters indicates data completeness in a given range of magnitude. Repetition of events in the data is avoided and as much as possible aftershocks and swarm types of seismic activity were eliminated through reduction of the number of events that are highly way off in the eye fitted magnitude frequency graph that is conducted in a given set of data. Such procedure could possibly diminish, but not entirely, the presence of aftershocks and swarm types of activity. Incremental magnitude of 0.1 is used in the calculations.

The space distribution of the parameters of the magnitude–frequency relation were intended to be covered in two aspects. These are their respective iso-curves and delineation of the spatial distribution of b-value into different zones from which the same consideration can be done for the other parameters on this basis.

Iso-curves

The first aspect requires that the values of the seismicity parameters have to be 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:

$$b = \log(e)/(M_a - M_0) \quad (1)$$

$$a = \log(N) + bM_0 \quad (2)$$

where M_a is the average magnitude, M_0 is the minimum magnitude, (N) is the number of events equal and larger than M_0 in a set of data, and (e) is the base of natural logarithm.

Practical purposes indicate that equations (1) and (2) are reasonable and simpler to use with approximately reliable results (Karnik, 1969; Bender, 1983). Owing to data limitation in some source compartment, this method is selected since a minimum number of four events can be used (Welkner, 1967). However, for small number of events, the upper and lower limits of confidence for the b value becomes large even for small probability as shown by Aki (1965). In (1), the value of b is unbounded without restriction so that the condition imposed in Utsu (1965) equation for total energy of a given group of earthquakes is taken.

The distribution of the parameters is intended to be located in every degree of latitude and longitude of the study area whenever data are available. To attain this goal, a moving 4 × 4 degree block as data source area for each latitude and longitude is applied (Hattori, 1974). The movement of the block is one degree interval in the latitudinal and longitudinal direction. The centers of the moving block are the latitudes and longitudes of the study area and are assumed to represent the set of data in each respective block. Since a square degree in the block is used 16 times at most, the parameter values obtained in its 4 corners could be considered as the representative values. The criteria that the difference of the highest and minimum observed magnitudes in a given set of data ($M_{max} - M_{min}$) be equal and greater than 2 and the product of the b value and magnitude interval is equal or less than 0.25 for unbiased results is not always satisfied. Therefore, the calculation of parameter b is allowed to vary with magnitude starting with the initial M_0. The value of b is selected when change in b value becomes insignificant when increasing M_0. This level is interpreted to be the range when the magnitude data is complete. The parameter a is calculated corresponding to the selected b value. Preferably, the minimum magnitude in a given set of data is 4.0.

Essential information of paramount importance can be deduced from equations (1) and (2). Significant information which can be considered another parameter of the magnitude–frequency relation is the concept of maximum magnitude (M_m) and expected magnitude (M_e) in a given interval of time. Corresponding M_m and M_e from the spatial distributions of the seismicity parameters were also determined from Pisarenko *et al.* (1996).

$$M_m = M_n + \left(\exp(B(M_n - M_0)) - 1\right)/NB \qquad (3)$$

and

$$\begin{aligned} M_e = M_0 - (1/B)\ln(1 - k(1 - \exp(-B(M_n - M_0) - 1))) \\ + (k/(BN))(1 - \exp(-B(M_n - M_0))) \\ (1 - k(1 - \exp(B(M_n - M_0)))) \end{aligned} \qquad (4)$$

for a given probability occurrence (p) in a time interval (t), where:

$$k = (1/(Ht))\ln(1 + p(\exp Ht) - 1)))$$
$$B = b\ln(10)$$

H is the mean rate of occurrence and M_n is the maximum magnitude in time period (T) of observation and t is the time interval of interest. The calculated values of the seismicity parameters from equations (1) and (2), M_m, and M_e from equations (3) and (4) were plotted separately in their respective locations in the study area as bases for contouring.

Zonal configuration of b

Point to point analysis of the plotted b values in relation to seismotectonic activities is not deemed advisable. Some of the obtained b values could probably be biased due to errors in location, magnitude determination and inadequacy of seismic data. These factors affect and do not reflect the general seismotectonic behavior of an independent compartment of a whole geological unit. Hence, delineation of the spatial distribution of the b values into different zones seems to be the appropriate procedure in the process of correlation.

