

ESTIMATING EARTHQUAKE RISK IN JAMAICA

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by

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ABSTRACT

A review of the history of earthquake observations in Jamaica is presented and the observed seismicity of the Jamaica region is discussed in the context of regional tectonics. Possible source regions of Jamaican earthquakes are identified but a comparison between instrumentally determined seismicity and macroseismicity shows that the instrumental data are of insufficient quantity or quality to permit direct assessment of earthquake risk. A study of the macroseismic record suggests that the peak acceleration in rock with 90% probability of not being exceeded in any 50-year period is of order 0.3g but that there are significant local variations caused by surface geology. A current apparent decline in the seismicity of the Jamaica region is noted but it is shown that the decline in the numbers of earthquakes of engineering interest is not yet statistically significant.

1) THE HISTORY OF SEISMIC OBSERVATIONS IN JAMAICA

i) Historical records

The first earthquake in Jamaica about which we have definite information happened in 1667. Prior to this the Spanish, who occupied Jamaica at the turn of the fifteenth century must have experienced many severe earthquakes since according to Sir Hans Sloane (1809) they had learned to take precautions against earthquakes in their buildings. Sloane, writing in the late seventeenth century also stated that "The inhabitants of Jamaica expect an earthquake every year. Some are of the opinion that they follow the great rains." (An opinion that survives to the present day). The British who took Jamaica from the Spanish in 1667 apparently did not absorb the lesson about building precautions and in 1692 an earthquake destroyed Port Royal which was then the capital and largest town and from that date many references to earthquakes can be found in government papers and in private letters and journals. Many of these references were included in the European earthquake catalogues of Mallet (1852) and Perrey (1847) but for the most part they refer to the parishes of Kingston, Port Royal and St. Andrew which were then, as they are now, the most thickly-populated parts of the island.

From about 1820 onwards daily newspapers began to appear on a regular basis in the West Indies and from this time onwards the record becomes more continuous and includes details even of quite minor earthquakes. In 1880 Maxwell Hall, the government meteorologist began the first comprehensive study of Jamaican earthquakes and published his observations in a series of Government weather reports culminating in a catalogue of Jamaican earthquakes covering the period 1688-1919 (Hall 1923). Hall assigned an intensity to each earthquake of which he had knowledge on a scale of his own devising (see Appendix 1) and his catalogue is particularly comprehensive for the period 1880-1919 when it is based largely on his personal observations.

Unfortunately, Hall's seismological knowledge was limited which is not surprising since modern seismology was in its infancy at the time that his investigations began. In particular, his intensity scale is ill-defined and his ideas about the causes and locations of earthquakes are now known to be unsound. The epicentre maps included in his catalogue are therefore of little use.

More recently Robson and Tomblin (1977) have prepared an earthquake catalogue for Jamaica from the sources cited above and from more recent newspaper reports and seismological publications. All of these sources were used by Shepherd (1971) to assess the level of earthquake risk in Jamaica.

ii) Instrumental Seismology

Instrumental seismology was slow to start in Jamaica as in the West Indies as a whole. No seismograph was in operation in Jamaica at the time of the 1907 earthquake and the instruments which were set up immediately after the event seem to have been seismoscopes rather than true seismographs, (see Hall (1923) for details), and no useable records have survived. Subsequently a Gray-Milne horizontal seismograph was operated for many years by the Government meteorological department and in more recent years a Wood-Anderson torsion seismograph has been in operation at St. George's College in Kingston. Unfortunately none of these instruments operated with accurate calibration or standardised timing and no regular seismological bulletins were published. The first modern seismographs with accurate timing and calibration were established by the Seismic Research Unit of the University of the West Indies in collaboration with the Geological Survey Department of Jamaica in 1963. The seismograph network has progressively been extended and now includes three three-component short-period seismographs, two single-component short-period seismographs and nine SMA-1 strong-motion accelerographs.

iii) Field studies of particular earthquakes

The 1907 earthquake which caused great destruction in Kingston and elsewhere received a great deal of attention in both the scientific and the popular literature but the intensity maps published are not very informative as the information gathered outside Kingston was very scanty. The earthquake of March 1, 1957 which was destructive in and around Montego Bay is the only large Jamaican earthquake for which detailed intensity statistics are available. This earthquake was studied by Robinson, Versey and Williams (1958) who published a detailed intensity map. Outline intensity maps for several earthquakes which have happened since 1964 exist in the records of the Seismic Research Unit.

iv) Other Studies

Taber (1920) reviewed the then-available data and suggested a connexion between Jamaican earthquakes and the Cayman Trough. He also suggested that the earthquakes of 1692 and 1907 were associated with this feature. Robson (1965) made a pilot study of Jamaica's earthquake history and suggested some guidelines for a Jamaican earthquake building code. Turnovsky (1976) has begun a study of earthquake mechanisms in the Jamaica region and Pereira (1977) has studied earthquake risk in Jamaica from an engineering seismology viewpoint. A series of recent reports (Tomblin et. al 1976, Turnovsky and Shepherd 1977, Aspinall and Shepherd 1977) deal with specific problems of earthquake risk in the Kingston area.

2) SOURCE REGIONS OF JAMAICAN EARTHQUAKES

i) The Cayman Trough

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The regional position of Jamaica is shown in Figure 1. The dominant structural feature in the vicinity of the island is the Cayman Trough which is a deep trench extending from the Gulf of Honduras in the West to the Windward Passage in the east. Recent studies of the trough (Jordan 1975, Heirtzler 1976) indicate that it consists of three distinct segments. The Oriente Fracture Zone runs from the Windward Passage to a point about 40 kilometres south of Grand Cayman and passes approximately mid-way between Cuba and Jamaica. At this point the axis of the trough is offset to the south by about 100 kilometers by the mid-Cayman rise which has many of the features of a mid-oceanic ridge. From the southern end of the rise the trough continues into the Gulf of Honduras as the Swan fracture zone and carries on inland as the Motagua fault. All three segments of the Cayman Trough are seismically active but the number of fault-plane solutions obtained to date is small. Turnovsky (1976) obtained a solution for the earthquake of February 19, 1976 (latitude 19.9°N, Longitude 78.8°W, $m_p = 5.3$) which showed left-lateral strike-slip motion with a slip vector alligned parallel to the axis of the trough. This solution is almost identical with that obtained by Molnar and Sykes (1969) for the earthquake of 25 July 1962 (18.9°N, 81.19°W). These are the only reliable solutions available for the Oriente fracture zone. No solutions are available for earthquakes on the mid-Cayman rise but the solutions for events on the Swan fracture zone (Molnar and Sykes 1969) and the associated Motagua fault (Dewey and Julian 1976) also indicate left-lateral slip on nearly vertical fault planes. All of these solutions are consistent with the idea that the Cayman trough forms part of the northern boundary of the Caribbean lithospheric plate which is moving in an approximately east-north-easterly direction with respect to the adjacent Americas plate. In plate-tectonica terminology the Oriente and Swan fracture zones are transform faults separated by a short sea-floor spreading centre. Seismological results (Sykes and Ewing 1965, Molnar and Sykes 1969) indicate that the rate of relative movement between the Caribbean and America plates is about 2 centimetres per year.

