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DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1977/31

THE EAST SOLOMON SEA EARTHQUAKE OF 20 JULY 1975; AND NOTES ON SEISMIC RISK IN BOUGAINVILLE

by

I.B. Everingham, B.A. Gaull and V.F. Dent.*

*Geological Survey of PNG

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SUMMARY

A major earthquake with magnitude ML 7.2 happened at 14 37 40 UT on 20 July 1975 beneath the Solomon Sea close to the southwest coast of Bougainville Island. On the southwestern part of this island, earthquake intensities reached at least MM VIII, and a two-metre high tsunami occurred there. There were no fatalities, but the cost of repairing or replacing damaged property was estimated to be $A300 000.

Aftershock epicentres were in a roughly elliptical area of 12 500 km^2 off the southwestern coast of Bougainville. Focal depths were in the range 30-70 km. A fault-plane solution and the pattern of aftershocks indicate that the principal earthquake was associated with northeasterly underthrusting of the Solomon Sea crust beneath Bougainville.

Earthquake intensity data gathered since 1916, and the seismicity pattern, suggest that seismic risk is highest in the western part of Bougainville Island; minimum return periods for intensity MM VIII are 15 years in western Bougainville and 50 years in eastern Bougainville.

INTRODUCTION

At about forty minutes after midnight, local time, on 21 July 1975, a major earthquake occurred near Bougainville Island (Fig. 1). In the southwestern part of the island many villages, roads, bridges, and mission buildings were extensively damaged by the earthquake, and subsequently a tsunami caused a little more damage in coastal settlements. The cost of repairing or replacing damaged property damage was estimated to be $A300 000. Inhabitants of the area were highly alarmed by the earthquake and by several large aftershocks during the next 48 hours. Fortunately there were no fatalities.

The principal subject of this report is the macroseismic data for the earthquake. In addition, unpublished data relating to major earthquakes which affected Bougainville Island in 1923 and 1939 are reported, and are used in a discussion of local earthquake risk.

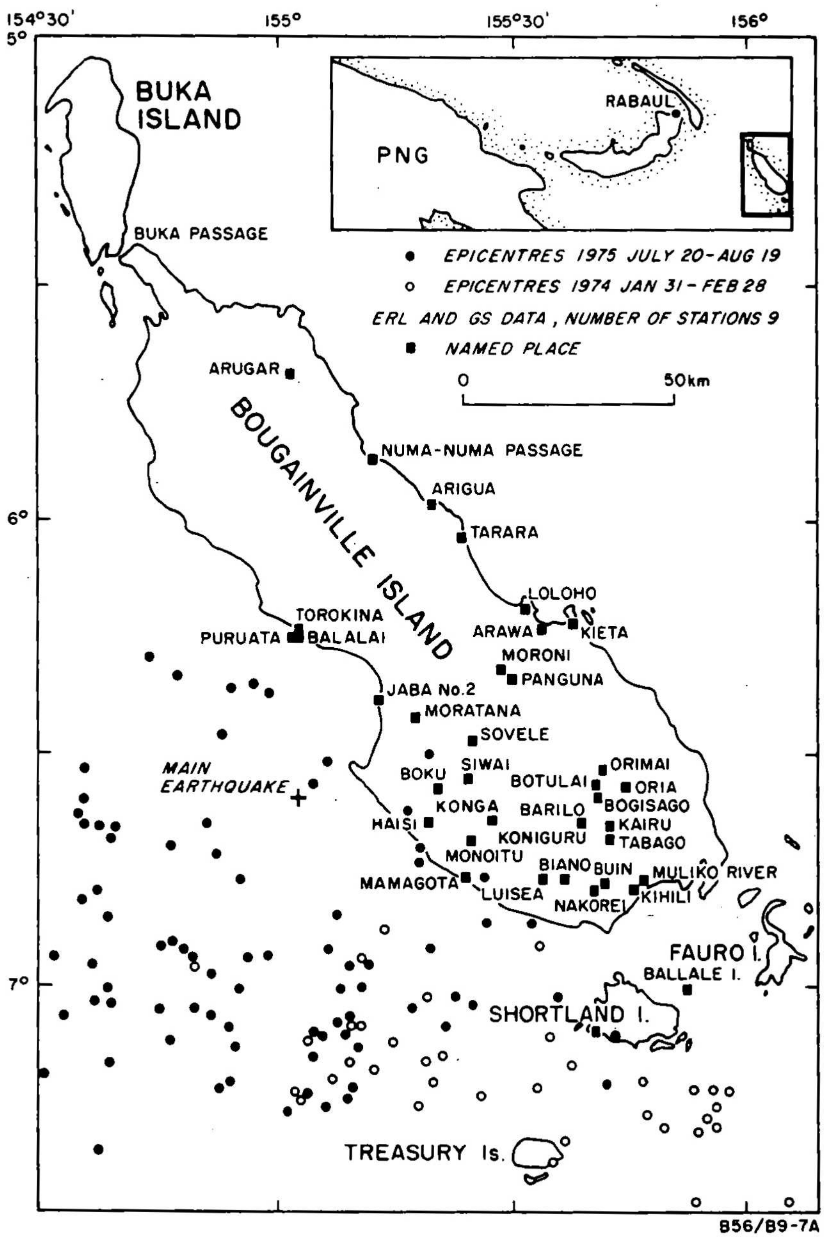


Fig. 1 Locality map and aftershock zone

Other unpublished reports on various aspects of the earthquake have been written on slope stabilities in the Bougainville Copper Ltd (BCL) mining area (Searle, Simon, Armstrong, & Lye, 1975); on damage to the Torokina Posts and Telegraph telecommunications station (Best, 1975); on damage to Public Works Department structures (George, 1975); and on damage to District Offices (Tanu, 1975).

THE EARTHQUAKE SEQUENCE

Details of the principal earthquake (143740 UT 20 July), given by the United States Geological Survey (USGS), are listed in Table 1. The local or 'Richter' magnitude (ML), determined at the Port Moresby Geophysical Observatory seismograph (PMG), was 7.2.

During the 24 hours following the earthquake, aftershock activity was intense and included four large aftershocks with magnitude ML 6.0 or greater. Subsequently, aftershock activity rapidly decreased. The aftershock sequence for 20 July-4 December is listed in Table 1. The decay of aftershock activity after the main shock is shown in Figure 2, where cumulative numbers of all aftershocks for which magnitudes (ML) could be scaled from Wood Anderson seismograms at Port Moresby are plotted. 41 aftershocks were recorded by the Wood Anderson seismographs within 10 days of the principal earthquake - 28 occurred within one day of the main shock, and 36 within four days. The decay in activity was rapid and roughly logarithmic with respect to time lapse.

In order to study the aftershock pattern, USGS epicentres determined for aftershocks within 10 days of the principal earthquake are plotted in Figure 3; and hypocentres, projected onto a vertical northeast-southwest profile are shown in Figure 4. To improve the resolution of focal depths, Figure 4 includes only shocks which were recorded at Panguna (PAA), very close to the aftershock zone, with a P-wave residual of $\pm$ 1.0s or less, and by 10 or more stations.

Plots of these aftershocks, which occur in, or very close to, the fault zone of the principal earthquake, suggest that faulting occurred in the depth range 30-70 km in a roughly elliptical zone, 6.25 - 7.25^{o}S, 154.4 - 156.0^{o}E, off the southwest coast of Bougainville. The area of the aftershock zone is about 1.25 x 10^4 km^2.

