SEISMICITY OF THE TERRITORY OF PAPUA AND NEW GUINEA

by J.A. Brooks*

SUMMARY.

The distribution of large earthquakes in the Territory is described, and provides the only practicable means at present to zone the region according to probable maximum intensities. Changing probabilities with time are illustrated by three maps compiled for 25, 50 and 100 year intervals respectively.

The pattern of seismic activity during the last 50 years is analysed from the standpoint of strain fluctuations. In 1963 the relative level of accumulated regional strain appeared to be high.

INTRODUCTION.

In describing the seismicity of the earth, Gutenberg and Richter (1) refer briefly to the high level of activity in the New Guinea-Solomon Islands region and outline the main features of the structural arcs of New Britain and the Solomon Islands, concerned. It can be inferred from their statistics that few regions are more active per unit area than this one, which accounts for possibly 5-10% of all shallow earthquakes of magnitude 6 or greater. The present account has evolved from a study of all available earthquake data for shocks of Richter magnitude 6 and over, which occur at an average rate of about 10 per annum in the area concerned.

One of the most useful general forms of seismicity information for construction authorities indicates zones of prescribed degrees of expected maximum intensity. These evaluations can be based on (a) historical accounts and reports of macroseismic effects, (b) detailed geological data, and (c) earthquake statistics (frequency and magnitude).

Papua-New Guinea is highly mountainous and extremely rugged. Population is not uniformly settled, and an account of earthquake history comprehensive enough to use for zoning purposes does not exist. Circumstances also preclude the incorporation of available geological data in a uniform study of the seismic risk of the region. The proposal made for zoning the region is based on the frequency and magnitude of large shocks. Further discussion concerns variability of regional strain with time as deduced from a study of magnitude data.

DISTRIBUTION.

For statistical reasons an assessment of general seismicity can be based only on shocks of magnitude 6 or greater as lists of the more numerous smaller events are incomplete. Figure 1 illustrates the positions of all published epicentres of earthquakes of magnitude 6 or greater from 1906 to

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1962. 255 earthquakes are listed. About 10% of these occurred before 1930 and only since then are the data thought sufficiently complete to use further.

Large earthquakes have occurred over almost the whole New Guinea land area north of the Papuan border. New Britain and Bougainville particularly are very earthquake prone. Relative frequency of shocks of magnitude equal to or exceeding 6, 7, 7½ are illustrated in Figs. 2, 3 and 4 respectively. 30 years data (50 years in Fig. 4) have been extrapolated to express frequency of occurrence as a number per square degree per century.

A comparison made between Territory and world-wide earthquake statistics, both of which are listed in Gutenberg and Richter(1), indicates an average rate of occurrence of 115 shocks per century of magnitude 7 or greater, and about 1050 shocks of magnitude 6.0-6.9, within the Territory. Although the numbers of earthquakes used are small for a statistical analysis, especially with respect to large earthquakes, and the conclusions reached express only a probability, they seem reasonable and compare favourably with century rates of occurrence estimated from areas enclosed by contours of Figs. 2 and 3 viz., 130 shocks of M.7 or greater and 710 of M.6 or greater. Figs. 2 and 3 are based on activity between 1930 and 1959 whereas Gutenberg and Richter's statistics for three classes of shocks were compiled for various periods between 1904 and 1945.

Agreement for larger shocks (magnitude 7 or greater) is excellent. Considerably less, but still fair, agreement results from the comparison of corresponding data for shocks of magnitude 6 or greater. The discrepancy of over 300 shocks per century may be partly explained by considering the strain release data (Figs. 8, 9) which suggest that the years 1932-1935.5, chosen by Gutenberg and Richter for statistical analysis of earthquakes of magnitude 6.0-6.9, may have been a period of higher than average activity in the Territory. It is estimated that the figure of 1050 should be reduced to about 900 for this reason. Moreover, in the interval 1940-46 only 29 earthquakes above M.6 are listed, of which more than two thirds are greater than M.7. Application of more accepted ratios of occurrence in these magnitude ranges leads to the conclusion that the value of 710 quoted earlier may be too low by as much as 200.

Thus earthquakes of Richter magnitude 6.0 or greater seem to occur at an estimated average rate of between 900-1000 per century within the borders of the Territory. Of these, perhaps 10-15% seem to be above magnitude 7.

SEISMIC ZONES.