The overall tectonic evidence therefore is that the major earthquake source in the immediate vicinity of Jamaica is the Oriente fracture zone in which the sense of faulting is left-lateral strike slip and earthquakes are expected to be shallow. From postulated relationships between fault length, fault displacement and magnitude an estimate of the largest earthquake likely

to originate in this zone can be made. From a study of the largest earthquake likely to originate in this zone can be made. From a study of 42 shallow strike-slip earthquakes King and Knopoff (1968) obtained the relationship:

$$\log (L D^2) = 2.24 M_S - 4.99 \quad (2.1)$$

where L is the fault length and D is the offset in an earthquake of surface-wave magnitude M_S . As a test of the applicability of this relationship to the north-western Caribbean we note that the Guatemalan earthquake of February 4, 1976 exhibited surface fault breakage over a distance of 300 kilometers with a mean offset of 100 centimeters. Applying 2.1 we obtain $M_S = 7.4$ compared with an observed $M_S = 7.5$ (Espinosa 1976). Macroseismic evidence (Shepherd 1971) indicates that the interval between major Jamaican earthquakes is of order 200 years so that if all the relative movement between the Caribbean and the Americas is absorbed as elastic strain and released in one event with fault breakage along the full length of the Oriente we have $D = 400$ cm., $L = 7 \times 10^7$ cm., $M_S = 8.0$. On the less extreme assumptions that strain accumulates for 100 years and that the fault ruptures along one half of its length we have $D = 200$ cm., $L = 3.5 \times 10^7$ cm., $M_S = 7.7$.

ii) The Southern Source Zone

Although bathymetric, gravity and magnetic studies to the south of Jamaica do not show any structure comparable in size to the Cayman trough there is seismological evidence (Figure 2) that an active seismic source exists to the south of Jamaica at approximately latitude 17.5° and extending from about 76°W to about 79.5°W . This latitude is approximately that of the southern termination of the mid-Cayman rise and it is conceivable that the feature represents an eastward continuation of the Swan fracture beyond its apparent termination. Up to the present only 7 earthquakes sufficiently large to be recorded at teleseismic distances have been recorded in this zone but its existence is confirmed by the detection of several low-magnitude events by instrumentation in Jamaica. No focal mechanisms have been determined. If a fault of the dimensions indicated does exist then by the reasoning of the previous section it might be the source of earthquakes of magnitude up to about $M_S = 7.5$. The largest earthquake which has in fact been observed was on April 27, 1941 with epicentre at 17.75°N , 79.5°W and magnitude (M_S) = 7.1.

iii) Internal Jamaican Sources

The surface geology of Jamaica is riddled with a series of faults which generally trend either north-south or east-west. According to Robinson et. al (1970), movement on the east-west faults was initiated during the Cretaceous and on the north-south faults in late Miocene. There is no evidence, either geological or seismological that these faults are active at the present time on land. The northern-most group of east-west faults step down the land surface of Jamaica to the Cayman trough and it is likely that transcurrent movement has been initiated on these submarine faults by the stress system associated with the trough.

iv) Seismicity of the Jamaica Region

Figure 2 shows the epicentres of all earthquakes in the Jamaica region which have been sufficiently well recorded at five or more seismograph stations (including at least one at a distance of more than 20°) for epicentral

co-ordinates to be calculated. Figures 3 and 4 show Jamaican seismicity in a regional context. In Figure 2 we do not distinguish between earthquakes on the ground of magnitude except in the sense that the requirement that the event should propagate to 20° imposes an effective lower magnitude cut-off which appears to be at about $M_s = 4.0$. As has been indicated in the previous section, the seismicity is in broad general agreement with the regional tectonics although there are differences in detail. Earthquake epicentres can be associated with three distinct zones each trending roughly east-west. Zone 1 almost coincides with the south coast of Oriente province in Cuba about 100-120 kilometers from the Jamaican north coast. Zone 2 brushes the Jamaican north coast in the west and is 10-20 kilometers off-shore in the east. Zone 3 passes 20-30 kilometers south of the Jamaican south coast. Of the three zones the most active appears to be Zone 1, followed by Zone 3 and then by Zone 2. The epicentre located in the centre of Jamaica is certainly inaccurate (see section 4.1) but we have no grounds on which to allocate it to any of the three source zones. The activity in Zone 2 is probably under-represented since there are good grounds for believing that the earthquakes of 1692 and 1907 originated in this zone (Taber 1920, Shepherd 1971).

3) JAMAICAN EARTHQUAKE INTENSITY STATISTICS

i) Basic Data

The main source of information for this section is the earthquake catalogue of Robson and Tomblin (1977) although wherever possible reference has been made to the original sources. Robson and Tomblin assign an intensity on the Modified Mercalli Scale of earthquake intensities to most of the earthquake reports and we have altered these in only a few cases where additional information was available. Intensities quoted in this paper all refer to the Modified Mercalli scale of earthquake intensities and are stated in Latin numerals.

The catalogue contains references to 357 earthquakes which happened between 1667 and 1970 and includes over 1,000 intensity reports. Inevitably the catalogue is incomplete especially for the lower intensities so that the first stage in the analysis of the data is to estimate the period of time and range of intensities for which it can be considered substantially complete. Intensity reports of MM III or less were ignored from the outset except in cases where they indicated particularly low intensities in particular earthquakes. We also split the data into two parts since it was obvious that reports from the parishes of Kingston (including Port Royal) and St. Andrew were more numerous than those from any other parish especially in the early part of the catalogue. We then counted the numbers of earthquakes with intensities greater than or equal to MM IV in each 10-year interval and plotted the results as a function of time. Earthquakes reported remained few in both regions during the first half of the eighteenth century but began to rise after 1750 as the population grew and the means of communication increased. From about 1820 the numbers in the Corporate Area ceased to increase although the numbers in the rest of the island did not level off until a few decades later. There was a sharp rise in numbers between 1880 and 1920 followed by a decline which has continued to the present.