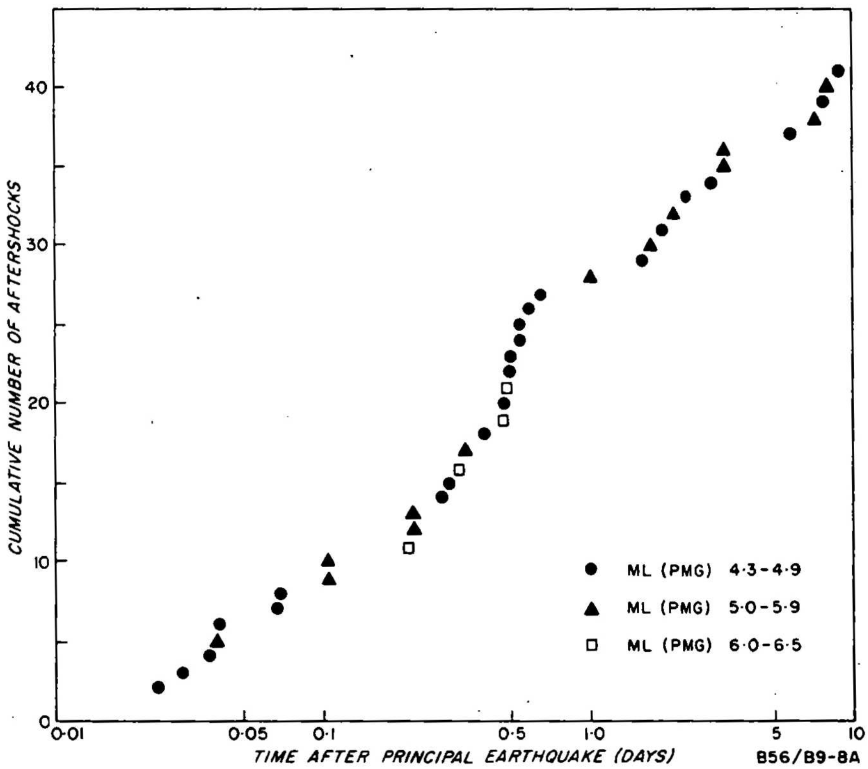


Fig. 2 Aftershocks/time plot

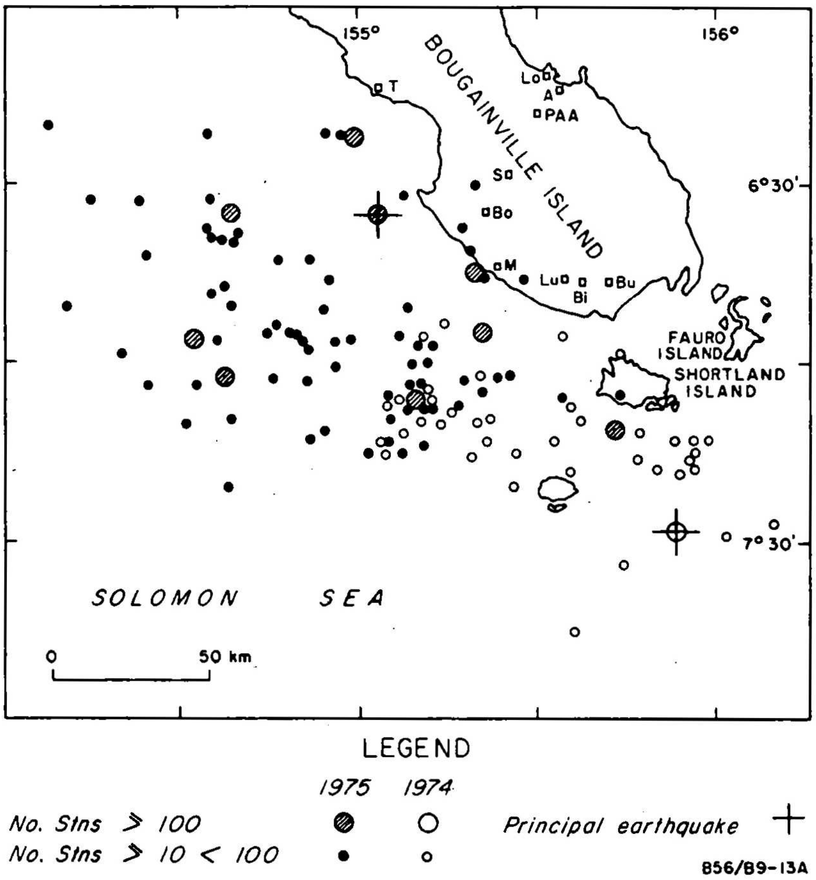
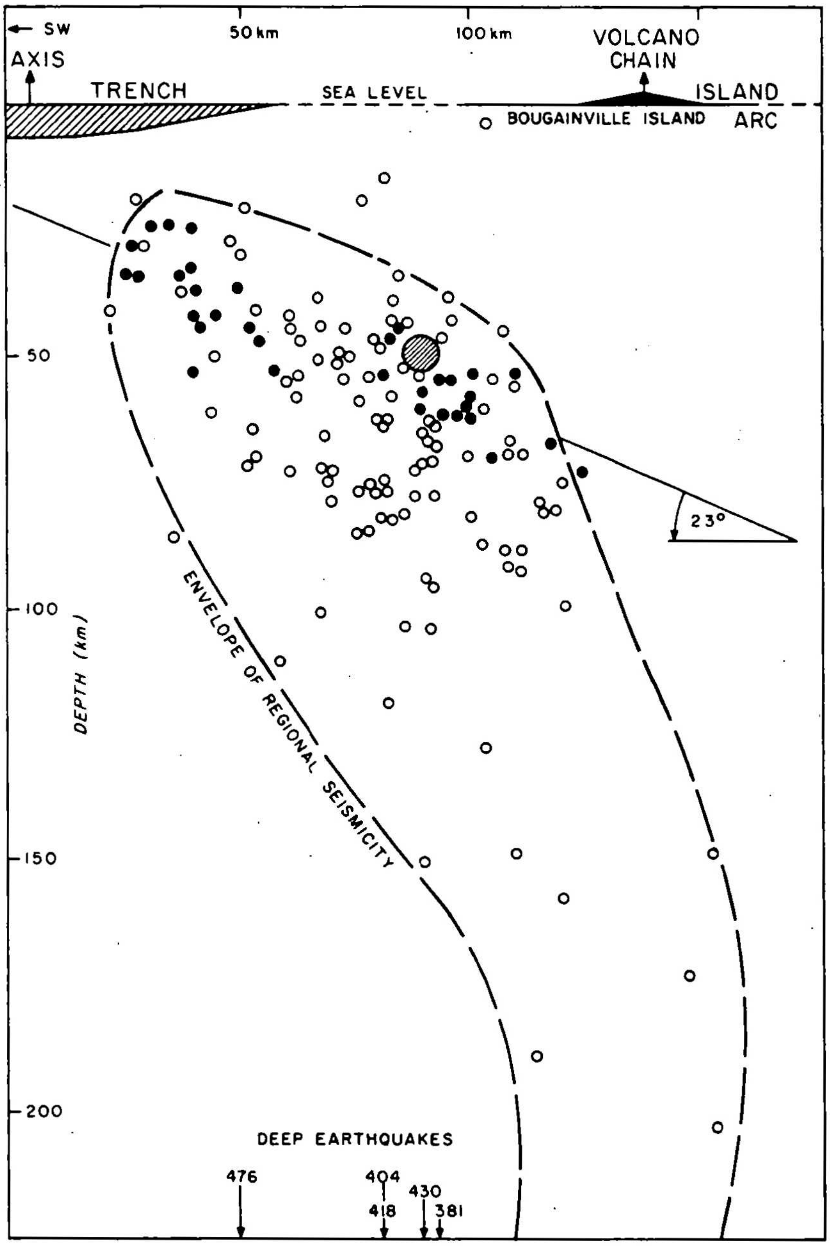


Fig.3 Aftershock epicentres determined within 10 days of the earthquakes of 20 July 1975 and 31 January 1974



LEGEND

- ● No. Stns > 10, 20 July–31 Oct 1975. USGS data recorded by PAA
- ○ No. Stns > 19, 1960 – 1975·5

B56/B9–14A

Fig. 4 Vertical profile of aftershock pattern. Hypocentres projected onto northeast-trending vertical plane across area of Figure 3

A fault-plane solution for the principal earthquake is shown in Figure 5. Details of the solution are:

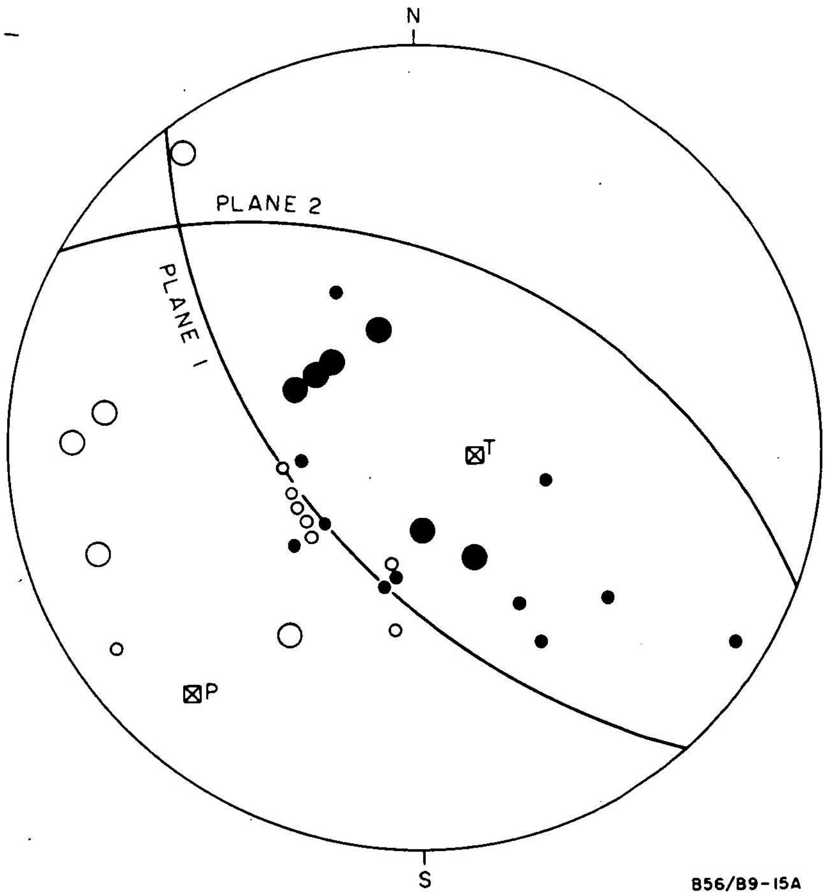
Pole of Nodal Plane 1		Pole of Nodal Plane 2		T Axis		P Axis	
Az°	Pl°	Az°	Pl°	Az°	Pl°	Az°	Pl°
051	034	206	053	093	074	221	010

Overthrusting is suggested by the fault-plane solution. In view of the aftershock pattern and the tectonic structure of the area in which the earthquake occurred, it can be assumed that nodal plane 2 is the fault plane - i.e., the Solomon Sea crust underthrust Bougainville along a fault dipping 37° and striking 116°; the direction of fault movement (given by the pole of nodal plane 1) was 051°. The fault-plane solution is similar to that determined by Everingham (1975) for an earthquake of similar magnitude which occurred on 14 July 1971 in the same northwest-trending zone of seismicity.

The aftershock pattern in Figure 4 suggests that fracturing may not have been in a single fault zone dipping at about 23° across the upper part of the subduction zone, but could have occurred in two more steeply dipping, en-echelon zones in the east and southwest areas of the overall aftershock zone. However, two aftershock zones do not show up clearly in Figure 3, possibly because aftershock parameters are relatively less accurate than in Figure 4, and in plan the two zones overlap.

A further confirmation of dual fault planes is provided by the agreement between the dip (37°) found in the fault-plane solution for the principal earthquake, and the dip of the northeastern fault zone - suggested in Figure 4 - in which the principal earthquake apparently occurred.

A notable feature of the 1975 earthquake was that it followed shortly after two major earthquakes (31 January and 1 February 1974) with epicentres about 30 km apart less than 120 km southeast of the 1975 epicentre. The merging of the aftershock zones of the 1974 and 1975 earthquakes (Figs. 1 and 3) indicates that the earthquake faulting in 1975 was probably a northwesterly extension of the earlier faulting. Between this region of faulting associated with major earthquakes, and a



●	*Long period*	*Compression*	○	*Long period*	*Dilatation*
•	*Short period*		o	*Short period*	
T	*Tensional stress axis*		P	*Compressional stress axis*	

Fig. 5 Fault-plane solution
First motions on lower hemisphere
(Wulf stereographic projection)

region farther northwest beneath the north Solomon Sea where faulting took place with major earthquakes on 14 and 26 July 1971 (Everingham, 1975) - is a relatively seismic region where no faulting has occurred (Fig. 6). Studies of aseismic zones in active belts of earthquakes (e.g., Mogi, 1968; Ando, 1975; Kelleher & Savino, 1975;) show that the risk of an earthquake is exceptionally high in such zones; the aseismic area west of Bougainville, centres on about 6°S, 154°E, must therefore be considered to be a likely place for a major earthquake in the future.

ISOSEISMAL MAP

Two hundred and ten intensity questionnaires were issued; about one hundred were answered, and these were used to construct a map of intensities (Fig. 7). Observations made during a field inspection of southern Bougainville (discussed later) are not plotted in order to keep the intensity assessments uniform. The chart shown in Appendix 1 was designed to assess uniformly intensity on the Modified Mercalli (MM) scale using the more common evidence available in Papua New Guinea, and a general idea of the effects of the earthquake at different intensity levels may be gathered from this chart.

Because the earthquake happened at night when most people were asleep, intensities of less than MM III were not reported and the 'waking' effect of the earthquake was useful in estimating intensities of MM IV and V.

The earthquake was felt clearly (MM IV or greater) as far away as Rabaul and Losuia, about 500 km from the epicentre. All Bougainville Island was shaken with intensities of MM V or more. However, significant damage was restricted to the southwestern part of the island, where intensities were MM VII or more, and in the Panguna mining area (see Fig. 1), where in places intensities were in the range MM VI and MM VII. High intensities also occurred in the northernmost Solomon Islands (e.g., Shortland Island), which were close to the epicentre.