Frequency and magnitude statistics of large earthquakes have provided the basic data to zone the region broadly according to expected maximum intensities (Modified Mercalli) per unit area for three time intervals, viz., 25, 50 and 100 years. (Figs. 5, 6, 7). As any serious risk of damage exists only because of the likelihood of large earthquakes, this approach seems logical. The three maps illustrate the changing probabilities of intensity values for three different time intervals.

Magnitudes can be assigned "equivalent" epicentral intensities (I_0) that represent maximum intensities on "average" ground. For zoning purposes here, the conversion relation used is

$$M = 1 + 2 I_o / 3$$

and the magnitudes from $6-7\frac{1}{2}$ thus correspond nominally to intensities ranging from VII+ to X (Modified Mercalli). Thus, in Figs. 5-7 the Territory is subdivided into areas of "expected highest intensities" within specified periods of time. The boundaries were determined by superimposing contours of corresponding frequency from Figs. 2-4.

Quantitative empirical treatment of the relation between magnitude, epicentral intensity, focal depth, and radius of perceptibility has been attempted by several investigators, principally in U.S.A., U.S.S.R., and Japan; e.g. Gutenberg and Richter(2), (3); Shebalin(4). Similar information is not available for earthquakes in the New Guinea area. Until it is, the results of empirical studies made elsewhere to determine these relations are being accepted as broadly valid for this region.

The equation used above relating M to I_o was derived by Gutenberg and Richter(3) from a study of Californian earthquakes at about 20-30 km. focal depth. About 40% of Territory shocks listed since 1930 and used in this study were assigned depths exceeding 30 km. including 15% exceeding 100 km. Estimates of corresponding values of I_o using the above equation could, therefore, be too high in some cases. However, it has been suggested (4) that in one region at least, shocks as deep as 100 km. may cause epicentral intensities usually expected from much shallower earthquakes of comparable magnitude. Thus, use of expressions selected according to depth of focus is not yet justified, and would complicate the analysis to no clear advantage. The equation chosen is adequate to meet the general aim of determining broad regional zones.

Earthquake statistics refer not to the history of every point in an area, but to the occurrence at specific points of events of a certain intensity. Therefore, to express the risk of damage at every point in the neighbouring region, an assumption must be made about the area affected by the earthquake. In this discussion it is assumed that the epicentral intensity applies to all points in the square degree (about 12,000 sq.km.) centred on the epicentre. Earthquakes with epicentres outside this square degree are ignored.

This assumption is undoubtedly controversial. Insufficient local empirical evidence is available to justify it, or any alternative. Attention has been given to published data on this subject. In practice some constraint is introduced by the low accuracy, often $\pm 1^o$ or more, of the epicentral coordinates (Fig. 1) which limited the allocation of frequency numbers, for the purpose of defining the contours in Figs. 2-4, to areas no smaller than about one half square degree. The choice of one half square degree as the epicentral area would be reasonable, but having regard to possible average depth of focus in the Territory, this could be too small for use as a base for the zoning diagrams. On the other hand, if one square degree is too large, its use does incorporate an arbitrary "safety factor."

A probable maximum or "expected highest" intensity (I) is defined such that earthquakes having epicentral intensities of I (or >I), occur on an average once per square degree per specified time interval, and the zone charts (Figs. 5, 6, 7) indicate different values of I that apply throughout the shaded areas. The probability that at least one earthquake causing an indicated intensity I (experienced over a 12,000 sq.km. area, and corresponding to the epicentral intensity related to the earthquake magnitude as discussed earlier) will occur in a given interval, i.e. 25, 50, 100 years is 63%.

VARIATION OF STRAIN.

The zoning method described above relies on the implication that earthquake activity observed over the last 30 years or so will continue at about the same average rate. This is now investigated.

It is generally believed that any significant pattern describing earthquake activity (excluding aftershock studies) may not become evident for perhaps thousands of years. Consequently seismic activity observed for 30-50 years may not indicate any feature of importance in this respect. Nevertheless, this is all the data we have and it therefore warrants close examination.

Benioff(5) has studied secular behaviour of earthquake activity both regionally and globally. By first assuming a particular relation between magnitude and energy release, he computed for each earthquake a "strain rebound increment" proportional to the square root of the amount of energy supposedly released. The procedure is dependent on a number of assumptions, but it has been used in various ways by Benioff and others to demonstrate the accumulation and distribution of strain release over a period of time and as an aid in describing the seismicity of particular areas.

