Copy 4

TECTONIC EARTHQUAKES AND VOLCANIC ACTIVITY

BOUGAINVILLE ISLAND, T.N.G.

RECORDS 1955/94

M. A. Reynolds
Geologist
Rabaul.
July, 1955

TECTONIC EARTHQUAKES AND VOLCANIC ACTIVITY

BOUGAINVILLE ISLAND

I. Introduction

In an unpublished report Taylor (1955) suggested that "both tectonic earthquakes and volcanic activity are related to prevailing conditions of regional stress. The diagnostic value of this relationship lies in the fact that abnormal stress conditions make their presence known first by tectonic earthquakes and later by volcanic eruption." This theory was developed as a result of intensive research following upon a study of the New Hebrides volcanic arc and recent vulcanism. References to the relationship between earthquakes and volcanic activity have been made also by Gutenberg and Richter (1941, 1949) and Benioff (1954). The former noticed that intermediate depth earthquakes frequently occur under lines of volcanic cones. They also (1949, p.100) state that true tectonic earthquakes "not infrequently ..... accompany or follow notable eruptions." The eruptions of Mauna Loa in 1868, and Sakurajima in 1914 are cited as examples and mention is made that although earthquakes associated with Katmai (1912) and Paricutin (1943) eruptions did not originate close to the volcanoes, their foci were located "at approximately the nearest points of the Pacific active belt, adjacent to the Aleutian Trench and the Acapulco Deep respectively." It is concluded, however, that there is no "cause and effect" relationship between intermediate earthquakes and eruptions and that they probably originate from "a single system of stresses." Benioff stated that volcanic activity is a manifestation of orogenic processes and offered an hypothesis for the origin of volcanoes, in which he suggested that "heat produced in fault rocks by the inelastic components of the repeated to-and-fro strains involved in the generation of the sequences of earthquakes and aftershocks" is the source of volcanic energy. Although he establishes a relationship between earthquakes and volcanic activity, Benioff (p.400) is careful to provide that "the present rate of volcanic energy release should be equated to a phase of seismic-heat generation which occurred long ago, rather than to the present rate."

Bougainville Island, with a deep trough (Planet Deep) situated west of and orientated parallel to its line of volcanoes, exhibits a similar structural pattern to the New Hebrides Islands and it was considered by Taylor that the relationship between tectonic earthquakes and volcanic eruptions might also apply here. He also suggested the possibility that localisation of the epicentres of earthquakes within seismic zones orientated similarly to a line of volcanoes would indicate an impending eruption of the volcano diametrically opposite. As a possible means of diagnosis an analysis of earthquakes and volcanic activity in the Bougainville area was undertaken to discover whether a positive relationship existed for Mt. Bagana, and if so, whether there were indications of impending eruption of the Lake Loloru Crater.

II. Compilation and Presentation of Data.

The preliminary step in this investigation was the plotting of such detail as available concerning the epicentres of the major earthquakes in the Bougainville area on maps and comparing their distribution and occurrence in relation to the more severe eruptions of Mt. Bagana. The sources of the latter information are somewhat limited and were taken from reports by Fisher (1939), Gutenberg and Richter (1949), from "Outline of the Volcanic Activity, 1941-1947 (T.N.G.)"[x] and reports from local observers. Earthquake epicentres were obtained from a

---

[x] The copy of this article was received at Rabaul but details of author, publication and date were not included.

list prepared by Taylor (mainly from the International Seismological Summary ?), from Gutenberg and Richter (1949) and from Seismological Bulletins from Riverview, Brisbane, Pasadena, U.S. Coast and Geodetic Survey and New Zealand. The earthquakes have been arranged in chronological order in the lists accompanying Figures I, II, and III, and are represented in the figures by symbols based on those employed by Gutenberg and Richter. It will be noticed that details of focal depth and/or magnitude of many of the earthquakes are not available and the positions of their epicentres have been marked with a "?" or a symbol accompanied by a "?". The compilation of the lists of earthquakes revealed that one or more alternative positions had been determined for some epicentres. Positions employed have been those considered to be the more accurate and which would correspond most readily to the strengths of the earthquakes reported from various centres within the area. The Planet Deep, whose position was taken from Glaessner (1955), probably represents two structurally independent components, one associated with the Bismarck Sea volcanic arc and the other with the "Outer Melanesian Zone" of Glaessner (p.873). The significance of some epicentres, therefore, especially those between the 153°E. and 154°E. meridians, is difficult to determine. For this reason only epicentres that occur within and east of the southeasterly, northwesterly orientated component are considered in the following discussion. Another difficulty arises because Mt. Bagana is in a state of continuous eruption and it is not possible to correlate seismic activity directly with a single, definite outburst. There are, however, some reliable reports of activity over specific periods and of the more severe eruptions. These are listed hereunder:

1. 4th September, 1937: "Heavy explosions", ("Outline of the Volcanic Activity, 1941-1947".*)

2. 15th May, 1938: "Heavy explosions", (As above - see also Fisher (1939).

3. 1945-1946: Occasional light explosions with ejection of "scoria", sometimes accompanied by earthquakes. (As above (1)).

4. 1950: A "very active period" commenced at the beginning of 1950 and although eruptions were spasmodic strong outbursts were still occurring in October. Noted also was the fact that Bagana was not very active during the war. (Correspondence from Mr. Wallace-Brown, Torokina, Bougainville.)

5. 8th March, 1951: Torokina reported "heavy flow red lava" at night. (Signal from District Commissioner, Sohano.)

6. June, 1951: "Bagana active Stop new crater on north side erupting steam and smoke....." (Signal from Mr. Wallace-Brown.)

7. August, September, 1952: Mt. Bagana appeared to be "most active" but the writer stated that he was not familiar with the pattern of activity. (Extract from report by Patrol Officer J.A. Erskine.)

8. June, 1953: New crater formed on northern side; eruption accompanied by strong blast. (Correspondence from Mrs. Wallace-Brown.)

---

* The copy of this article was received at Rabaul but details of author, publication and date were not included.

9. July, 1953: Bagana erupted on the 10th, "usual smoke formation, sound of eruption quite loud," (Signal from Radio Numa Numa); 25th: "Bagana blew with great blast," (Signal from Inus, Bougainville.)