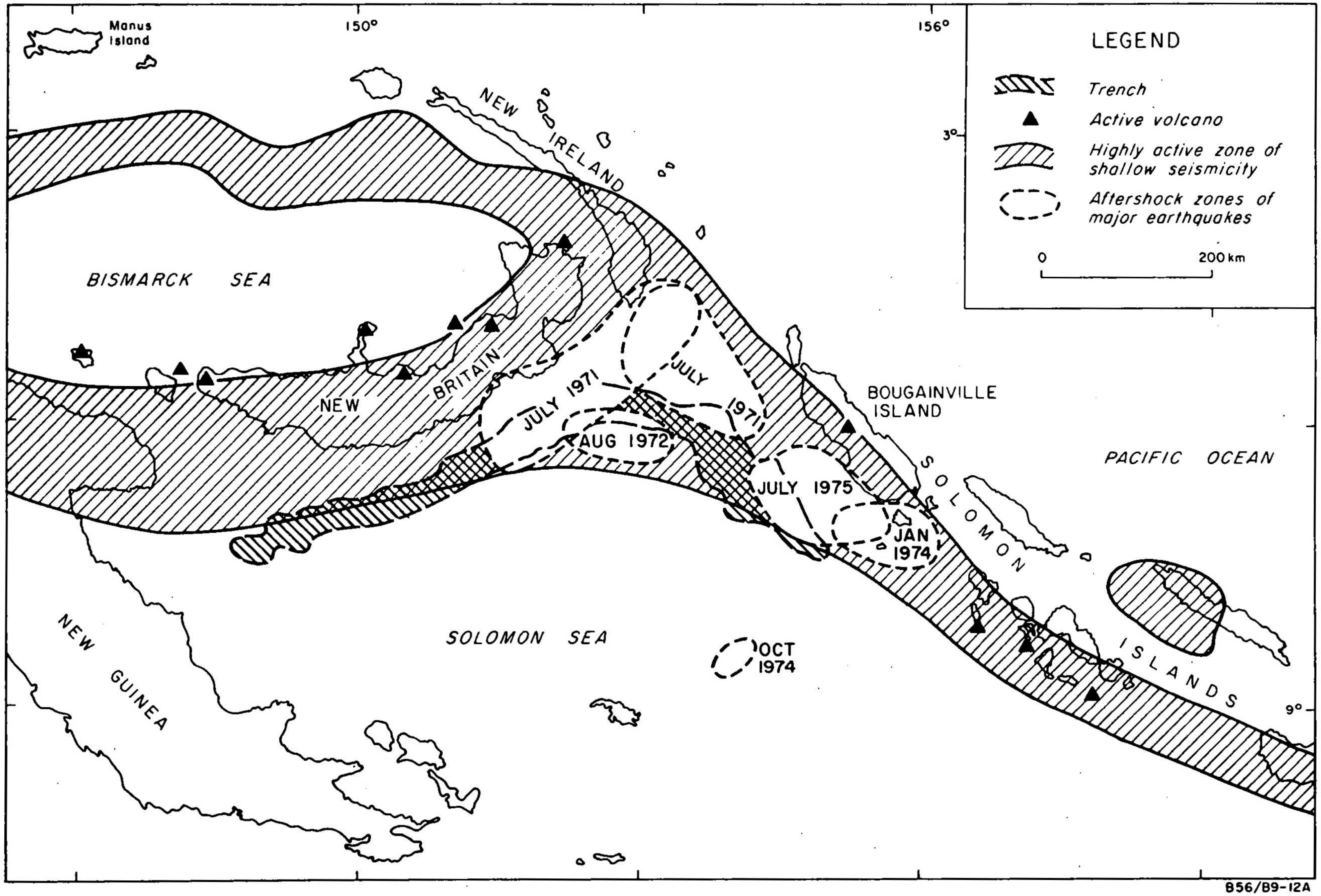


Fig. 6 Tectonic sketch map

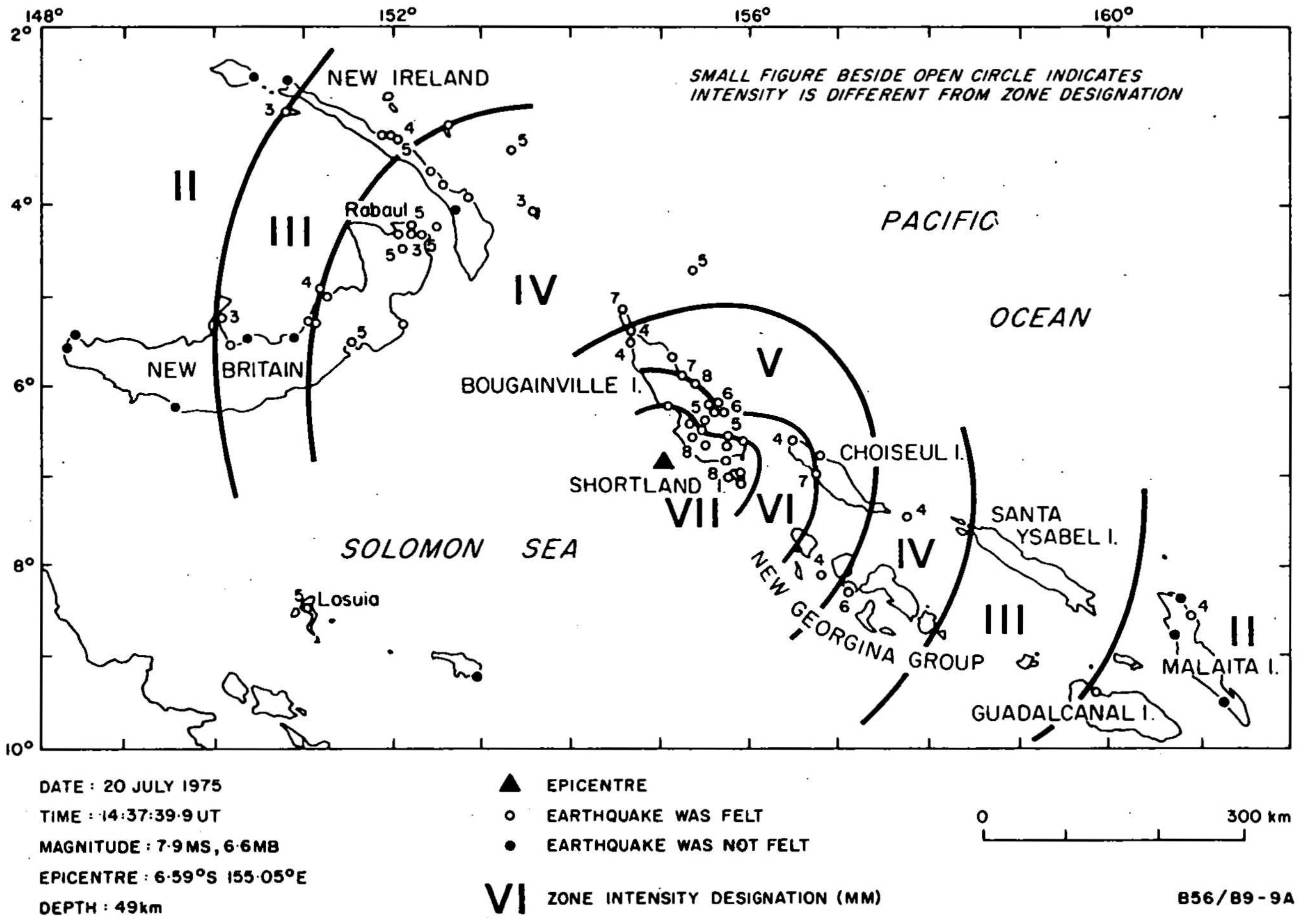


Fig. 7 Isoseismal map

Generally, in the area with intensities MM VII or more, landslides were common, bridges were damaged, roads cracked, and people had difficulty standing. Unreinforced concrete masonry structures, weaker village homes, and cylindrical corrugated iron water tanks were badly damaged. Structures not fastened securely to their stumps were shaken off them; wharves, and particularly their approaches, were damaged. Some areas along the coastlines subsided.

In the area between the MM VI and MM VII isoseismals, damage was slight and included breakage of articles shaken from shelves, minor subsidences, landslides, and road damage. The MM VI isoseismal averaged at about 150 km from the epicentre. Beyond this distance damage was negligible.

During the 24 hours after the main earthquake, the four largest aftershocks (ML 6.0-6.5) were felt with moderate intensity (MM V-VI) in the southwestern part of Bougainville Island. Although aftershocks caused considerable alarm, only a small amount of extra damage resulted from them. Isoseismal maps for the aftershocks were not drawn because of the difficulty in differentiating between aftershock and main shock damage.

FIELD OBSERVATIONS

Localities mentioned below are shown in Figure 1 or their positions are described with reference to a locality shown in Figure 1.

Boku area

The District Commissioner estimated that 500 houses were rendered uninhabitable, and the cost for reconstruction would be K23 000. Ten percent of water tanks were irreparable.

Substantial damage was incurred at Boku airstrip, where the concrete-based fibro-timber Welfare building was rendered unserviceable, and three structures which were built mostly from local bush materials collapsed completely (Fig. 8). None of these structures was well designed.

The patrol post and adjoining houses at Boku were not damaged, but the buildings are dangerously close to a 10-m unconsolidated cliff face which slumped badly during the earthquake; two village-styled houses about 500 m farther along the cliff slumped down the cliff face.

A BCL hydrologist reported seeing cracks as wide as 30 cm in the flat ground between the Moratana mission and the river nearby; the mission building, however, which is well constructed, was not damaged. The Officer-in-Charge of the Boku patrol post also reported cracks of 30 cm (with lengths and depths up to 3 m and 2 m respectively) in sections of the road made of coral. He also stated that some of the bridges in the area had moved about 15 cm with respect to the road. Most of this damage had been repaired before the arrival of one of the authors (BAG) on 23 July.

AtbJaba No. 2, the concrete stumps of one small fibro house failed because they had been supported only by topsoil. A nearby house with steel-piping stumps set in concrete footings did not suffer. The remaining 18 houses in the village (made mostly from local materials) were undamaged.

At Sovele mission, two timber houses fell off their concrete supports. In three other houses, the walls became detached from their concrete bases. The damage at Sovele mission was attributed to poor concrete: very little sand was available at the time the mission was built and the concrete was made up mainly from pebbles from a nearby creek. Only a few tanks were damaged, possibly because most of them were nearly empty.

About 3 km west of Sovele mission, two unreinforced concrete block walls of the new council building at Bana collapsed (Fig. 9).

In the Haisi Mission area, about one quarter of the village houses were damaged extensively, and the tank and concrete stand at the Mission were wrecked. One village elder reported that it was the worst earthquake he could remember since he was a small boy (about 35 years ago); this was probably the earthquake of 30 January 1939 (discussed later).

Buin area

A Monoitu mission priest reported that the large mission bell, which is mounted in a wood-framed tower, rang loudly at the time of the earthquake. Two timber-fibro mission houses not tied to their 50 cm stumps were thrown off them and were badly damaged.

Slumping occurred at a gorge 2 km north of Konga, and two village houses were lost over the edge. At Tutaugu village, 5 km farther north, 8 out of 17 huts collapsed. The relatively high damage in this area may be attributed to topographical effects: damage to village houses generally increased from a ratio of about one-in-four wrecked on the coastal plain to about one-in-two in the foothills area north of Konga, even though Konga was slightly farther from the epicentre. The estimated intensities on the plain and on the foothills were MM VII and MM VIII respectively.

About half of the houses at Luisea village were damaged: nine collapsed completely and five others fell off their stumps. At nearby Biano only minor damage was observed, but half the water tanks were unserviceable. At Nakorei, only two village houses out of 14 fell off their stumps.

Damage at Buin was minor and included a collapsed unreinforced brick wall, a few split water tanks, and a collapsed concrete table at the local food market.

Twenty kilometres north of Buin on the Buin-Koniguru road, slumping and cracking of the ground was prominent, especially on the ridges (Fig. 10). The estimated intensities for Buin and Koniguru were about MM VI and MM VIII respectively. This difference is again attributed to the geological/topographical amplification of ground motion on ridges.

Kieta

The earthfill approach road, 10 m wide, to the Government wharf subsided 15 cm.

In the two-storey telephone exchange, gaps up to 1 cm wide developed because the mortar between the concrete-block walls and the concrete girders supporting the upper floor was damaged.

Arawa

Damage to town council property included hairline cracking in plaster, a broken large plate-glass window in the new Arawa Town Council building, four burst water pipes, and one broken water pump. Water splashed out of the main Arawa reservoir through vent holes 6 cm above the level of the water.

About one-tenth of the fibro-cement ceiling panels (50 cm x 50 cm x 1 cm) in the supermarket fell down, and those remaining were left sagging. About 10 panels felllfrom some ceiling areas leaving large holes. The ceiling was suspended by metal straps. The manager stated that typically the front rows of items such as glasses and thermos flasks were thrown from the shelves, and hanging pictures fell; estimated stock loss was K13 000.

