Effects of a major earthquake near Bougainville, 20 July 1975

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On 20 July 1975 a major earthquake (MS7.9) shook the northern islands of the Solomon Islands chain. Damage amounting to at least $300,000 (Australian) occurred in the southern Bougainville/Shortland Islands region, where earthquake intensities were estimated to be MMVII-VIII. A tsunami with maximum amplitude of about two metres followed the earthquake and caused further damage. The earthquake caused landsliding, liquefaction, subsidence, slumping of roads and wharfs, and damage to villages, small government and mission buildings, and to the mining installations at Panguna.

Aftershock epicentres were in a roughly elliptical area of 12 500 square kilometres 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 underthrusting of the Solomon Sea crust beneath Bougainville, in a northeasterly direction and with a dip of about 37°.

The faulting associated with the 20 July 1975 earthquake appears to be the extension of faulting associated with a 1974 earthquake series.

An aseismic zone, centred at 6°S, 154°E, exists immediately northwest of the 1975 earthquake fault zone, between zones where major earthquakes have occurred since 1970. It is considered to be a likely place for a major earthquake in future.

Introduction

At approximately 40 minutes after local midnight (150° EMT), on 21 July 1975, a major earthquake occurred near Bougainville Island (Fig. 1). In the southwestern part of the island many village abodes, roads and bridges and mission buildings were extensively damaged by the earthquake, and subsequently a tsunami caused some more damage in coastal settlements. Inhabitants of the area were highly alarmed by this earthquake, and by several large aftershocks which occurred during the following 48 hours. Fortunately there were no fatalities.

The main earthquake and aftershocks occurred in the well-known region of seismicity associated with the New Britain/Bougainville Trench and island-arc structure in the north Solomon Sea, (Denham, 1971; Johnson & Molner, 1972) (Figs. 1, 4). Here shallow earthquakes result, most commonly from thrust faulting (Ripper, 1975), and deep earthquakes indicate a subduction zone which is nearly vertical beneath Bougainville (Fig. 4). The tectonic trend in the Bougainville area is northwest as a consequence of southwesterly convergency of the Pacific Plate relative to the Solomon Sea Plate.

The north Solomon Sea seismic region is one of the Earth's most active, and Bougainville has frequently been shaken by earlier earthquakes. However, because of the low population density and extensive use of local materials in building, damage and loss of life have never been serious.

The earthquake sequence

Details of the principal earthquake (143740 U.T. 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 largest aftershocks, those recorded at over 100 stations, are listed in Table 1 for the period 20 July-19 October. The decay of 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. Forty-one Wood Anderson aftershocks were recorded 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 only includes shocks which were recorded at Panguna (PAA), very close to the aftershock zone, with a P-wave residual of ± 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°S, 154.4-156.0°E, off the southwest coast of Bougainville. The area of the aftershock zone is about 1.25×10^4 km^2.

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. The aftershock pattern and the tectonic structure of the area in which the earthquake occurred suggest that Nodal Plane 2 is the fault plane, i.e. the Solomon Sea crust underthrust Bougainville. The fault dip is 37°, the strike 116°, and the direction of fault movement (given by the azimuth of the pole of nodal plane 1) is 051°.

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 because in plan the two zones overlap.

