Bulletin of the Indian Society of Earthquake Technology. Vol. 5, No. 1-2, pp. 63–78. March–June, 1968

QUANTITATIVE MEASURES OF SEISMICITY APPLIED TO INDIAN REGIONS

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Abstract

Three Measures of seismicity have been discussed and their comparative significance analysed. These are (a) The rate of strain generation and relaxation (b) Tectonic flux and (c) Frequency magnitude analysis. Examples of the behaviour of Indian regions is given and relevant results have been tabulated.

Introduction

Seismicity studies have evolved greatly since the time when Oldham (1911) and Montessus de Ballore (1911) first sought to express the seismic susceptibility of Assam by plotting the epicentres of earthquake as circles of varying dimensions to depict their relative sizes. Later, as more data accrued, other parameters such as radii of perceptibility and maximum observed intensities were variously used to denote the seismic activity of a region. However, they all suffered from an undue weightage on personal judgement and local rock conditions. The adoption of the Magnitude scale which related it to the energy released by an earthquake, although subject to certain constraints of experimental requirement, greatly changed the picture and has given earthquake statistics an objective look and a promising future.

Depending upon their completeness, earthquake data pertaining to a given region can be put to three different kinds of analyses—(a) Studies of the strain rebound increments, (b) Studies of the tectonic flux and (c) Frequency–Magnitude analysis.

These studies have several advantages over the older one of merely plottiug the sizes and locations of earthquakes. Apart from their objective character related to the physically sensible quantity representative of an earthquake i.e., its energy, they are relatively less susceptible to errors in epicentral determinations. They also emphasize the remarkable coherence which seismic activities possess both on region as well as on global scales.

Studies of the Strain Rebound Increments

Tectonic earthquakes occur in regions which are undergoing strain in response to certain geological processes. When the consequent stresses exceed the breaking strength of rocks, the potential energy of strain is released by fracturing and subsequent rebound of the rock masses toward equilibrium. The adoption of the earthquake magnitude which has made it possible to determine an objective quantity related to earthqukes i.e., the energy released by them, in turn permits the calculation of a quantity related to the strain rebound or of the equivalent fault slip.

If an elementary volume 'dv' within a fault rock suffers a strain e_{ij}, the resulting strain energy per unit volume can be considered to consist of two parts : one due to symmetrical or hydrostatic stresses and the remaining due to deviatoric stresses. In order to calculate a quantity proportional to strain, the following symbols are used.

1. $T_{ij} = \frac{1}{3} \sum_k T_{kk}.\delta_{ij} + P_{ij}$ — components of the stress tensor
2. $\frac{1}{3} \sum T_{kk} = - p$ — hydrostatic stress

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3.	P_{ij}	— components of the deviatoric stress tensor
4.	$e_{ij} = \frac{1}{3} \Sigma e_{kk} \delta_{ij} + E_{ij}$	— components of the strain tensor
5.	$\Sigma e_{kk} = \theta$	— cubical strain
6.	E_{ij}	— components of the deviatoric strain tensor
7.	μ	— coefficient of rigidity
8.	K	— bulk modulus
9.	W	— Potential strain energy per unit volume
10.	J	— Seismic wave energy
11.	V	— Total volume of rocks involved in the strain
12.	γ	— Fraction of potential strain energy converted into seismic wave energy. This is taken as constant for the entire volume V.

Where $p = -k\theta$, $P_{ij} = 2\mu E_{ij}$ (Bullen, 1963, p. 32), and the subscripts 'h' and 'd' signify quantities explained above relating to hydrostatic and deviatoric components. We then have the following relations :

$$W_h = \tfrac{1}{2} p\theta = \tfrac{1}{2} K\theta^2 \quad (6)$$

$$W_d = \tfrac{1}{2} P_{ij} . E_{ij} = \mu (E_{ij})^2 \quad (7)$$

$$= \mu (e_{ij} - \tfrac{1}{3} \Sigma e_{kk} \delta_{ij}) (e_{ij} - \tfrac{1}{3} \Sigma e_{mm} \delta_{ij})$$

$$= \mu (e^2_{ij} - \tfrac{1}{3} \theta^2)$$

Also, $$J = \gamma \int_0^V W \, dv \quad (9)$$

If a simplification is introduced by considering $\gamma_h = \gamma_d = \gamma$, and $V_h = V_d = V$ and further if $K = 2\mu$ (Bullen 1963 pp. 233) we get,

$$J = J_h + J_d = \gamma\mu \int_0^V (e^2_{ij} + \tfrac{2}{3} \theta^2) \, dv \quad (10)$$

The above integral can be replaced by a more tractable expression by assuming an average value of strain ϵ which is constant throughout the valume V, so that,

$$J = \tfrac{1}{2} \gamma\mu V\epsilon^2 = C^2 . \epsilon^2 \quad (11)$$

where $\epsilon^2 = (2e^2_{ij} + \tfrac{4}{3} \theta^2)$

or $$C.\epsilon = J^{1/2} \quad (12)$$

where C is a constant dependent upon the volume of the strained rock mass and the elastic coefficients. In general. it is not possible to determine this constant but it may be assumed to be uniform for a given fault system.

Further, if it is assumed that the total strain ϵ is completely released by a slip X_f along a fault then,

$$\epsilon = C_1 . X_f$$

or $$C'.X_f = J^{1/2} \quad (13)$$

where C' is another constant dependent upon the elastic coefficients and the shape and volume of the strained rock.

The square root of the seismic wave energy released by an earthquaqe i.e. $J^{1/2}$ which can be readily calculated from the value of the magnitude is thus a measure of the associated strain release or the equivalent fault slip. A study of the cumulative strain release over a given period thus offers a useful means of comparing the seismic activities of different regions and also of the same region over different periods of time. In practice, this is done by plotting the cumulative values of $J^{1/2}$ corressponding to all the earthquakes considered, against the time of their occurrences which are reckoned in terms of Julian days. Studies of the elastic strain rebound characteristics over varying periods of time have been carried out for a number of regions of the world by Benioff (1949, 1951, 1954, 1955) both for shallow as well as deep focus earthquakes. He also plotted these values corresponding to the shallow and deep focus earthquakes (Benioff, 1951) for the whole world in order to study the total strain build-up in the world. These curves prove the understandable result that whilst in the upper elastic layer, where locking of a fault can only be relieved by subsequent fracture, the strain release occurs in active periods which alternate with relatively quiescent periods, the strain release in deeper regions is almost steady.

