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The Kokopo (New Britain) Earthquakes of the 14th August 1967

by

R.F. Heming

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SUMMARY

On 14th August, 1967, two major earthquakes shook the Kokopo and Kabaleo areas of the Gazelle Peninsula, New Britain. They caused material damage estimated at $172,000 and this amount might have been greatly exceeded had the affected area been more densely populated but, equally, would have been reduced had building standards been higher.

The two major earthquakes which occurred at 0254 hrs and at 0815 hrs formed part of a complex sequence of seismic events and aftershocks were recorded during the following two weeks. Their epicentres were located in St. George's Channel but, unlike the 1941 earthquake (Fisher, 1944) which was preceeded by large ground tilt and followed by considerable tidal effects, there were few, if any, tidal and tilt effects associated with these events.

The larger of the two major earthquakes, which had a Magnitude of 5.3, occurred at 0815 hrs and was the cause of most of the damage. Brooks (1965) has shown that Rabaul lies in an area of very high seismicity and severe earthquakes such as these can be expected on average at least once in a 25-year period. The details of the 1967 earthquakes and their effects are, therefore, of importance in future development planning in the Gazelle Peninsula.

Note: Times and dates are, unless otherwise indicated, local, i.e.: Australian Eastern Standard Time (G.M.T. + 10 hours). The 24-hour clock convention is used throughout.

THE KOKOPO (NEW BRITAIN) EARTHQUAKES OF THE 14TH AUGUST 1967

INTRODUCTION

Two severe earthquakes shook eastern New Britain and nearby parts of New Ireland on the 14th August, 1967. The first was at 0254 hrs on the 14th August (1654 hrs G.M.T. 13th August) and was felt severely over a large area of eastern New Britain and less severely over southern New Ireland, northern Bougainville and some outlying islands. Many aftershocks followed this earthquake and some of these were felt at Intensity IV on the Modified Mercalli Scale in the Kokopo area.

Another large earthquake at 0815 hrs (2215 hrs G.M.T.) was preceeded by a smaller earthquake at 0811 hrs (2211 hrs G.M.T.). Most of the visible damage occurred at this time.

After this event, activity declined; rapidly at first and then more gradually. Occasional earthquakes which were strong enough to be felt at the eastern end of the Peninsula continued to occur up to two weeks later. Over two hundred aftershocks were recorded at the Rabaul Observatory in the two weeks following the main earthquakes.

GENERAL DESCRIPTION OF THE EARTHQUAKES

The first earthquake produced extremely violent ground motion in the eastern part of the Gazelle Peninsula: that is to the north of the Keravat-Warangoi depression. In Rabaul, small objects such as books, ornaments and crockery were thrown about; while near Kokopo many people reported that heavy furniture such as refrigerators, radiograms and bookcases were knocked over. Landslides occurred in the high pumice cliffs along the coastal road from Rabaul to Kokopo and the road was closed. Some damage to buildings may have occurred at this time, but none was reported.

This large earthquake was followed by numerous small ones. Mr. Simpson of Gilalum Plantation in the Warangoi Valley reported feeling seven between 0300 hrs and 0400 hrs. A larger earthquake occurred at 0650 hrs (2050 G.M.T.) and reached Intensity M.M.IV in Rabaul. After this came a period of comparative calm and many thought that the major activity had ended. However, the climax did not come until after 0800 hrs.

The two earthquakes at 0811 hrs and 0815 hrs represented a considerable release of energy in a very short time and undoubtedly caused most of the damage that is described in this report.

The earthquake at 0811 hrs was felt as a comparatively gentle motion but was quickly followed by the larger earthquake which had a more violent motion. More landslides occurred along the coastal road to Kokopo so that a fine dust haze hung over the shores of Keravia Bay. The earthquake at 0815 hrs reached M.M.VII at Rabaul, VII or VIII at Kokopo and almost certainly VIII at Kabaleo and Vunapau to the south of Kokopo.

Small pockets of higher intensity occurred away from this central area. For instance at Toboi, near Rabaul, a woman reported that the steering of her car was affected, indicating an Intensity of M.M.VII. Sand and water were thrown from cracks in the sand bar at the mouth of the Warangoi River, which would place the Intensity in this area as high as M.M.IX.

No major earthquakes were felt after this, although numerous small ones were felt in the Kokopo district throughout the day. Aftershocks were recorded at Rabaul for over two weeks (see Figures 1 and 2).

THE ISOSEISMAL MAP

The information on the Felt Intensities was gathered in a number of ways. The Rabaul Observatory already had a number of observers throughout the Territory who report the Modified Mercalli Intensity of earthquakes and any other phenomena which may have some volcanological significance. Other information was obtained both from questionaires distributed by the Port Moresby Geophysical Observatory and from radio conversations with a number of people throughout the area. Modified Mercalli Intensities were determined from this information and these values, together with the reported Modified Mercalli Intensities supplied by the observers, were used to plot isoseismals (Plate 18).

The most striking feature of the resulting pattern of isoseismals is their extension south east towards Bougainville Island, over 270 kilometres away from the epicentre. Cape Hoskins, which is a comparable distance away to the north west, did not feel any tremors; neither did Kavieng which is on the tip of New Ireland, only 220 kilometres to the north west of the epicentre.

This southeasterly extension may be explained by its coincidence with the general structural lineament of the area along which little loss of energy would occur. It is not yet known why the energy was not similarly transmitted along New Ireland. However, a recent Crustal Study Project in the area found that a geophone spread at Kalili just north of Namatanai and on the western coast failed to record signals other than the water waves, from explosions set off in the sea along the north coast of the Gazelle Peninsula. It is also worth noting that the 1941 earthquake (Fisher 1944), which was the most severe earthquake recorded in the Gazelle Peninsula prior to the 1967 shocks, was not felt at Kavieng, but was felt at Intensity IV R.F. (approximately M.M.IV) at Talasea, 230 kilometres from its epicentre at Wunga in the Keravat Valley.