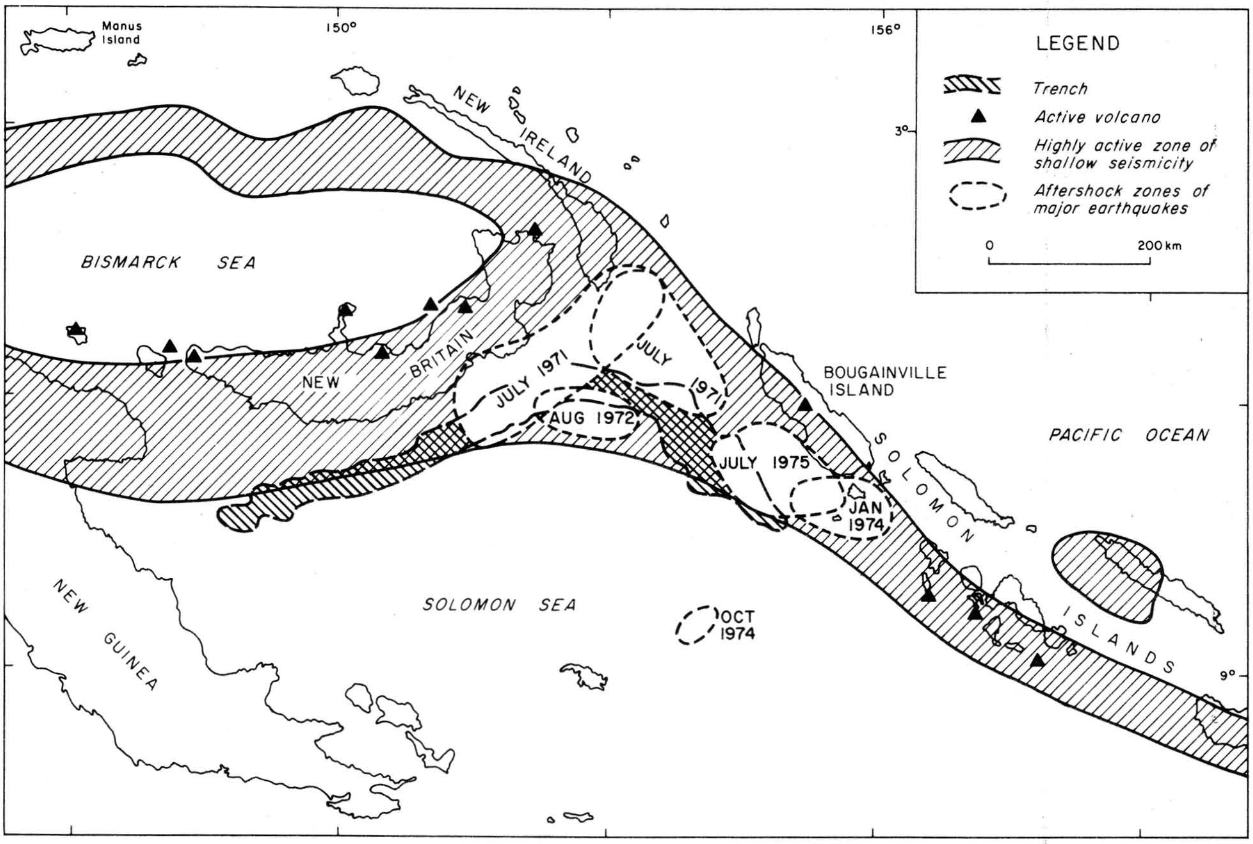


Figure 1. Tectonic sketch map

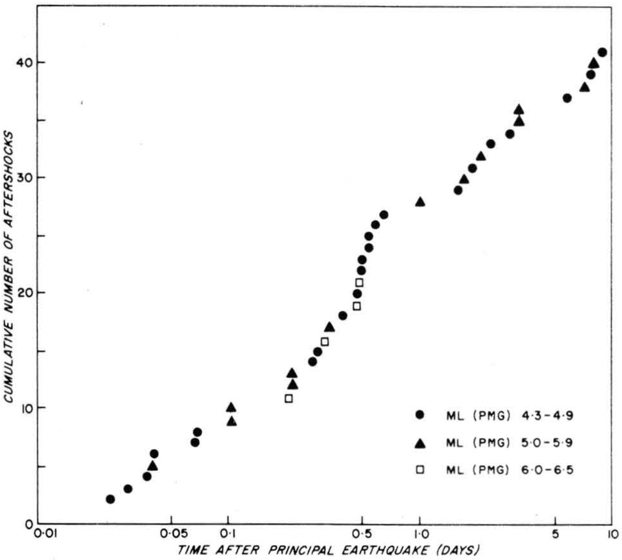


Figure 2. Aftershocks/time plot

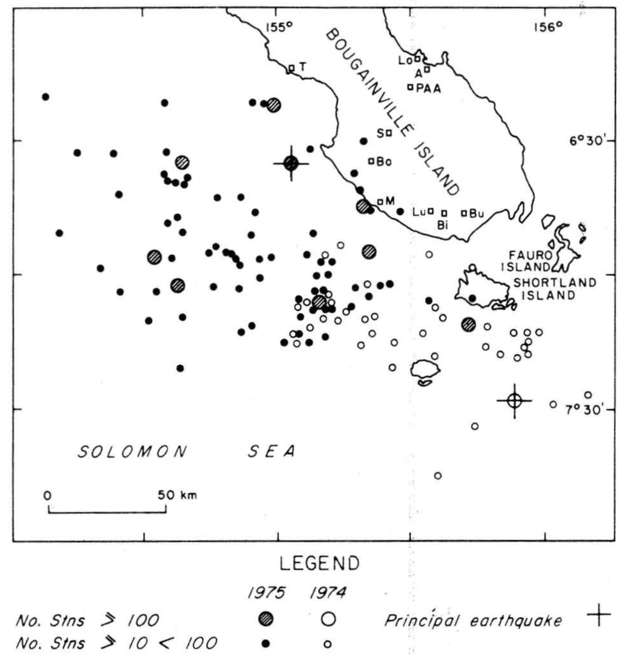
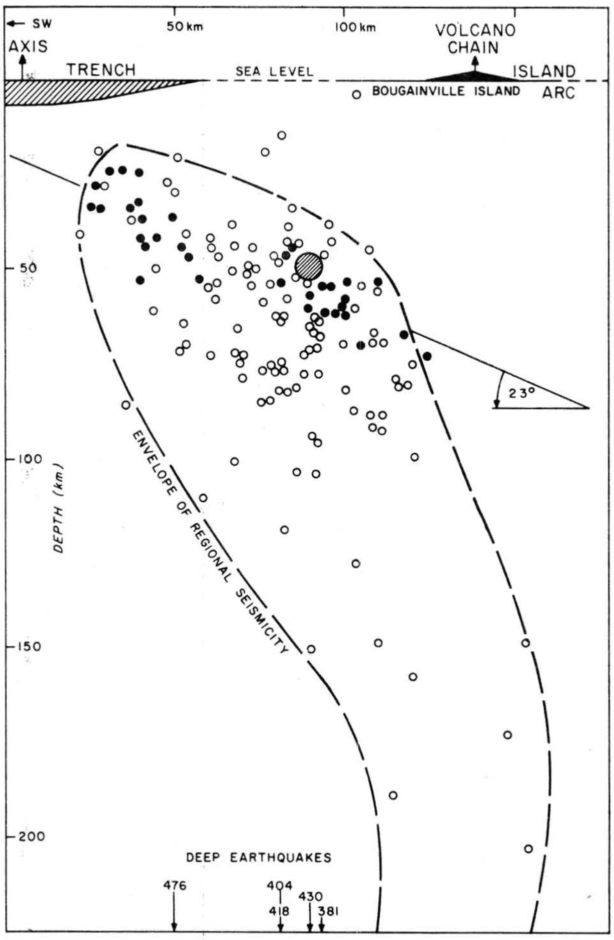


Figure 3. Aftershock epicentres. Seismicity within 10 days following major earthquakes of 20 July 1975 and 31 January 1974 (USGS data)

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 & 3), indicates that the earthquake faulting which occurred in 1975 was probably a northwesterly extension of the earlier faulting. Between this region of faulting associated with major earthquakes and the region to the northwest, beneath the north Solomon Sea where faulting took place with major earthquakes on 14 and 26 July 1971 (Everingham, 1975)—is a relatively aseismic region where no faulting has occurred (Fig. 1). 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, centred on about 6°S, 154°E, must therefore be considered to be a likely place for a major earthquake in the future.



LEGEND

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

Figure 4. Vertical profile of aftershock pattern. Hypocentres projected onto a northeasterly trending vertical plane across the area of Figure 3. 20 July-31 October 1975. No. Stations > 9, recorded by PAA with P-residual 1.0s (USGS data). X 1960-May 1975 No. Stations > 19. (ISC & USGS data).

Macroseismic data

Details of field observations of the earthquake effects with various aspects, are given in unpublished reports by Searle and others, (1975), Best (1975), George (1975), Tanu (1975), and Everingham and others (in prep.).

Intensities

Two hundred and ten intensity questionnaires were issued and about one hundred were answered. The map of intensities, on the Modified Mercalli (MM) scale, is shown in Figure 6. The majority of intensities shown in this map are derived from the questionnaires; many observations made during field inspections of southern Bougainville are not plotted because they duplicate the questionnaire results.