10. August, 1953: Some strong explosions during month. (Reports from local observers, Bougainville.)

To enable a comparison to be made with the above references, seismic activity was listed and plotted on 3 figures to cover the periods from 1931 until immediately prior to the eruption on 15th May, 1938; from 1938 (post eruption) until January, 1950 (commencement of period of stronger activity); and from 1950 until 1955. Further, to facilitate discussion, a fourth figure has been prepared showing the sequence of all tremors listed with magnitude 6 or greater. This is based on work done by Benioff (1949, 1951, 1954) who has shown that the elastic strain-rebound accompanying or producing an earthquake can be calculated from the seismic energy liberated. He found that the square root of the earthquake energy ($J^{\frac{1}{2}}$) is proportional to the elastic strain rebound. J can be derived from a formula due to Gutenberg and Richter (1942; see also 1949, p.10), and expressed by Benioff (1949, p. 1838) as

$$\text{Log } J^{\frac{1}{2}} = 6.0 + 0.9M$$

A graph of the accumulated sum S of the increments $J^{\frac{1}{2}}$ plotted against time, represents the elastic strain-rebound characteristic (x constant C) of the sequence. This method has been used to construct figure 4 which has been divided into three sections to show the different characteristics of N (surface) shocks, those originating a depths between 40 and under 70 kilometers and intermediate shocks (70-300 kms.). Days and periods of stronger eruptions of Mt. Bagana are indicated by broken vertical lines which are numbered according to the text.

III. Comparison of Details of Earthquakes and Volcanic Activity at Mt. Bagana.

The three major periods of seismic activity (as determined above) are discussed separately hereunder:

A. 1931 - pre-eruption 15/5/38 (Fig. I): During the period April 1931 until February 1932 seismic activity consisted of the only two deep shocks which occurred in this area between 1931 and 1955, and eight shallow shocks in the vicinity of Bougainville. Four of the latter, Nos. 6, 7 and 9(2), originated on the west coast opposite Mt. Bagana on 29th and 31st January, 1932.

After February 1932 and prior to the eruption in 1937, only shocks Nos. 10, 11, 14-17 and 28 can be considered in the vicinity of Bougainville. (Details of depth and magnitude are not available for Nos. 18, 20, 21.) The first six of these, which occurred between February 1932 and June 1934, are arranged, with the exception of No. 17 whose position suggests that it would have little influence on volcanic activity, in an arc between the Planet Deep and 4,000 meter line, approximately equidistant from the line of volcanoes. The depths of these shocks vary between 50 and 180 kilometers and their magnitudes range from 6 to 6¾. No.28 earthquake originated at a depth of 100 kilometers in the zone below the Planet Deep and occurred within four months before the eruption.

Between the 1937 and 1938 eruptions, only 1 epicentre occurs opposite Bougainville, and this is situated south-west of the Planet Deep. The original shock in this position, No.29, has the greatest magnitude of all shocks discussed in this section A, but because of its position, its significance is doubtful.

If the relationship between earthquake and volcanic activity exists the positions and magnitudes of shocks in 1931 and early 1932 could easily be considered as indicative of an impending eruption. It is also noted that subsequent shocks prior to the eruption occurred in zones whose distances from the line of volcanoes became progressively greater as their times of occurrence approached the times of eruptions.

B. 1938 (post eruption) - January 1950 (Fig. II): In notes compiled by Best but not included in a report the following relevant information concerning activity at Mt. Bagana was noticed: "from information available it appears that little or no explosive activity occurred during the war years. Towards the end of 1948, spasmodic activity commenced and prevailed for about 12 months. Towards the end of 1949, the frequency and violence of the eruptions increased appreciably and continued until about the end of October 1950".

In the two years following the May 1938 eruption there were five earthquakes which could be related to volcanic activity. (The very strong earthquake, No.5, apparently has no significance in this discussion). These are Nos. 1, 3, 4, 8 and 12, and are situated in the zone between the west coast of Bougainville and the 4,000 meter line. It is considered that these, in particular Nos. 1, 3 and 4, should be regarded as following the 1938 eruption rather than preceding activity in 1950.

Between 1940 and 1945 only shocks Nos. 16, 20, 23-26 originated in the vicinity of Bougainville, and of these, only three (Nos. 20, 23, 26) occur in close proximity to the volcanoes of Bougainville.

Shock No. 31 of Magnitude 7 originated in the same position as No.28 of the preceding discussion A, but it is not known whether its focus was at the same depth. It occurred in 1946 when there were light explosions, but because of lack of detail of the latter and since local observers do not mention any major eruptions at this time, it is considered that a relationship did not exist.

Prior to the spasmodic activity at the end of 1948, there were three small, widely dispersed shocks of no apparent significance, (Nos. 35, 37, 38) and one shallow shock of Magnitude 6-7 which occurred in June 1948. This shock, No. 40, originated in close proximity to Mt. Bagana, and may have been related to the activity at the end of 1948 referred to by Best.

Perhaps the most significant earthquakes in this period are the ten shocks covered by Nos. 42 and 44, which occurred in September, October 1949. The initial shocks in each sequence were of Magnitudes 7 and $6\frac{3}{4}$-$7\frac{1}{4}$ and the strain-rebound characteristic of the series is quite appreciable. Unfortunately the depths of foci are not available. It must be noted, however, that the shocks of No.42 did not originate diametrically opposite Mt. Bagana and that the following sequence of No.44 were to the north and away from Mt. Bagana.

C. February 1950 - June 1955 (Fig. III): In addition to information reported on activity at Mt. Bagana, it is to be noted also that Best gives from June until about September as the strongest period of activity during 1950. It will be more convenient in this section to discuss the eruption sequence as numbered 4 to 10 and the corresponding occurrences of earthquakes.

(a) 4. 1950: One strong intermediate depth shock No.3, occurred during the strongest period of activity.

The epicentre was south-south-west of Mt. Bagana in the zone between the west coast of Bougainville and the 4,000 meter line. A small (?) shock, No.6, occurred at the same epicentre in October.

(b) 5. 8/3/51: Two small (?) shocks, Nos. 10 and 12, occurred in the vicinity of Mt. Bagana and in the zone just west of the volcano line, the former 2 months before the eruption and the latter 2 days after the eruption. Earthquake No.11 originated at a depth of 60 kms. at the eastern edge of the Planet Deep on the day of the eruption.