Similar study has been made for both shallow and intermediate focus earthquakes for the Indian subscontinent including Baluchistan and Tibet, covering a period of sixty years from 1905 to 1964. The resulting strain rebound characterestics are shown in Figures 1 and 2. The study has been further extended to different seismic regions of the country and will be published elsewhere.

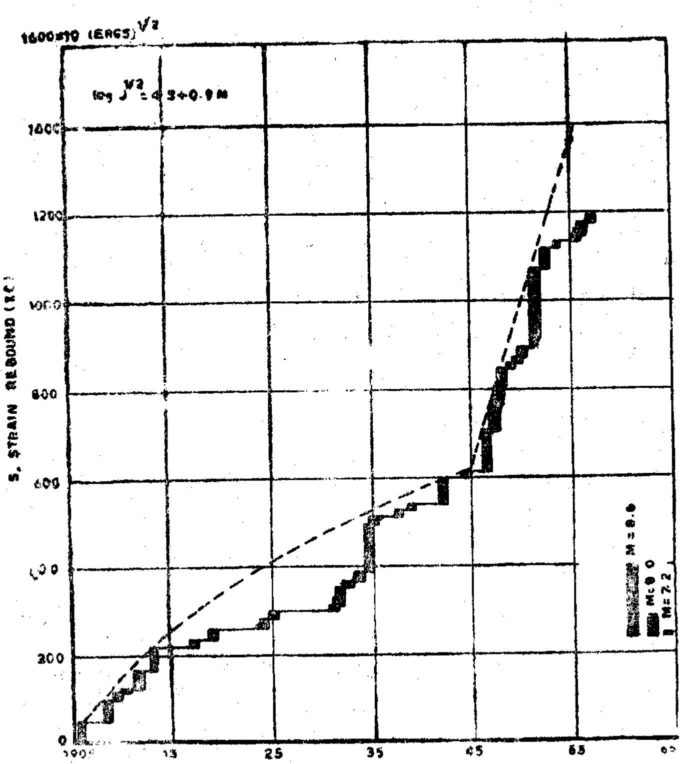

Fig. 1. Strain Accumulation and Release by Indian Shallow Earthquakes

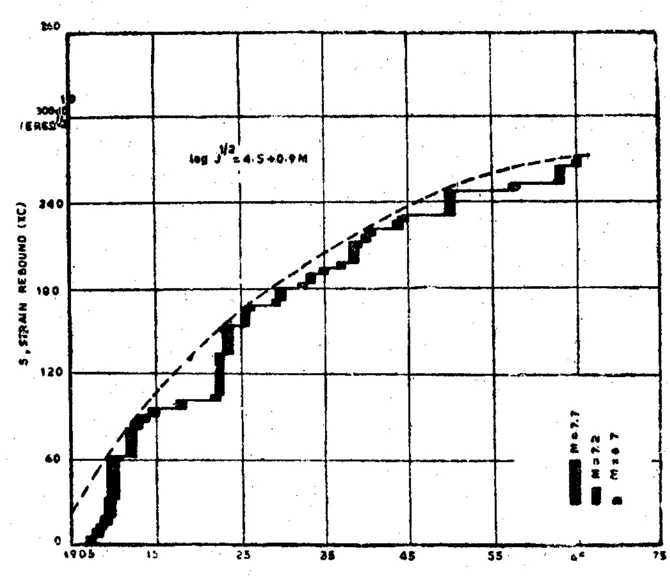

Fig. 2. Strain Accumulation and Release by deep Earthquakes having focal depth greater than 70 kilometers

It is well to recall here the various assumptions which are made whilst drawing the cumulative strain rebound curves and to examine their validity in the light of the results obtained. These assumptions are :

1. That the constant C which relates the strain to the square root of seismic wave energy is uniform throuhout the region. As C is a function of three quantities γ, μ and V as defined by equation (11) let us consider them one by one. γ which in fact represents the conversion efficiency of strain energy into wave energy can almost be taken to be unity as the pattern of energy release in earthquake aftershock sequences suggests that the principal earthquake is produced mainly by almost instantaneous elastic processess. However, variations in the values of the remaining two quantities μ and V from one fault system to another would be expected to destroy the coherence, if any, in the pattern of strain rebound increments. On the contrary, the strain rebound characteristics of various regions and even of the whole world considerd as a single unit (Benioff 1951, 1954) show remarkable consistency, and demostrate that possibly both μ and V or their product remains substantially constant for the fault systems.

2. That all the strain energy stored purely elastically is released by a single principal earthquake.

3. That seismic wave energy is radiated equally in all directions—an assumption which is implicit in the definition of M values which, in turn, form the raw material for the above studies.

Strain Relaxation

Strain rebound characteristics of all but deep focus shocks exhibit spurts of seismic activity separated by relatively quiescent periods. The resulting figure is thus a saw-tooth curve, the upper peaks of which, marking the end of an active period, represent a near exhaustion of the accumulated strain. A line drawn through these points (see straight line in figure 3a) therefore represents the rate of secular strain generation. Considering a mean rate for this in a given region it is then possible to illustrate the relative strain level obtaining in that region at different times, by means of a strain accumulation and relaxation curve. One such curve can be seen in figure 3b. At the begining of the period under study, the strain curve starts from an arbitrary level which represents the store of accumulated strain in that region at that time. It is then made to follow a slope equal to the