Because the event happened at night, intensities of less than MMIII were not reported. The 'waking' effect of the earthquake was useful in estimating intensities of MMIV and MMV. Intensities of more than MMVIII could not be determined, because evidence of the type used in the standard MM intensity scale was not available.

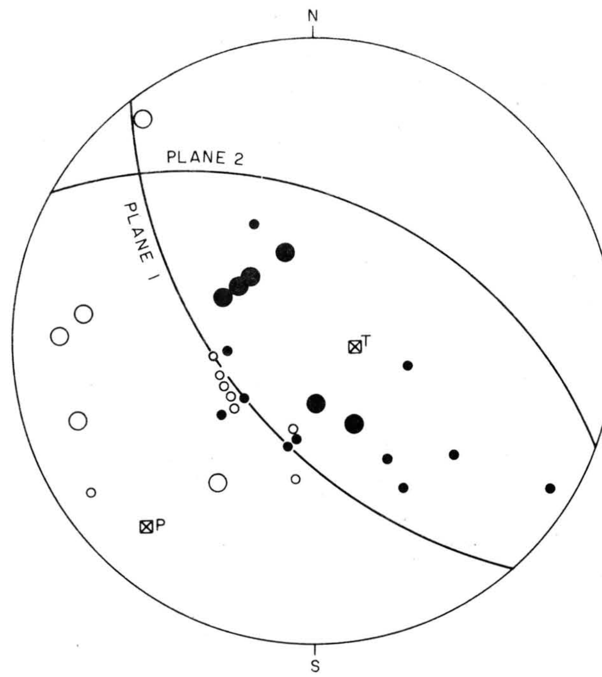


Figure 5. Fault-plane solution. First motions on lower hemisphere. Wulf stereographic projection. Larger solid circles—long period, smaller solid circles—short period, compression; larger open circles—long period, smaller open circles—short period, dilation. T—Tensional stress axis, P—Compressional stress axis.

Figure 6 shows that intensities vary over fairly short distances, e.g. at about 6°S on the east Bougainville coast where intensity ranges from MMV to VIII. This could result from the manner in which the questionnaires were answered, but it is considered that the effect is more likely to be real and result from differences in the foundation subsoil and the topography. The tendency for mountain ridges to be shaken more strongly than flat areas and sites in valleys in Papua New Guinea had frequently been observed, and the effect has been proven instrumentally by accelerographs (Everingham, 1973; Gaull, 1976).

The earthquake was felt clearly (MMIV or greater) as far afield as Rabaul and Losuia, about 500 km from the epicentre. Although Bougainville Island was shaken with intensities of MMV or more, significant damage was restricted to the southwestern region of the island, where intensities of MMVII or greater were experienced, and the Panguna mining area, where local intensities were MMVI to VII. The northernmost Solomon Islands, e.g. Shortland Island, lying close to the epicentre were also subjected to high intensities.

In the area with intensities of MMVII or more, landslides were common, bridges were damaged, roads cracked, and people had difficulty in standing during the earthquake. Concrete masonry structures lacking reinforcing, weaker village homes, and a considerable proportion of circular corrugated-iron water tanks were badly damaged. Structures not fastened securely to their stumps were shaken off them, and wharves, particularly their approaches, were damaged. Subsidence of areas along the coastlines were also noted in the region of these high intensities.

In the area between the MMVI and VII isoseismals, damage was slight and included breakage of articles shaken from shelves, minor subsidences, landslides, and road damage. The MMVI isoseismal is, on average, about

150 km from the epicentre. Beyond this distance damage was negligible.

Overall, the earthquake effects were very similar to those of the 1970 Madang earthquake (Everingham 1975), and are typical of Papua New Guinea.

During the 24 hours following the major quake, the four largest aftershocks (MLVI-VI.5) (Table 1) were felt with moderate intensity (MMV-VI) in the southwestern part of Bougainville Island. Although the aftershocks caused considerable alarm, only a small amount of extra damage resulted from them. Isoseismal maps for the aftershocks were not attempted because of the difficulty in differentiating between aftershock and main shock damage.