(c) 6. June 1951: Preceded by strong earthquake, No. 15, on 21st May in the same zone but north-west of epicentre No.3 and with focal depth of 150 kms. Two other epicentres, Nos. 18 and 22 were in the same position as No.15 and the earthquakes, one small, shallow (?) and the other small (?), intermediate depth, occurred at the end of June and in December 1951 respectively.

(d) 7. August, September 1952: This activity preceded by earthquake No.24 in May 1952. The epicentre is the same as that for No. 3, the shock was Magnitude 7 and the focus at a depth of 50± kms. During the eruptive period 4 earthquakes originated in close proximity to Mt. Bagana in the zone immediately west of the volcano line. These are Nos. 25 and 27 to 29 and mainly occurred at shallow depths. In November of the same year, an intermediate depth shock, No. 30, occurred in the same zone but south-east of the shallow shocks. Its epicentre was very close to the Lake Loloru crater.

(e) 8-10. June-August, 1953: An earthquake, No. 36 in March 1953, preceded this activity and was strongly felt in Buin. The focus was at a depth of 60 feet and was situated in the zone adjoining the volcano line. Another shock, No. 38, apparently strong as determined from report from Buin, and a smaller shock, No.40, occurred during June in the same position as the strong earthquakes, Nos. 3 and 24.

The analysis of the comparison between earthquakes and volcanic activity at Mt. Bagana results in the following generalisations.

(1) As stated earlier, if the relation between tectonic earthquakes and volcanic activity existed, the earthquakes of 1931 and 1932 should logically have preceded an eruption. In a literal sense, they preceded the eruptions of 1937 and 1938. In the intervening period, however, there was an unusual movement of earthquakes outward to the zone between the Planet Deep and 4,000 meter line and just prior to the eruption to beneath the trough itself. This outward trend was further expressed by the earthquake south-west of the trough in the period between the two major eruptions, although the significance of this latter epicentre is doubtful.

More significance should possibly be attached to the distribution and movement of epicentres in 1933, 1934. These shocks originated in an arc extending along the eastern margin of the Planet Deep to a position (No.17) east of the 4,000 meter line. The movement of the foci of the earthquakes was from south to north along this arc.

concentrated/ Epicentres after 1938 up to 1945 were generally/ along the zone bordering the western margin of Bougainville between the coast and 4,000 meter line. It has already been mentioned that those occurring in the two years after the 1938 eruption should be regarded as belonging to a post-eruption phase.

(2) Apart from the earthquake, No. 40, in June 1948, there is a somewhat analagous series of seismic events associated with the 1950 eruptions. The 1949 shocks, Nos. 42 and 44, for which depths of foci are unfortunately not available, originated at the northern end of the 1933-34 arc and, furthermore, the movement was from south to north. Although there is a considerable difference in the time lag between events in 1933-34 and the 1937 eruption and that between 1949 seismic activity and the 1950 eruption, it is also noted that the energy release in the latter case was considerably greater.

During 1950 and in the following years the largest magnitude shocks occurred along the zone bordering the western margin of Bougainville in positions similar to those of epicentres in the 1938-1945 period, while some smaller earthquakes occurred along the volcanic line. Most of the latter were centred in close proximity to Mt. Bagana and occurred during periods of eruption.

IV. Conclusion

A. Although the events described in the two sets of generalisations above exhibit a common trend, much more information is necessary before it is possible to theorise on the relationship between tectonic earthquakes and volcanic activity on Bougainville.

B. The positions of epicentres Nos. 24, 30, 36, 38 and 40 (May 1952- June 1953) in the vicinity of the Lake Loloru could lead to speculation regarding a possible eruption at that centre. It must be borne in mind, however, that:

(1) Earthquakes have originated in positions in the vicinity of Lake Loloru in each of the three periods discussed; and

(2) although seismic activity cannot be directly associated with the original report of increased thermal activity in 1951, later reports of increased activity at Lake Loloru and at the Piras River thermal area correspond with strong earthquakes No. 24 on 9/5/52 and No.25 on 14/8/52 respectively. It is considered that the latter reports, originating from indigenes, were based on the earthquakes rather than any significant alteration in thermal activity.

C. The common trend established between earthquakes and volcanic eruptions in the two main periods of activity on Bougainville is similar, although not entirely compatible, with that determined for the New Hebrides Islands by Taylor (1955). He summarised the results of his findings as follows:

"(1) During the twelve months before the eruption a marked increase in the frequency of tectonic earthquakes occurred throughout the whole of the New Hebrides region.

(2) Most of the earthquake epicentres lay in a structural plane which includes the island deep westward and parallel to the general trend of the island group.

(3) The greatest concentration of epicentres occurred in the deep opposite the Ambrym volcano. This is in a position almost normal to Ambrym in the line of the general structural arc.

(4) After the eruption began the earthquakes moved eastward into a parallel plane which includes the islands and active volcano."

V. <u>Additional information relating to the Structure and Geotectonic position of Bougainville as compared with the New Hebrides Islands.</u>

This investigation has shown that there are certain features relating to the structures of the two areas which indicate that the crustal structural planes are different and that the apparent structural similarity between them is not due to a common diastrophic origin. The full significance of these features can only be determined in research which is beyond the scope of this report but they are mentioned hereunder as a basis for future discussion.

A. The distribution of earthquakes in the vicinity of Bougainville is plotted in Figures I to III is not in accordance with the results obtained by Gutenberg and Richter (1949) who found that in the New Hebrides and Solomon Islands "the troughs are on the south-western, or continental side, the shallow shocks are between these and the island chains, while intermediate shocks are under the islands or beyond them towards the open Pacific, with a few deep shocks farther out." Most of the established epicentres of shallow (surface) shocks in the Bougainville area occur along the western portion of the island but there are two other positions which extend south-east from the southern limit of the Planet Deep where one major shallow earthquake and some smaller shocks have originated. Most of the earthquakes, classed as shallow, but which originate at depths close to the upper (70 km.) limit of the intermediate shock zone are associated with intermediate shocks below the area between the trough and the mainland. The two deep shocks plotted had foci situated beneath the belt between the 4,000 meter line and the western margin of the island. The distribution is illustrated in Figure 5 which is composed in the same manner as that employed by Benioff (1949, 1954) with an upper section representing an average profile of the region normal to the line of volcanoes and exaggerated to show the Planet Deep and a lower section showing depths and positions of epicentres relative to the line of volcanoes. For convenience a different set of symbols has been employed, to show the relation of shocks before and after periods of volcanic activity. The complexity in the disposition of epicentres is in contrast to the New Hebrides where the above-mentioned conditions described by Gutenberg and Richter apply. This may be due to the existence beneath Bougainville of structural planes which are different from those established by Benioff for the New Hebrides. On the other hand, the number of epicentres plotted may be insufficient to show the true structural trend.