Scholz (1968) has derived from theoretical consideration in his experimental results the parameter b related to the applied stress and the number of events (N) as a function of the rupture area (A). The distribution is governed by the applied stress (P) and strength (S) by:

$$N(A) = A^{(-(1-f(P,S)))} \qquad (5)$$

where $f(P,S)$ is the probability that locally the stress exceed the strength. On the other hand, Wyss (1973) has shown that the reduction of the magnitude/moment frequency relation to one parameter function leads to

$$N(A) = eA^{(-(q+3)/2)R} \qquad (6)$$

$$N(T) = fT^{(-(q+3)/q)R} \qquad (7)$$

where e, f, q are constants, T is the stress-drop and R is the ratio of the coefficients of the magnitude and moment in their respective frequency relations. Reasonably, Wyss (1973) equated respective exponents of equations (5) and (6) as follows:

$$((q+3)/2)R = 1 - f(P,S) \qquad (8)$$

to express the probability in terms of the constants. Deducing from (6) and (7), Wyss (1973) gave value range for q from 0 to 2. Due to randomness of earthquake events in space–time and their characterization with physical parameters, it is deemed appropriate to apply (8) for the delineation of the spatial distribution of the parameter b into different zones and their corresponding correlation to tectonic structures and other geophysical phenomena when probable.

Results and discussion

The results obtained from application of equations (1) and (2) are shown in Figs 2 and 3. The figures represent maps of contoured iso-curves for the seismicity parameters a and b, respectively. A higher level of concern is given to parameter b, for it is correlated to tectonic structures in a given area and, hence, 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 minimum magnitude and therefore a function of b. The range of the obtained b values in the study area was from 0.59 to 2.07. The encountered constraints, the criteria imposed for reliable results, and the broadness of the confidence limits of the applied methods are factors that may confine the results to some restrictions. The restrictions are generally applied to the outermost portions of the study area. These are along longitudes 37°–38°E in the western flank, 45°–47°E in the eastern flank and along latitude 22°N. These outer boundaries have 5–10 events in their respective data set. Because of the small number of events in these areas, the

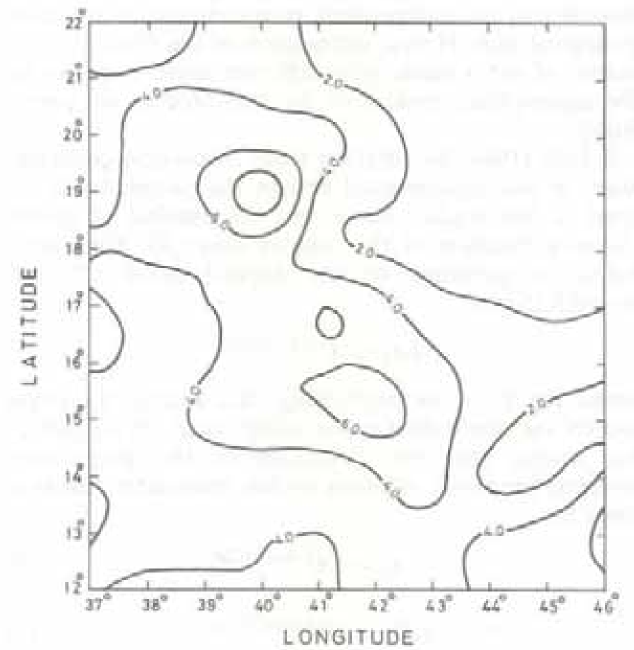

Fig. 2. Spatial distribution of *a*-value parameter.

confidence limits are broad. The central part down to 12°N has 40–100 events. Likewise, the outer boundaries have also the lowest level of minimum magnitude of 4–4.3 which indicates that the seismic data in these areas are recently acquired events. The minimum magnitude in the central part ranges from 4.5 to 4.8.

Utsu (1965) has shown that the *b* value should be less than 2.48 if the coefficient of mb in its conversion to energy is used. On this argument and in comparison to some previous results (Gutenberg and Richter, 1954; Miyamura, 1962; Karnik, 1969; Hattori, 1974) the range of the *b* value obtained in this study is within reasonable limits.