Not all of these fluctuations are due to variations in the rate of earthquake activity. The levelling-off after 1820 coincides with the regular

appearance of daily newspapers in the West Indies and it is probably from this date that every earthquake felt by more than a few people was also reported. The large peak between 1880 and 1920 can be attributed at least in part to the fact that this was the period during which Maxwell Hall kept a careful record of all earthquakes felt in Jamaica and by careful observation he may have kept a record of many small earthquakes which would otherwise have gone unnoticed. To test this possibility all earthquakes of Intensity IV were removed from the data set and the results are presented in Figure 5. The large peak is much less noticeable and reflects mainly the 1907 earthquake and its aftershocks. We are confident that for Intensity V and greater the catalogue is complete for the whole island from 1880 to the present. A more significant feature of Figure 5 than the peak between 1900 and 1920 is the fact that since about 1930 the numbers of felt earthquakes in both the Corporate Area and the rest of the island has declined continuously and are now at the lowest level since the beginning of the nineteenth century and possibly since long before then. This cannot be the result of less-careful monitoring; since the early 1950's careful records of all felt earthquakes have been kept by trained observers and the level of surveillance is at least as high as in the time of Maxwell Hall. The decline in the number of felt earthquakes becomes even more significant when compared with the regional seismicity pattern (Figure 3 and 4). This shows that between 1899 and 1953 the distribution of earthquakes around the circum-Caribbean belt, of earthquakes of magnitude (m_b) greater than 5.0 was fairly uniform. In the Oriente fracture zone there were at least 16 such earthquakes or about one every three years. Since then, the pattern in the circum-Caribbean belt as a whole has remained essentially uniform with the notable exception of the Oriente fracture zone. On the northern fracture only one earthquake (February 19, 1976 $m_b = 5.3$) exceeded 5.0, with one other on the southern section (March 2, 1957 $m_b = 6.5$). Again, the decline in the number of instrumentally determined epicentres cannot be attributed to a decline in detection capability since the seismograph networks in Jamaica, the West Indies and the world have all improved considerably during the period in question. We believe therefore that the decline in earthquake activity in the Jamaica region is real. This conclusion has serious and not very reassuring implications for the assessment of earthquake risk in Jamaica.

ii) Maximum intensities

The highest intensity reported in the catalogue is MM X for the earthquake of June 7, 1692. The reports of this earthquake are fragmentary and perhaps exaggerated but the intensity at Port Royal was at least MM X. At the upper end of the intensity scale, assignment of intensity depends partly on the effects of ground shaking and partly on other earthquake effects such as surface fault breakage, tectonic warping and failure of unstable ground. In Port Royal the assignment of MMX largely results from the failure of unstable ground. Elsewhere, as in the Liguanea/Passage Fort area (now however St. Andrew) and St. Ann's Bay intensity X can be assigned on the basis of the violence of shaking alone.

The next highest intensities reported in the catalogue were on January 14, 1907 when intensity IX was reported for Kingston and Port Royal and intensity VIII-IX was widespread in the eastern part of the island and along the North Coast from Kempshot in St. James to Buff Bay in Portland. The higher intensity in Kingston does not necessarily indicate more violent

shaking. Much of the damage can be attributed to the widespread use of poor quality brick and mortar construction and as in 1692 there was some failure of unstable ground though on a much smaller scale.

Other earthquakes where high intensities are reported were on September 3, 1771 (MM VIII, Kingston and Port Royal), November 11, 1812 (MM VIII, Kingston) and March 1, 1957 (March 2 C.U.T. MM VIII, Montego Bay region).

iii) Intensity Distribution

The only Jamaican earthquake for which a carefully-compiled intensity map exists is that of March 1, 1957 (Robinson, Versey and Williams 1957). In order to obtain a broad picture of the historical distribution of earthquakes in the upper intensity range we have drawn a contour map of the number of earthquakes of intensity VI or greater reported felt in Jamaica during the period 1880-1960.

First of all the number of intensity reports of MM VI or greater were listed by parish and plotted on a map of Jamaica. This gave the main features of the distribution but the borders between the different regions were artificially defined. The borders were then successively modified by individual study of those earthquakes for which multiple intensity reports were available. The final result therefore depends to some extent on the individual judgement of the first author. The resulting map (Figure (4)) must be viewed with caution. Since it is based on reported intensities it is heavily influenced by population density and biased towards the main centre of population along the Kingston/Spanish Town axis. Too much reliance should not be placed on the boundaries between regions with different recurrence rates and in particular it must be recognized that where the incidence of high-intensity earthquakes is shown as zero it means that no high-intensity earthquakes have been reported - not that none have occurred. The two regions in which this is so are in fact the two least populated regions of Jamaica but the effect is not totally spurious since there are numerous examples of lower intensity reports in the regions than in adjacent regions in particular earthquakes.

The most striking feature of the map is the high overall damage frequency. Although not as high as in the most seismically active parts of the world such as western South America and Japan the frequency of high-intensity earthquakes in Jamaica is directly comparable with that in areas of intermediate risk. A comparison with the equivalent map for the State of California shows that the highest damage-frequency rate in Jamaica (20 per century in downtown Kingston) is exceeded in California only in downtown Los Angeles (24 per century) and that the damage frequency rate for Jamaica as a whole is directly comparable with that in the highest risk zone of the United States Uniform Building Code classification.

The second feature is that, even when allowance is made for the effects of population distribution there are significant differences between the reported rates of damaging earthquakes in different parts of the island. In particular the damage frequency rate around the margin of Kingston harbour and on the Liguanea/St. Catherine plain in general is higher than elsewhere in the island. We believe that these differences are caused mainly by

variations in near sub-surface geology and research is actively in progress to determine the relevant factors.

4) ASSESSMENT OF EARTHQUAKE RISK IN JAMAICA

1) Methods of assessing earthquake risk

(a) From seismicity data:

Several techniques now exist for the assessment of earthquake risk but there is no universal agreement in the seismological profession as to which is the best technique or the best method of presenting the results. In the United States within recent years the most widely-accepted method of seismic regionalization has been to present large scale maps of the horizontal acceleration (expressed as percent of gravity) in rock with 90% probability of not being exceeded in any 50-year period. Maps of this type have most commonly been prepared by a technique introduced by Cornell (1968) and a similar technique been applied to the contiguous United States by Algermissen and Perkins (1976) and to Jamaica by Pereira (1977).

Basically the technique consists of the following steps:-

1) Source zones and faults, within which or along which significant earthquakes can occur are identified and brought together on a source zone map.

2) For each source zone or fault the maximum magnitude of any earthquake which can occur is estimated and the available magnitude data are fitted to an equation of the form

$$\log N_c = a - bM \tag{4.1}$$

where N_c is the number of earthquakes in the source zone of magnitude M or greater.