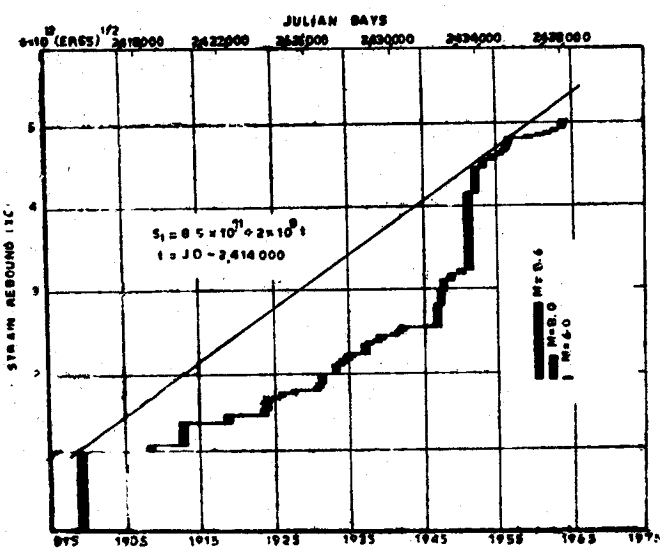

Fig 3a. Elastic strain rebound increments (times constant) of the assam region using shallow earthquakes having M $\leqslant$ 6.0

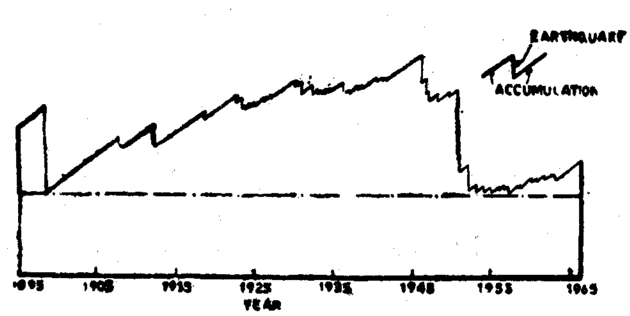

Fig. 3b. Relative strain accumulation and relaxation of the Assam region

mean rate of strain generation, which is derived from the strain rebound increments in a manner described above, until an earthquake representing a discontinuous release of strain takes place. At this point on the time axis, the curve drops vertically by an amount equivalent to the strain released by the earthquake and again follows the slope of strain generation until the occurrence of the next earthquake. Thus we have a yearwise strain accumulation and relaxation curve. Figure 3 referred to above pertains to the Assam region. Similar curves have been obtained for other seismic regions of the country.

A remarkable point illustrated by these curves is that although the strain level in a given region following an earthquake or a series of earthquakes may fluctuate from one active period to another, every region is characterised by a certain minimum level of strain which is perhaps seldom crossed.

This minimum level of strain which may or may not be zero perhaps represents the remanent strain that may persist even after the entire accumulated strain had an opportunity to be released by a large earthquake and therefore suggests itself as a suitable reference from which to estimate the amount of strain available in a region for future earthquakes. Assuming the worst possible situation that all the strain available at a given time in the near future is released by a singile earthquake it is then possible to predict the maximum probable magnitude of that earthquake. Thus the curve for Assam shows that around the year 1950, the region had enough strain to produce an earthquake of magnitude 8.5, which actually did occur.

Estimates of magnitudes of earthquakes liable to occur in the near future in other regions of the country are given in table 1, though it must be noted that these values refer to the maximum probable magnitudes and do not preclude the occurrence of smaller shocks. It is felt that this method would prove valuable for the purpose of general statistical risk prediction.

Table 1

Result of strain release characteristics of various regions giving the maximum probable size (Richter magnitude) of an earthquake that may occur there in the near furture.

Region, Magnitude range Period	Rate of strain generation $\times 10^7$	Maximum probable size of earthquake that may occur in near future
The Andman-Nicobr region M = 5.5 to 8.1, 1915–1964	7.2	7.4
The Assam region M = 6.0 to 8.6, 1897–1964	20.0	8.2
The Bihar-Nepal region, M = 5.5 to 8.3, 1913–1964	8.5	7.3
The Kashmir region M = 5.5 to 7.6, 1924–1964	9.3	7.4
The Kutch region M = 5.0 to 7.0, 1928–1964	0.96	6.5

Tectonic Flux

If instead of plotting the strain released in a given region against time without regard to the spatial distribution of earthquakes, the rate of strain release per unit area is calculated for small units of the region and contoured the resulting map reveals some striking trends of seismic activity in close parallelism with the tectonic features. Such a map is called a tectonic flux map. The quantity plotted is the rate of flux of $J^{1/2}$ or simply the flux $J^{1/2}$ over a given period and is defined after Amand (1956) as follows :

$$F = \frac{1}{AT} \int_A \int_T J^{1/2} \, dA dt \quad (14)$$

where, A — is the area chosen

T — is the duration for wich the sum has been formed, and

$J^{1/2}$ — is the elastic strain times a constant.

A tectonic flux map has the built-in advantage of compromising the number of shocks with their sizes. The visual impressions produced by such maps can indeed be quite revealing and may help unify many a hiatus in an incomplete tectonic map of a region.

In order to prepare a tectonic flux map the region under consideration is first divided into small units of area by parallels of longitudes and latitudes. The strain release times a constant, which is given by the square root of the wave energy, is then calculated from the magnitude values corresponding to all the earthquakes above a certain magnitude that have occured in the region during the selected period. These are distributed amongst the various areal units as follows :

(a) If the epicentre is located within the boundary of the unit, the entire strain is assigned to it.

(b) If the epicentre is located on a boundary of two units, the strain released by the earthquake is divided equally between the two units.

(c) If the epicentre is located at the intersection of two boundaries, a quarter of the strain is assigned to each of the four adjoining units.

Finally for every unit area the sum of all the $J^{1/2}$ values assigned according to the above criteria is calculated, plotted at the centre of the unit and contoured. Before discussing a practical example however, it is well to question the unit of area and time interval chosen for preparing the tectonic flux map of a region. The smallest unit of area is largely limited by the accuracy of epicentral determinations. Thus in many cases, particularly if past earthquake records are used, a unit of area larger than desirable may have to be used, although this may partially compensate for the fact that the strain released by an earthquake covers a finite area, usually elongate, parallel to the fault system and not just a point represented by the epicentre.