A builder reported sighting waves in freshly laid concrete during the large aftershock at 1240 local time on 21 July. He estimated that their wavelength was about 5-6 m and amplitude 2-3 cm, and that waves could be seen for a few seconds. Such waves were not observed in adjacent set concrete.

<u>Panguna</u>

Earthquake intensities at the Panguna mining area ranged from MM V-VII, with the result that extensive tension cracking of the ground, minor landslides, and damage to housing occurred. Although houses were not badly damaged many had to be abandoned or repositioned because the potential danger from landsliding became apparent after the earthquake. The damage included broken and cracked drains and water pipes, chipped and cracked foundation piles, warped fencing, and warped house frames caused by foundation movements. One steel storage tank used in the reticulated water supply burst, but generally water supplies were not seriously interrupted.

BCL reported the following earthquake effects in the Panguna mine and township area.

> 'In the Panguna area most of the damage again occurred to slopes covered with weak superficial material. The housing areas of Karoona Creek, Married Hill and Mud Valley suffered severe shaking with tension cracking and minor failures. These sites have probably suffered some of the most severe shaking within the mine area and although the failures and tension crakcs were of relatively small volume, the proximity of several houses to these problem areas made the personal safety of occupants a very important consideration. Camp 10 and Moroni also suffered tension cracking and minor failures. Moroni village suffered a lot of reactivation of an old slide area which put three

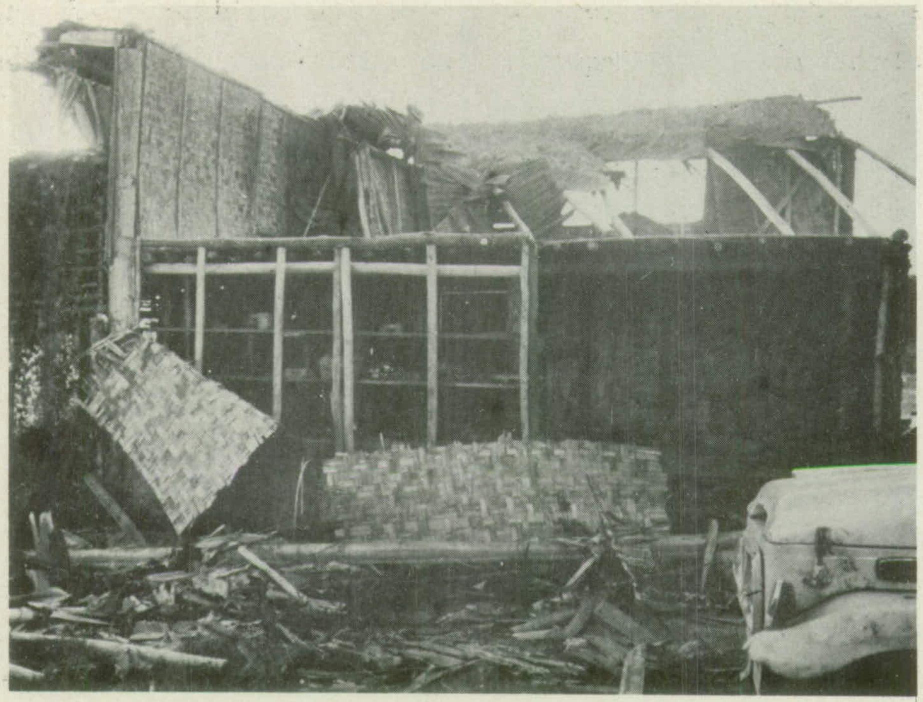


Figure 8. Collapsed local material buildings near Boku airstrip.

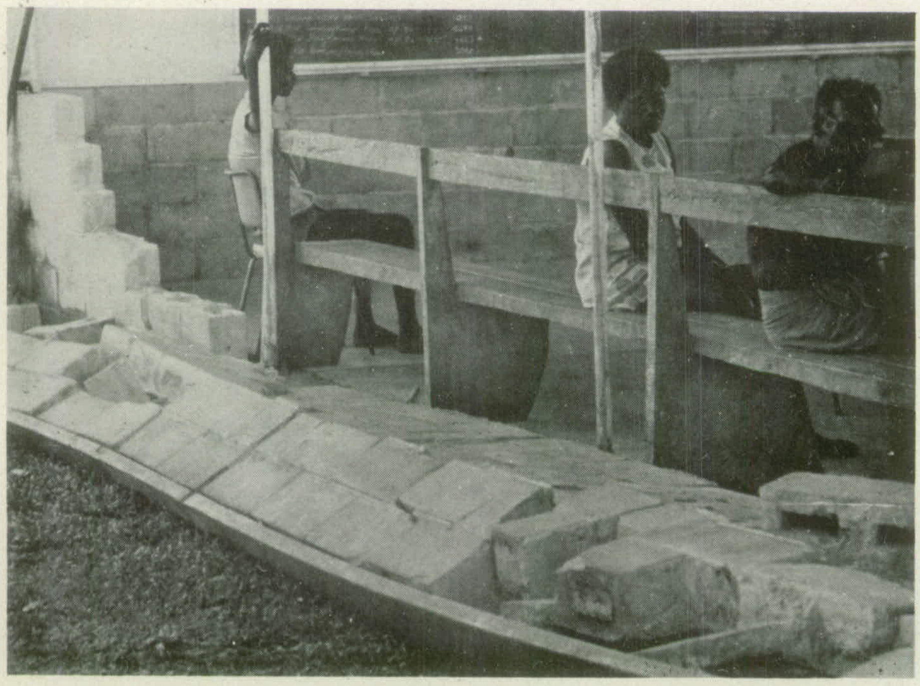


Figure 9. Collapsed concrete besser-block wall, council building, Bana. Note that ties were made to the vertical pipe columns.

houses in danger and Camp 10 dormitory buildings suffered disturbances of the ground supports' such as in Fig. 11.

'Negligible movement of tension cracks on rock was recorded within the mine area; however tension cracks on the Kurua Road and around power pole 6C19 together with settlement of the north dump showed increased rates of movement during the event.

'In Kawerong town site very few failures and relatively minor tension cracking was observed. Nearly all the areas affected were in side-cast material. The houses in the upper part of the valley seemed more vulnerable in this respect. At Camp 1 water tanks a large failure occurred as a result of water leakage from a fractured pipe flowing into tension cracks. Side-cast from the current box-cut construction developed tension cracks and the helipad also suffered in a similar manner.

'In the Concentrator area the slopes appear to have been little affected by seismic activity. The tension cracks, previously recorded near power pole 14 on the north perimeter cut, showed an increase in rate of movement and it is possible that a base monitoring station near the Mill Water Cut has moved.'

A detailed map of the Panguna area showing localities mentioned above is given in the BCL report; most of them lie within a circle with radius about 2 km. The report contains a lot of detailed information on damage at numerous sites around Panguna and at other sites where parts of the BCL mining complex are based, and provides invaluable engineering-geological data.

The tsunami

South coast. With an amplitude up to 2 m and period in the range 5 to 15 minutes, the sea surged inland and receded several times along about 100 km of the southwestern and southern coasts of Bougainville. A minor tsunami was also observed on the Shortland and Fauro Islands. The tsunami occurred during the period of high tide (1.2 m), so that its effects were amplified.

Figure 10. Cracking typical of built up road edges, Buin-Koniguru road.

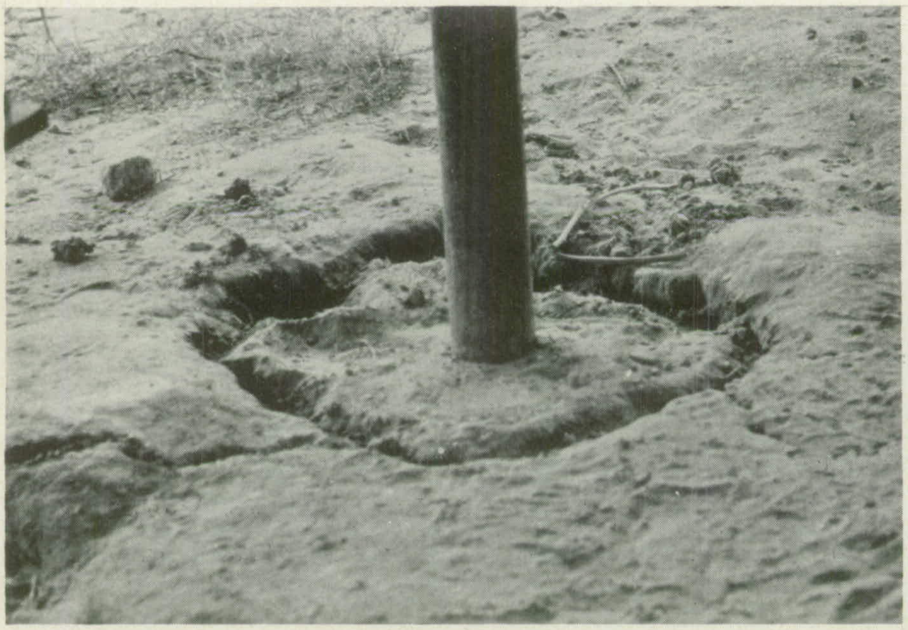


Figure 11. Disturbed foundation pile of residence in Panguna indicates considerable movement during earthquake.

Villagers at Mamagota village, on the southwestern coast, reported that the waves entered the bush and caused the river to flood and subsequently change its course at the mouth. This village had recently been positioned about 1 km inland because of recent tsunamis. The earthquake collapsed 3 of the 12 houses in the village. The wave did not reach the village where it now stands, but probably helped to destroy one solitary village-styled abode at the beach. Evidence in the form of swept vines and grass and leaf strandlines indicated that water had risen at least 1 m above high-water level at the time of the tsunami. Coarse beach sand particles trapped in the elevated end of a log also provided evidence of a wave greater than 1 m above high-water level.

Soon after the earthquake, several waves with 10-cm amplitude and 15-minute period were recorded on the tide gauge at the Loloho wharf on the eastern Bougainville coast. A very similar wave train was recorded after the earthquake on 1 February, 1974. The tsunami waves must have been diffracted around the southeast coast of Bougainville after both earthquakes.

<u>Torokina</u> The sea wave was observed by the residents of Torokina village, which is on the shore about 0.5 m above high-water level. People in the area expected a sea wave after the strong earthquake (MM VII) because they had also experienced waves in July 1971 and in February 1974. Having been awakened by the earthquake, the people stood outside their village and awaited the wave. It was a moonlit night and visibility was good.

About 15 minutes after the earthquake the wave could be seen approaching. It was described as a long low north-south hump. At this stage most of the villagers departed into the bush.

One young man climbed a coconut palm, and the wave passed under him. He said that the wave rose fairly quietly and that he could run faster than the speed at which it crossed the beach. On the other hand, other villagers said that the wave crossed the beach like a breaker, and that it moved faster than they could run. In general, it was agreed that had they been caught in the wave they would have probably drowned. About half of the village chickens and several dogs dissappeared as a result of the tsunami.

The villager who had climbed the palm remained there for about 10 minutes. He reported that the first wave came through at a height of about 1 m above ground level. The water-level then seemed to remain high until a second larger wave arrived 5 minutes after the first. About 5 minutes after this wave, he climbed down from the palm tree and ran through ankle deep water to the safety of slightly higher ground. A third and smaller wave followed shortly after.

Some of the people then returned to the village. A fourth wave came in at about ankle height, but this did not worry the people who had returned.

A small light kitchen was washed behind the village into a swamp and smashed. Two houses were taken off their stumps by the wave (apparently the second wave), and moved about 30 m inland (Fig. 12). Canoes on the beach were carried about 50 m to the rear of the village.