3) Attenuation laws are used to give the peak acceleration (or velocity) of ground motion as a function of magnitude and distance from an epicenter.

4) From the foregoing information and using probabilistic principles values are generated which are used to produce contours of locations of equal likelihood of a given peak acceleration. The peak accelerations computed refer to rock and among the assumptions are that earthquake occurrence is a Poisson process.

The main factor which limits the applicability of this technique to Jamaica is the inadequacy of the instrumental data-set (Table 1 and Figure 2). The data set includes 67 events of which 12 were reported felt in Jamaica. During the same time-period over 300 earthquakes were in fact felt in Jamaica (Robson and Tomblin 1977). Many of these were of low intensity, but events which are excluded from the instrumental data set include the earthquake of January 14, 1907 and its numerous aftershocks and about 20 other events which generated maximum intensities of VI or greater. In some cases the data which do appear in Table I are of questionable value. For example the event of June 14, 1899 which is assigned the highest magnitude in the table ($M_s = 7.8$) is given an epicentre at $18^{\circ}N \ 77^{\circ}W$ which is directly in the centre of Spanish Town. This event was felt throughout Jamaica but at a maximum intensity of MM V. Gutenberg (1956) considered that the magnitude

was accurate to ± 0.1 which may be a little optimistic but it was certainly a larger event than that of January 14, 1907 which was much less well-recorded at teleseismic distances. The epicentre of the 1899 event is therefore in error but there is no way of knowing in what sense it is in error and it could equally well be assigned to any of the three source zones of Fig (2). The accuracy of later determinations is probably much better but a great deal of uncertainty remains. Even if all the earthquakes could be confidently assigned to source zones the magnitudes assigned do not provide a statistically adequate data base for the determination of the constants in (4.1). Of the 67 events, magnitudes are assigned to 43, of which 25 are M_s estimates and 18 are m_b estimates. The mean magnitude of the m_b data set is 4.61 with a standard-deviation of 0.4. Since the standard error of any single m_b determination is of order 0.5, fitting the data to equations such as 4.1 is statistically meaningless.

The data set could be expanded by estimating epicentres and magnitudes from the maximum intensities as was done for example by Algermissen and Perkins (1976) in estimating maximum accelerations on rock in the United States. This would make little sense in Jamaica; since the source zones are submarine, epicentral intensities are unobservable and the maximum intensity observed in any single earthquake is unlikely to be the maximum intensity which would have been observed had the epicentre been on land.

We have therefore used the seismicity data in the following way: having established the probable source zones of Jamaican earthquakes we estimate from tectonic considerations the probable maximum magnitude earthquake likely to occur in each zone and estimate the severity of ground shaking which would be produced by each of these earthquakes at specific locations in Jamaica. The influence of local surface geology is taken into account as far as it is known. Results for the economically most-important region of Jamaica - the Liguanea/St. Catherine plain- are in Aspinall and Shepherd (1977).

(b) From intensity data

Engineers are notoriously suspicious about the use of intensities to estimate earthquake risk generally on the grounds that intensity scales are subjective and that intensity ratings cannot easily be converted into quantitative figures such as acceleration and velocity. As has been pointed out by Eiby (1976) it is more correct to say that earthquake intensities are non-instrumental than that they are subjective and "Intensity values are still the best index to the behaviour of structures during a particular earthquake and provide the readiest comparison of the damaging ground motions in different earthquakes or at different places in the same earthquake". In any event engineers (perhaps unknowingly) do use intensity data. The most recent seismic hazard maps of the United States (Applied Technology Council 1976) are based on the hazard maps of Algermissen and Perkins (1976) which are themselves largely based on intensity data. In Jamaica the intensity statistics, with their admitted limitations, are the most comprehensive statistics about the effects of earthquakes and are likely to remain so for some time.

In Section 3 we showed that the intensity statistics are probably complete down to intensity V. Earthquakes of intensity VII and greater can be analysed in a different way. Earthquakes of these intensities frighten most people and may cause severe damage to structures. They will certainly

be reported if there is anyone to report them who has access to the normal means of communication. In view of the detailed search of all literature which has been carried out we believe that it is unlikely that any earthquake of intensity VII or greater has gone unrecorded in the Corporate Area since 1690 and in the rest of the island since 1800. We have also carefully examined the accounts of all earthquakes of these intensities and believe that the intensity estimates are lower limits - i.e. that if an earthquake is said to be of intensity VII, VIII, IX or X then it was in fact of at least that intensity.

From the available data we can therefore establish the return periods of earthquakes of the various intensities.

Table II shows the return periods R of earthquakes of intensity I and greater for the highest-risk area of Kingston.

TABLE II

| I | VII | VIII | IX | X |
|---|-----|------|-----|------|
| R | 38 | 87 | 137 | >273 |

The fact that the return period for earthquakes of intensity VII or greater is 38 years does not mean that the probability of occurrence in any 38 year period is 100% nor does it mean that the probability is zero for 38 years following the last earthquake of intensity VII or greater. If earthquakes follow a Poisson process - i.e. if the earthquakes are independent events - then the probability of an event with return period R years occurring within any time period t years is

$$P(t) = 1 - \exp(-t/R) \quad 4.2$$

From equation 4.2 the probability of an event occurring within its own return period is 63.2%. Equation 4.2 can also be used to estimate the probability that an event will occur within any given period of time. If we choose 50 years as a reasonable design period over which to estimate risk we can estimate the probability P(I) that Kingston will experience an intensity I or greater during any 50-year period:

TABLE III

| I | VII | VIII | IX | X |
|----------------|-------|-------|-------|-------|
| P(I) | 73% | 44% | 30% | <16% |
| acceleration/g | 0.068 | 0.145 | 0.315 | 0.692 |

The data of Table III can be converted to the accelerations and velocities which are apparently required by engineers by making certain assumptions about the relationship between intensity and acceleration. Postulated relationships are legion and none seems to be better than the one suggested by Gutenberg and Richter (1956):

$$\log a = \frac{I}{3} - 0.5 \quad 4.3$$

where a is the acceleration in cm/sec^2 corresponding to intensity I . At the upper end of the intensity scale all relationships such as 4.2 are particularly suspect since the assignment of these intensities often depends on factors other than ground acceleration. With these limitations in mind the third row of Table III can be interpreted as the peak accelerations corresponding to the various intensities. The highest acceleration on which any reliance can be placed is $31.5\%g$ corresponding to intensity IX with a corresponding 30% probability of occurrence in any 50-year period. There is thus only a 70% probability that this acceleration will not be exceeded. The acceleration which has a 90% probability of not being exceeded can be estimated by extrapolation to be about 100% g .