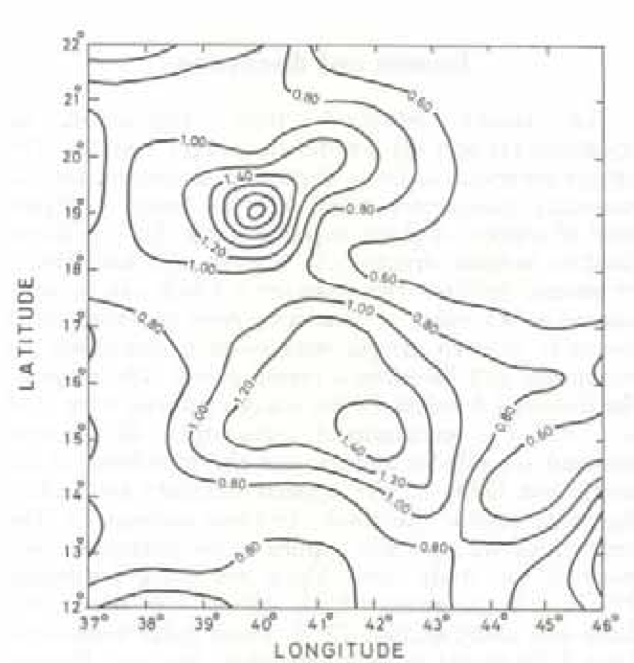

Fig. 3. Spatial distribution of *b*-value parameter.

Figure 3 shows asymmetry seems to prevail over the entire study area even for seemingly similar tectonic structures. The asymmetry is supportive to the observations that structural complexities exist on both flanks and in the basin of the southern Red Sea. The complexities were expressed in appearance of larger interval in *b* values at some adjacent points. The variations of *b* value in the region tend to agree with observations that a single zone from geological point of view seems to include several compartments that are independent. Differences in densities of earthquake events occur, likewise, over small distances within separate zones (Ritsema, 1969). The tectonic structures in the study area are complex which could reasonably be one indication in the variations of adjacent *b* values. *b* values are grouped into different ranges for simplified correlation to seismic sources and structures. The range of *b* value from 0.59–0.8 is seen to cover the continental portion of the study area. These are as follows.

The southwestern part of the N–E oriented Ad Damm fault is near lat. 19°N that runs NE from the coastal plain. This fault has been reported to have Precambrian right-lateral movement The off-shore continuation of this fault is inferred from magnetic (Hall, 1979) and seismic data (El-Isa and Al-Shanti, 1989). Historical earthquakes of 1481 could probably be attributed to the movement of this fault. The southwestern part of the Arabian shield is a region of continental stretching (Makris and Rihm, 1991). Ambrasey (1988) located earthquakes of 1941 and 1955 in the vicinity of the Sadah fault (lat. 15°N). The seismic activities of the Danakil block and Djibouti which are located in the triple junction of spreading ridge (Red Sea, East African and Aden rifts) are confined to the western extension of the southern Red Sea. The northern Afar rift could probably be a continuation of the Red Sea rift and its depression was created by the separation of the Danakil. Structural maps indicate that the iso-curves seem to follow structural boundaries and dislocation lines.

The *b* value range of greater than 0.8–1.0 covers some continental and oceanic portions. The continental portions are generally narrow continental margins and some interior parts on the eastern and western flank of the Red Sea. On the eastern flank, the seismotectonic correlation can be attributed to a portion of Yemen volcanic ranges where historical earthquakes were located by Ambrasey (1988). The western flank is probably due to the extension of the Afar rift, the transform fault of the Danakil block, and the Ad Darb transform fault. The other interior parts are approximately between 17.5–18.5°N with no report of seismic activity. It is probable that this *b* value range could be associated to the tectonic boundary on the eastern edge of the Red Sea which is characterized by complex faulting and Tertiary dyke injection and volcanism. The western side, particularly in Sudan could be due to stretched continental crust of different domains that is composed of an older remnant of an ocean pull apart basin separating the younger ocean crust that thins progressively toward the Red Sea ridge (Egloff *et al.*, 1991). This range also covers part of the volcanic region in northern Afar.