B. Glaessner (1950, p. 873) states that "The Solomons and New Hebrides, although obviously very similar in geological history and structure, are at present separated by deep sea (below 4,000 meters.)" He also suggests that the Solomons are possibly linked with Eastern New Guinea between the Planet Deep and the trough west of the southernmost members of the Solomon Islands and through Woodlark Island. An easterly extension of the latter deep trough is considered to be the most likely cause of the deep water between the New Hebrides and Solomons.

The Pelean nature of recent volcanic activity in Eastern New Guinea and Bougainville and the fact that rock types from Mt. Lamington, Mt. Bagana and the Lake Loloru dome are andesitic, almost identical in appearance and quite distinct from the predominantly basic type of effusive rock of the Bismarck Archipelago volcanic arc support the possibility that there is a link between the Solomons and Eastern New Guinea. Taylor (1952) states that Ambrym Island in the New Hebrides is an open conduit type of volcano and that the lavas are basic in composition. In view of these facts it is considered that, although Bougainville and the New Hebrides appear to have similar structures, the forces which produced them and are still operating are comparatively recent in origin and different from those which operated when diastrophic processes began to form the island chains in the region.

VI. References

Benioff, Hugo (1949), - "Seismic Evidence for the Fault Origin of Oceanic Deeps," Bull.Geol.Soc.Amer., Vol. 60, pp. 1837-1856.

(1951), - "Global Strain Accumulation and Release as Revealed by Great Earthquakes," ibid, Vol. 62, pp. 331-338.

(1954), - "Orogenesis and Deep Crustal Structure - Additional Evidence from Seismology," ibid, Vol. 65, pp. 385-400.

Fisher, N.H. (1939) - "Report on the Volcanoes of the Territory of New Guinea," Geol.Bull. No. 2, T.N.G.

Glaessner, M.F. (1950) - "Geotectonic Position of New Guinea," Bull.Am.Assoc.Petrol.Geol. Vol. 34, No.5, pp. 856-881.

Gutenberg, B., and C.F. Richter (1941) - "Seismicity of the Earth," Geol.Soc.America Spec. Paper 34.

(1942) - "Earthquake Magnitude, Intensity, Energy and Acceleration," Bull.Seismol.Soc.Amer. Vol. 32, pp. 163-191.

(1949) - "Seismicity of the Earth and Associated Phenomena," Princeton Univ. Press.

Taylor, G.A. (1952) - "Report on Volcanic Activity on Ambrim Island, 1950, 1951", Records. 1952/4 of Bur.Min.Resources, Canberra.

(1955) - "Tectonic Earthquakes and Recent Volcanic Activity," Unpublished Report, Bur.Min. Resources, Canberra.