The interval of time chosen, on the other hand depends upon the purpose behind the map. Tectonic flux maps covering shorter periods will normally be useful for studying the changing pattern of seismic activity of isolated regions. Longer period on the other hand will obliterate such temporal changes and tend to produce a more unified spatial picture of the seismic activity.

Tectonic flux maps are especially useful in studying the seismic behaviour of geologically complex regions, such as the Himalayas. Accordingly, a map was prepared for the entire Himalayan region including Baluchistan in the west and Tibet in the north. A period of 60 years from the year 1905 to 1964 was chosen in order to delineate most of the active seismic trends in this region which may have widely separated return periods. As the purpose of this study was only to mark the spatial pattern of active weak zones rather than emphasize the absolute values of strain released, values of $J^{1/2}$ were plotted directly without being reduced to unit time, which is constant for all points.

The above map (see figure 4) shows a boundary line dividing a northern zone having $\Sigma J^{1/2}$ greater than 10^9 $(ergs)^{1/2}$ from a southern zone having $\Sigma J^{1/2}$ values less than this. This boundry line closely follows the great boundry fault of the lesser Himalayas which runs from Kashmir to Assam. Of course this parallelism does not exist at the western and eastern extremeties as the tectonic patterns in these regions have been greatly infiuenced by the wedged in blocks of the Peninsular shield. However, it is quite apparent thatt his great boundary fault is more or less active all along its length, which incidently controverts the general feeling amongst geologists that only some parts of it are active. This is a significant result obtained purely from seismic studies. Further, the distribution of tectonic flux north of the boundry correspond to the not so continuous great boundary thrusts of the Himalayas. The maximum value of the flux is found to be in the Sadiya region north east of Assam which was the seat of one of the biggest earthquakes in history having a magnitude of 8.6.

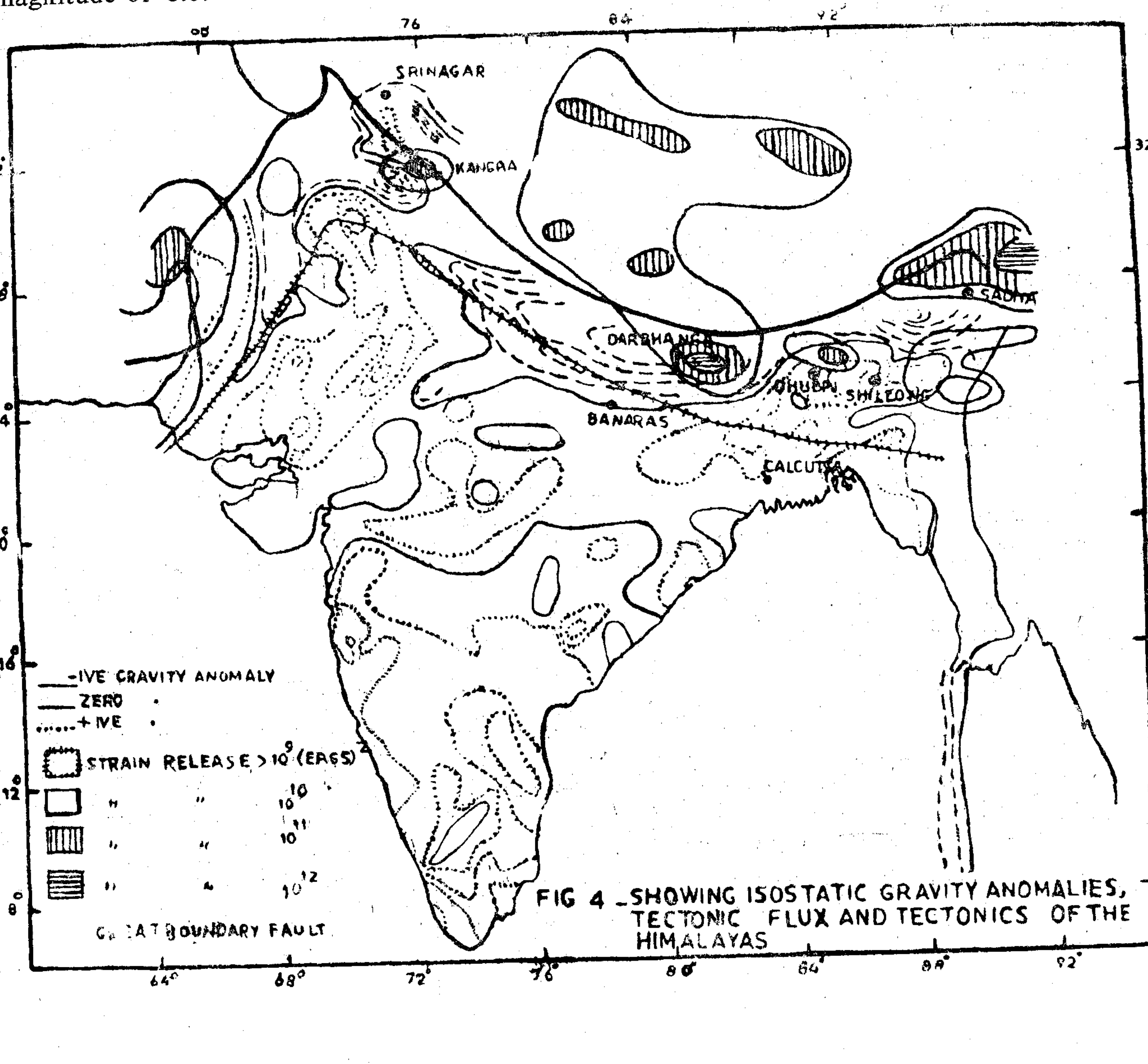

FIG 4 – SHOWING ISOSTATIC GRAVITY ANOMALIES, TECTONIC FLUX AND TECTONICS OF THE HIMALAYAS

The only other region of India for which sufficient data exist to enable the preperation of a tectonic flux map is the Assam region. For this purpose the Assam region was divided into small units of 0.01 square degree by parallels of Latitudes and Longitudes 0.1° apart (Chouhan, Gaur and Mithal 1966). This interval was chosen in view of the errors in epicentral determinations as quoted by the U.S. Coast and Geodetic Survey. All earthquakes of magnitude 5 and above which occurred during the 12 year period between January 1953 and December 1964 were considered for this study. The choice of the beginning of the interval was dictated by the availability of data having the above mentioned accuracy, whereas the length of the period was chosen after trial and error, so as to reveal maximum coherence in the prominent trends of seismic activity.