In the Department of Posts and Telegraphs (P & T) communications station, water marks were visible on walls at several places. Inside the main P & T building the marks formed by horizontally placed grass cuttings were fairly straight. On the outside of this building the top water mark at 1.14 m was choppy with a wave length of about 25 mm; straight water marks were left at various levels as the water receded (Fig. 13).

A pile of drums, some empty and others full, was moved completely from where it was stored. The farthest the drums travelled was about 60 m. Many were caught in the corner of a cyclone wire fence around the site; others drifted past the fence, which was flattened at the rear of the building; and missing drums were probably washed out to sea.

At Torokina a sandbar roughly 0.8 m high, and a creek running nearly parallel to the coastline, are between the mission and the sea. The wave moved in at right-angles to the coastline and a considerable quantity of water passed over the bar into the creek but did not reach the mission.

P & T station, Torokina

The communications station at Torokina consists of a 38-m tower for a dish aerial, two dish aerials on about 10 m towers, an electronics building adjoining the main tower, a power house, and a residence; all are about 1 m above high-tide level, close to the sea, on land which has been

Figure 12. Village house removed from stumps (in centre of picture) by tsunami, Torokina.

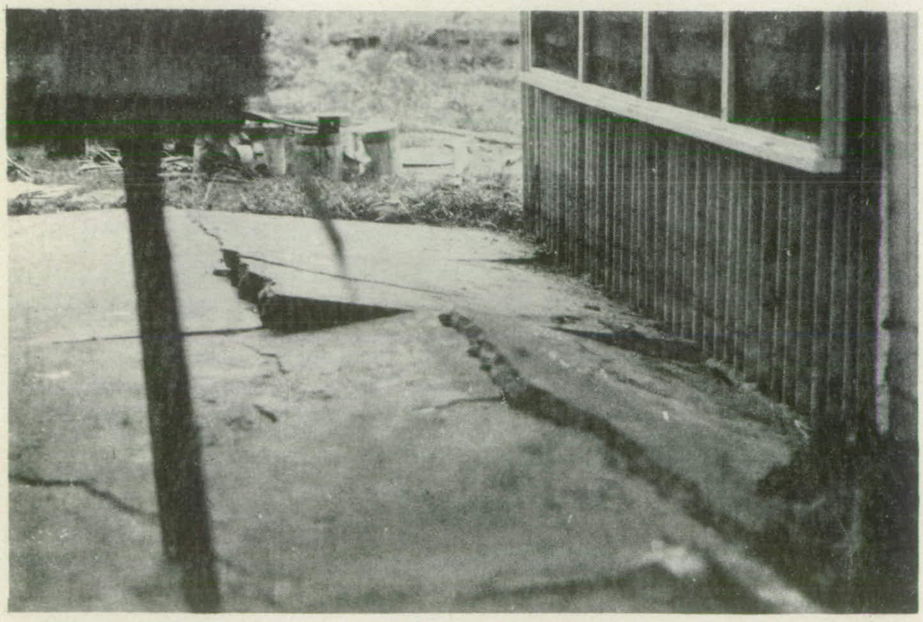


Figure 13. Subsidence of building containing heavy machinery, and tsunami strandlines on walls, P & T power house, Torokina.

built up naturally since World War II - i.e., the coast was inland from the station some 30 years ago. Some typical effects of the tsunami and earthquakes are shown in Figures 14 and 15.

Buildings subsided, probably during the main earthquake, before the tsunami. However, further subsidence occurred during strong aftershocks, notably those about 9.30 a.m. and 12.30 a.m. local time on 21 July. Engineering staff who had flown in to repair the station reported that during the second aftershock the tower base appeared to sway horizontally back and forth over an estimated range of 400 mm, and liquefaction of the ground was apparent. Liquefaction was also indicated by the movement of the wharf piles (driven down to a depth of about 14 m), which were tilted out towards the sea at an angle of about 10-15° from the vertical (Fig. 14); and by the fact that heavy objects tended to sink and light objects such as buried empty petrol drums rose out of the ground. Startling effect of the liquefaction associated with the largest aftershock was the emergence of old buried piles of a discarded World War II landing wharf (Fig. 15).

Best (1975) gave this account of the damage to the station.

'The scene on first arrival was most disheartening in that all the equipment had in fact been flooded to a depth of 4½ feet. At this stage, there was still approximately 18 ins of water in the building. A quick examination of the towers revealed that as far as was possible to tell they had not shifted and no structural damage to the tower was visible, although the ground around the tower appeared to have sunk from 6 to 9 ins ....

'At approximately 12.30 there was another severe earthquake and the personnel assembled on the base of the 125 ft tower. It was clear that during the quake the site became a suspended solution of sand and water and most heavy objects on the site sank even further, including the buildings. The buildings were now sunken to a depth of approximately 10 ins in the Equipment Room and up to 18 ins in the Diesel Shed. The battery installation appeared to be sound as it was still above the 4 ft tide level and the batteries were tested and appeared to be in reasonable recharged condition.

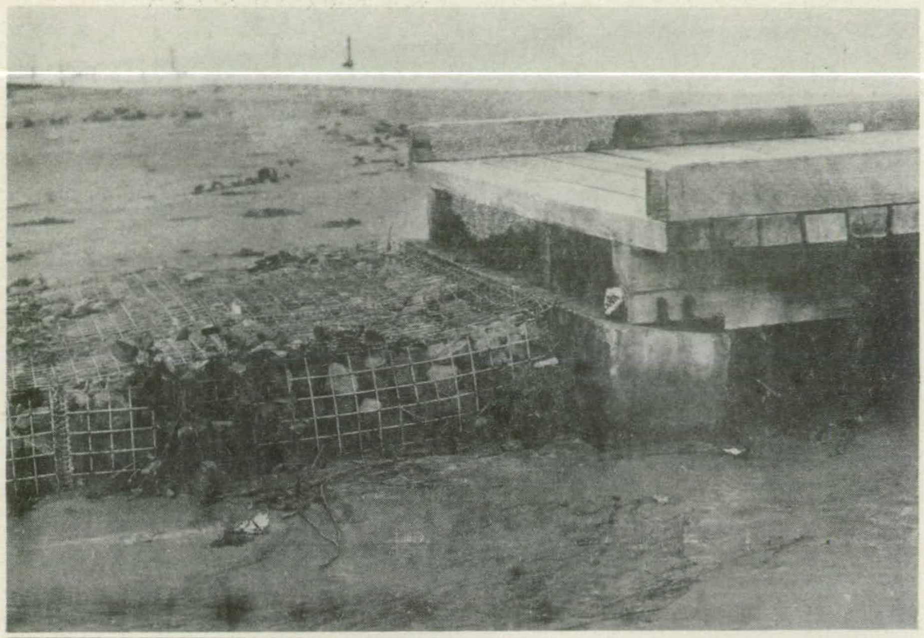


Figure 14. Wharf at Torokina. Eight piles similar to that in the foreground and about 14 m long were tilted seaward 15° from the vertical as a result of shaking and liquefaction.

Figure 15. Old wharf piles at Torokina extruded by the effects of liquefaction caused by aftershocks. The tops of the piles were formerly below ground level, as indicated by the grass and plants growing on them.

'Unfortunately the earthquake had meant that the water which was slowly draining from the building flowed back to a depth of 6 to 8 ins so further deepening of the trenches was necessary to reverse the flow again.........

'The building was scrutinized for damage and except for a broken door, 7 fibro panels broken, the disintegration of the cement surround and driveway between the buildings, the building was structurally sound.

'However, it appeared to have sunk at this stage by up to a foot in places and the Diesel Shed had sunk to approximately 18 ins. The water tank had been dislodged from its stand by a distance of 8 ft and the concrete stand itself had disappeared from view into the earth.

'The diesel exhausts had been exposed by the sinking ground to a height of 15 ins and the diesel fuel tank had sunk by up to 2 ft.

'The fence surrounding the site had been flattened in parts which tended to indicate that the tidal wave had gone straight into the front of the site. There may have been some funnelling effect through the two islands immediately across from the site which exaggerated the tidal wave at Torokina. Fuel drums were carried up to a distance of 100 yds from the site towards the village. A further indication that the wave came straight into the site from the beach.'

Shortland Islands

The Geology Division of the Ministry of Natural Resources, Solomon Islands, gave the following information on the earthquake's effects in islands immediately south of Bougainville Island.

'Very briefly, the most severe effects occurred in the Shortland Islands, where a concrete wharf collapsed, a similar one (at Ballale) was tilted, depressions up to a foot deep occurred in Balalai airstrip, a wall of a prefabricated house was cracked, weak water tanks were split, and some houses of bush materials were slightly damaged.

The earthquake was also strongly felt on Choiseul and at Gizo, but little or no damage was caused. Apparently no one in Honiara felt the shock.'

Estimated costs of repairing or replacing damaged property

The estimated cost of repairs to the Public Works Department's property was $73 000 (George, 1975). Details are given in Appendix 4.

BCL estimated that the costs of repairing the earthquake damage to their Panguna mine, township, access roads and other facilities totalled $100 000. Details are given in Appendix 5.

The P & T estimate of cost of repairs was $25 000 (Best, 1975). Adding the cost of reconstruction or repair of 500 village homes ($23 000), stores and equipment ruined in homes and privately owned shops (say $20 000), damage to mission buildings (conservatively estimated at $50 000) gives an approximate total cost of $300 000 for the earthquake damage.

THE MAJOR EARTHQUAKES OF 1923 AND 1939

Between 1900 and July 1975, the most noticeable earthquakes felt on Bougainville were in 1923 and 1939. The earthquake details (Everingham, 1974) are:

YEAR	DATE	ORIGIN TIME			LAT $^{\circ}$E	LONG $^{\circ}$E	DEPTH	MAG (MS)
1923	Nov 02	21	08	06	4.5	151.5	50	7.2
1923	Nov 04	00	04	30	5.0	152.0	shallow	7.2
1939	Jan 30	02	18	27	6.5	155.5	shallow	7.9

Brief reports of the felt effects of these earthquakes are given in Appendices 2 and 3, and intensities as reported on 'Earthquake Notes' and 'Earthquake Records' forms (routinely completed by government officials from 1916 to 1941) are given in Table 2 and 3. MM intensities in these Tables were estimated from the available information on the earthquake effects. Intensities of MM VIII or more were felt on Bougainville during all three events, and the effects were similar to those observed in July 1975. Although other earthquakes have been felt - e.g., 14 July 1971, MM VI in northern Bougainville - the 1923 and 1939 earthquakes appear to have been the most destructive since early in the 1900s; the 1939 one was remembered by older residents of the island.

The 1923 epicentres listed above must be incorrect, because more recent evidence (B. Gaull, pers. comm.) shows the MM VIII intensities could not possibly be experienced in Bougainville unless the epicentre was several degrees farther southeast. Also east New Britain would have been shaken severely if these major earthquakes had happened in the regions of their listed epicentres. Earthquake parameters redetermined by BMR, using Jefferies-Bullen travel times, were:-

(a) Nov 02, 21 07 56.4, 5.04°S 153.31°E
(b) Nov 04, 00 04 26.2, 4.40°S 152.99°E

These epicentres are still considered to be too far from Bougainville Island, and epicentres near 6°S, 155°E seem more likely.

EARTHQUAKE RISK

Bougainville Island lies immediately east of a zone of very intense, shallow seismicity extending around the northern Solomon Sea (Fig. 16). The seismic activity here is the highest in Papua New Guinea and about equal to the most active regions on Earth.

Brooks (1965, plates 8-10) results based on earthquake statistics show that the return periods for a given intensity in eastern New Britain (e.g., Rabaul) and southern Bougainville (including Panguna) are about equal; a similar result was calculated by BMR using different methods and additional, modern information (A. McEwin, pers. comm.). Hence in assessing risk in Bougainville it is interesting to examine the series of felt reports from Rabaul.