This figure is high and will no doubt be greeted with horror by practising engineers. The highest figure obtained by Algermissen and Perkins (1976) for the contiguous United States is 80% g for the fault zones of the San Andreas and Garlock faults. It must be remembered however that the Algermissen and Perkins figures refer to accelerations on rock whereas our figures refer to accelerations on the Liguanea alluvial plain. To make them comparable with the bedrock figures we must make allowance for possible amplification by the alluvial formation. Preliminary results (Aspinall and Shepherd 1977) indicate that bed rock accelerations are amplified by a factor of 3-4 by the Liguanea formation. Applying this correction, 1.0 g accelerations on the formation are equivalent to 25-33% accelerations in bed rock. We suggest therefore that a figure of 30% of gravity should be used in Jamaica as the bed rock acceleration with 90% possibility of not being exceeded in any 50 year period. Modifications of this figure to take account of purely local effects will depend on the results of the microzonation project now in progress in Jamaica (Tomblin et al., 1975).

5)

THE JAMAICA SEISMICITY GAP

The results of section 4 are based on data for the period 1690-1960 and we have deliberately excluded data collected since 1960. In fact the data collected since 1960 show that no earthquake has been felt in Kingston at intensity V or greater since 1957. This is a symptom of the phenomenon noted in section 3 - the decline of activity in the Jamaican region in the past few decades. Whether or not this a real effect or simply a statistical fluctuation is not yet clear. During the period 1880-1960 the return period of earthquakes of intensity V or greater in Kingston was 5 years. If such earthquakes follow a poisson process then, from equation 4.2 the probability that a 20-year period could pass without such an earthquake purely by chance is about 2%. In statistical terms the lack of earthquakes is marginally significant. If we restrict our attention to earthquakes of intensity VII

or greater with return period 38 years, there have been 70 years since the last event and the probability that this could happen by chance is about 16%. We conclude that the decline in the numbers of intermediate-intensity earthquakes is marginally significant but that the decline in the numbers of high intensity earthquakes is not yet significant. The most reasonable further conclusion to be drawn from these observations is that low intensity earthquakes do not follow a Poisson process, perhaps because aftershock sequences tend to be felt at low intensities, but that there is no statistically significant evidence to show that high-intensity earthquakes do not follow a Poisson process.

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TABLE 1 EARTHQUAKES IN THE JAMAICAN REGION

| Date | Lat °N | Long °W | Depth | M _D | M _S | Source |
|--------|--------|---------|-------|----------------|----------------|------------------------------|
| 990614 | 18.0 | 77.00 | | | 7.8 | Gutenberg (1956) |
| 000621 | 20.0 | 80.00 | 25 | | 7.5 | " " |
| 030816 | 20.00 | 72.00 | | | | " |
| 140803 | 18.50 | 76.50 | | | 6.3 | Gutenberg and Richter (1954) |
| 170217 | 19.50 | 78.50 | | | 7.5 | " |
| 240130 | 20.00 | 77.50 | | | 5.6 | " |
| 320203 | 19.50 | 75.50 | | | 6 3/4 | " |
| 320606 | 19.50 | 76.50 | | | 6 | " |
| 320706 | 19.00 | 74.00 | | | 5.6 | " |
| 340710 | 19.00 | 80.50 | | | 5.6 | " |
| 381110 | 20.75 | 74.00 | | | 5.6 | " |
| 400710 | 19.40 | 75.10 | | | | U.S.C.G.S. |
| 401230 | 19.25 | 75.25 | | | 5.6 | Gutenberg and Richter (1954) |
| 410407 | 17.75 | 78.50 | | | 7.1 | " |
| 410408 | 18.00 | 79.00 | | | | U.S.C.G.S. |
| 410408 | 17.50 | 78.50 | | | 5.6 | Gutenberg & Richter (1954) |
| 410424 | 17.50 | 78.00 | | | 5.6 | " |
| 410427 | 17.75 | 79.50 | | | 5.6 | " |
| 430715 | 17.00 | 76.00 | | | 5.0 | B.C.I.S. |
| 450111 | 18.50 | 76.50 | | | | U.S.C.G.S. |
| 460325 | 19.75 | 74.75 | | | 6.0 | Gutenberg & Richter (1954) |
| 470807 | 19.75 | 75.25 | 50 | | 6 3/4 | " |
| 491123 | 19.50 | 78.50 | | | | U.S.C.G.S. |
| 510513 | 19.68 | 75.46 | 55 | | 4.0 | Sykes and Ewing (1965) |
| 510802 | 17.00 | 75.00 | | | | B.C.I.S. |
| 540613 | 19.95 | 75.51 | | | 4.0 | Sykes and Ewing (1965) |
| 550424 | 19.28 | 74.14 | 8 | | 4.2 | " |
| 561001 | 18.28 | 76.95 | 50 | | 4.0 | " |
| 570302 | 1835 | 78.11 | | | 6 3/4 | " |
| 570316 | 19.88 | 75.07 | | | 4.3 | " |
| 571112 | 18.77 | 81.27 | 68 | | | " |
| 590531 | 19.11 | 80.97 | | | 4.0 | I.S.S. |
| 590628 | 17.94 | 81.35 | | | 4.0 | Sykes and Ewing (1965) |
| 591201 | 16.64 | 82.03 | | | 4.0 | " |
| 620725 | 19.00 | 81.26 | 33 | | 6.2 | U.S.C.G.S. |
| 620802 | 19.30 | 81.00 | 47 | | | " |
| 621114 | 18.70 | 81.10 | | | | " |
| 630102 | 17.90 | 82.00 | 33 | | | " |
| 630202 | 18.80 | 81.60 | 33 | | | " |
| 640808 | 18.00 | 74.00 | 10 | 5.1 | | " |
| 651107 | 18.00 | 81.60 | 28 | 4.0 | | " |
| 651109 | 19.00 | 81.40 | 33 | 3.9 | | " |
| 671126 | 18.60 | 76.60 | 33 | 4.2 | | I.S.C. |
| 680229 | 17.80 | 81.60 | 33 | 4.1 | | U. S. C.G.S. |
| 680229 | 17.70 | 81.60 | 30 | 4.6 | | " |