The tectonic flux for the entire period was calculated for each unit of areas and plotted accordingly. Thereafter, contours of equal tectonic flux were drawn at intervals of 0.5×10^{10} $(\text{ergs})^{1/2}$.

A visual inspection of this map shown in figure 5 reveals some conspicuous features which appear to coincide with known tectonic trends of the Assam region. Thus the dashed line in the EW direction at about 25.2°N which joins two centres of high activity, follows the Dauki transcurrent fault pointed out by Evans (1964). Further, their close coincidence corrobarates the strike slip nature of the fault. Two other trends of seismic activity can be similarly noted on the north and the south east corner of the Shillong Plateau. These are respectiveiy parallel to (a) the Brahamputra valley which flows in a trough and (b) the NE-SW running belt of Schuppen. They, however, do not coincide with them. This offset is indeed to be expected as the thrusts dip into the crust at a low angle.

It may, however be mentioned that in a tectonic fiux map such as this covering a limited period, certain tectonic features associated with seismic activity of longer return periods may be entirely missed. Thus figure 5 referred to above is silent about the Sadiya region (28.6°N, 96.6°E) where a big earthquake of magnitude 8.6 occurred on 15th August 1950. This can, however, be seen in figure 6 showing a similar map for the 12 year period between 1940 and 1952. The map of course shows only the values of tectonic flux at discrete points as contouring was not possible owing to widely scattered epicentres. A better course would have been to superimpose these values on to other map and draw new contours, but the large differences between the errors of epicentral determinations made before and after the year 1952 would render this meaningless.

Inspite of what has been said above, which was meant to emphasize the possible defects of tectonic flux maps when constructed indiscriminately, the map obtained for the Assam region (1953–1964) appears to be remarkably objective. In fact an examination of the second map (1940–1952) suggests that a superposition of the tectonic flux values indicated therein on to the previous map would have the effect of leaving most of the trends unaltered apart from introducing another region of significant activity near Sadiya.

Frequency Magnitude Analysis

Both the studies of time variation of the strain release as well as of the tectonic flux of a region basically make use of cumulative values of strain released over a predetermined period without emphasizing the magnitudes of individual activity. This is indeed the purpose of these studies that is to highlight the relative capacity of a region to store strain and to delineate prominent zones of high activity.

However, if instead of plotting the cumulative strain release with time, the cumulative frequency of occurrence of shocks is plotted against tne corresponding magnitudes,

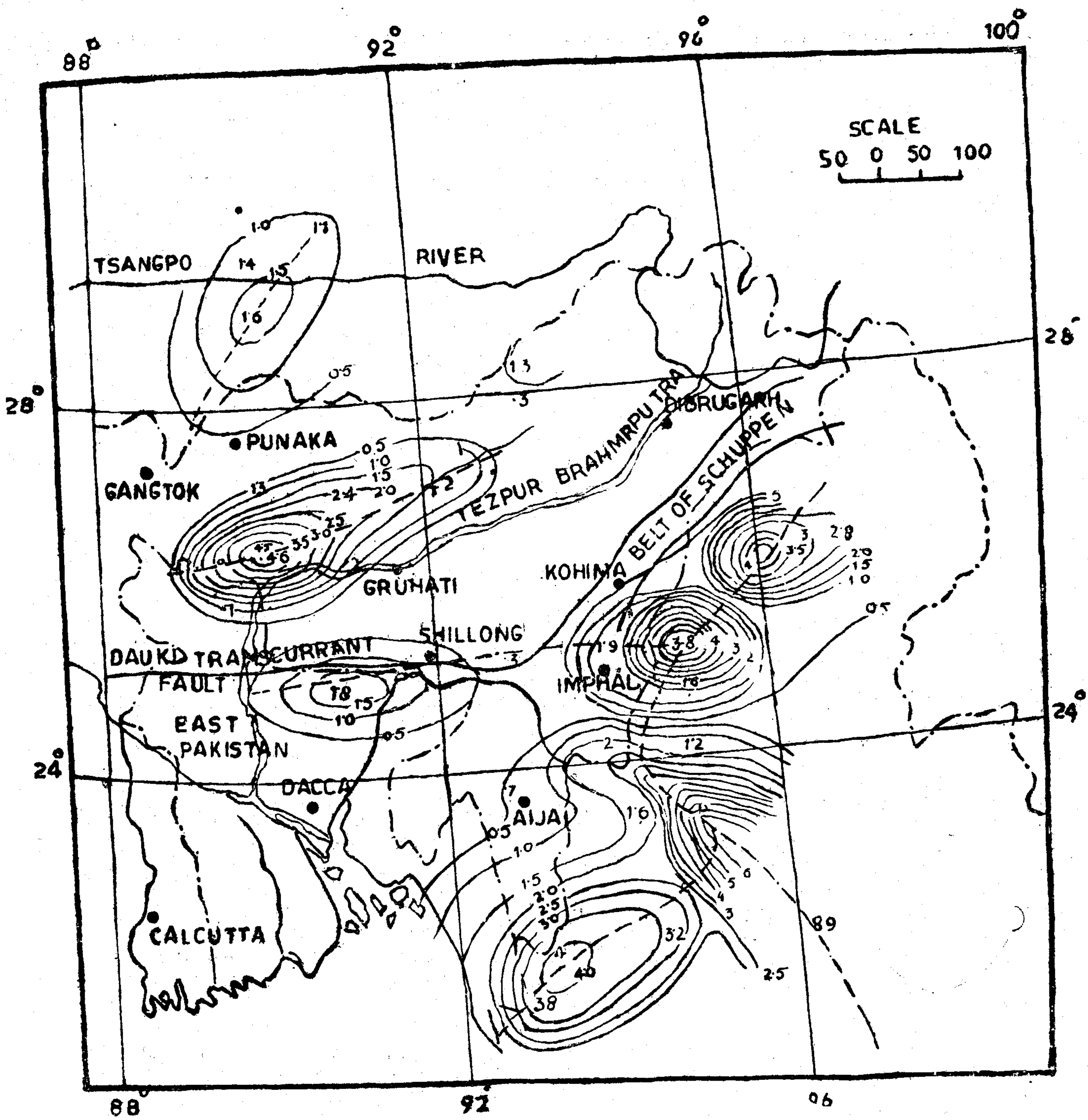

Fig. 5. Strain Energy Release Map of the Assam Shallow Eartquakes in the Unit of 10^{10} [ERGS]$^{1/2}$ Period 1953–64 Using M $\geq$ 5