The present investigation has used this method to examine the relationship between earthquakes, strain and time in the Territory. The relation assumed between magnitude M and energy released E is:

$$\log E = 11.4 + 1.5M \qquad \text{.......... Richter(6)}$$

Strain released by earthquakes since 1907 is illustrated in Fig.8. Annual increments of strain, in arbitrary units, were found from $\sum E^{\frac{1}{2}}$. The cumulative totals forming the ordinates of the graph are plotted annually and joined by a smoothed "strain variation curve" which is considered to approximately represent the true pattern of strain release only since about 1930.

Although the method allows estimation of total strain release over a time interval it does not necessarily follow that departures from the average rate indicate real changes, i.e. relative increases or decreases in the rate of strain release. To ascertain the likelihood of this, the series of annual increments of strain release (1930-1962) for the whole Territory (TPNG) as well as for a number of smaller regions designated A-G (Fig. 1) were tested for indications of positive conservation by the serial correlation technique described by Chapman and Bartels(7), i.e. to see if each sequence consisted of a series of values predominantly random in character, or whether groups of high and low values tended to occur together. Table 1 lists values of $\theta(h) = s(h).h/s$ where h = number of successive annual strain increments grouped together (1,2...5), s(h) = variance of means of groups of h = 1, 2, 3, 4, 5 years respectively, and s = variance of sequence for h = 1. Positive conservation is indicated if $\theta(h) > 1$, and the value of h corresponding to the maximum value of $\theta(h)$ indicates the number of repetitions of high (and low) values tending to occur in the data. There are indications of positive conservation for TPNG as well as regions B and E. Because $\theta(h)$ maximises at h = 4 years, it is inferred that, for the Territory as a whole, there is a tendency for years of high activity to be grouped in fours, and likewise for years of low activity. The extent to which this might also occur within smaller regions is not clear.

Any data sequence consisting essentially of observations of earthquake magnitude undoubtedly contains some random component because, inter alia, the earthquake energy spectrum is so broad between magnitudes 6 and 8, where it is frequently described only by one of 9 levels of activity. Therefore it might be expected that areas where the frequency of large earthquakes is highest are most likely to indicate positive conservation. The techniques, or data, used to determine magnitude of most earthquakes which occurred in the Territory between 1930 and 1962 may have been insufficiently refined to avoid obscuring further evidence of serial correlation that might exist within small regions such as A-G. These subdivisions are largely artificial, although in B, C, D and F, G, an effort was made to separate activity associated with the two structural arcs of New Britain and the Solomon Islands.

The search for "trends" in earthquake data is as old as modern seismology and, justifiably, is regarded with suspicion. In this case we are concerned with energy release, and although the list of earthquakes, even above M.6, since 1930 is probably incomplete, it is unlikely to exclude shocks of M.7 or larger, and thus we are able to consider a high percentage of total energy release, most of which is associated with these largest earthquakes. Thus, relative variations in the rate of strain release might be meaningful.

The positive conservation of incremental strain release values for the whole Territory (TPNG) indicates that the variations shown in Fig.8 might have physical significance. If so, the average of these variations (average rate of strain release) should also be meaningful. This is fairly constant for the period concerned and the data therefore supports the assumption of constant average activity on which the zoning diagrams were based.

A method of describing relative changes in "regional strain" conditions is illustrated in Fig. 9. Richter(6) has pointed out that this concept of regional strain "presupposes a mechanical coherence in the strain represented by the earthquakes being studied". The evidence of positive conservation leaves the impression that individual large earthquakes within the Territory may not be entirely unrelated events.

Referring to Fig. 8, it is implied that the constant average rate of strain release observed since 1930 has required for its maintenance an equal rate of strain accumulation. Thus strain is relaxed by each occurrence of an earthquake and accumulates at this rate between earthquakes. For simplicity, only annual increments of strain release are shown in Fig. 9, rather than individual earthquakes. Over a period of years changes in the relative state of strain become apparent from the diagram. Clearly, at the end of 1962, strain was accumulating throughout the Territory and may be close to its highest level since 1930. If the general pattern of activity continues, one would expect the rate of strain release for a period beginning 1963-64 to be higher than observed from 1956-1962.

CONCLUSIONS.