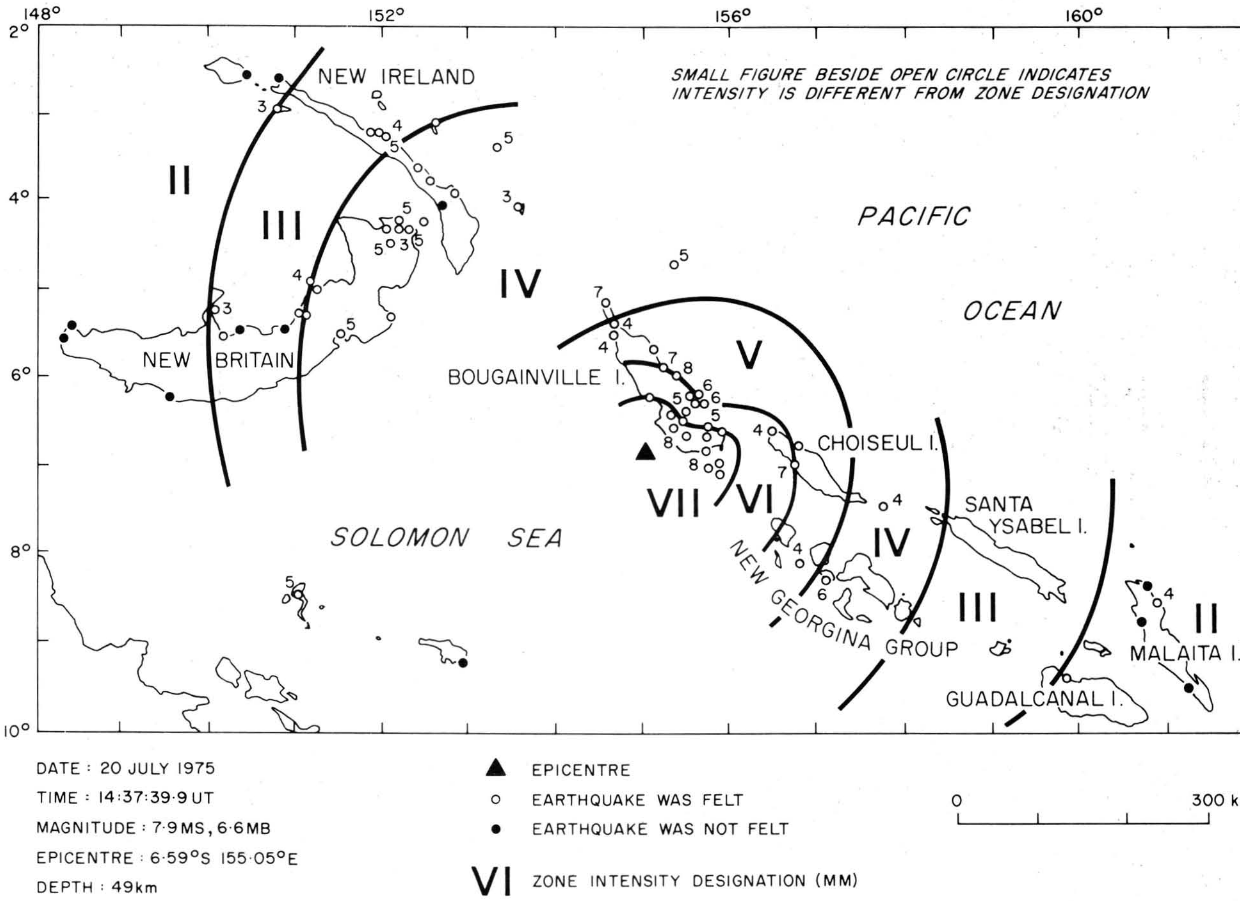


Figure 6. Isoseismal map for 20 July 1975 earthquake.