some additional information regarding the seismic behaviour of the region can be obtained. The frequency of higher magnitude shocks in any region drops off for obvious reasons and those of lower magnitude shocks become comparatively more numerous. A closer scrutiny however reveals that even with this general behaviour, the variation of frequency with magnitude is characteristic for a given region

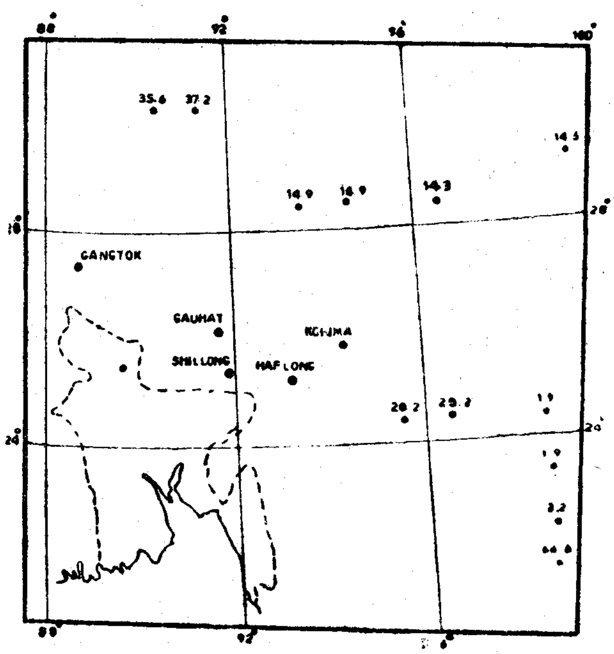

Fig. 6. Strain release map of the Assam shallow earthquake in the unit of 10^{10} [ERGS]$^{1/2}$ period 1940-1952

In 1939 Ishmito and Lida, observed that small earthquakes occurring in the Kanto district of Japan satisfied the following relationship.

$$NA^p = K \qquad (15)$$

where N is the number of earthquake which produced a trace amplitude between A and (A+dA) and p and K are constants. If we now consider the definition of the earthquake magnitude M in terms of a constant trace amplitude A_f produced by an earthquake of fiducial magnitude under standard conditions of observation,

$$M = \log A' - \log A_f \qquad (16)$$

Eliminating A from the above two equations we get,

$$\text{Log } N = a - bM \qquad (17)$$

where a and b are now modified constants. Another way of writing this equation is in terms of the wave energy J

$$\log N = A' + \beta \log J \qquad (18)$$

This last equation has been extensivly used by Russion seismologists for frequency-magnitude sudies but it is felt that no additional advantage can be gained by merely rearranging the terms, which incidentally increases the arithmatical work.

The simpler relation of the type Log N = a − bM was used for the present studies. It has been suggested by many workers in this field that one or the other of the constants a and b may be used as a suitable measure of seismicity though both these suggestions seem to suffer from being effectively a measure of either low or high magnitude activity. For, 'a' represents the frequency of earthquakes whose magnitudes in the limit pass to zero and 'b' of those whose magnitudes attain very high values.

In fact a more meaningful quantity appears to be the ratio (a/b) which signifies a certain reference magnitude, which will be characteristic of the region, corresponding to a unit frequency. The only arbitrariness thus introduced will be on account of the unit of time chosen for frequency determinations.

However, if the frequency is conventionally denoted as the number per year for all studies, this arbitrariness is ironed out whilst comparing the ratio (a/b) for different regions. If, however, a different time unit is chosen say δ years, the new frequency will be defined as the number of events per δ years. Incidentally, such a choice will only have the effect of increasing the value of 'a' by log δ, whilst leaving 'b' unchanged.

In order to bring out the coherence, if any, in the values of the ratio (a/b) for different seismic zones of the country, frequency-magnitude analyses have been made which show that that the relative values of the ratios (a/b) obtained for these regions are atleast qualitatively correct. This work has been further extended to include the statistics of shallow earthquakes in other seismic regions of the world covering earthquakes of magnitudes equal to or greater than 5 as data for lower magnitudes tend to be less reliable.

Figures 7 to 13 show the frequency-magnitude curves pertaining to Indian regions and figures 14 to 20 represent shallow earthquakes of various regions of the world. The resulting values of a and b are compared in tables 2 and 3 respectively.