The 1967 earthquake hypocentres were at a shallower depth than the 1941 earthquake hypocentre, 30 kms as against 67 kms for the 1941 earthquake (J.H. Latter pers comm). The pattern of isoseismals is also typical of a shallow earthquake with elongation along the structural lineament. The isoseismals drawn by Fisher are almost circular and are more typical of an intermediate hypocentre.

INSTRUMENTAL EVIDENCE

RABAUL INSTRUMENTATION

A World Wide Standard Set and an Omori smoked paper seismograph are installed at the Rabaul Observatory. The Harbour Network, which was not completely operational until 1968, consists of Benioff Variable Reluctance Seismometers installed at five sites around the caldera, the signals from which are transmitted to recorders at the Observatory. Details of the

Instrumentation are included in Appendix 3.

THE SEISMOGRAMS

The records of the main shocks from the World Wide Standard set and from the Harbour Network all show an impulsive arrival and the traces are lost soon after the first motion (Plates 1 and 2). The Omori seismograph, which usually gives a reasonably clear record of local shocks of high magnitude, was partly unserviceable. The pen on the north-south component was displaced during the earthquake at 0254 hrs on 14th August and consequently the record is of poor quality. The pen arm on the east-west component was knocked completely off and only an indifferent record of the first twenty seconds was obtained. A lot of information was also lost owing to the overlapping of the traces. For instance, the 0815 hrs earthquake began while surface waves from the 0811 hrs shock were still being recorded.

The first motion of each earthquake was found to be in the same sense at all of the Rabaul stations. Of the three major earthquakes only the 0254 hrs earthquake showed a dilatation: the other two showed compressions. Throughout the aftershock sequence, compressions outnumbered dilatations. Those earthquakes with dilatations rarely occurred singly, and were sometimes in groups of three. (Figure 4 and Appendix 4).

The P waves of the major shocks were all of very large amplitude. The majority of the aftershocks began with an impulsive movement with a period of between 0.3 and 0.5 seconds and of relatively large amplitude compared to the rest of the P group. A second arrival after two or three seconds was also very clear in many of the aftershocks, although the amplitude was relatively small.

The S waves of the aftershocks were sharp events with amplitudes as much as ten times as great as the P waves and following them after an interval of from three to six seconds. Normally the period of the S waves was half a second. Typical aftershocks are shown in Plate 3, and a more detailed analysis of the characteristics of the Kokopo earthquakes is presented in Appendix 4 and Figure 4.

DETERMINATION OF AN EPICENTRE

In determining an epicentre, emphasis was given to arrival data from New Guinea Stations, but information from Honiara, Brisbane and Charters Towers was also used. Goroka and Wau stations were only temporary installations. The one at Wau was installed to monitor possible volcanic activity in the area, while the Goroka station was installed by the Port Moresby Observatory staff as part of a crustal structure investigation.

The method used in working out an epicentre was that outlined by Eiby and Muir (Eiby and Muir 1961). All arrivals were tabulated and origin times were calculated for each station using Eiby and Muir's Tables (Eiby and Muir 1961). The origin times were compared, uncertain readings were eliminated, and an average of the remaining times was made giving an "adopted origin time". Using this origin time the travel times of P were recalculated and the distance of each station from the epicentre was found. From the macroseismie evidence a normal depth was assumed for the epicentres. The information on the 0815 hrs earthquake was very sparse and consequently only the epicentres of the 0254 hrs and 0811 hrs earthquakes were determined. The epicentre obtained has an accuracy of plus or minus 10 miles (class B epicentre) and it was therefore, expressed to the nearest quarter of a degree. By this method epicentres for both the 0254 hrs and 0811 hrs earthquakes were found to lie just south of the Duke of York Islands (Plate 16). This is further north than the U.S.C.G.S. epicentre for the 0254 hrs earthquake and nearly twenty five kilometres NNE of the U.S.C.G.S. epicentre for the 0811 hrs earthquake. Using the clear first motions on the Rabaul seismograms, an azimuth from Rabaul for both the 0254 hrs and 0811 hrs shocks was found. This suggests an epicentre in the ESE octant for both earthquakes. Macroseismic evidence also supports the siting of the 0811 hrs earthquake some way offshore in St. George's Channel. At Kabanga Bay, where the U.S.C.G.S. epicentre is located, the intensity was not very high; probably less than M.M.VI. Damage here was minimal and, although there were movements in sea level, they were not large and similar movements probably occurred at many other points along that coast.

The existence of large surface waves and the high intensities in the meizoseismal area coupled with its limited extent, suggest a shallow depth. The U.S.C.G.S. hypocentres for the main earthquakes all lie at between 20 and 36 kilometres.

THE RELATIONSHIP BETWEEN THE MAIN EARTHQUAKES

Richter (1958) mentions New Britain as an area which habitually produces complex earthquakes of a high order of magnitude. The Kokopo earthquakes form one of these complex events. The whole sequence is shown in Figures 1 and 2. Figure 1 shows that the 0254 hrs earthquake had an aftershock sequence and, because of this, it cannot be regarded as a foreshock to the 0815 hrs earthquake.