EARTHQUAKE EPICENTRES 1899 - 1978

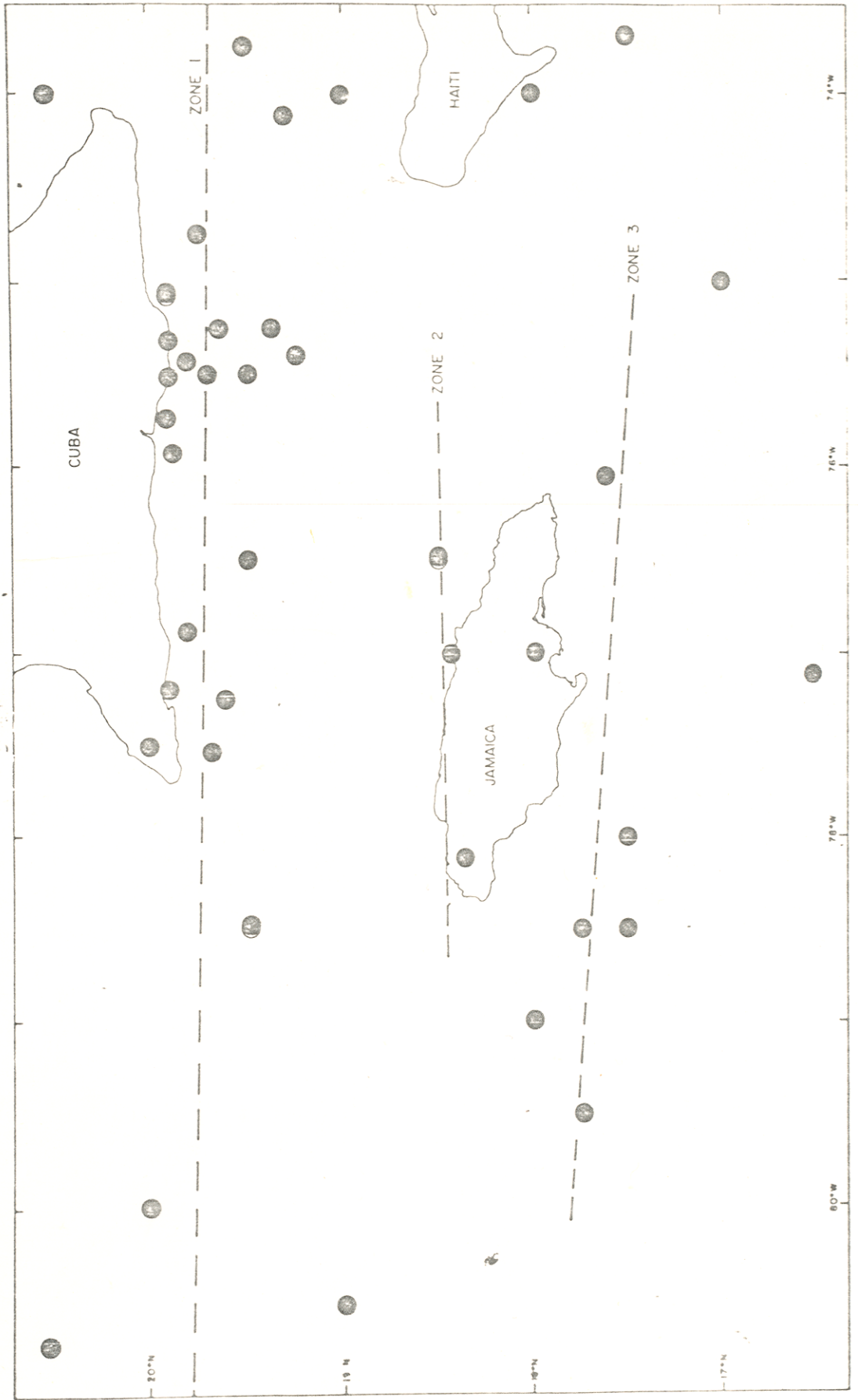


FIGURE 2. EARTHQUAKE EPICENTRES NEAR JAMAICA - 1899 to 1978 .