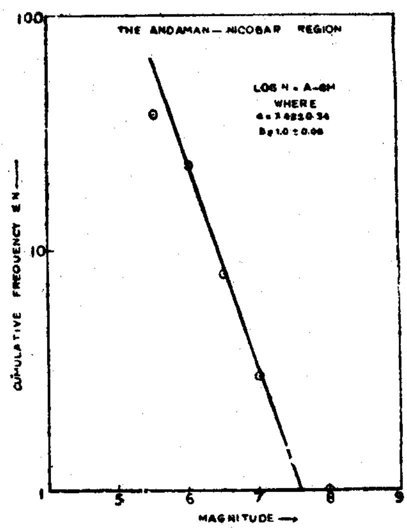

Fig. 7. Magnitude versus fiequency of occurence period 1915–64

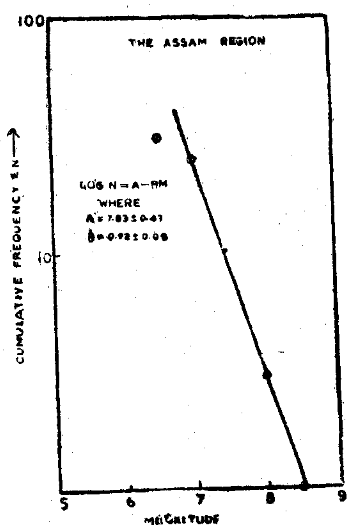

Fig. 8 Magnitude versus frequency of occurence

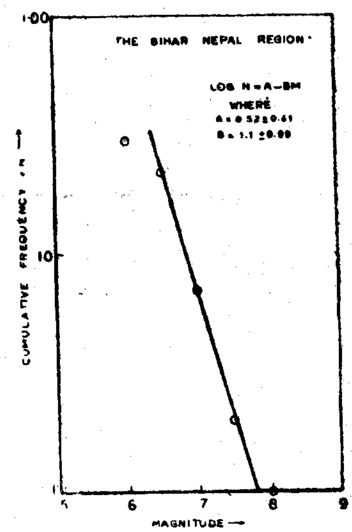

Fig. 9. Magnitu le versus frequency of occurrence period 1913–64

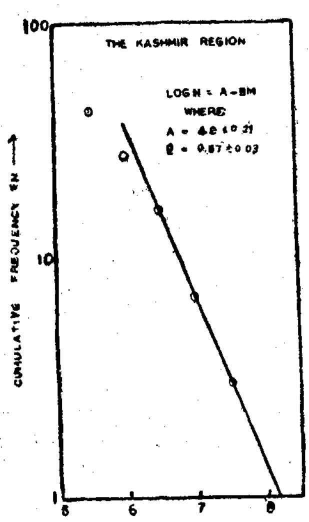

Fig. 10. Magnitude vers us frequency of occurrence period 1924–64

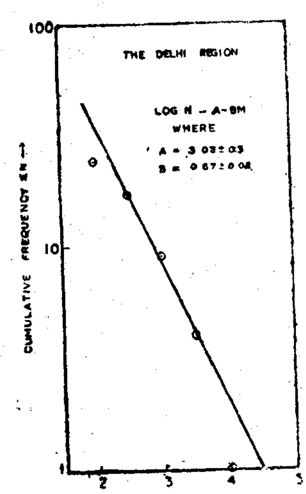

Fig. 11. Magnitude varsus frequency of occurrence period 1963–64

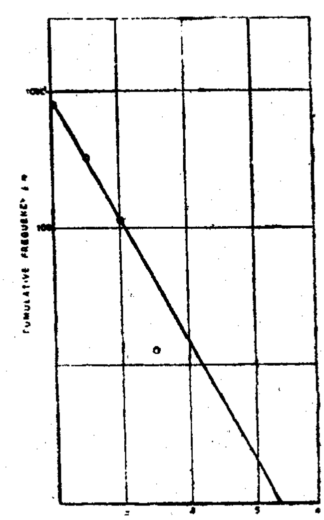

Fig. 12. Magnitude of versus frequency Koyna microtremors period 1963–67

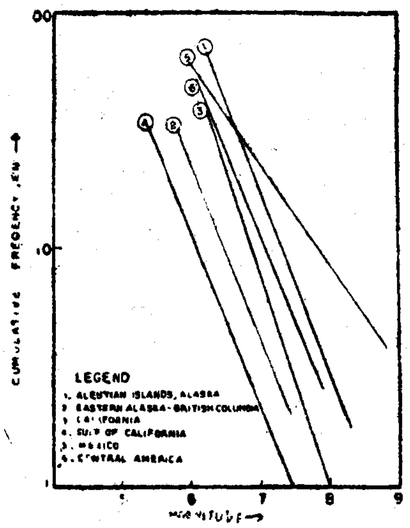

Fig. 13. Magnitude versus frequency of occurrence

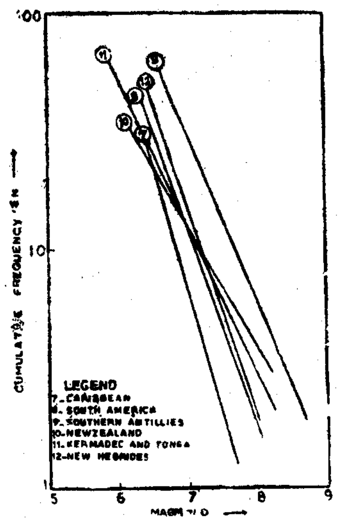

Fig. 14. Magnitude versus frequency of occurrence

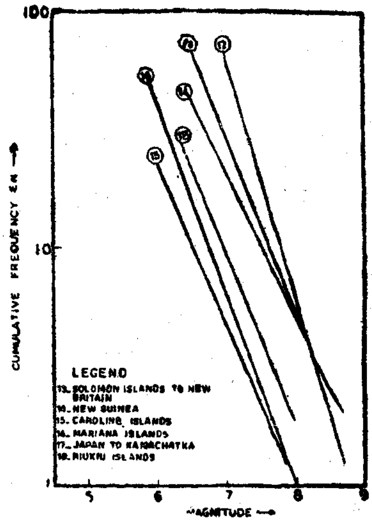

Fig. 15. Magnitude versus frequency of occurrence

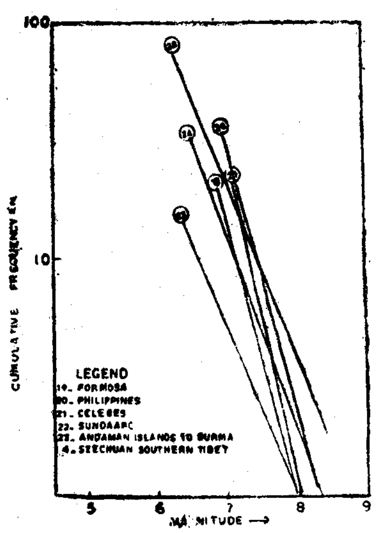

Fig. 16. Magnitude versus frequency of occurrence

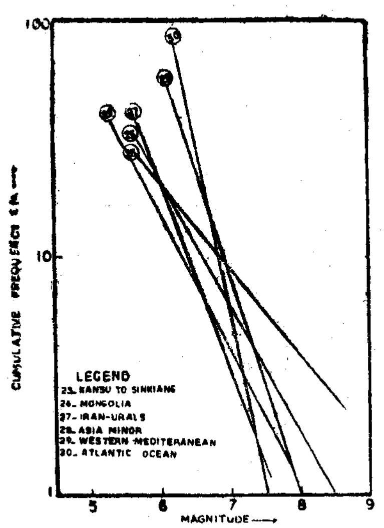

Fig. 17. Magnitude versus frequeney of occurrene

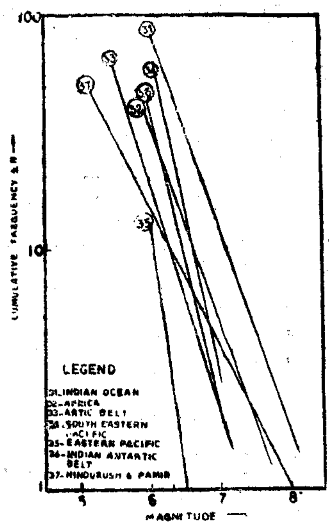

Fig 18 Magnitude versus frequency of occurrence

Table 2

Results of frequeney–magnitude analysis showing the ratio a/b and the return periods for earthquake of given magnitude

Calculated parameters Regio ı period and magnitude range	Values reduced for unit of time = 1 yr		a/b	Return periods for various magnitudes in years				
	a	b		8.5	8.0	7.5	7.0	6.5
The Assam region 1915–1964 M=6 to 8.6	6.13	0.92	6.6	53	22	7	2	
The Bihar Nepal region 1913–1964 M=5.5 to 8.3	6.82	1.1	6.2	...	78	28	8	
The Andman-Nicobar region, 1915–1964 M = 5.5 to 8.1	4.62	0.80	5.8	...	74	26	8	
The Kashmir region 1924–1964 M=5.5 to 7.6	3.2	5.7	5.6	...	...	14	6	
The Kutch region 1928–1964 M=5 to 7	3.38	0.71	4.7	...	...	...	40	
The Koyna region	4.05	0.87	4.6	...	...	...	80	
The Delhi region Jan. 1963 Dec. 1964 M = 2 to 4	2.27	0.67	4.1	...	...	...	100	
Deccan (South India)	...	...	...	...	...	...	...	62±5

Table 3

Showing the values of a/b obtained from the frequency magnitude analyses (world's shallow earthquake)

Region and period	Values of constants reduced correspond to annual frequency		a/b
	a	b	
1	2	3	4
1. Aleution Island Alaska, 1906–1945	5.17	0.79	6.36
2. Eastern Alaska, British Columbia 1908–1955	4.04	0.73	5.54
3. California, 1906–1945	5.16	0.86	5.99