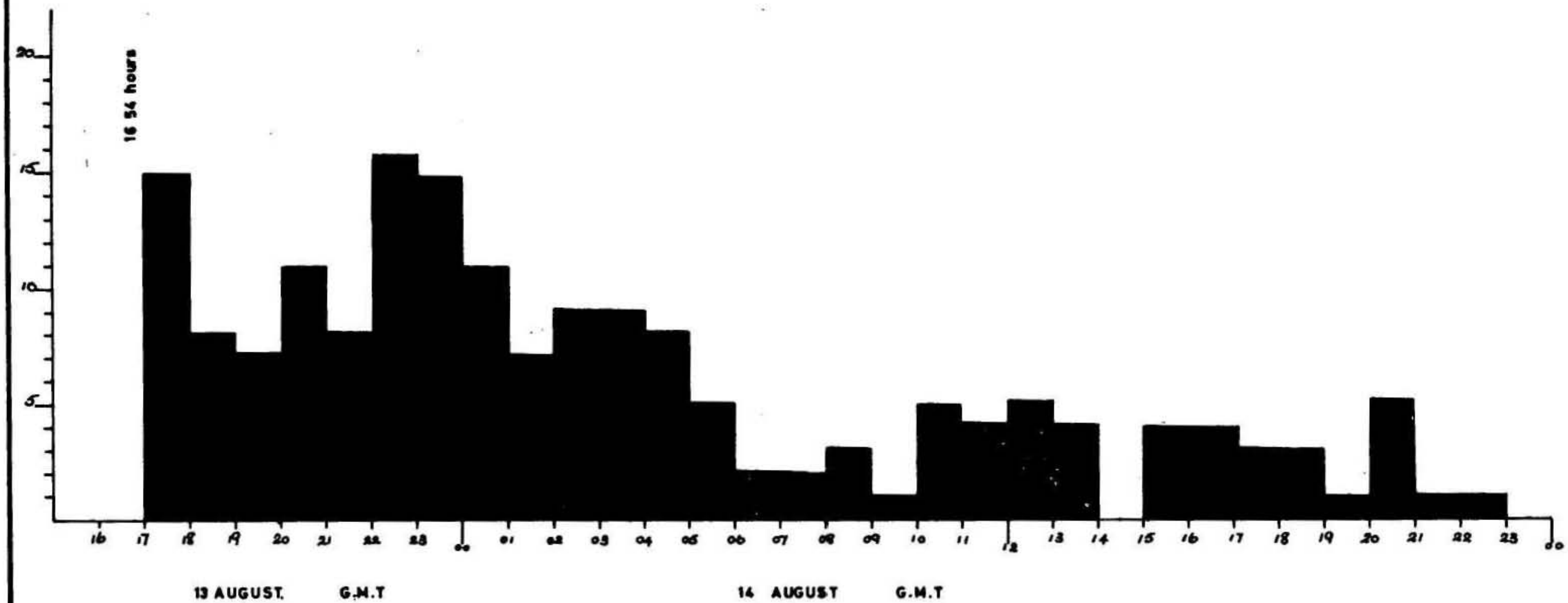
The 0811 and 0815 hrs earthquakes form a complex pair. Latter (1966) quotes examples of pairs of earthquakes, but his examples have epicentres as much as one degree apart, whereas in the case of the Kokopo earthquakes they are extremely close. It is possible that the 0811 hrs shock provided a trigger for the later one. The greatest problem however is the relationship between the 0254 hrs earthquake and the later pair. They are obviously closely related in time and space but the 0254 hrs earthquake shows a dilatational arrival while many aftershocks show compressional arrivals as do the later pair. Except for one earthquake which occurred at the southern end of St. George's Channel in April, other notable earthquakes recorded from there in 1967 show compressions.

There are no detailed descriptions of faulting in the area. French (1967) presents geological evidence for tear faulting on a major scale in southern New Ireland on a NNW trend, while Fisher (1944) gives circumstantial evidence for normal faulting near the 1944 earthquake epicentre in the Warangoi-Keravat depression. Undoubtedly there is movement taking place between New Ireland and New Britain and it is possibly a zone of transcurrent faulting along a NNW trend. As Rabaul is in the north ~~east~~ west quadrant for any fault movements in the St. George's channel south of the Duke of York Islands, a dextral motion would give a compressional first arrival, and a sinistral motion a dilatational one.

However, to explain the whole complex of events in terms solely of tear faulting, it would be necessary to assume a change in direction of fault movement between the time of the first and second major shocks. This suggests that the faulting is probably not restricted to one type, but that both transcurrent and normal faulting may have occurred.

Fig 1.

NUMBER OF AFTERSHOCKS PER HOUR FOLLOWING THE EARTHQUAKE AT 1654 HOURS G.M.T. AUGUST 13, 1967.



RABAUL 1968.

Fig 2.