The b value range of greater than 1.0 almost generally covers the Red Sea basin. High b values are almost centered along the mid-ridge. The Red Sea which separates the Nubian shield from the Arabian shield is generally accepted as a divergent plate margin which is the locus of sea-floor spreading. The Red Sea can be divided into three physiographic regions. These are the narrow continental margins, the main trough, and the deep axial trough. Intense structural deformation is concentrated in the axial zone by normal faulting and heat flow due to intrusion and presence of deep holes. Marine and land magnetic surveys indicate the presence of many N-E trending transform faults which could have probable extension inland and displace prominent Cenozoic structural features. Concentration of seismic activities is seen to be mainly along the axial zone, but not uniformly distributed (Fig. 1). The cluster of epicenters are observed to be located in areas where the presence of a transform fault and high heat flow is inferred. These are approximately at 19°N, 17°N, and 15'N. At latitude 17°N, the Ad Darb transform fault is located, whose probable extension to the western flank above the gulf of Zula is prominently displayed by the line of earthquake epicenters. However, its extension to the eastern side is still uncertain due to the narrow zone of the axial trough. Although moderate seismic activity could be seen inland, it is uncertain whether this could be attributed to the presence of the Sadah fault. Concentration of seismic activities above 18°N could probably be due to the presence of an inferred and proposed leaky transform fault where high transverse magnetic anomalies and heat flow are detected (Hall, 1979). Likewise, at 15°N, the seismic activities thereat could well be associated to an inferred transform fault and presence of high heat flow. Some continental portions covered by this range could probably be due to inland extension of inferred transform faults altering orientation of some prominent structural formation.. Since high b value are mostly found to occur along mid-ocean ridges, it would seem that along the axial zone of the Red Sea, the b value is likewise more prominently influenced by the presence of heat flow (Miyamura, 1962; Hattori, 1974; Francis, 1968), since some of the iso-curves do not generally follow the orientation of inferred transform fault. On the other hand, inferred transform faults can be considered not yet fully developed since the Red Sea rift is a young divergent ridge. The shallow depth of the asthenosphere in the Red Sea reflected by high heat flow makes it probable that not all movements in the area are due to displacement but also are in the form of creeps. The highest b value obtained in the basin is 2.07 and it is located at 19°N and 40°E. This area is characterized by the presence of regional dykes associated with magnetic lineaments: On land, the highest b value is 1.37 and it is located at 20°N and 41°E where NNW trending faults are present but in the vicinity of a volcanic terrain at point (21°N, 42°E). It could be reasonable but uncertain that the presence of some geophysical phenomena could diminish the effects of tectonic structures when these are less dominating in size.

Owing to constraints encountered in the study area, the representativeness of the parameter values cannot be ascertained, but could only be inferred from previous findings related to this study. Variations in bvalues occurring in a geological unit with a known b value range on the basis of previous findings seem to suggest independence of compartments belonging to respective discrepancies within the unit. The compartments which correspond to different b value ranges need to be segregated for interpretation of the variations whenever possible in relation to tectonic structures, geophysical phenomena and seismic activities thereat. The segregation requires each compartment be delineated. To draw the boundaries of the delineated compartments and assign a zone for each needs some preliminary basis of approximation.

Forming the different compartments into independent zones with more or less similar seismic activities in a confined area is done by applying equation (8), from which the b-value range for each zone is determined. The different zones correspond to the assumed values of $q = 0, 1, 2$ and $d = 1.5$. When each of the q values is substituted one at a time with the d and the b values in their respective locations in (8) positive and negative results are given. The positive and negative results were used in the segregation process and in delineating the respective boundaries of the different zones. Since probability could have only values from 0 to 1, the negative results are excluded from a particular zone. Zone III corresponds to the value of $q = 2$ and the obtained b-value range is equal to or less than 0.6. Zone II corresponds to the value of $q = 1$ excluding those that belong to Zone III and the b-value range is from 0.61 to 0.8. Zone I corresponds to $q = 0$ excluding those that belong to Zones III and II. Its bvalue ranges from 0.81 to 1.0. Values greater than 1 were considered as another zone, Zone 0, and these include the negative values in (8). Explanation for the negative values, however, is not physically feasible and needs further studies. The selected q values gave preliminary good results from trial and error procedures. Other possibilities within the given range of q and d are open for different interpretations. The different zones and respective compartment of coverage are shown in Fig. 4.

Zone III mainly covers the Tihamat-Asir region and the southern portion of the Arabian shield in Yemen in a portion of its volcanic terrain and plateau, portions of the volcanic terrain in northern Afar, Danakil block, and Djibouti. Depth of crustal structure in the Arabian shield is composed of two layers of 20 km thickness, while the Yemen area thickens in several steps to 35 km (Egloff et al., 1991) and can be considered relatively as rigid, thick, and large crustal structures capable of resisting larger applied stress (Wyss, 1973; Scholz, 1968). Zone II corresponds to continental seismic zone composed of younger tectonic and active regions seeming to conform with the delineation (Mogi, 1962; Welkner, 1967). Zone I covers the coastal areas of the Asir region, shale structures of Yemen, southern end of the Red Sea, and continental margins in the western flank.