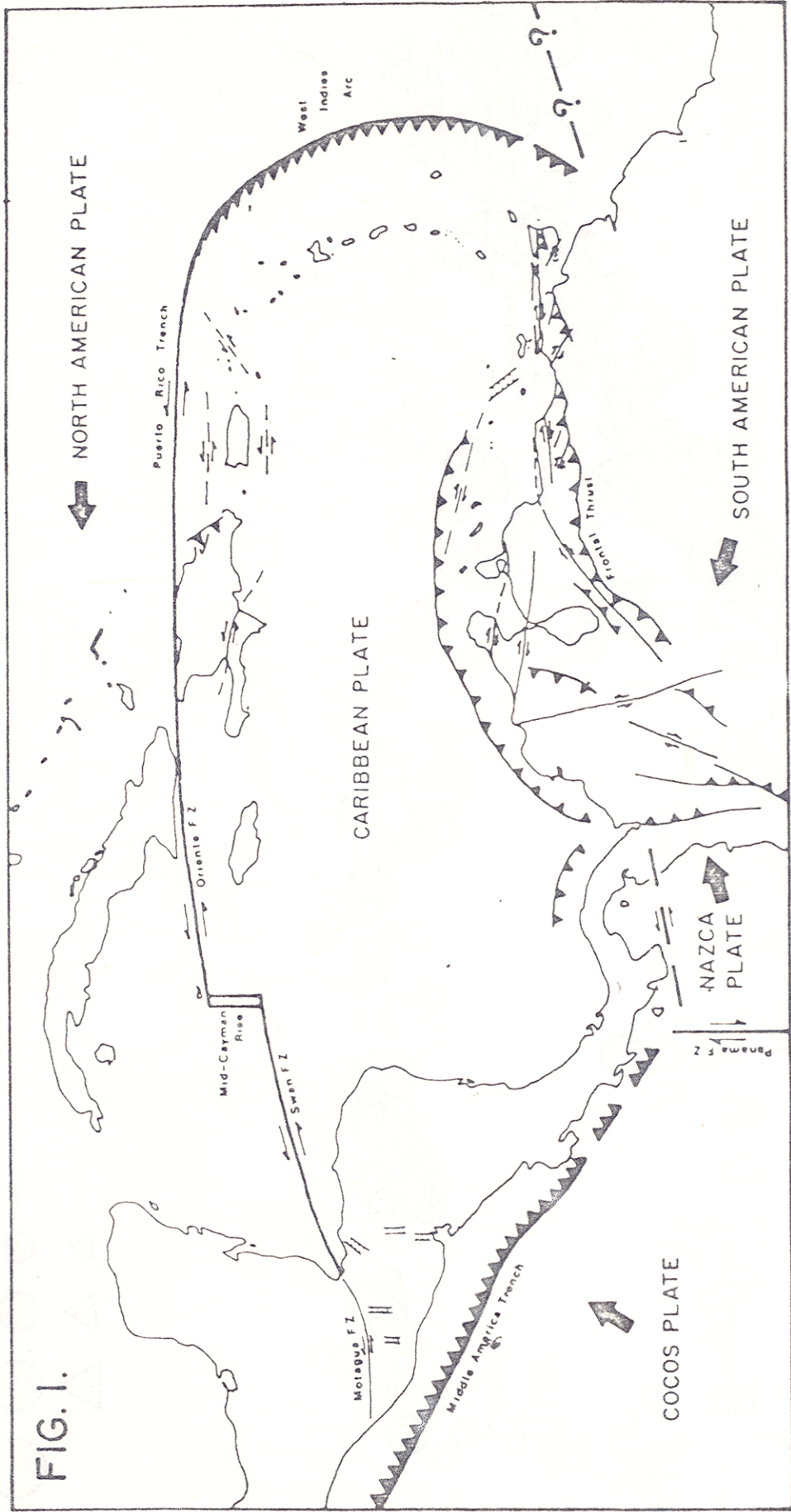
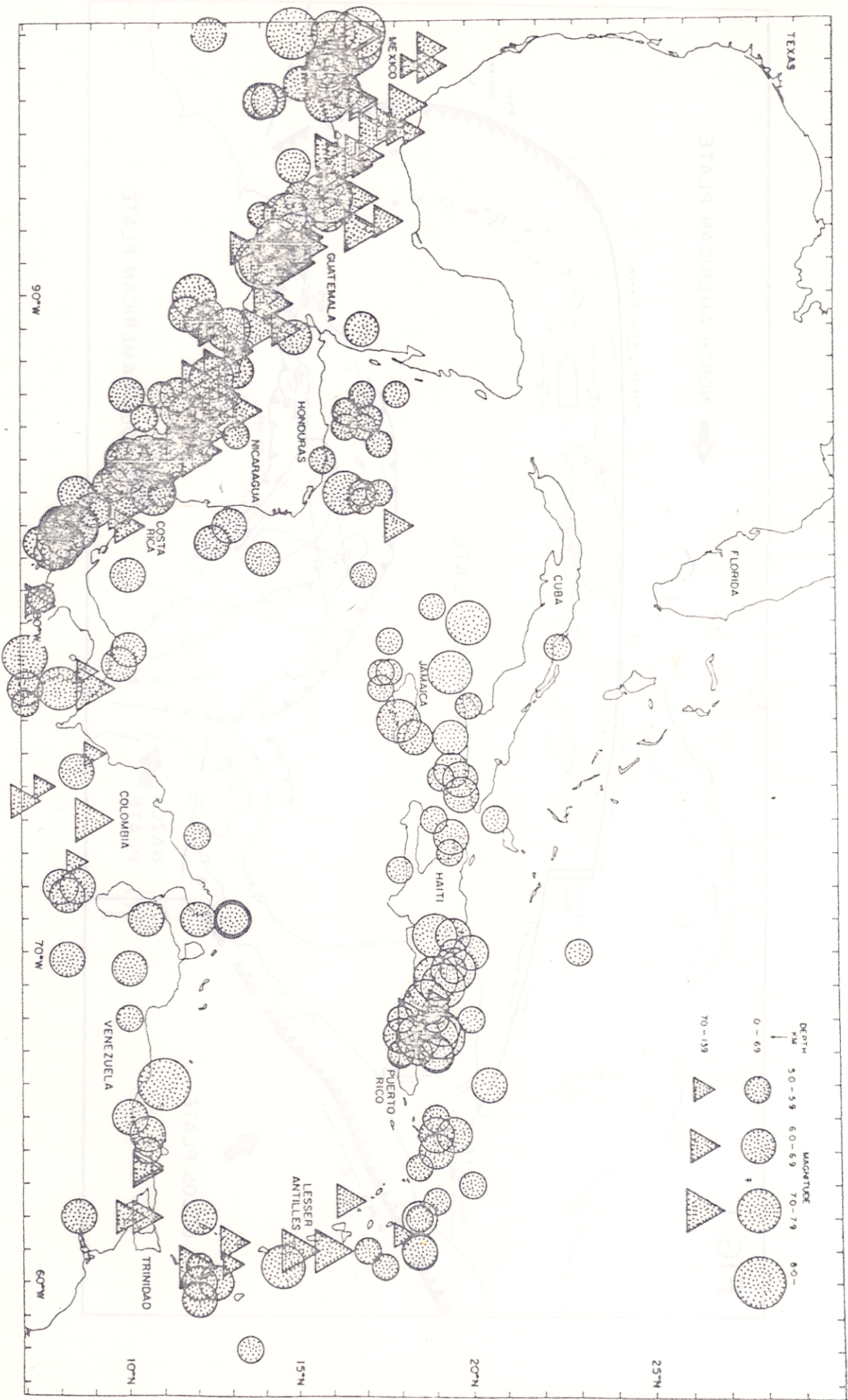


FIG. 1.

FIGURE 1. TECTONIC SETTING OF THE ISLAND OF JAMAICA.

FIGURE 3. CARIBBEAN REGIONAL SEISMICITY - 1898 to 1952 .