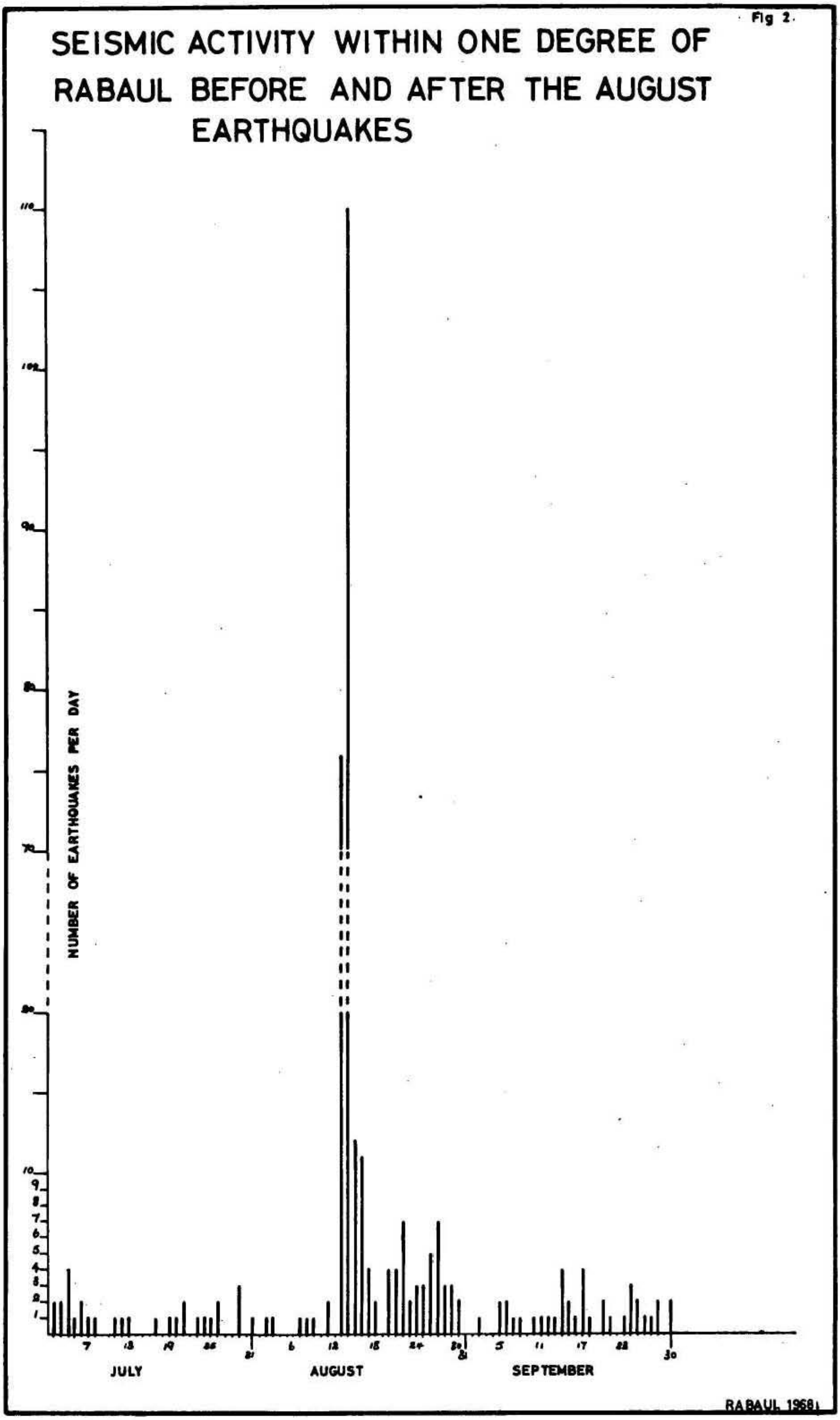
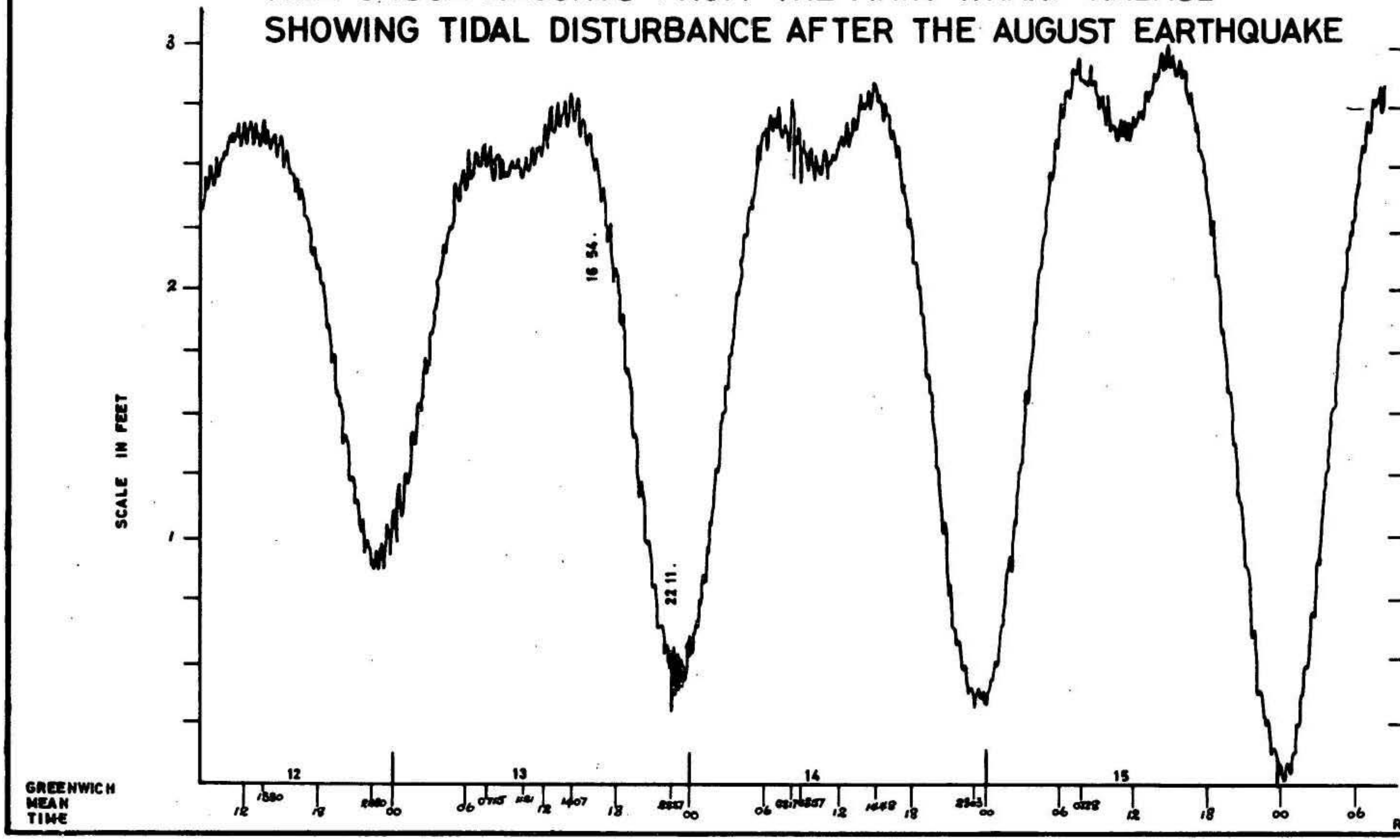

SEISMIC ACTIVITY WITHIN ONE DEGREE OF RABAUL BEFORE AND AFTER THE AUGUST EARTHQUAKES
NUMBER OF EARTHQUAKES PER DAY
JULY
AUGUST
SEPTEMBER
RABAUL 1968

Fig 3.