1. A zoning method based only on the distribution of large earthquakes is practicable in Papua and New Guinea where earthquakes of magnitude 6 or greater occur at an average rate of almost 10 per annum.

2. Considering the Territory as a whole, the pattern of activity indicated by variations in the relative condition of strain may be meaningful, and if so, an increased rate of strain release by large earthquakes ($M > 6$) is expected for a few years beginning 1963 or 1964.

ACKNOWLEDGEMENT.

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h (years) =	1	2	3	4	5
TPNG $\theta(h)$ =	1.00	1.36	1.48	1.50	1.40
Region A $\theta(h)$ =	1.00	0.93	0.95	0.93	-
" B $\theta(h)$ =	1.00	1.12	1.28	1.24	1.23
" C $\theta(h)$ =	1.00	1.02	0.73	-	-
" D $\theta(h)$ =	1.00	0.88	0.71	-	-
" E $\theta(h)$ =	1.00	1.23	1.30	1.30	1.21
" F $\theta(h)$ =	1.00	0.71	0.53	-	-
" G $\theta(h)$ =	1.00	0.98	1.06	1.04	1.05
" CD $\theta(h)$ =	1.00	0.97	1.14	0.90	-

Table 1 - Conservation of Strain Release.

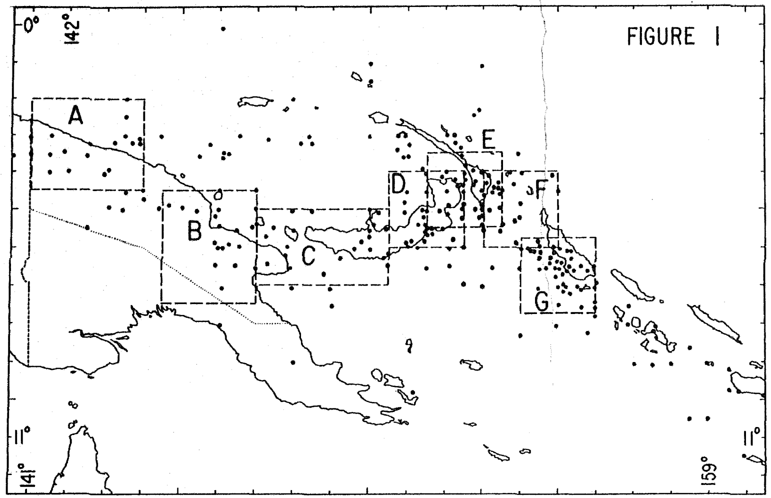


Fig. 1—EARTHQUAKE EPICENTRES 1906-1962

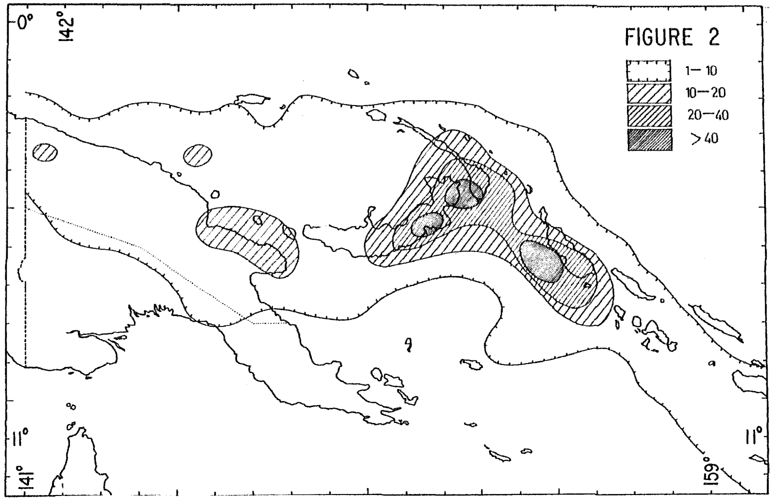


Fig. 2—EARTHQUAKE FREQUENCY PER SQUARE DEGREE PER CENTURY.
MAGNITUDE 6 OR GREATER

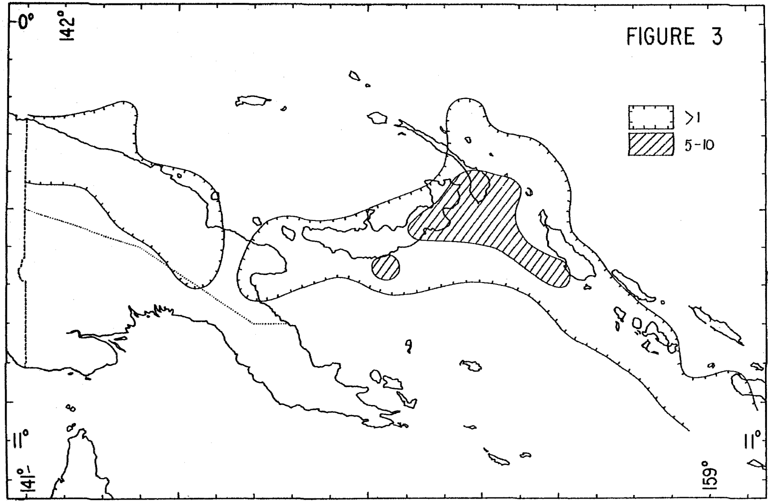


Fig. 3—EARTHQUAKE FREQUENCY PER SQUARE DEGREE PER CENTURY.
MAGNITUDE 7 OR GREATER

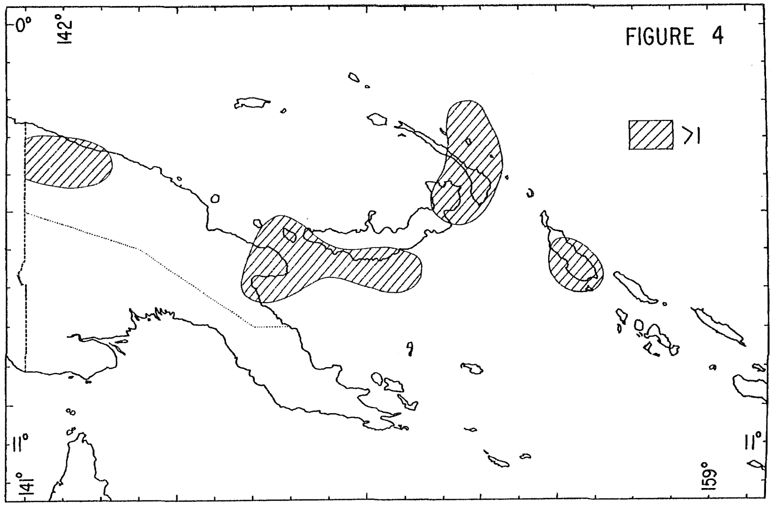


Fig. 4—EARTHQUAKE FREQUENCY PER SQUARE DEGREE PER CENTURY.
MAGNITUDE 7½ OR GREATER

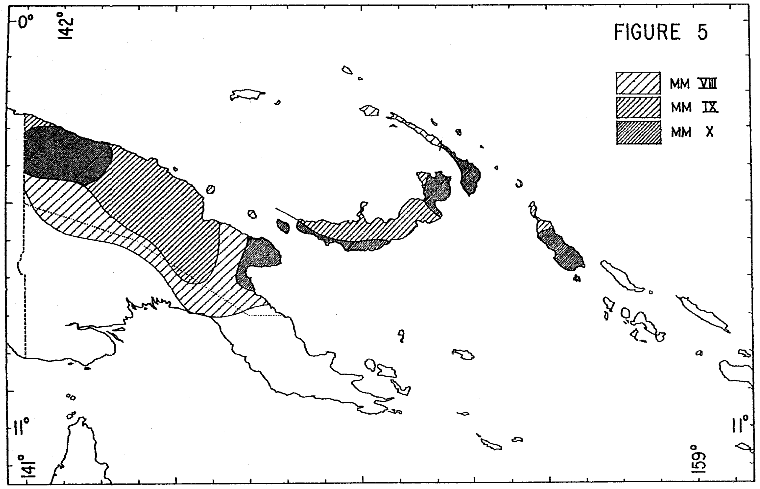


Fig. 5—INTENSITY ZONE MAP
100-YEAR PERIOD

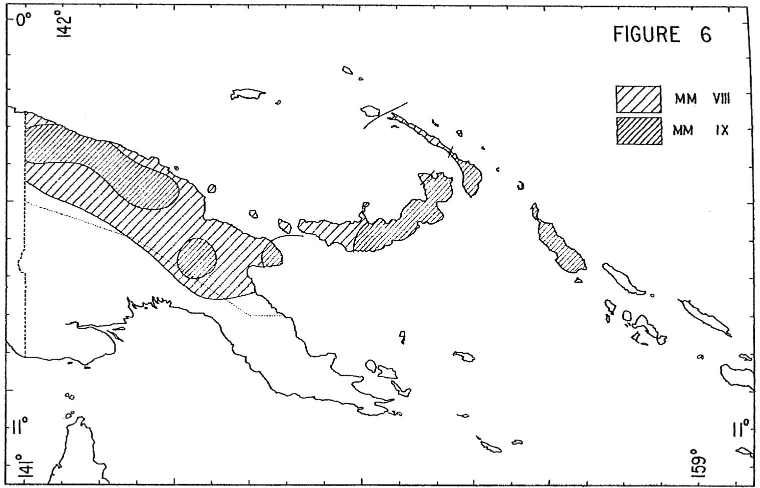


Fig. 6—INTENSITY ZONE MAP
50-YEAR PERIOD