Because Rabaul has been the administrative centre for surrounding islands since about 1900, records of earthquakes have been maintained there more reliably than anywhere else in the area. Rabaul intensity reports are the most numerous for any part of Papua New Guinea. 'Earthquake Notes' and 'Earthquake Records' forms were routinely completed from 1916 to 1941 and the Port Moresby Geophysical Observatory has lists of all data since 1960. Intensity/frequency results are plotted in Figure 17 and the following

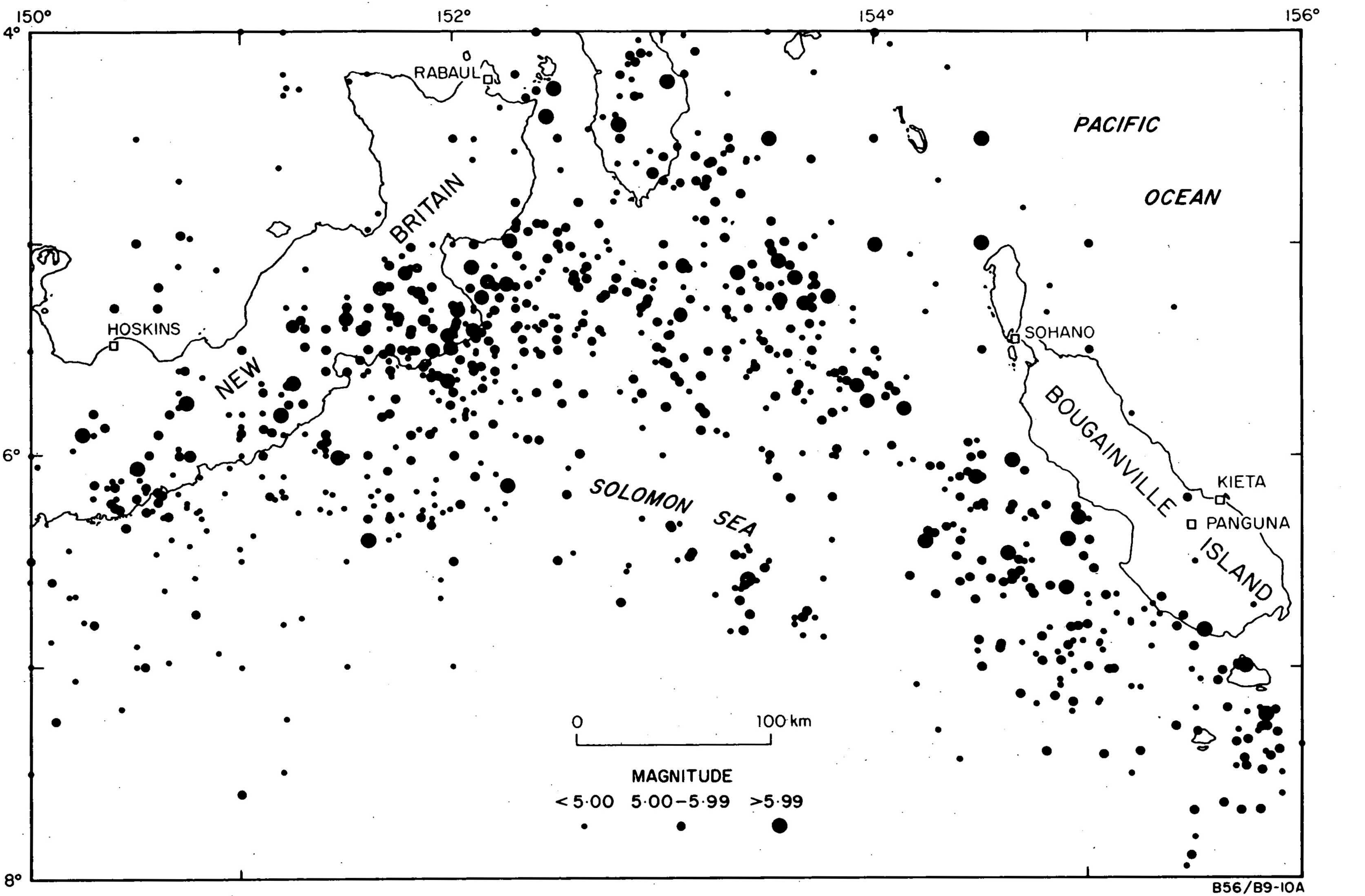


Fig. 16 North Solomon Sea shallow seismicity

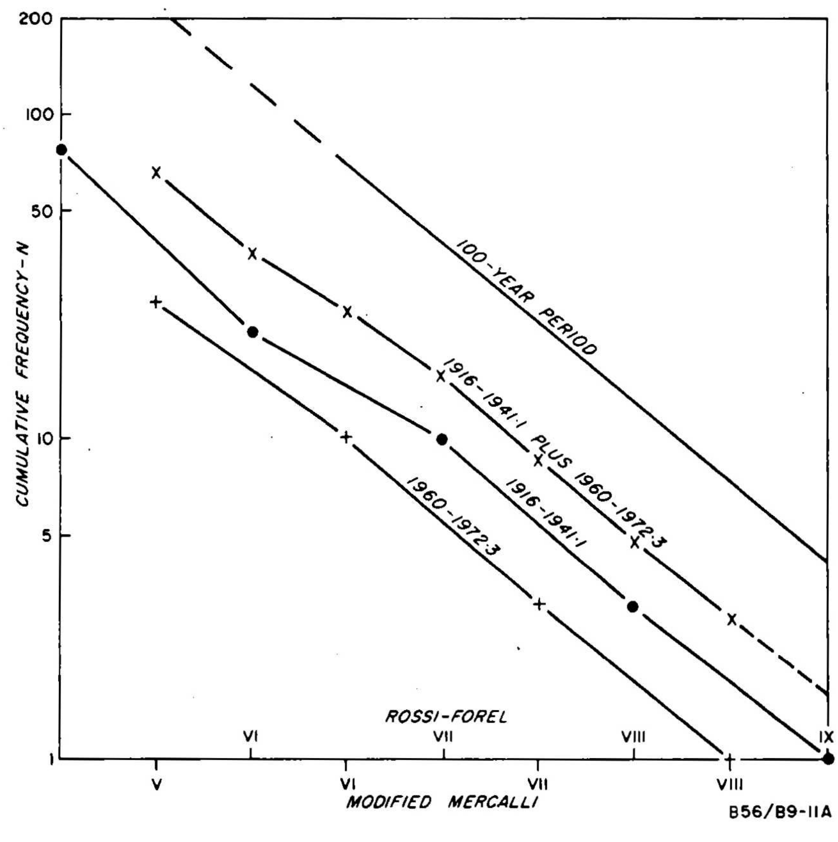


Fig.17 Rabaul intensity-return periods

formula was derived:-

$$\log N \text{ (100 yr)} = 4.85 - 0.50\, I \quad \text{..........(1)}$$

where N is the number of times an intensity MM I or greater was noted. The formula indicates a 14-year return period for intensity MM VIII and a 5-year return period for MM VII in Rabaul.

These return periods are slightly shorter than the values obtained by Brooks and McEwin.

The statistical methods for calculating return periods provide only relative risk in extensive regions and cannot take into account site and local or regional factors in detail. For instance differences in topography or geology can result in differences of 3 in the intensity at sites a very short distance apart. Because observers tend to concentrate on reporting the most spectacular effects, the Rabaul intensity results possibly tend to emphasise maximum intensities at sites badly effected by earthquakes. If this is so average intensities would be somewhat lower, and return periods for average sites longer, than given in formula 1.

Assuming that, as Brooks' and McEwin's results suggest, risk in the Panguna and Kieta region is much the same as it is around Rabaul, then formula 1 should also apply to Panguna and Kieta. However, historical evidence shows that for Kieta this is not so, because, although Kieta earthquake reports have also been kept since 1916 (with less reliability than at Rabaul), there is no record of an MM VIII intensity, and the return period for MM VI is about equal to Rabaul's MM VIII return period. However, MM VIII intensities in other parts of Bougainville have been reported on several occasions (see Tables 2 & 3), and high intensities probably have occurred on yet other occasions but have not been recorded because of the communication difficulties in Bougainville, particularly in the first half of this century.

Kieta appears to be on a favourable foundation, and during recent years intensities here, and at Arawa (in a similar setting), have been noticeably less than at Panguna.

However, intensity maps indicate that lack of strong intensities is also due in part to the fact that Kieta is far enough to the east of the fairly well defined northwest-trending zone of shallow seismicity (Fig. 16) to avoid the high degree of shaking reported from the more western areas of Bougainville, which are very close to this zone. This effect is clearly seen in the 20 July 1975 (Fig. 7) and the 14 July 1971 (Everingham, 1975) isoseismal maps for the earthquakes .

It can be concluded that throughout the island return periods are reduced considerably at sites on mountain and ridge tops and steeply sloping areas, and that at an average Bougainville site:
(a) return periods for the highly damaging intensity MM VIII are in the approximate range 15 - 50 years, and for intensity MM VII, about 5 - 15 years; (b) western areas are more risky, and the return period for MM VIII intensity is likely to be about 15 years; and (c) the return period for intensity MM VIII in easternmost areas is probably about 50 years.

Acceleration data are far less numerous than intensity data. Several accelerograms have been obtained from Panguna during the past few years (Denham, Small, & Everingham, 1973) but, because of the short period during which the accelerographs have operated, results cannot be used directly to obtain return periods for acceleration. However, B. Gaull (pers. comm.) has found a relation between maximum acceleration (A, in units of g, the acceleration due to gravity) and intensity (I):

$$\log A = I/3.1 - 3.3 \quad .... \quad (2)$$

This may be used to derive acceleration return periods from the intensity results (formula 1).

CONCLUSIONS

(a) On 20 July 1975 at 14 37 40 UT a major earthquake with Richter magnitude 7.2 occurred beneath the eastern Solomon Sea close to southwestern Bougainville.

(b) Plots of aftershocks suggested that faulting occurred at a mean depth of 50 km in a roughly elliptical zone - 6.25 - 7.25°S, 154.4 - 156.0°E - off the southwest coast of Bougainville.

(c) The earthquake caused considerable damage in southwestern Bougainville Island and Shortland Island, where intensities reached MM VII and VIII. The average radius of the MM VII isoseismal was roughly 90 km. The average radius of the MM VI isoseismal, outside which damage was negligible, was roughly 140 km.

(d) Most of the badly damaged structures were not designed to withstand earthquakes or were in poor condition. Village houses should be strengthened with timber or wire bracing, and retaining notches should be cut in the tops of supporting stumps. Likewise, larger buildings should be strongly braced, and concrete-block buildings should be avoided unless correctly reinforced.

(e) Landslides were prevalent where intensities were MM VII or more and also occurred to some extent in areas where intensities were MM VI-VII. Fortunately a long spell of dry weather undoubtedly reduced landsliding. The facts that many hilltop areas shake more strongly than average flat low-lying areas, and that many landslides start from hilltops, should be kept in mind when siting structures and villages. Sites with solid rock foundations in areas without risk from potential landslides should be sought.

(f) A minor tsunami with a maximum rise of about 2 m was generated. The sea wave or its strandline was observed along about 100 km of the southwestern part of Bougainville Island and on Shortland Island, and recorded on a tide-gauge at Arawa harbour, where the amplitude was only about 4 cm. The only place to suffer much damage from the tsunami was Torokina, where a P & T communication station was partially immersed. Because tsunamis in this area rarely rise above a height of 2 m (Everingham, 1977) a simple precaution against damage from them is to build structures at least 2 m above high-water level.

(g) The earthquake did not cause fatalities, but resulted in damage that will cost about $300 000 to repair.