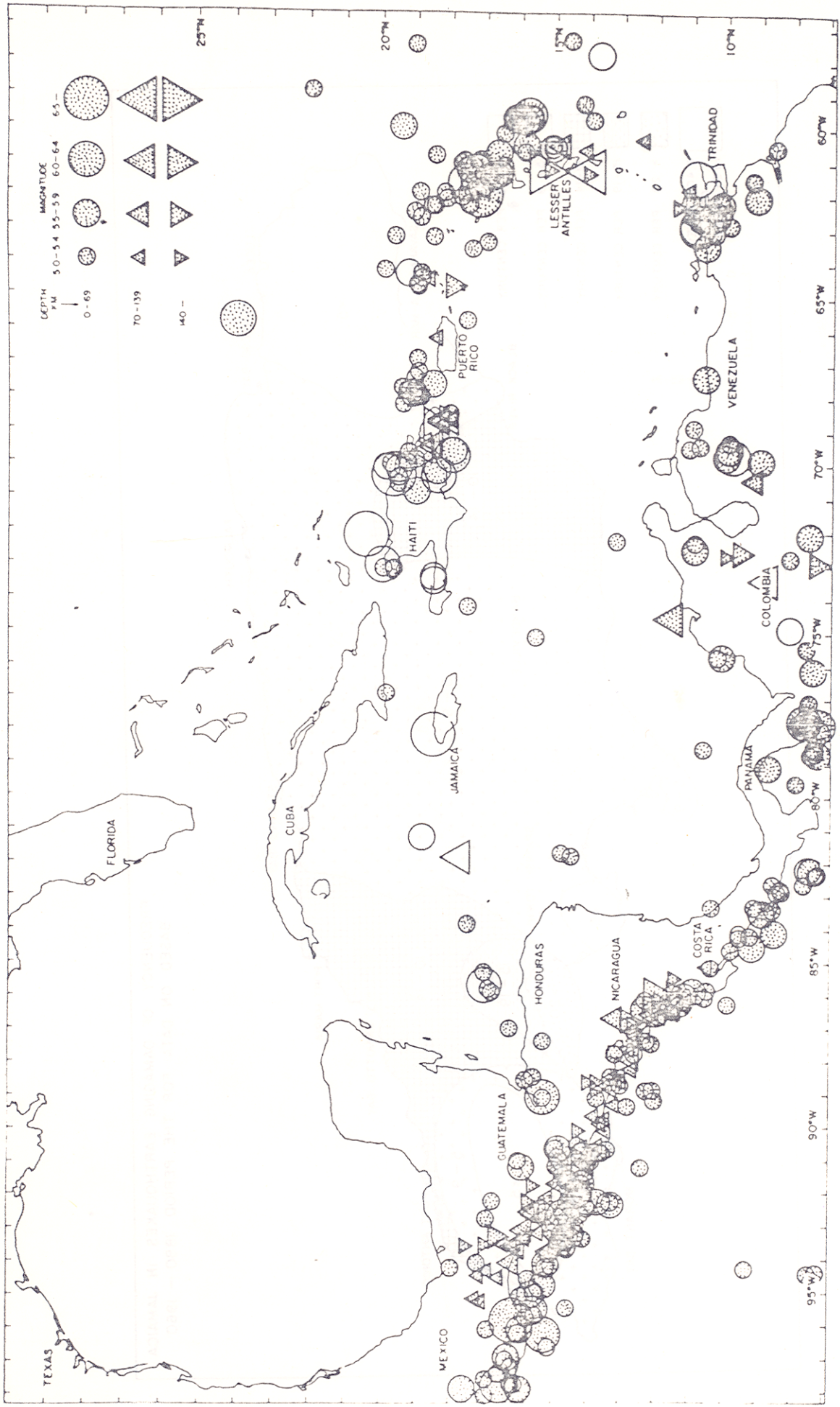


FIGURE 4. CARIBBEAN REGIONAL SEISMICITY - 1953 to 1976 .

FREQUENCY OF DAMAGING EARTHQUAKES IN JAMAICA
 BASED ON DATA FOR THE PERIOD 1880 - 1960

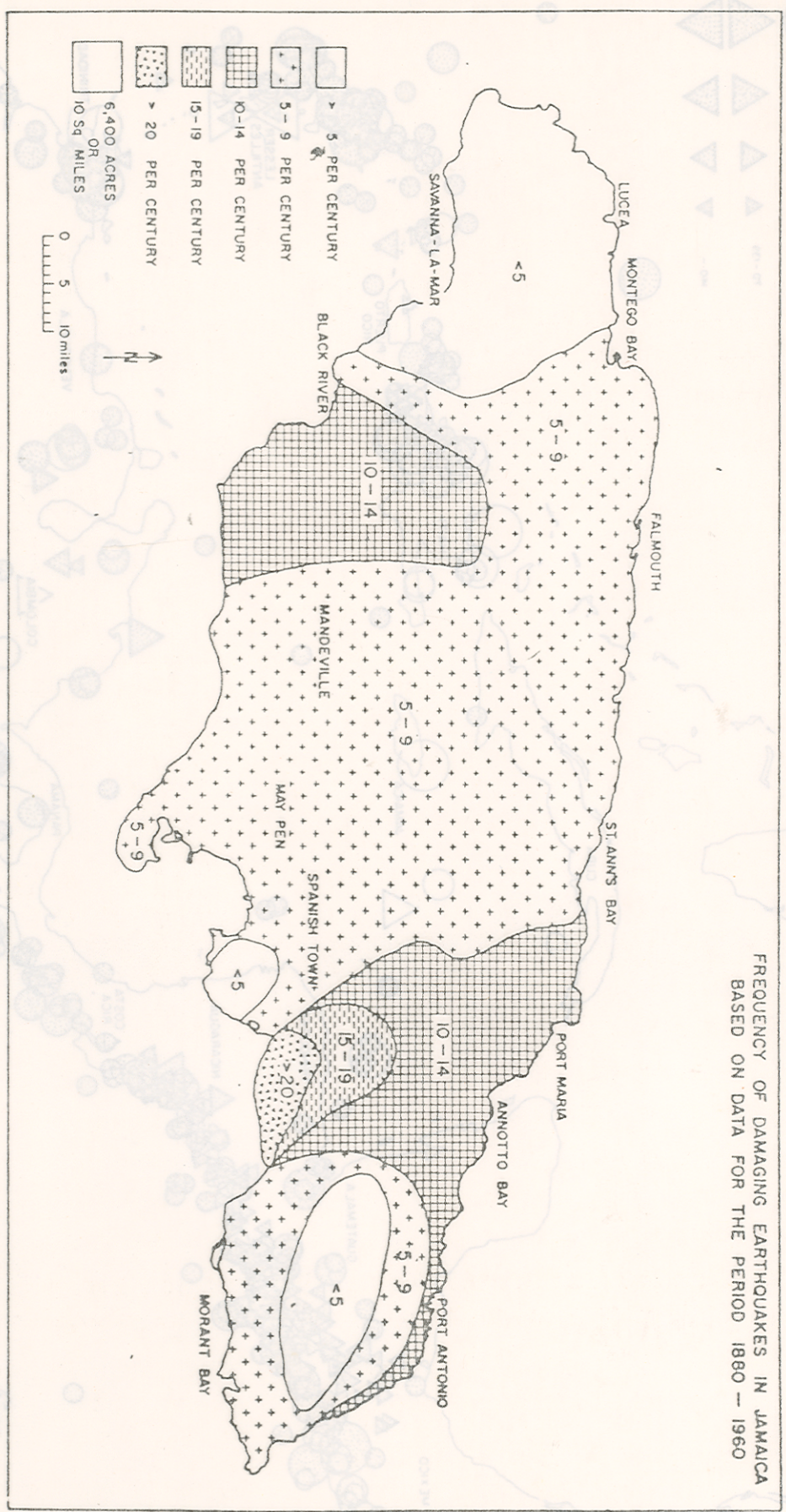


FIGURE 5. FREQUENCY OF DAMAGING EARTHQUAKES IN JAMAICA - 1880 to 1960 .

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NUMBERS OF EARTHQUAKES REPORTED
FELT ($M \geq V$) PER DECADE 1690 - 1978.