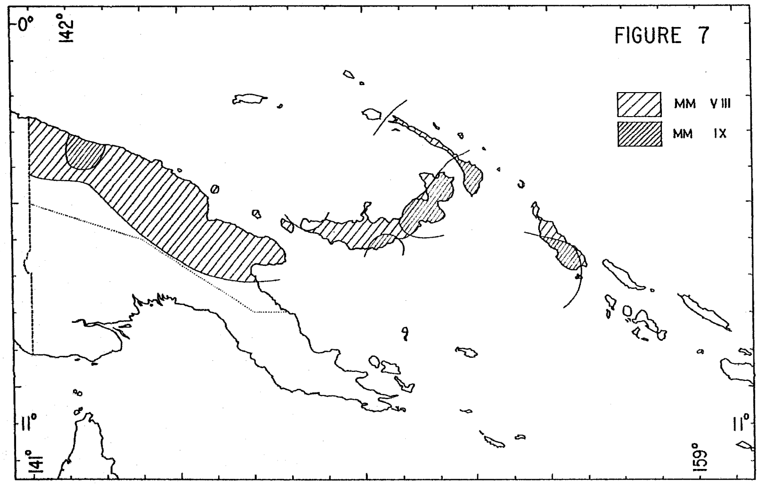


Fig. 7—INTENSITY ZONE MAP
25-YEAR PERIOD

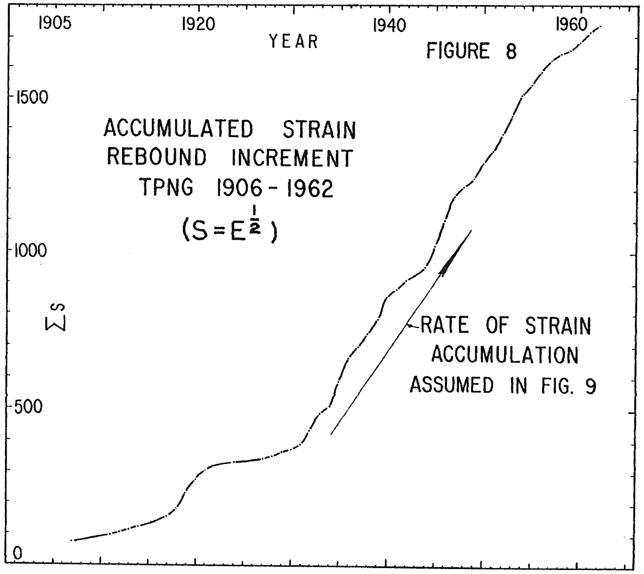
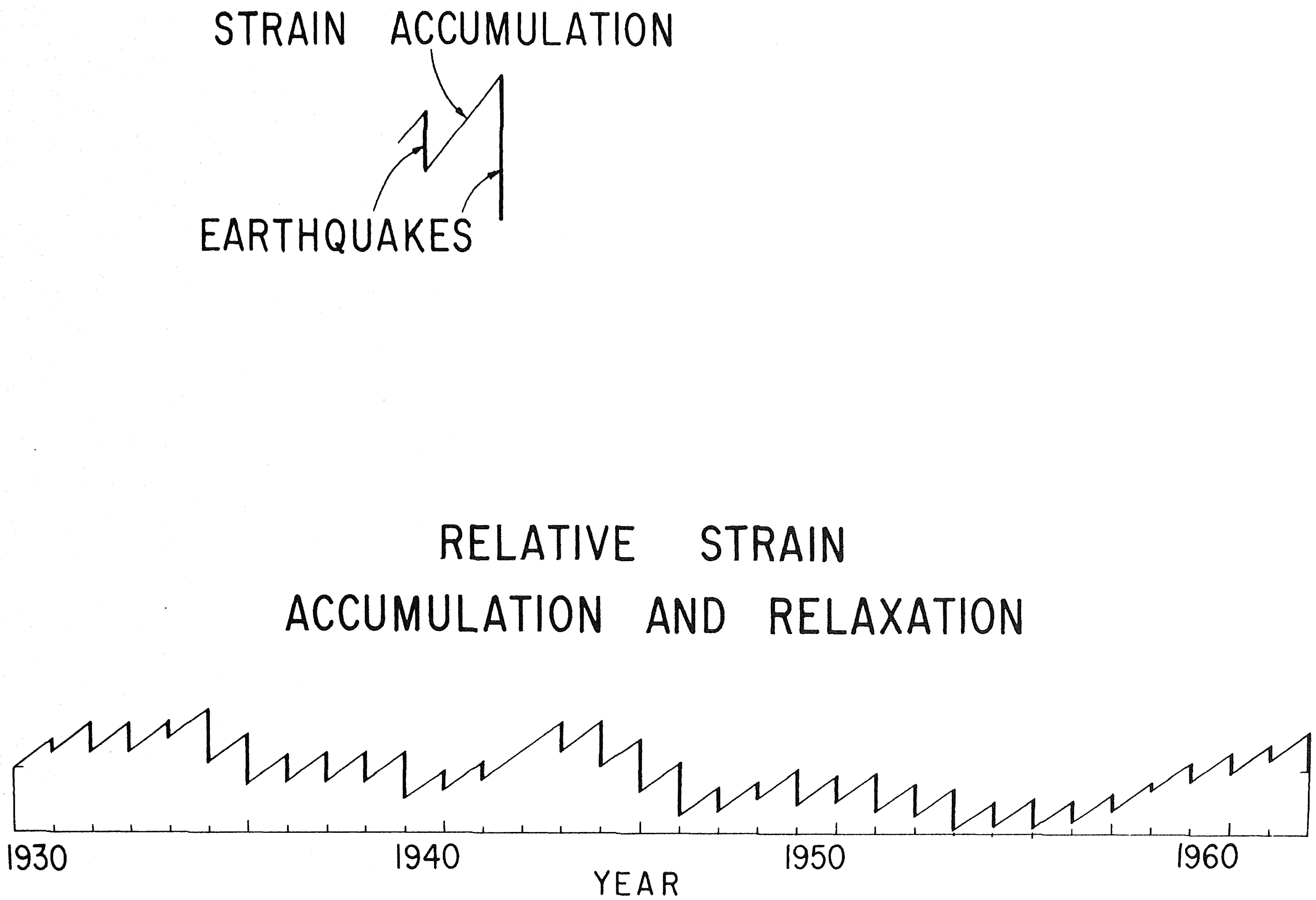


FIGURE 9



RELATIVE STRAIN ACCUMULATION AND RELAXATION

ERRATA

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PAGE 19: 1st paragraph, line 5; delete .... "the value of corresponding"..

1st paragraph, line 9; replace "h = 4 years" by "1.5".

1st paragraph, line10; replace "fours" by "twos".

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AUTHOR'S ADDITIONAL COMMENT

Another statistical test that can be applied is the mean-square difference test (Brownlee (1960): "Statistical Theory and Methodology in Science and Engineering", Chapter 6). An estimate of the variance of individual annual strain release is made in two ways : firstly, an unbiased estimate from the square of the difference between each annual value and the overall mean; secondly the variance is estimated from the differences between successive annual values. The latter estimate is lower than the former with a statistical significance of about 2% indicating that the amount of strain release in one year is not independent of that released the year before.

These conclusions apply when annual strain increments are compiled for calendar years. When compiled for successive twelve monthly periods in other ways, the significance level is not consistently high e.g. in the series from July to June, no correlation between adjacent values is found and therefore the author is not yet convinced of the physical significance of serial correlation in the data as it stands.