TIDE GAUGE RECORDS FROM THE MAIN WHARF RABAUL SHOWING TIDAL DISTURBANCE AFTER THE AUGUST EARTHQUAKE



RABAUL 1968.

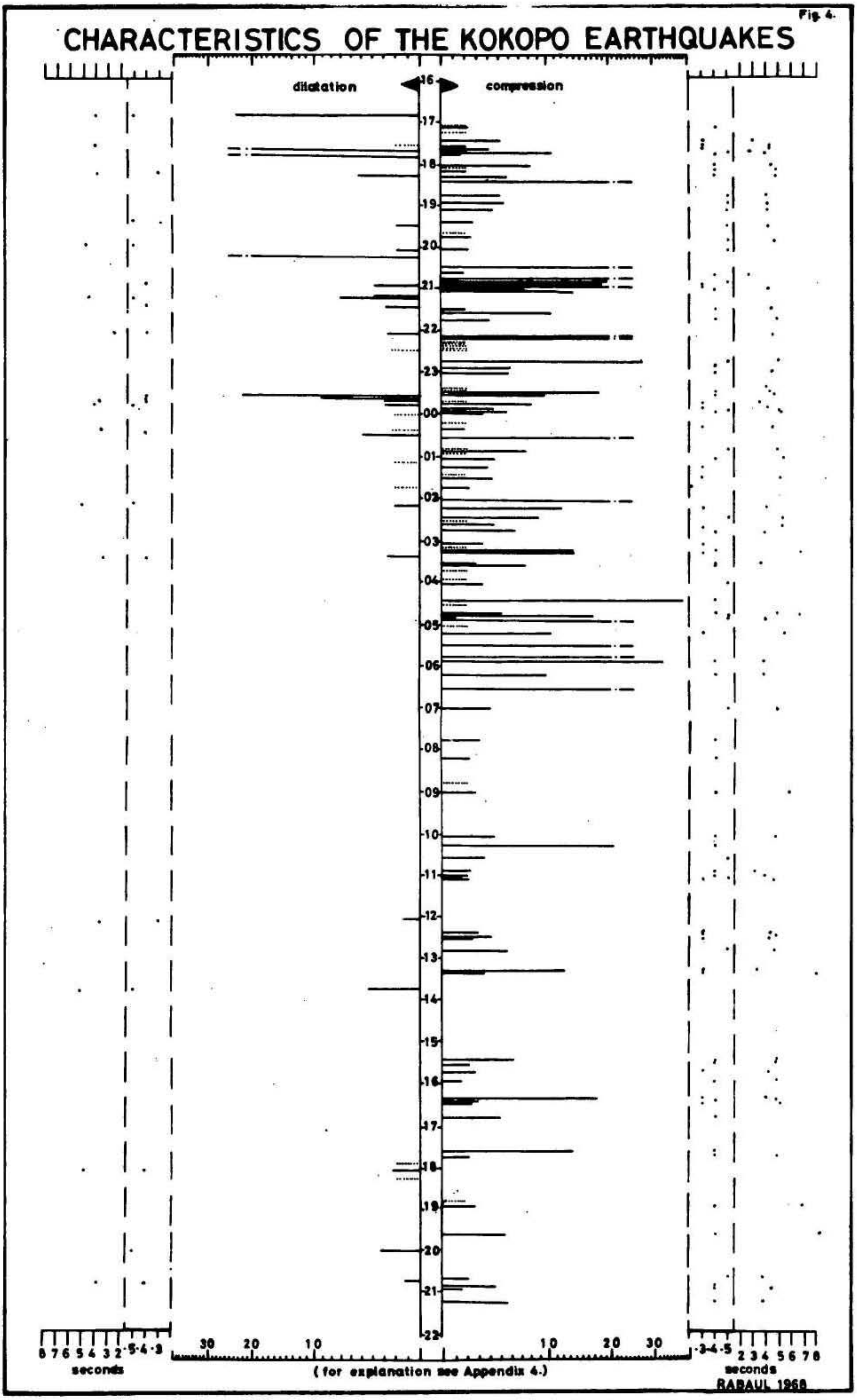


Fig. 4.
CHARACTERISTICS OF THE KOKOPO EARTHQUAKES
dilatation
compression
16
17
18
19
20
21
22
23
00
01
02
03
04
05
06
07
08
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20
21
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30 20 10
10 20 30
8 7 6 5 4 3 2 ·5 ·4 ·3
·3 ·4 ·5 2 3 4 5 6 7 8
seconds
(for explanation see Appendix 4.)
seconds
RABAUL 1968

EFFECTS OF THE EARTHQUAKES

INTRODUCTION

A noticeable feature of these earthquakes was the extent and shape of the meizoseismal area. The belt of maximum accelerations and damage was a thin strip twenty kilometres long and five to seven kilometres wide. The reduced effects of the earthquake outside this belt were quite marked.

Kokopo suffered very little damage to buildings while two kilometres away at Kalamangunan the damage included collapse of brick walls and the shifting of heavy objects such as combustion stoves. If the variation in intensity had resulted from the nature of the ground, greater damage would have been expected at Kokopo which has areas of pumice fill, yet it did not suffer as much damage despite the poor construction of many of the older buildings. The marked falling off of the intensity was probably caused by structural focussing of the energy.