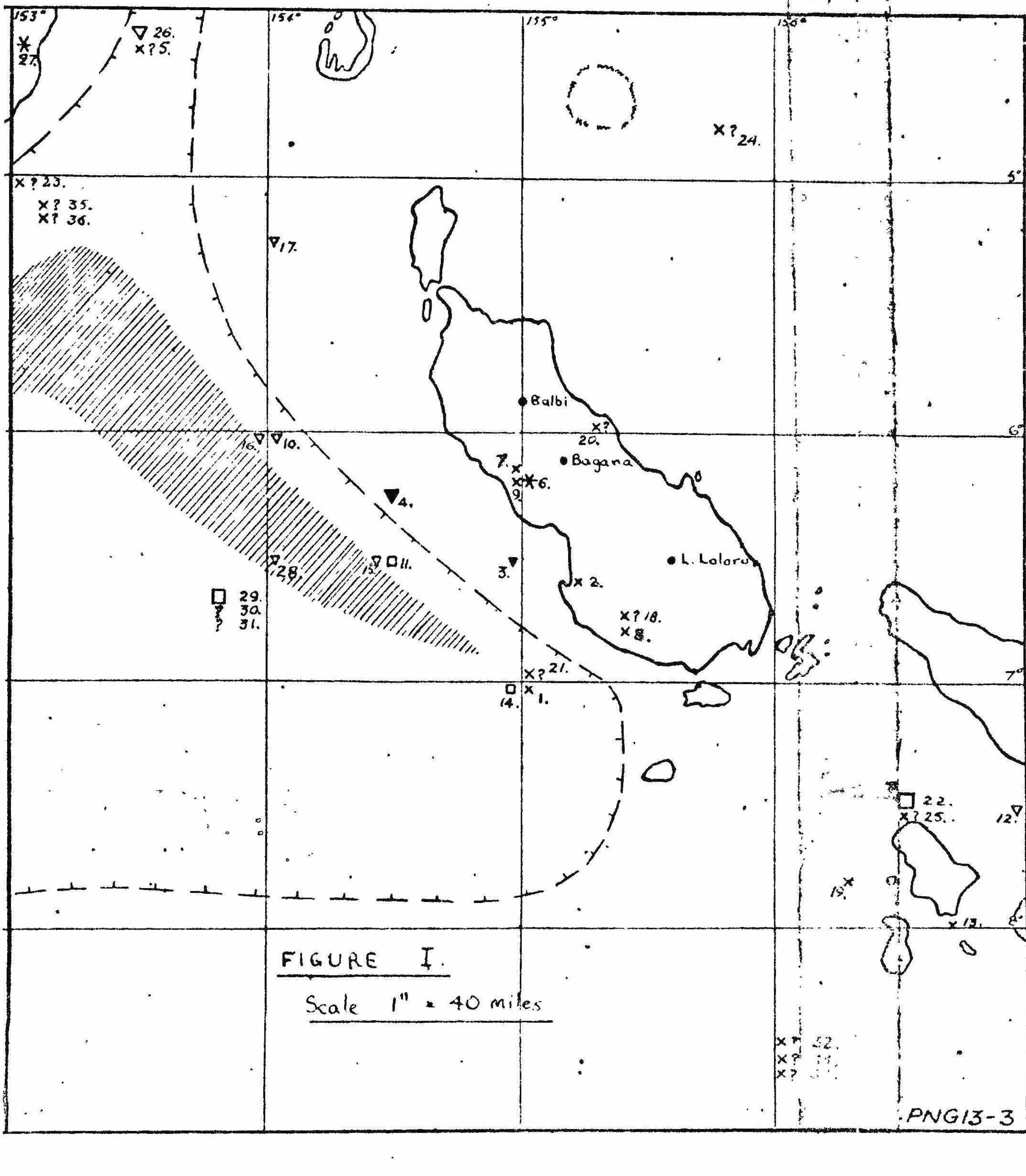

FIGURE I.

Scale 1" = 40 miles

FIGURE I

EPICENTRES FOR THE PERIOD JAN. 1931 - APRIL 1938.

No.	Date	Lat. ° S	Long. ° E	M	Depth in Kms.	Remarks
1	6. 4.31	7	155	6¾	N	Felt Kalili RF2
2	24. 4.31	6.6	155.2	6.9	N	cf 7°S 155°E (G&R); felt Kalili RF5, Buin RF8, Rabaul RF4.
	25. 4.31	6.6	155.2			
3	23. 7.31	6.5	155	6¾	400	Class. B (G&R); cf 7°S, 155°E; felt Kieta RF3, Kokopo RF3.
4	9. 1.32	6¼	154½	7.3	380	Class. A (G&R); cf 6°S, 155.30E; felt Duke of York Is. RF5, Kokopo RF4, Rabaul RF3.
5	29. 1.32	4.5	153.5			
6	29. 1.32	6.2	155.0	7	N	cf 6°S, 155°E (G&R); felt Kieta RF6.
7	29. 1.32	6.2	155.0	6½	N	cf 6½°S, 155°E (G&R).
8	30. 1.32	6.8	155.4	6¼	N	cf 7½°S, 155°E (G&R), 7°S, 155°E (R).
	30. 1.32	6.8	155.4			
9	31. 1.32	6.2	155.0	6	N	cf 6°S, 155°E (G&R).
	31. 1.32	6.2	155.0			
10	8. 3.32	6	154	6½	70	Class. B (G&R); cf 5°S, 155°E (R)
11	30. 3.32	6½	154½	6	50	(G&R); cf 6.2°S, 155.0°E.
12	17.10.32	7½	157	6¼	100	Class. B (G&R); cf 7°S, 157°E.
13	7. 6.33	8	156.7	5.3-5.9	N	(G&R)
14	18.11.33	7	155	6¼	60	cf 7°S, 154½°E (G&R).
15	11. 2.34	6½	154½	6½	80	Class. B (G&R); cf 6.2°S, 155°E.
16	27. 2.34	6	154	6½	180	Class. A (G&R); cf 5.5°S, 153.5°E.
17	13. 5.34	5¼	154	6¾	100	Class. A (G&R); cf 5°S, 153.9°E. felt Rabaul RF5.
18	13. 3.35	6.8	155.4			
19	20. 3.35	7.8	156.3	6½	N	cf 7¾°S, 156°E (G&R).
20	12. 5.35	6.0	155.3			
21	23. 8.35	7.0	155.0			
22	19. 4.36	7.5	156.5	7.4	40	cf 7½°S, 156°E (G&R).
23	11. 5.36	5.0	153.0			
24	17. 8.36	4.8	155.8			
25	28..8.36	7.5	156.5			
26	29.12.36	4.5	153.5	7.0	100	Class. B (G&R); cf 4.5°S, 153.9°E.
	29.12.36	4.5	153.5			
27	23. 1.37	4.5	153.0	7.0	N	(G&R); cf 5.1°S, 153.1°E.
28	31. 5.37	6.5	154.0	6½	100	Class. B (G&R); cf 6.7°S, 153°E.
29	23. 9.37	6.7	153.8	7.4	60	cf 6°S, 154°E (G&R).
	23. 9.37	6.7	153.8			
30	26. 9.37	6.7	153.8			
31	6.10.37	6.7	153.8			
32	8.12.37	8.5	156.0			
33	20.12.37	8.5	156.0			
34	22. 2.38	8.5	156.0			
35	6. 3.38	5.1	153.1			
36	8. 3.38	5.1	153.1			