(h) Return periods of intensity increase from west to east across Bougainville; minimum return periods for intensity MM VIII are 15 years and 50 years for average sites in western and eastern Bougainville respectively. Sites on mountain and ridge tops have a higher risk potential. Acceleration return periods may be derived from the intensity return periods by use of formulas 1 and 2.

ACKNOWLEDGEMENTS

The Directors of Bougainville Copper Ltd.; Posts and Telegraphs; the Geology Division of the Solomon Islands Ministry of Natural Resources; and Department of Public Works are thanked for their permission to include information from their unpublished reports and files. We also thank the various Bougainville District Offices; and the Director, Civil Defence and Emergencies, who readily assisted in every possible way.

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APPENDIX 1

EARTHQUAKES

TABLE FOR EVALUATION OF INTENSITY

EFFECT	M.M. INTENSITY					
	III	IV	V	VI	VII	VIII
GROUND MOVEMENTS	Faint Felt by half population.	Moderate Felt by most.	Strong Felt by all.	Very strong Slightly affects walking.	Difficult to stand.	People thrown down.
SEEN/HEARD (other sounds apart from rumbling)	Faint rattle of windows, house creaks. Hanging objects swing slightly.	Windows, crockery, etc., rattle, building creaks. Trees shake slightly. Slight sloshing of tank water.	Unstable objects move. Pictures swing. Tree movements obvious. Water sloshes in tanks.	Objects fall, furniture moves. Trees strongly shaken. Water sloshes out from tanks.	Ground waves. Water waves.	Odd trees fall.
AWAKENED	Few	Many	All except few heavy sleepers.	All	All	All
ALARMED	Nil	Very few alarmed.	Few alarmed.	Many alarmed, run out of doors.	All alarmed.	Some terrified.
DAMAGE	Nil	Nil	Weaker water tanks leak.	Few water tanks burst. Obvious cracks in weak masonry. A few weak village huts collapse.	Many burst tanks. Unreinforced brick walls collapse. Weaker village huts collapse. Minor damage to house stumps.	Timber framed huts and houses off stumps. Roughly half, village huts off stumps or thrown down.
SLUMPING and LANDSLIDES		Rare landslides.	Occasional landslides	Occasional landslides	A few landslides. Settlement and cracking of unconsolidated ground.	Extensive landslides. Bad slumping of built up areas. Reef settlement.

Port Moresby Geophysical Observatory,
Box 323, Post Office, Port Moresby,
Papua New Guinea.

Govt. Print.—4395/500.—2.73.

APPENDIX 2

REPORTS ON THE EARTHQUAKES OF 2 AND 4 NOVEMBER 1923

Internal Memorandum, Department of Agriculture, Rabaul, dated 21 December 1923

The report describing effects in Bougainville follows.

'I had left the native villages of Beito 3/11/23 in the Kieta District and was on my way to Tarara when the first shock occurred. Time by my watch 7.20 am, and the duration of same about 40 seconds. This shock was so heavy that it was impossible to stand. Both myself and natives reeled about and eventually sat down. Large branches of scrub timber falling around but none of us were hit. On going along road a little further I found a new native bridge (piles and logs) of about 50 feet long completely demolished. I was just off the sea coast but did not notice any difference in water. There were minor tremors the whole of the morning and another fairly severe one at about 2.30 pm, my time, but this was not severe enough to cause damage.

'The following morning 4/11/23 I proceeded to Arugar and arrived there about 10 am and was sitting on the verandah of bungalow when just about 11 am local time, a very severe shock occurred, duration 30 seconds. The bungalow which had been badly shaken, started to collapse, the kitchen went over to an angle of about 45 degrees and connecting verandah gave way, one set of steps fell down and a good many of the piles that carry the main building were shifted off their blocks. The water in the Numa-Numa passage seemed to boil up for a few seconds but did not notice any difference in the level of same. There was another slight shock in afternoon but this did no damage.

'On Monday 5/11/23 I proceed to Numa-Numa and during the afternoon felt a slight shock about 3 pm but nothing to speak of, after that the shocks finished on the coast in this vicinity.
'The direction of shocks all seemed to be travelling northeast to southwest.'

Department of Agriculture, Rabaul, report dated 6 November

The report describing effects in Rabaul follows.

'There were two main shocks - first at 7.18 on 3rd and other at 10.20 on 4th. Intensity estimated at 6 (Rossi-Forel).

'A preliminary rumbling was heard by some and reported. Direction of first shock east to west, and of second south-east to north-west, which was judged by the spilling of water from rain-water tanks (400 gal square "ships" tanks on concrete bases) which were filled by rain on 2nd and 3rd (88 and 70 points respectively).

'The motion of the tremors was a rolling or swaying one which gradually increased and decreased. Minor tremors which were not noticeable when walking out of doors but which were apparent to persons sitting or lying down and which caused windows and doors, glasses, etc., to rattle, and amounting every one or two hours to an intensity of 2 or 3 were practically continuous.

'Probably a seismograph would have shown continuous slight movement for 24 to 48 hours.

'As many as nine noticeable tremors were counted at Namanula, a ridge about 300 feet high adjoining the Mother Mountain, during the 3rd, but count was lost at night. There was general alarm, but no actual damage was reported in the main shocks, though heavy furniture (not beds) was moved as much as six inches from the wall, tanks spilled water, houses (wooden) were moved one inch or so on their concrete piles, many ladies stated they felt sea-sick.

'After the first shock the water in Blanche Bay and Simpson Harbour (Rabaul), which was at about high tide, receded rapidly to about low water mark, returning within about 15 minutes; repeating the process within half an hour.

'After the second shock on Sunday the 4th, no report of any disturbance of the water of the bay at Rabaul was recorded, but a somewhat similar disturbance is reported on the North Coast of New Britain about 18 miles from Rabaul, by an officer of this Department who happened to be there.'

Kieta 'Earthquake Notes'

'Earthquake Notes' forms were routinely completed for each felt earthquake. Remarks follow.

'Practically one long shock but very pronounced in the middle.

'Bungalow swaying, also coconut palms swaying violently. This shock in the opinion of old residents of this district is the worst experienced for many years. Kieta itself appears to have been in the middle and escaped the worst shocks. Reports from Buka Passage and Faisi indicate greater intensity. At the Passage, tanks were thrown from stands and at Faisi the mission church was badly damaged.'

APPENDIX 3

KIETA DISTRICT OFFICE REPORTS ON THE EARTHQUAKE OF 30 JANUARY 1939

From a report dated 10 February

Kieta. On Monday 30 January, seven shocks were recorded. The first, and most severe, was at 12.20 p.m.; it had an intensity of six, direction northwest-southeast, and duration of 45 seconds. This shock was noted on the *Malaita*, at sea off Arigua, when passengers and crew thought that the vessel had touched ground. The remaining shocks lasted two to three seconds, and had intensities of three to four and direction invariably northwest to southeast.

Damage was slight: the tap of a water tank was wrenched loose; crockery fell from shelves; and a few bottles were broken in Burns Philp's store as a result of shocks at 12.20 and 3.14 p.m.

Tremors at the rate of one or two a day - intensity four to five, duration several seconds, direction northwest to southeast - were still evident when the report was being written.

Buin. A Mr Bilston reported that he was working on the erection of a new bridge across the Muliko River on 30 January, when, at about 12.20 p.m., without warning, the ground shook violently and the staging for the new bridge collapsed. Two other shocks followed within a few minutes, the earth movement making it practically impossible to stand up. Several trees fell and the old bridge was completely broken. Tremors of varying intensity continued at intervals of five to ten minutes all that day and night. On the following day, the tremors became less frequent - at half-hourly intervals -and were at about hourly intervals on 3 February. The direction of the shock was north to south and the severest shocks appear to have been felt along a line north-northwest of Kihili Methodist Mission.

Casualties. At Barilo, two women were killed by falling ground, and one woman by a falling tree; another woman was injured as a result of being partly buried in falling ground. Falling trees resulted in the death of a youth at Tualagai and another youth at Lukararu, and one woman of Kabaku died as the result, it was thought, of shock. Other natives were reported to have been injured, though probably not seriously.

Damage to Property. The missionary house at Kihili leaned over to a dangerous angle and had to be abandoned. A number of bridges on the property were destroyed. The Marist Mission Church at Tureboiru collapsed, and the Father's house was partly dislodged from its piles and had to be propped up. At the Marist Mission at Muguai, the Father's house and the Refectory collapsed, and the Sisters' quarters had to be propped up. At the Marist Mission at Papaputuai, the Father's house, on ten-foot piles, leaned to a dangerous angle, but was propped up and saved. Mr Ebery reported the destruction of a shed.

The bridge over the Loloru River was left standing, but its approaches were badly cracked and broken. Shelters over other bridges were broken, and their approaches cracked and generally damaged. Many roads show crevasses and, on the road traversed by Mr Bilston from Muliko River to Kangu station, a number of cracks in the ground were observed. Fences surrounding native gardens were broken and three or four houses were destroyed in each village near the station. Falling trees blocked roads.

Kangu (Buin) station escaped lightly and none of the buildings were damaged. In the residence, the stove overturned and started a small fire, but this was quickly extinguished. Crockery was broken, and a cupboard in the office overturned.

The damage reported was all done during the three major shocks on 30 January. The worst damage appeared to be in Buin native district, an area northwest of Kangu.

Puruata No abnormal tremor was reported on 30 January although one of usual intensity was noted by the native constable in charge at about noon, according to his time; he did not notice any subsequent shocks.

On 2 February, an observer on the deck of Maiwara noted that Bagana volcano was erupting apparently molten lava at irregular intervals but averaging about twelve times per hour over a period of six hours. The smoke did not appear heavy and was blowing to the north, so he could see the 'red ball' of lava emerge from the crater at the top and the 'rivers of fire' flow down the mountain sides. A channel to the northwest took four flows, and channels to the west and southwest shared the other flows. The observer watched the lava flows descend the top one-third of Mount Bagana, after which 'the streams disappeared', but, at a distance of fifteen miles, he was unable to estimate the width of the lava flows.

The native constable in charge of the base camp had not heard of any damage in the area, and was surprised to learn that there had been a series of major shocks in Buin.

From a report dated 7 March

Buin. Moisuru village, about five miles north west of Kangu, suffered severely on 30 January, when every house collapsed and a number of coconut palms snapped off at the roots.

Kaitu to Lukauko road. Definite fissures in road, which runs along a razorback.

Lukauko to Bogisago road. Edges of precipices near road were cracked. Near Bogisago, dangerous landslides had slipped from razorbacks and bluffs. Narrow deep fissures and slight depressions in the road were common. In several places the road had been reduced to mere footholes with precipices on either side. About one quarter of a mile from Bogisago towards Pauroko, fissures were noted and precipices had slipped.

Near the village of Umbo above Tabago, the precipitous bank of the river had partly collapsed.

Bogisago to Pagui Road. Outside Pauroko where the road passes over a razorback between two precipitous ravines, the road was fissured, and numerous landslides had carried away large trees; the remaining trees were loose. Small fissures and slides were noticed on the way to Korio. Between Korio and Botulai, a few boulders had fallen into a ravine, and, between Botulai and Orimai, a few fissures but no landslides were observed.

Some boulders near Kikimanu had been split.

The main course of the tremor seemed to have been along the line from Bogisago towards Paupoko and its continuance.