Within the meizoseismal area, the accelerations were high, especially in the Vunapau and Kabaleo area. The Father in charge at Vunapau was thrown to the ground and could not regain his feet until the shaking had ceased. Others at Vunapau also said that they could stand but found walking almost impossible.

Some idea of the violence of the earthquake at Vunapau can be gained from its effects on a Volkswagen utility truck. The truck was kept in a shelter at Vunapau and, after the earthquake at 0815 hrs on the 14th August, the Father found the rear right hand side tyre torn off the rim and hanging over the axle, and a rectangular dent in the roof about ¼ inch deep. The roof of the garage was examined and some green paint from the roof of the truck was found on a beam. During the earthquake, the truck must have rocked sideways until the roof hit the beam and the side panel above the rear wheel knocked out one of the wooden supporting posts of the garage. The truck then fell back onto all four wheels and the tyre must have been pulled off at the same time. The accelerations were very high indeed and it is quite remarkable that both tyre and rim were undamaged.

The directions of movement of damaged buildings and of various other objects which were seen immediately after the earthquakes is plotted in Plate 17. The dominant directions are northwards and westwards. Shaking in the north-south direction lasted longer than in the east-west direction, probably 15 seconds N-S and 10 seconds E-W (Denham & Skinner 1967).

BUILDING DAMAGE

The writer visited the area of damage soon after the earthquake occurred. The area extended twenty kilometres from Gire Gire Plantation on the Taliligap road to Reiven Plantation on the coast, and was five to seven kilometres wide.

The most severe damage was found at Kabaleo and Vunapau, approximately three kilometres south of Vunapope, and in the nearby villages of Bitagalip and Livuan.

Total damage to buildings resulting from these earthquakes has been estimated at $172,000.

Vunapope

At Vunapope, most buildings suffered comparatively minor damage, but there were a few notable exceptions. A steel-framed storeshed at the western end of Vunapope was completely demolished. The failure of the structure occurred at the junctions of the columns with the cross-bracing and the entire building collapsed carrying the roof six to eight feet towards the north.

The most noticeable damage in the timber yards nearby was caused to the timber stacks which collapsed (Plate 4). The planks were laid on wooden beams supported on squat concrete piers. The piers were turned over, throwing the stacks northwards. In the workshops, some minor damage was caused to the timber frame structure, mostly owing to subsidence of the floor. A grinding tool on a high pedestal was thrown northwards and other machines, some very heavy ones, were also moved.

Kabaleo, Vunapau and the Surrounding Villages

The Kabaleo Teacher Training College and Vunapau Seminary suffered considerable damage and reports indicated intensities in this area of M.M. VIII. The surrounding villages also suffered considerable damage. All the buildings at Kabaleo and Vunapau were of timber frame construction: some, such as the school classrooms, set on concrete slabs; the others built on concrete posts rising 2½ feet above ground. The displacement of the majority of the buildings was northwards. A classroom at the northern end of the grounds, which was built up on concrete posts, showed evidence of 9½ inches of movement with a residual displacement of 3½ inches to the north. The Sisters' house (Plates 5 and 6) would have collapsed but for the anchoring effect of the large concrete base beneath the rear wing of the house. In all of the buildings with concrete slab foundations, the wooden stanchions jumped off their dowels and were moved as much as one foot from their original position (Plate 7) causing the buildings to be severely warped (Plate 8). Most of the dowels were only slightly bent unless they had been pulled out of the concrete, which would mean that the building was warped upwards as much as two or three inches before moving laterally.

The five classroom buildings on the western side of the college grounds were twisted so that the displacement was greatest at the western end. This could have been due to the slumping of uncompacted fill material in this area.

Severe damage occurred at Vunapau. The type of construction was the same as that at Kabaleo and was of a similar age. A heavy wooden altar was moved 18 inches southeastwards, and it took six men to return it to its original position. The church was of the same construction as the classrooms at Kabaleo and suffered the same type of damage. Again the dominant direction of movement was northwards.

At Bitagalip cocoa fermentery, only a few miles south of Vunapau, the heavy rotary drier was torn from its mountings in the concrete floor. Some lighter machinery was also shifted. All the movements were northwards. The church which is situated a little further south was virtually undamaged, except for some cracking of the concrete on the north western corner where the pumice fill had subsided.

A number of native material houses in Livuan village collapsed (Plate 9) and many others had to be demolished as they had been dangerously weakened. One house built after the European fashion collapsed completely and was moved towards the south (Plate 10). Its collapse resulted from the concrete piers not being set far enough into the ground.

Rainau, Makurapau and Malakuna

These three places sustained less severe damage than the Vunapau-Kabaleo area, but show typical features of the type of damage found in the area extending east and west of Kabaleo.

Much of the damage was to buildings of a unit type construction using stabilised earth or low quality concrete with insufficient reinforcement (Type D masonry - see Plate 11).

At Rainau Plantation, one house which was being constructed on concrete slabs collapsed like a house of cards because of the lack of reinforcement between the slabs. Another residence on the same plantation was severely damaged (Plates 12 and 13) and was eventually demolished. At Makurapau, where a similar type of construction was used, one labourer's quarters collapsed spectacularly(Plate 14). The walls failed completely allowing the very heavy roof to collapse, demolishing what remained of the walls almost to their foundations. An engine house nearby shows an early stage in the failure of this type of construction. (Plate 11). The plantation house at Makurapau was supported on piers made of shell cases filled with cement and set in the ground within a concrete base. Most of the bases remained firm, but some had moved east or west of their original positions and others which were resting on a concrete pavement were rotated clockwise through 30°.

The teacher's house at nearby Malakuna suffered only minor damage mainly owing to its sound construction and adequate cross-bracing. Heavy articles inside the house moved; the stove was knocked over and the refrigerator was moved 6 inches to the west. The corrugations at the base of a 1000 gallon corrugated iron water tank were flattened; a feature which was noted at many other places where the tanks were not knocked over.