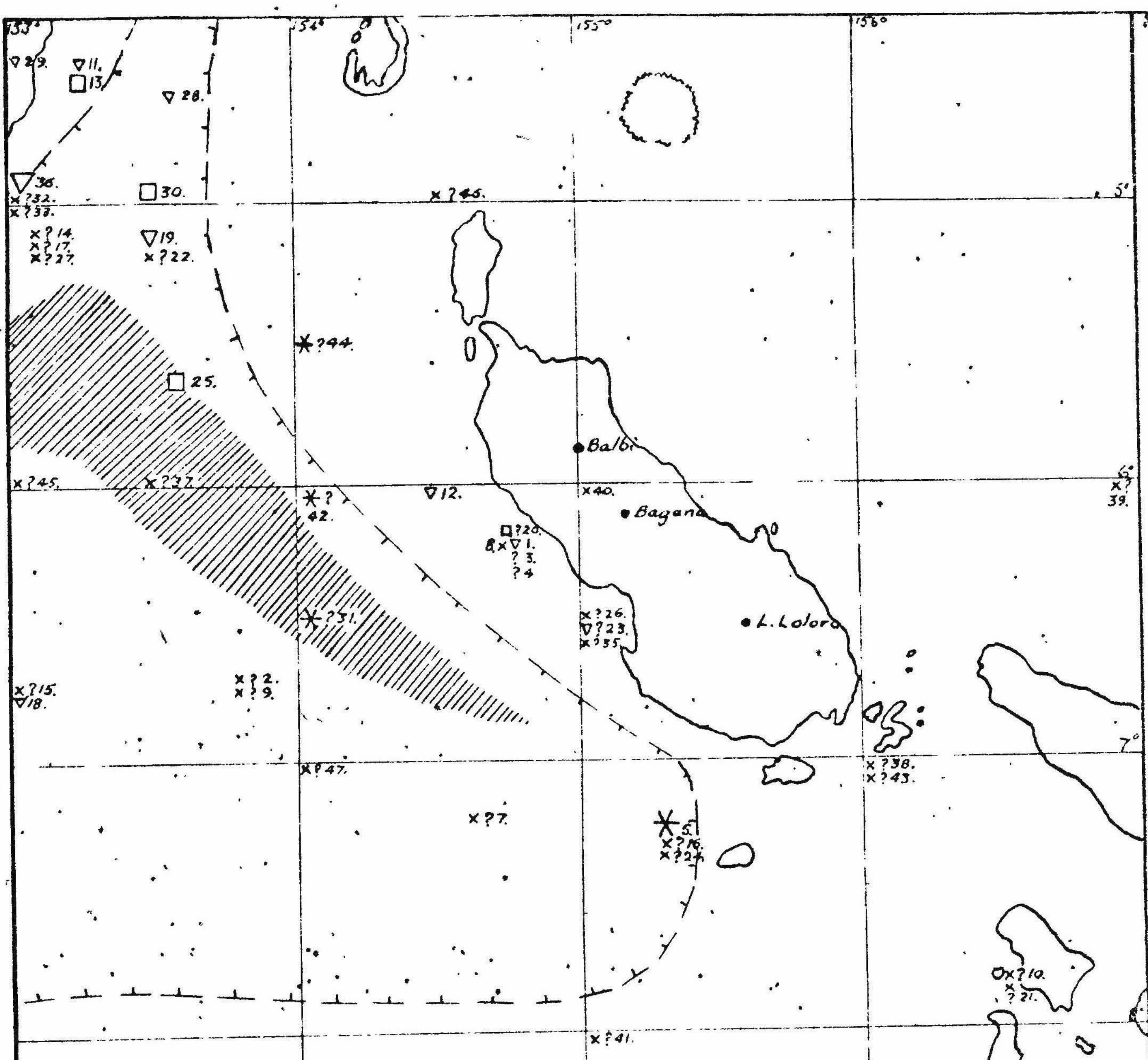

FIGURE II

Scale: 1" = 40 Miles

PNG 13-4

FIGURE II

EPICENTRES FOR THE PERIOD MAY 1938 - JANUARY 1950

No.	Date	Lat. ° S	Long. ° E	M	Depth in Kms.	Remarks
1	7. 9.38	6.2	154.8	6½	160	cf 6½°S, 155°E (G&R), Class.B.
2	11.11.38	6.7	153.8			
3	7.12.38	6.2	154.8			
4	22. 1.39	6.2	154.8			
5	30. 1.39	7.2	155.3	7.8	N	cf 6½°S, 155½°E (G&R).
	30. 1.39	7.2	155.3			
	31. 1.39	7.2	155.3			
6	2. 2.39	8.5	156			
7	20. 2.39	7.2	154.6			
8	8. 3.39	6.2	154.8	6¾	N	cf 6°S, 155°E (G&R).
9	8. 6.39	6.7	153.8			
10	8. 8.39	7.8	156.5			
11	25. 8.39	4.5	153.3	6¾	90	cf 5°S, 152¾°E Class. B (G&R).
12	17.11.39	6	154.5	6	140	Class. C (G&R).
13	12. 9.40	4.5	153.3	7	40	cf 4½°S, 153°E (G&R).
14	21.10.40	5.1	153.1			
15	31.10.40	6.7	153.0			
16	11. 1.41	7.2	155.3			
17	24. 1.41	5.1	153.1			
18	2. 5.41	6.7	153.0	6½	80	cf 6°S, 152.5°E Class.B (G&R).
19	4. 9.41	5.1	153.5	7.1	90	cf 4¾°S, 154°E Class.A (G&R).
-20	9. 9.41	6.2	154.8		30	
21	12. 1.42	7.8	156.5			
22	2. 2.42	5.1	153.5			
-23	6.10.42	6.5	155		70	
	6.10.42	6.5	155			
24	18.10.43	7.2	155.3			
25	23.12.43	5.6	153.6	7.3	50	cf 5½°S, 153½°E (G&R); 5½°S, 154°E (NZ).
	24.12.43	5.6	153.6			
	25.12.43	5.6	153.6			
	30.12.43	5.6	153.6			
-26	24.12.43	6.5	155.0			
	24.12.43	6.5	155.0			
27	15. 5.44	5.1	153.1			
28	5.10.44	4.6	153.6	6.9	110	cf 4½°S, 152½°E Class.B (G&R); 4°S, 154°E (BCIS).
29	23. 4.45	4.5	153	6¾	160	Class. B (G&R).
30	5. 9.45	5	153.5	7.1	50	(G&R); cf 6°S, 155°E; 5°S, 154° (JSA).
	6. 9.45	5	153.5			cf 6°S, 155°E.
31	16. 5.46	6.5	154	7		
32	1. 7.46	5	153	6½		cf 5°S, 152°E (URSS).
33	24. 7.46	5	153			
34	11. 8.46	8.4	155.9	6¾	90-100	(JSA); cf 8°S, 155°E (USCGS), 8½°S, 155½°E (NZ).
35	3. 9.46	6.5	155			
36	29. 9.46	5	153	7¾	100	cf 5½°S, 154°E (NZ).
37	2. 1.47	6	153.5			
38	4. 1.47	7	156		N	cf 6°S, 155°E (NZ).
39	8. 3.48	6	157			
40	18. 6.48	6	155	6-7	N	(USCGS); cf 7½°S, 156°E (NZ).
41	21.10.48	8	155	6½		(USCGS); cf 7½°S, 156°E (NZ), 7.2°S, 156°E (JSA).
42	24. 9.49	6	154	7		(USCGS); cf 6.2°S, 153.3°E (JSA)
	24. 9.49	6	154	6¼		
	25. 9.49	6	154			
	26. 9.49	6	154			
	26. 9.49	6	154			
	26. 9.49	6	154			

No.	Date	Lat. °S	Long. °E	M	Depth in Kms.	Remarks
43	30. 9.49	7	156			(BCIS).
44	19.10.49	5.5	154	$6\frac{3}{4}-7\frac{1}{4}$		(BCIS).
	20.10.49	5.5	154	$6\frac{1}{2}$		
	21.10.49	5.5	154	$6\frac{1}{2}$		
	26.10.49	5.5	154			
45	28.10.49	6	153			(BCIS).
46	1.11.49	5	154.5			(BCIS).
47	15. 1.50	7	154			(BCIS).