4. Gulf of California, 1907–1945	3.92	0.71	5.49

1		2	3	4
5.	Mexico, 1907–1945	2.61	0.41	6.37
6.	Central America, 1904–1945	4.42	0.71	6.19
7.	Caribbean, 1910–1945	6.98	1.10	6.35
8.	South America, 1909–1944	4.84	0.70	6.92
9.	Southern Antilles, 1910–1945	6.64	0.87	7.60
10.	New Zealand, 1914–1945	3.18	0.51	6.23
11.	Karmadec and Tonga, 1910–1943	4.57	0.71	6.40
12.	New Hebrides, 1910–1945	5.94	0.90	6.59
13.	Solomon Islands to New Britain 1910–1945	4.84	0.75	6.44
14.	New Guinea, 1906–1945	4.04	0.64	6.30
15.	Caroline Islands, 1909–1943	3.76	0.66	5.58
16.	Mariana Islands, 1906–1945	4.87	0.81	5.99
17.	Japan to Kamachatka, 1905–1945	7.18	1.00	7.18
18.	Riukiu Islands, 1904–1945	4.24	0.70	6.02
19.	Formosa, 1914–1943	5.68	0.89	6.36
20.	Philippines, 1907–1943	6.72	0.98	6.85
21.	Celebes, 1910–1945	8.29	1.42	5.80
22.	Sunda arc, 1909–1943	4.95	0.75	6.48
23.	Andaman Islands to Burma 1912–1940	4.36	0.73	5.97
24.	Szechuan, Southern Tibet 1905–1945	5.22	0.82	6.37
25.	Kansu to Sinkiang, 1920–1945	3.00	0.51	5.88
26.	Mongolia, 1905–1944	2.64	0.35	6.55
27.	Iran–Urals, 1911–1945	3.92	0.79	4.98
28.	Asia Minor. 1909–1944	5.76	0.91	6.34
29.	Western Mediteranean, 1908–1945	3.12	0.58	5.34
30.	Atlantic Ocean, 1922–1944	6.99	1.10	6.36
31.	Indian Ocean, 1904–1944	5.64	0.88	6.43
32.	Africa, 1906–1945	5.33	0.91	5.86
33.	Arctic Belt, 1908–1945	5.72	1.00	5.70
34.	Southeastern Pacific, 1912–1944	8.91	1.42	6.24
35.	Eastern Pacific, 1926–1944	7.96	1.42	5.57
36.	Indian Antarctic belt, 1921–1942	5.06	0.83	6-07
37.	Hindukush and Pamir, 1907–1944	3.12	5.90	5.27

The curves are plotted on a semi-logarithmic paper in order to handle long periods of time on a convenient scale. It may also be mentioned here that whilst drawing these curves, the unit of time was chosen to equal the entire period for which data were used. This was done in order to be able to plot whole numbers rather than fractions. The values of a and b have, however, been reduced for all these cases to conform to the annual frequency in a manner described above.

The data used in the above studies have been abstracted from the Catalogue given by Gutenberg and Richter in their book Seismicity of the Earth and from the records of the U.S.C.G.S. and of the Indian observatories. Complete details are given in the first five appendices of the Ph. D. thesis of R.K.S. Chouhan submitted at the University of Roorkee in August 1968.

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