Narrow spacing of contour curves is observed between zones I and 0 except at 21°N and 18°N in the Red Sea basin. The close spacing is located where this could be a probable boundary of two or more different source zones. Relatively wider spacing is observed to

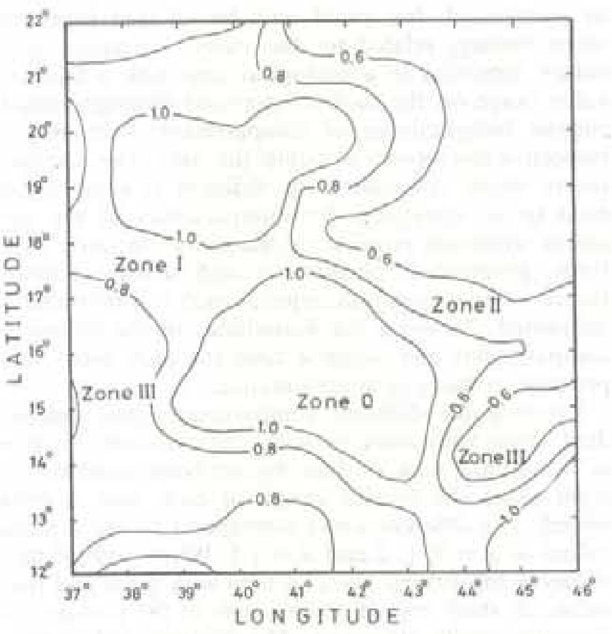

Fig. 4. Zonal map of *b*-values. Four zones were classified as follows: zone III has *b* value ≤0.6; zone II has b value 0.6–0.8; zone I has *b* value 0.8–1.0 and zone 0 has *b* value > 1.0.

occur in continental portions. Zone I covers two areas. These are the oceanic at 21°N, 18°N and 14.5°N and along the coasts on the Nubian side from 14.5°N up to 21°N and at 16°N in the eastern flank of the basin. Zone 0 generally covers the Red Sea basin and divides it into three parts at latitudes 15–16°N, 19°N, and 22°N wherein two of these are considered seismically active at present.

Since the parameter *a* is dependent on parameter *b*, it is expected that the contour shapes shall be quite similar (Fig. 2). The *a*-values of 4.0 and 6.0 are seen to be expanded in almost the same directions as with the 1.0 and 1.2 b-values respectively. Figure 4 shows that the most active zone is Zone 0 (Red Sea basin) in terms of number of events.

The estimated maximum magnitude and expected magnitude values from equations (3) and (4) respectively are seen to be within the respective zonal configurations for the parameter *b* (Fig.5). The range of maximum magnitude from 7.0 to 7.5 is seen to be located in the Afar region, Danakil block, Djibouti, and Yemen (Fig. 5). The maximum magnitude for the Red Sea is 7.0, the same as inland in the vicinity of point (18°N, 42°E) in the Tihamat–Asir region. South of latitude 17°N up to 14°N, the maximum magnitude is 6.5. On both flanks of the basin the maximum magnitude decreases in value. The wide areas on the possibility of the probable occurrence of the estimated maximum magnitude seem credible due to the presence of many dislocation lines, structural boundaries, rigid, and large crustal structures in the study area.

Figure 6 shows the expected magnitude in the study area at 90% non-exceedance in 50 years. In comparing Figs 5 and 6, the magnitude values are almost equal, except in their spatial coverage. The spatial distribution of the expected magnitudes is decreased in area in comparison to the estimated maximum magnitude which could be interpreted that their likely occurrence