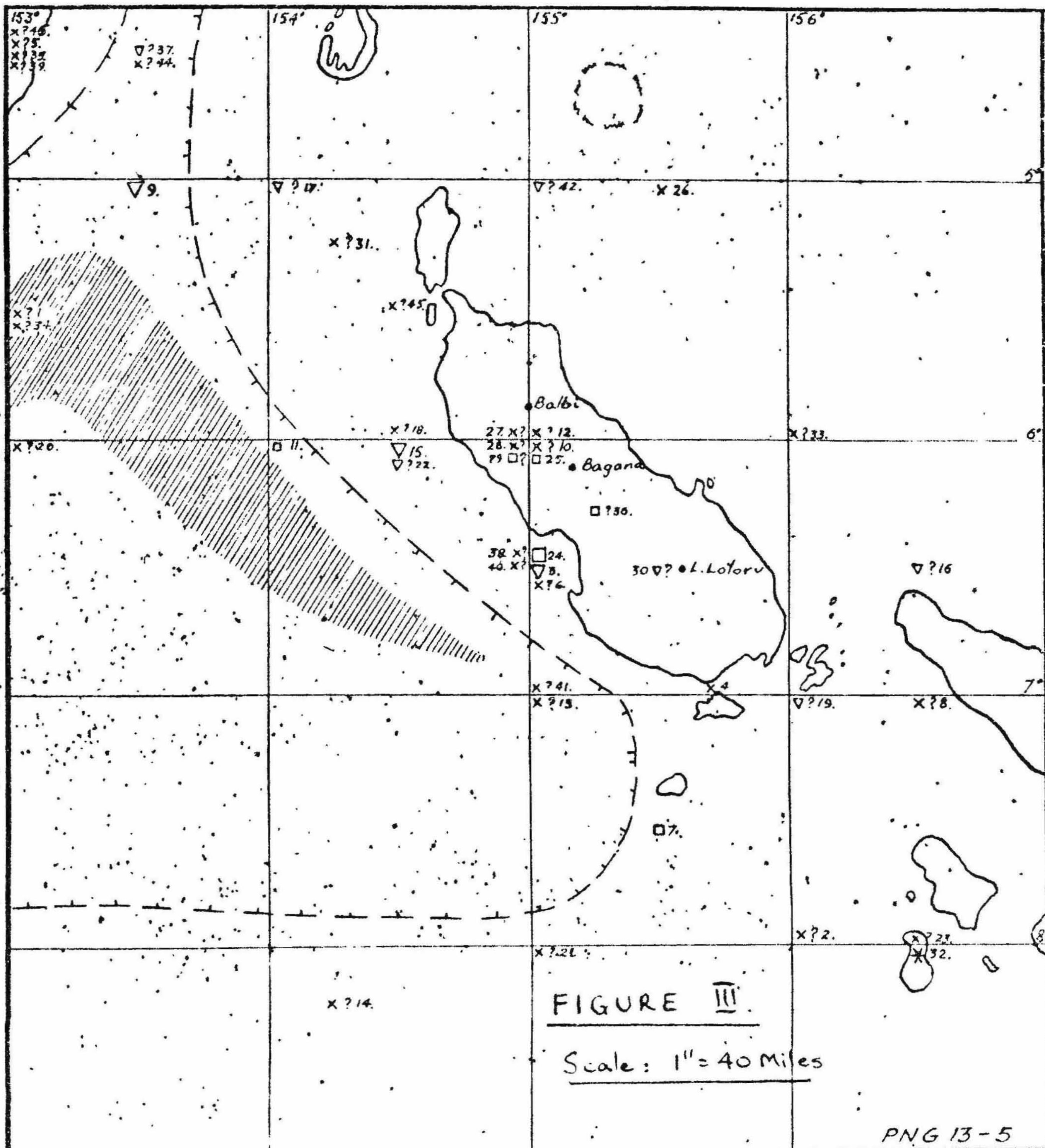

FIGURE III

Scale: 1" = 40 Miles

PNG 13-5

FIGURE III

EPICENTRES FOR THE PERIOD FEBRUARY 1950 - JUNE 1955

No.	Date	Lat. °S	Long. °E	M.	Depth in Kms.	Remarks
1	13. 2.50	5.5	153			
2	10. 6.50	8	156			(USCGS)
3	29. 7.50	6.5	155	7.1	70	(USCGS, P); cf 6.8°S, 155.1°E (JSA).
4	10. 8.50	7	155.7	5.7		
5	8.10.50	4.5	153			
6	25.10.50	6.5	155			(USCGS)
7	6.11.50	7.5	155.5	6½-6¾	50?	(USCGS)
8	7.11.50	7	156.5			(BCIS, USCGS).
9	4.12.50	5	153.5	7-7¼	100+	(BCIS); cf 7°S, 151°E (Poona)
10	14. 1.51	6	155			(BCIS, USCGS).
11	8. 3.51	6	154	6½?	60	(BCIS, USCGS); felt Buin, NumaNuma, Torokina, Aropa and Inus strength 3.
12	10. 3.51	6	155			(BCIS); felt Buin.
13	21. 4.51	7	155			(BCIS, USCGS); felt Buin strength 3.
14	30. 4.51	8¼	154¼	6¼-6½		(BCIS); cf 8°S, 153°E (USCGS)
15	21. 5.51	6	154.5	7	150	(BCIS, P & USCGS); felt St. 5 at Buin, Namatanai, Inus, 4 Tovanakus, NumaNuma, Kokopo, 3-5 Torokina, 5 Kieta.
16	30. 5.51	6.5	156.5		100	(BCIS)
17	24. 6.51	5	154		100?	(USCGS).
18	30. 6.51	6	154.5			(USCGS).
19	13. 7.51	7	156		100	(USCGS).
20	6. 8.51	6	153			(BCIS).
21	10.10.51	8	155			(BCIS).
22	8.12.51	6	154.5		100	(BCIS, USCGS).
23	12. 2.52	8	156.5			(USCGS).