Damage of the same order was found at many other places in this zone.

Damage Outside the Meizoseismal Area

Damage was comparatively light in reasonably well constructed buildings outside the meizoseismal area. Mr. Simpson's copra drier at Gilalaum near the Warangoi River was cracked and the wharf and storeshed at Rakanda, on the Duke of York Islands, were damaged. Otherwise damage was confined to furniture, ornaments and some older water tanks.

COMMENTS ON BUILDING DAMAGE

The damaged buildings were inspected by a number of engineers who pointed out many weak points in their construction. Mr. R.I. Skinner, Engineer Seismologist from the New Zealand Department of Scientific and Industrial Research, made a number of suggestions regarding building design which would result in more earthquake resistant buildings (Skinner & Denham 1967). The most common causes of damage were inadequate bracing in the building and poor foundations with minimal reinforcement. A lot of concrete work was also of poor quality.

OTHER SECONDARY EFFECTS

Many reports of landslides, slumping, cracking of the ground and water spouts reached the Central Observatory in Rabaul. As many as possible were investigated.

Slumping

One of the main effects of the shaking in Vunapope was the settling of sediment along the shore and just offshore. Timber columns at the western end of the workshops were left suspended three inches above the ground and in other parts of the workshops the concrete pavement had collapsed or cracked. The landward end of the wharf subsided by as much as six inches leaving some narrow guage railway lines suspended. A reinforced concrete arch, which spanned the wharf about twenty-five yards off-shore, was broken when the eastern column subsided nine inches and moved 6" towards the shore. A subsidence, 15 to 20 feet long by five feet wide and four or five inches deep, occurred at the side of the bitumen road which runs through Vunapope. There was also some slumping offshore, particularly at the Kokopo Garage where sediment slumped away leaving very deep water only ten yards from the beach.

Landslides

There were a large number of landslides from the vertical cut pumice cliffs alongside roads. The area particularly affected was Keravia Bay where the pumice cliffs are very high and steep (Plate 15), but many other roads in the same area were either blocked or obstructed by landslides. Engineers from the Commonwealth Department of Works estimate that 12,000 cubic yards of material fell in landslides in this area. At Chinaman's Creek near Vunapope, landslides brought approximately 20,000 cubic yards of pumice and ash into the narrow valley, completely blocking it. There were fears of a flash flood occurring after heavy rain, and warning signs were erected as a precaution, but no flooding occurred.

Tidal Effects

After the previous destructive earthquake in Rabaul in 1941, there were variations in sea level of up to one foot which went on for nearly four hours. (Fisher 1941). The tidal effects measured at Rabaul after the 1967 earthquakes were very small. The maximum height of the tidal rythmn was only four inches and the effects lasted for less than two hours. (Fig. 3). The disturbance followed the 0815 hrs earthquake only; no measurable disturbance followed the 0254 hrs earthquake.

Abnormal tides were reported from Kabanga after the 0815 hrs shock. The offshore reef appeared above the water for a short time and then the sea returned to its normal level.

Tilt Effects

Again, unlike the 1941 earthquake there was no noticeable effect on the tiltmeters. Movements through about 1 second of arc occurred, but these do not stand out from the equally large or larger movements normally recorded. Movements just before the earthquake indicated a rise to the east and to the south but both were small.

Sound Effects

Most of the noise that accompanied the earthquake was caused by creaking house frames and the noise of ornaments and other objects hitting the ground. (All reported effects, including intensities, are listed in Appendix 2). Some people reported various sounds described as sounding like the rolling of a galvanised iron tank, thunder, an explosion, and even the rumble of a goods train. These sounds were low pitched and seem to have been genuine earthquake sounds (Richter 1958) caused by the transfer of energy to the air.

At Rongamatane a rumbling sound was heard before the shaking began at 0254 hrs. The writer also noticed a sound which preceeded the shaking during one of the aftershocks on the 14th. There have been other recorded instances of a sound being heard before the shaking and it seems to be from energy transferred into the air from the P waves while only the later P and S waves, or, in the case of small aftershocks, possibly only the S waves are felt (Richter 1958).

CHANGES IN VOLCANIC ACTIVITY

Not all earthquakes in the area are directly connected with volcanic activity, although large volcanic earthquakes have been felt in Rabaul notably before the 1850, 1878, 1937 and 1941 eruptions in Blanche Bay. (Fisher, 1939; Latter, 1966). Their characteristics are fairly well known and they are usually felt over a small area. For instance, the severe volcanic earthquakes preceeding the 1878 eruption were barely felt in the Duke of York Islands (Latter, 1966).

The Kokopo earthquakes were not of volcanic origin. There were reports of a noticeable sulphurous smell at Kabanga and Put Put after 0800 hrs and warm springs were reported to have appeared in Kabanga Bay. At Kabanga some holes were found in the sandy sea floor but no water or gas was coming from them. They were caused by sand settling into holes in the reef after the earthquake.

The sulphurous smells reported from Kabanga and Put Put only lasted for a short while. At Kabanga, no source for the smell was found and it was decided that it could have come from the disturbing of rotting vegetation and mud in the pools behind the beach bar. Septic tanks could be another source of the smell.

There were no changes in any of the Blanche Bay volcanoes after the earthquake. In Tavurvur some loose rubble fell down over vent No. 8 and it was not possible to take any temperatures until the gas found another outlet. No fluctuations in temperature were recorded at any of the other measuring points.

SEISMIC HISTORY OF THE AREA AND THE PERIODICITY OF LARGE EARTHQUAKES

Fisher (1941) lists seven earthquakes of intensity Rossi-Fore P VIII (Modified Mercalli VII) which are known to have been felt in Rabaul. They were in 1916, 1919, 1923, 1927, 1933, 1937 and 1940.