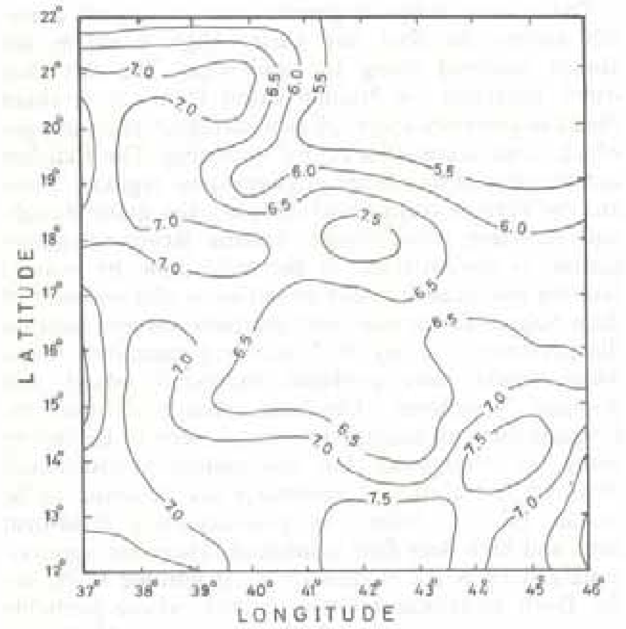

Fig. 5. Iso-contour map of maximum expected magnitude in the study area.

is confined over a relatively smaller area of coverage. The observation that the estimated maximum magnitude and the expected magnitude are almost equal could be interpreted that the return time of the estimated maximum magnitude may be approximately equal to the expected magnitude with some degree of certainty of occurrence over overlapping areas of coverage.

Al-Haddad *et al.* (1994) and Al-Amri (1994) estimated the peak ground acceleration (pga) in the southern Red Sea was 0.2 g at 10% exceedance in 50 years. Comparison of above results to Fig. 6 upon

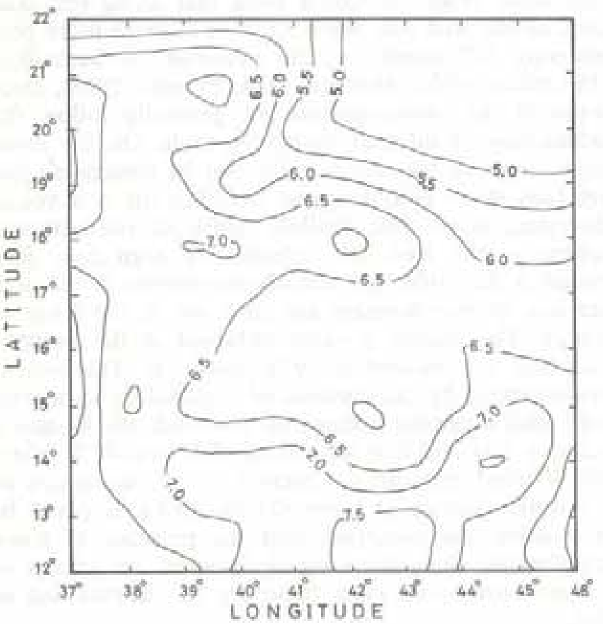

Fig. 6. Spatial distribution of expected maximum magnitude in 50 years at 90 % probability of non-exceedance.

conversion to pga shows that compatibility exists between present and previous findings based on the same attenuation model.

Conclusions

Different zonal configurations were preliminarily established from the space distributions of parameter b. The distributions were the results from the applications of the maximum likelihood methods of Utsu (1965) and Aki (1965) to the moving block method of Hattori (1974) as data source area. Boundaries between delineated zones were determined from the applications of the proposed models of Scholz (1968) and Wyss (1973).

Four zones were formed from the models for simplicity. Characteristics of each zone were preliminarily defined in correlation to seismotectonic and geophysical observations from previous studies and investigations. Correspondingly, the space distributions of the other seismic parameters were also prepared. The different zones which correspond to respective b-value range are generally agreeable to previously established correlation for approximately the same b value range. Zone III, whose b-value range is less than 0.61 covers stable and mobile continental areas whose structures are mainly composed of stress resisting materials. Zone II has the b value range from 0.61-0.8. The areas covered by Zone II are characterized by the presence of younger structures and dislocations. Zone I whose bvalue range from 0.81 to 1.0 covers the coastal areas on both flanks of the Red Sea basin and the southern tip of the Red Sea. Zone 0 has the b value greater than 1.0. Areas covered by this zone are the oceanic portions where normal and transform faults, heat flows and magnetic anomalies are prominent and relatively high seismic activities are present.

Spatial distribution of the seismicity parameters obtained in this study in the southern Red Sea regions may be the first of its kind in this area. The findings may be preliminary due to the encountered constraints. However, the results show strong agreement with previous work done in larger area of coverage. The advantages are due to the applications of the methodologies, procedures and models that reduce dependence on arbitrariness and yielded quantitative bases in characterizing the seemingly observed complex seismic activities. The results have shown some degree of appropriateness of the applied methods in correlation to seismotectonic activities and to some extent to the geophysical phenomena observed in the study region.