24	9. 5.52	6.5	155	7	50±	(P, USCGS); felt Str. 5 at Buin, Namatanai, Inus, 6 Kieta, 3-4 Hilalon, 4 Kokopo.
25	14. 8.52	6	155	6¾±	60	(USCGS).
26	16. 8.52	5	155.5	6¼±	N	(BCIS).
27	17. 8.52	6	155			(USCGS).
28	5. 9.52	6	155			(USCGS).
29	19. 9.52	6	155		60±	(BCIS); felt str. 3 Buin.
30	28.11.52	6.5	155.5		100	(USCGS).
31	2.12.52	5¼	154¼			(BCIS).
32	6.12.52	8	156.5	7.1	N	(P); cf 8°S, 157°E (USCGS).
33	15.12.52	6	156			(USCGS).
34	25.12.52	5.5	153			(USCGS).
35	27. 1.53	4.5	153			(USCGS).
36	2. 3.53	6¼	155¼		60	(BCIS); felt Str. 5 Buin.
37	9. 3.53	4.5	153.5	6½-6¾	Intermediate?	(P, USCGS); felt Str. 3,2,3 Buin, 4 Feed Is., Kokopo and Sohano.
38	18. 6.53	6.5	155			(USCGS); felt Str. 6 Buin.
39	27. 6.53	4.5	153			(USCGS).
40	23. 6.53	6.5	155			(BCIS).
41	25. 6.53	7	155			(USCGS).
42	19.10.53	5	155		200?	(BCIS); cf 5°S, 150°E (NZ).
	No records available between January and June 1954.					
43	Tremor felt at Buin in April 1954, (11. 4.54).					
44	17. 9.54	4.5	153.5			(USCGS).
45	22.12.54	5.5	154.5			(USCGS).
46	28.12.54	4.5	153			(USCGS).

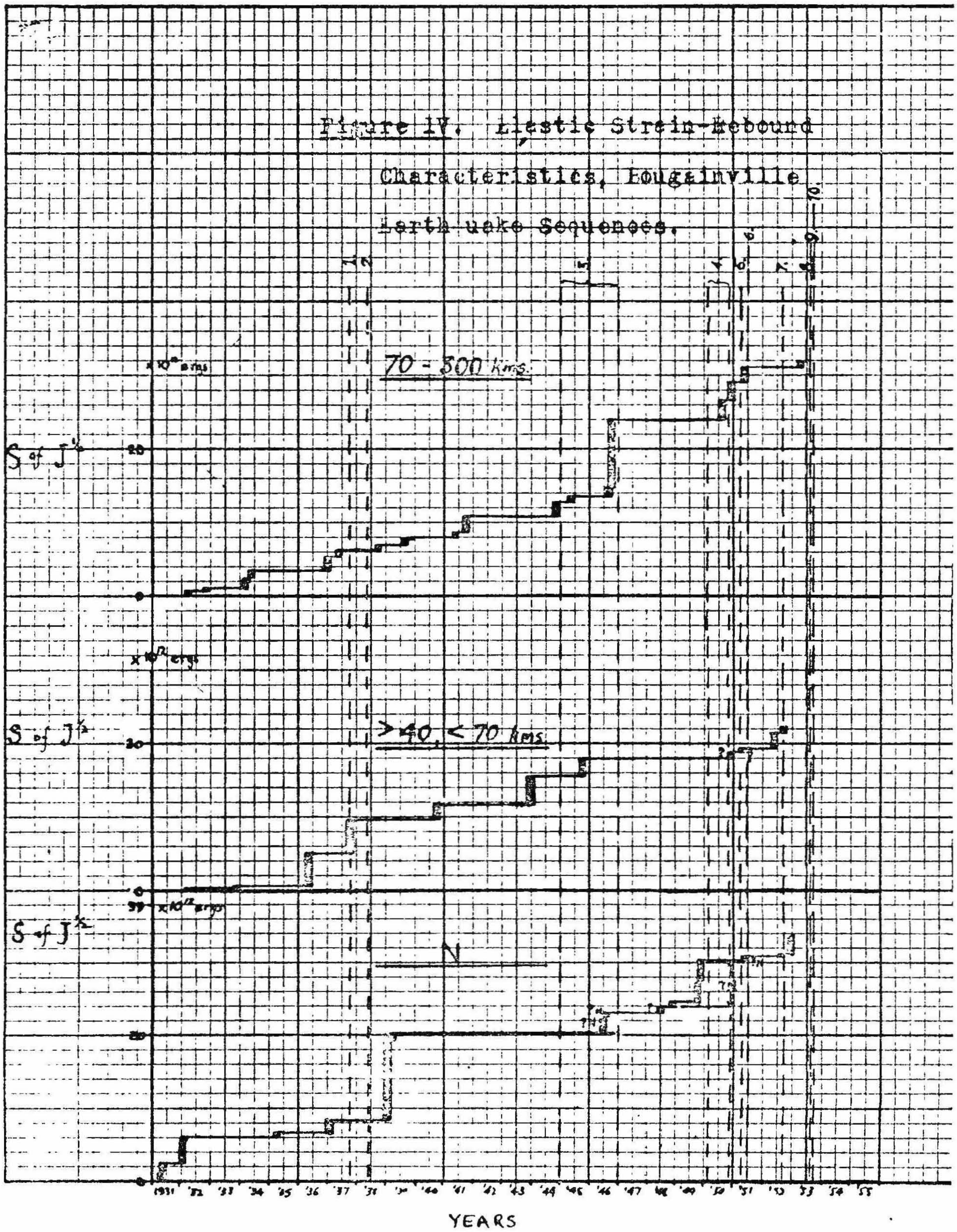

Figure IV. Elastic Strain-Rebound Characteristics, Bougainville Earthquake Sequences.

FIGURE V: Composite profile showing earthquake foci, Bougainville, 1931-1955.