Date 1975		*Origin Time*	*Lat °S*	*Long °E*	*Depth (km)*	*MB GS*	*MS GS*	*ML PMG*	*No. Stn*
July	20	14 37 39.9	6.59	155.05	49	6.6	7.9	7.2	158
	20	19 54 27.7	7.10	155.15	44	6.1	7.7	6.3	141
	20	23 05 18.8	6.58	154.65	50	6.2	6.7	6.4	151
	21	02 03 59.8	6.74	155.31	47	5.7	6.8	6.1	233
	21	02 39 01.2	6.91	155.33	95D	6.1		6.5	209
	21	04 09 54.8	7.03	154.63	33N	5.4		5.6	116
	22	04 50 19.5	6.37	154.99	73	5.5		5.1	122
	22	19 20 13.8	7.21	155.72	36	5.7	6.1	5.5	183
	28	08 44 55.3	6.93	154.54	38	5.7	5.7	5.8	109
August	21	09 46 42.4	6.57	154.94	50	5.8	5.9	5.8	180

Table 1. Earthquakes* recorded by over 100 stations—20 July-20 October 1975 (USGS data)

* Earthquakes in area of Figure 3.

The tsunami

As a result of the overthrust faulting a tsunami occurred. The sea surged inland, and receded, several times along about 100 km of the southwestern and southern coasts of Bougainville with an amplitude up to 2 m and period in the range 5 to 15 minutes. 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.

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.

Villagers at Mamagota village reported that the waves entered the bush and caused the river to flood and subsequently change its course at the mouth. This village had been re-sited about 1 km inland following recent tsunamis. Grass and leaf strandlines, and vines and small bushes uprooted and rolled together, indicated that water rose at least 1 m above the 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 higher than 1 m above high-water level.

Torokina. The sea wave was observed by the population at Torokina village. Having experienced waves in July 1971 and in February 1974, people in the area were expecting a sea wave after the 1975 earthquake (MMVII).

About 15 minutes after the earthquake the wave was seen approaching. It was described as a long low hump, stretching from north to south. At this stage most of the villagers left, but one villager, who had climbed a coconut palm, remained there for about 10 minutes. He reported that the first wave came through at a height of about one metre above ground level. The water level then remained high until a second larger wave arrived 5 minutes later. About 5 minutes after this second 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 thereafter.

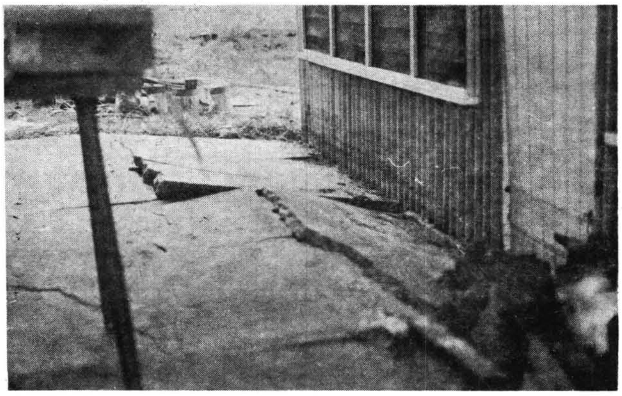


Figure 7. P & T power station at Torokina. Note subsidence of building carrying heavy machinery.

Damage in the village was not extensive. A small, light kitchen was washed into a swamp and smashed. Two houses were taken off their stumps, apparently by the second wave, and moved about 30 metres inland. Canoes on the beach were carried about 50 metres behind the village, while half the village chickens and a few dogs disappeared.

In the Department of Posts & Telegraphs (P & T) communications station at Torokina water marks were visible on walls. Inside the main building the marks were fairly straight. On the outside of this building the top water mark at 1.14 m was irregular. Straight water marks were left at various levels as the water receded (Fig. 7).

Figure 8. P & T station, Torokina. Petrol drums and debris washed inland and piled against wire-mesh fence.

Liquefaction at Torokina

The communications station at Torokina (Fig. 9) consists of a 38 m tower for a dish aerial, two further dish aerials on about 10 m towers, an electronics building adjoining the main tower, a power house, and a residence. All the buildings are sited about one metre above high-tide level, close to the sea, on land which has been built up naturally since World War II—i.e. the coast was inland from the station some 30 years ago.