APPENDIX 4

ESTIMATED COST OF REPAIRING OR REPLACING DAMAGED PROPERTY OF THE PUBLIC WORKS DEPARTMENT

	Description	$ (Aust.)
1.	Water tanks	23 000
2.	Minor roads, Buin area	10 000
3.	Materials to assist villagers rebuild their houses	600
4.	Womens centre, Boku	1 500
5.	Truck road, Boku to Buin	17 000
6.	New 18-m bridge needed at Womai River on main Boku to Buin road	16 400
7.	Replace one minor bridge	3 600
8.	Minor damage in Kieta and Arawa (miscellaneous)	700
	TOTAL	72 800

APPENDIX 5

ESTIMATED COST OF REPAIRING OR REPLACING DAMAGED PROPERTY OF BOUGAINVILLE COPPER LTD

	Description	$ (Aust.)
1.	Central warehouse	10 000
2.	Central workshop	1 000
3.	Kawerong and Karoona houses; married flats	2 000
4.	78 000-litre water tank - Married Hill	10 000
5.	Boru Boru Crescent	20 000
6.	Camp 10	2 000
7.	Camp 10 road	5 000
8.	Sundry locations - Married Hill area	10 000
9.	Hot-water systems	2 000
10.	Jaba River road	1 000
11.	Port Mine access road	1 000
12.	Pink Palace	500
13.	Moroni village	4 000
14.	Slips along Old Port Mine access track adjacent to 132 000-volt transmission line	5 000
15.	Radios	1 000
16.	Road centreline reflectors	-
17.	Slip under 455 000-litre water tank at Camp 1	5 000
18.	Married Hill houses vacated	-
19.	Realignment of forced draft fan and motor on Unit 3	2 000
20.	Spalling of rock face at rear of power station	1 000
		86 500
	Contingency	13 500
		$100 000

TABLE 1

1975 EAST SOLOMON SEA EARTHQUAKE SERIES
USGS DATA

DATE 1975	ORIGIN TIME			LAT °S	LONG °E	DEPTH (km)	MB	MS	NO. STN
JULY									
20	14	37	39.9	6.59	155.05	49	6.6	7.9	158
20	15	12	13.8	7.03	155.42	33 N	5.1		17
20	15	24	16.0	7.07	154.41	33 N	5.5		17
20	15	32	24.1	7.06	154.87	33 N			22
20	16	08	32.5	6.84	154.19	33 N	4.7		22
20	17	00	48.8	6.93	154.83	40	5.4		19
20	17	10	51.5	6.93	154.83	24	5.4		67
20	17	16	26.2	6.85	154.65	51	4.9		31
20	17	22	21.3	6.97	154.87	52	5.3		24
20	17	29	32.7	6.71	154.79	33 N			13
20	17	36	12.4	7.00	155.14	33 N	4.8		16
20	18	01	40.4	6.75	154.90	34	4.8		9
20	19	23	13.0	6.84	155.13	49	4.8		17
20	19	47	16.1	6.95	155.20	53	5.3		27
20	19	54	27.7	7.10	155.15	44	6.1	7.7	141
20	20	09	28.7	6.93	154.99	34	5.6		73
20	21	27	40.3	7.1	155.1	58	5.2		21
20	21	49	12.6	7.22	155.17	37	5.2		39
20	23	05	20.6	6.6	154.6	64	6.3		119
20	23	27	50.5	6.66	154.63	7	5.4		62
20	23	46	44.9	7.25	155.11	40	5.2		33
21	00	03	56.5	6.54	154.26	33 N	4.6		15
21	00	49	11.9	6.92	155.11	77	4.5		15
21	02	03	59.8	6.73	155.31	47	5.7	6.8	233
21	02	39	01.2	6.91	155.33	95 D	6.1		209
21	03	17	29.4	6.99	154.34	61	5.4		25
21	04	09	54.8	7.03	154.62	33 N	5.4		116

DATE 1975	ORIGIN TIME			LAT °S	LONG °E	DEPTH (km)	MB	MS	NO. STN
21	04	21	05.3	6.95	154.62	28	5.2		70
21	04	36	48.5	7.20	154.91	68	5.1		26
21	04	44	02.7	6.47	154.36	33 N			7
21	05	08	11.1	6.69	155.31	68			13
21	05	22	01.7	7.04	154.76	68	5.1		20
21	06	35	03.9	7.06	155.16	46	5.4	4.9	66
21	06	56	14.0	7.00	155.18	56	5.2		37
21	09	54	55.0	7.04	155.29	40	5.1		41
21	10	51	58.5	6.83	154.63	41	5.0		9
21	12	48	55.8	7.16	154.65	173			10
21	13	34	30.5	6.36	154.91	50 D	5.5	5.2	70
21	17	17	19.2	6.42	154.95	51 D	4.8		9
21	18	56	11.1	6.50	155.33	67	4.3		11
21	19	00	21.8	6.77	154.93	75	5.2		14
21	20	10	59.5	6.91	154.76	44	4.7		15
21	23	11	51.4	7.08	155.34	33 N	5.5		17
21	23	43	17.8	6.65	154.60	36	5.5		54
22	03	12	54.3	7.09	155.08	45	5.1	4.9	67
22	03	25	02.7	7.35	154.63	33 N	5.2		18
22	04	50	19.5	6.37	154.99	73	5.5		122
22	13	31	43.1	6.34	154.96	68	5.5		96
22	14	08	39.4	6.01	155.21	24			7
22	14	31	36.7	6.54	154.28	72	4.8		9
22	16	01	55.7	6.67	154.67	47	4.9		36
22	19	20	13.8	7.20	155.71	36	5.7	6.1	183
23	04	06	53.9	7.02	155.38	54	4.9		40
23	12	48	23.8	6.66	154.93	33 N	4.0		5
23	17	42	15.1	7.21	154.88	35	5.1		55
23	20	05	32.9	7.39	154.18	33 N			7
23	22	20	00.8	6.49	154.88	33 N	5.1		8
23	23	22	43.8	7.22	155.07	42	5.6	5.7	58
24	00	02	32.6	6.57	154.39	56	5.0		46
24	07	21	18.0	6.06	155.26	75			7

DATE 1975	ORIGIN TIME			LAT °S	LONG °E	DEPTH (km)	MB	MS	NO. STN
24	13	20	34.0	6.63	154.59	35	4.8		11
24	16	05	14.5	6.63	154.60	33 N	4.6		8
24	18	49	00.2	7.10	155.73	54	5.4		12
25	14	18	16.8	6.70	154.41	24		3,9	10
25	16	36	40.6	6.92	154.81	42	5.0		17
26	13	19	42.1	6.62	155.28	33 N	5.1		20
26	17	39	32.0	7.06	154.55	42	4.6		20
26	18	24	07.7	7.18	154.51	39	5.2		47
28	08	44	55.3	6.93	154.53	38	5.7	5.7	109
28	18	11	22.7	7.26	155.03	24	4.9		11
28	18	22	53.6	6.90	154.79	44	4.9	5.3	40
28	21	25	04.7	6.79	154.63	37	5.3		57
29	16	53	29.1	6.52	155.12	59			14
30	14	40	38.8	7.15	155.08	39	4.9		19
30	16	02	33.0	6.97	155.15	33 N	4.7		8
AUGUST									
01	22	10	8.4	6.33	154.80	57	4.8		30
03	04	13	54.2	7.03	154.66	43	4.7		18
05	02	54	38.9	6.57	155.08	55	4.9		35
05	19	49	39.8	6.86	155.45	62			11
07	03	10	27.2	6.46	154.89	55	5.0		40
08	16	34	24.2	7.02	155.60	62			11
08	21	43	03.5	6.87	155.54	70			13
10	02	24	54.4	7.23	155.16	33	5.1		13
10	03	28	25.8	7.08	154.91	53			13
10	04	10	38.9	7.04	154.83	34	5.1		40
10	04	13	13.3	7.00	154.65	25	5.3		21
10	05	08	19.0	7.19	154.98	29	4.6		12
10	05	39	55.9	7.11	154.78	34	4.9		12
14	05	57	53.8	6.92	154.98	53	4.2		6
21	05	29	29.2	6.34	154.86	60	5.0		52
21	06	48	30.3	5.87	154.44	430 D	5.3		98

DATE 1975	ORIGIN TIME			LAT °S	LONG °E	DEPTH (km)	MB	MS	NO. STN
21	09	25	14.9	7.16	154.72	48			8
21	09	46	42.4	6.56	154.94	50	5.8	5.9	180
22	13	13	14.7	6.55	154.96	45	4.9		16
24	10	47	29.6	6.50	154.87	5.0	4.2		17
25	08	11	24.5	6.87	155.78	73	5.6		49
30	17	42	30.3	5.62	154.46	106			14
31	04	48	58.7	6.50	155.10	58	4.6		14
<u>SEPTEMBER</u>									
02	08	12	15.0	7.13	154.81	34	5.1		17
05	06	04	20.9	5.70	154.41	106	5.1		28
05	22	41	26.6	6.78	154.40	35	5.2		28
07	21	26	40.2	6.95	154.47	13	4.8		7
10	07	26	58.1	7.07	154.81	47	4.9		9
13	21	17	39.2	7.20	154.51	43			7
18	14	29	49.8	7.26	156.00	54	5.6		26
19	23	15	34.0	6.42	154.89	47 D	5.4	5.6	74
21	02	05	46.0	6.13	154.48	33 N			12
23	07	14	39.8	6.34	154.71	33 N	5.1		9
25	18	10	16.4	6.47	154.92	61	5.5		61
26	00	52	27.0	6.92	155.00	62			5
27	07	23	16.2	7.31	154.71	41	5.0		5
30	00	21	45.2	6.80	156.14	86	5.7		9
<u>OCTOBER</u>									
03	04	10	59.2	7.88	156.51	44	4.5		13
04	11	51	39.1	6.44	154.64	43	4.5		6
05	01	30	50.4	6.80	154.26	47	4.7		10
08	17	13	59.8	6.57	154.83	62	5.3		9
20	15	59	19.0	6.87	155.17	56	5.1		14
23	23	18	07.8	6.68	154.65	52	5.2		24

DATE 1975	ORIGIN TIME			LAT °S	LONG °E	DEPTH (km)	MB	MS	NO. STN.
NOVEMBER									
19	03	51	26.6	6.86	154.39	42	5.2		17
23	00	36	35.8	6.34	154.84	56 D	5.4		61
24	10	52	07.3	6.23	154.70	416	4.5		8
DECEMBER									
14	04	21	16.3	6.58	155.08	59	4.5		9

TABLE 2

NOVEMBER 1923 EARTHQUAKE INTENSITIES

Place	Lat. S	Long. E	Nov. 02 Intensity		Nov. 04 Intensity	
			MM	RF	MM	RF
Tarara	06° 02'	155° 24'	VIII	IX		
Arugar	05° 41'	155° 02'			VIII	
Buka Passage	05° 26'	154° 40'	VII			
Faisi Is.	07° 09'	156° 45'	VII			
Kieta	06° 13'	155° 37'	VI	VI		IV
Rabaul	04° 12'	152°11'	VI	VI		VI
Vunadadir	04° 21'	152°08'		VI		V-VI
Baining	04° 31'	155°42'		V		IV
Namatanai	03° 39'	152°27'	IV-V			V
Tamalili	04° 22'	152°23'		III		III
Morobe	07° 45'	147°36'		II		II

MM = Modified Mercalli Scale

RF = Rossi-Forel Scale

TABLE 3

30 JANUARY 1939 EARTHQUAKE INTENSITIES

Place	Lat. S	Long. E	Intensity	
Buin area	06° 46'	155° 41'	VIII	IX
Kieta	06° 13'	155° 37'	VI	VI
Purata	06° 15'	155° 01'	V	
Rapopo	04° 20'	152° 19'		III
Kolube	03° 20'	151° 48'		III
Kokopo	04° 20'	152° 16'		III
Rabaul	04° 12'	152° 11'		III
Losuia	08° 32'	151° 04'		III
Neinduk	04° 12'	151° 41'		II