Acknowledgements-We wish to express our appreciation to Dr Ali Gharib and Ahmed Rabie of the Seismic Studies Center of King Saud university for their valuable assistance.

REFERENCES

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,* 237-240.

Al-Amri A. (1994) Seismicity of the south-western region of the Arabian Shield and southern Red Sea. *Jour. Aft. Earth Sci. 19,* 17-25.

AI-Haddad M., Siddiqi G., Al-Zaid R., Arafah A., Necioglu A. and Turkelli N. (1994) A basis for evaluation of seismic hazard and design criteria for the Kingdom of Saudi Arabia. *Earthquake Spectra* 10, 231-258.

Ambrasey A. (1988) *Seismicity of' Saudi Arabia and adjacent areas.* Imperial College of Science and Technology, London, U.K. Bender B. (1983) Maximum likelihood estimation of b values for magnitude grouped data. *Bull. Seism. Soc. Am. 73,* 831-851. Eg1off F., Rihm J., Makris Y., Izzeldin M., Bobsien K., Meier P., Junge T., Noman T. and Warsi W. (1991) Contrasting structural styles of the eastern and western margins of the southern Red Sea. *Tectonophysics 198,* 329-353.

El-Isa Z. and Al-Shanti A. (1989) Seismicity and tectonics of the Red Sea and western Arabia. *Geoph. Jour. Astr. Soc. 97,* 449-457. Francis T. (1968) Seismicity of mid-oceanic ridges. *Earth Planet. Sci. Lett. 4,* 39-46.

Gutenberg B. and Richter C. (1954) *Seismicity of the Earth and Associated Phenomena.* Princeton *Univ.* Press.

Hall S. (1979) A total intensity map magnetic anomaly map of the Red Sea and its interpretation. *In Directorate General of Mineral Resources, Vol.* 275, p. 260 p. Jeddah, Saudi Arabia.

Hattori S. (1974) Regional distribution of b value in the world. Bull. Inter. Inst. Seism. Earthq. Engineering *12,* 39-57.

Karnik V. (1969) *Sei.smicity of the European area, Geophys. Monograph, The earth's crust and upper mantle. Am. Geophys. Union, Washington, D.C.* Seismicity of the European area, part 2, Academia, Publishing house of the Czechoslovak Academy of Sciences, Praha, Czechoslovakia, pp. 123-169.

Makris J. and Rihm R. (1991) Shear-controlled evolution of the Red Sea: pull apart model. *Tectonophysics 198,* 441-466.

Miyamura S. (1962) Magnitude-frequency relation of earthquakes and its bearing to geotectonics. *Proc. Japan Academy 38 (1),* 27 PP.

Mogi K. (1962) Magnitude-frequency relation for elastic shocks accompanying fractures of various materials and some related problems in earthquakes.. *Bull. Earthg. Res. Inst. 40,* 831.

Pisarenko V., Lyubushin A., Lysenko V. and Golubeba T. (1996) Statistical estimation of seismic hazard parameters: maximum possible magnitude and related parameters. *Bull. Seism. Soc. Am. 86,* 691-700.

Ritsema A. (1969) *Seismology and upper mantle investigations, Geophys. Monograph, The earth's crust and upper mantle.* Amer. Geophys. Union, Washington D.C..

Scholz C. (1968) Microfractures, aftershocks and seismicity. *Bull. Seism. Soc. Am. 58,* 1117-1130.

Thenhaus P., Algermissen S., Perkins D., Hanson S. and Diment W. (1988) *Probabilistics estimates of seismic ground-motion hazard in western Saudi Arabia. U.S.* Geol. Bull., p. 1868..

Utsu T. (1965) A method for determining the value of b in a formula log n = a-bM showing the magnitude-frequency relation for earthquakes. *Geophys. Bull. Hokkaido Univ. 13,* 99-103.

Welkner P. (1967) On space distribution of some seismic parameters in Japan.. Bull. Inter-. Inst. Seism. Engineering *4,* 1-18.

Wyss M. (1973) Towards a physical understanding of the earthquake frequency distribution. *Geophys. Journ. Astr. Soc. 31,* 341-359.