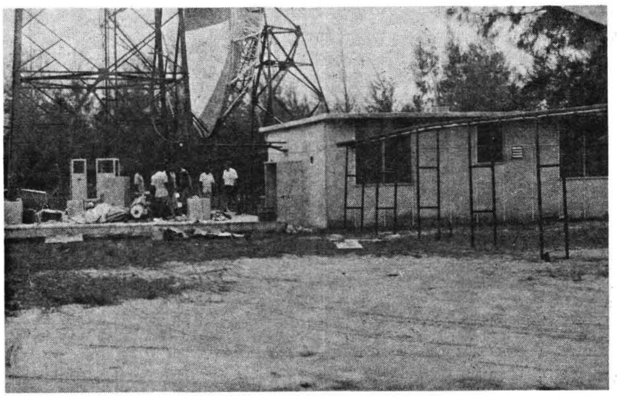


Figure 9. P & T station, Torokina. Equipment building on right subsided 250 mm. Tower and platform on left did not subside being based on deep piles. Sand in foreground was ejected by aftershocks.

Subsidence of the P & T buildings (Figs. 7 and 9) probably took place during the main earthquake, but before the tsunami. However, further subsidence occurred during strong aftershocks, notably those about 0930 and 1230 local time on 21 July. During the latter earthquake, engineering staff who had flown in to repair the station reported that the tower base swayed over an estimated range of 400 mm, and that liquefaction of the ground occurred. Liquefaction in the vicinity was also shown by the movement of the wharf piles (driven down to a depth of about 14 m), which now slope out towards the sea at an angle of about 10-15° from the vertical (Fig. 10), and by the fact that heavy objects tended to sink while light objects, such as buried empty petrol drums, rose out of the ground. Old buried piles of a discarded World War II landing wharf emerged after the largest aftershock (Fig. 11).

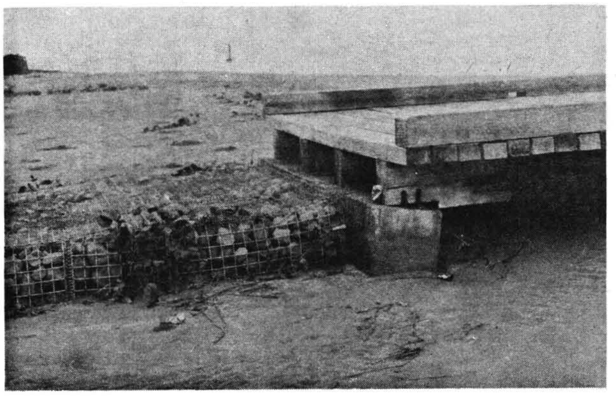


Figure 10. Wharf at Torokina. Eight piles similar to that in foreground, driven about 14 metres into the ground, were forced to slope about 15° from vertical by effects of liquefaction.

Damage costs

The estimated cost of repairs incurred by the Public Works Department is $73 000 (George, 1975). Bougainville

Copper Ltd estimated that the costs of repairing the earthquake damage to their Panguna mine, township, access roads and other facilities totalled $100 000, and 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 a $300 000 total approximate cost of earthquake damage in Bougainville.

Estimates of damage costs in the northern British Solomon Islands are unavailable.

Figure 11. Old wharf piles at Torokina extruded by effects of liquefaction caused by aftershocks. Tops of piles were formerly below ground level as evidenced by plants growing on them.

Discussion

The earthquake of 20 July 1975 could be regarded as a model in planning to minimise damage from future earthquakes in the north Solomon Islands. The earthquake occurred in a well-defined zone of shallow seismicity, the mechanism was typical for that zone, and the magnitude was considerable, so that shaking effects should not be greatly exceeded in future earthquakes.

The collision zone between the Pacific and Solomon Sea Plates dips to the east, and is about 50 km deep beneath western Bougainville and the Shortland Islands so that earthquakes in the zone must have a high magnitude in order to cause severe damage. Very shallow earthquakes have occurred above the collision zone, but they are rare and are not considered to be a major hazard.

Everingham and others (in prep.) conclude that return periods for an earthquake intensity of MMVIII is about 15 and 50 years for western and eastern Bougainville respectively. These estimates are for average sites; mountain and ridge tops, and steeply sloping areas, have smaller return periods and higher risk.

The effects of the 1975 earthquake also highlight the tsunami risk close to an active seismic zone in which thrust faulting predominates. For example, the P & T station at Torokina has been badly damaged by two tsunamis in a period of 4 years (July 1971, July 1975). The coastal population was prepared for the July 1975 tsunami because significant tsunamis were experienced during July 1971 and February 1974.

Acknowledgements

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