A number of earthquake epicentres occur close to Rabaul and a number are listed by Latter (1966), some of which were felt at Rabaul at

Intensity M.M. IV or V. Since 1950, when observations were resumed in Rabaul, large earthquakes or earthquake swarms, with epicentres close to Rabaul have been recorded on a number of occasions. The most notable of these was on the 24th and 25th December 1952 when a series of earthquakes were felt in the Rabaul and Kokopo areas at Intensities M.M.VI or M.M.VII. Landslides occurred and some damage, especially to water tanks was reported.

Brooks (1965), in his comprehensive treatment of Territory earthquakes, is the best published source of information on the periodicity of earthquakes and general earthquake risk in the area. Brooks compiled a number of maps from the available information delineating zones showing the frequency of large earthquakes and high intensities. From these it is obvious that eastern New Britain, southern New Ireland and parts of Bougainville are the most active seismic areas in New Guinea. Statistically, there is a high probability of an earthquake of Intensity M.M.IX in the Gazelle Peninsula area once in every period of twenty five years; and one of Intensity M.M.X every century.

St. George's Channel is the locus of epicentres of frequently occurring shallow earthquakes which are sometimes very large. Two earthquakes with a magnitude on the Richter scale greater than 7 occurred in this area between 1910 and 1962.

Immediately to the west and north of Rabaul is an area in which earthquakes occur at an intermediate depth, (there was an earthquake during June, 1967 at a depth of 155 kilometres with an epicentre near Keravat). Further to the north is a zone of even deeper earthquakes with hypocentres up to 400 kilometres deep. Many of these deep and intermediate depth earthquakes are felt in Rabaul, but usually at low intensities. Earthquakes which can be expected to cause extensive damage in the future are most likely to have their epicentres located in St. George's Channel.

Rabaul,

July, 1968.

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APPENDIX 1

PRELIMINARY COMPUTATION OF EPICENTRES AND ORIGIN TIMES OF THE KOKOPO EARTHQUAKES USING STANDARD TRAVEL TIME TABLES+

EARTHQUAKE AT 1654 G.M.T. (0254 E.S.T.)

Station		Arrival Times			S-P	P-O	Origin Time	T-O	Distance
RAB	iP	16	54	53.0d	4.0	6.5	16 54 47	10	0.46^{o}
	i(S)			57					
RAL	iP	16	54	52.(8)d					
SUL	iP	16	54	52.7d					
WAN	iP	16	54	52.5d					
PMG	eP	16	56	34	1-26.4	1-51.9	16 54 42	1-51	7.59^{o} *
	iS		58	00.4					
WAU	eP	16	56	02				1-19	5.31^{o} *
HNR	eP	16	56	59	1-37.0	2-05.2	16 54 54	2-16	9.39^{o} *
	eS		58	36					
ESA	eP(N)[1]	16	56	08	1-06.0	1-25.5	16 54 42	1-25	5.73^{o} *
	iS(N)[1]		57	14					
AGE	eiP	16	56	15½	1-10.5	1-31.3	16 54 44	1-32½	6.26^{o} *
	i(S)[2]		57	26					
GRK	eP	16	56	38				1-55	7.88^{o} *
CTA	iP	16	58	41.2	3-08.8	4-01	16 54 40	3-58.2	17.1^{o}
	iS		01	50					
BRS	iP	16	59	50.3	4-07.7	5-08	16 54 42.3	5-07.3	23^{o}
	iS		03	58					

RABAUL OBSERVATORY ADOPTED ORIGIN TIME: 16 54 43 EPICENTRE: $4\frac{1}{4}^{o}$S $152\frac{1}{2}^{o}$E

AZIMUTH FROM RABAUL: 107^{o}

U.S.C.G.S.	ORIGIN TIME	16 54 45.7 (29 stns).
	EPICENTRE	4.33S 152.47E
	DEPTH	25 km ± 6.1 kms.
	MAGNITUDE	MB 5.0 (6 stns).
P.M.G.	MAGNITUDE	ML 6.2

EARTHQUAKE AT 2211 G.M.T. (0811 E.S.T.)

Station		Arrival Times			S-P	P-O	Origin Time			T-O	Distance
RAB	iP!	22	11	20c	4¼	6½	22	11	14	08	0.32°*
	iS			24½							
RAL	iP	22	11	19.0c							
SUL	iP	22	11	19.2c							
WAN	iP	22	11	19.4c							
PMG	eP	22	13	01	1-26	1-51.3	22	11	09.7	1-49	7.44° *
	eS		14	27							
WAU				No reading							
HNR	eP	22	13	25	1-55	2-28	22	10	57	2-13	9.17° *
	eS		15	20							
ESA				No reading							
AGE	iP	22	12	44½	1-07	1-26.7	22	11	17.8	1-32	6.23° *
	i(S)²		13	51½							
CTA				No reading							
BRS	iP	22	16	17.6						5-05	23°

RABAUL OBSERVATORY ADOPTED ORIGIN TIME: 22 11 12 EPICENTRE: 4¼°S 152½° E

AZIMUTH FROM RABAUL: 98°

U.S.C.G.S. ORIGIN TIME 22 11 12.8 (10 stns)

EPICENTRE 4.44S 152.36E

DEPTH 30 kms ± 6.3 kms

MAGNITUDE MB 4.7 (1 stn)

P.M.G. MAGNITUDE No magnitude computed.

EARTHQUAKE AT 2215 G.M.T. (0815 E.S.T.)

Station		Arrival times			S-P	P-O	Origin Time	T-O	Distance
RAB	iP	22	15	18c				10	0.46°
RAL	iP	22	15	14.6c					
SUL	iP	22	15	14.8c					

EARTHQUAKE AT 2215 G.M.T. (0815 E.S.T.) Cont.

Station		Arrival Times			S-P	P-O	Origin Time			T-O	Distance
WAN	iP	22	15	(15.0)c							
PMG	eP	22	16	58	1-21	1-45.0	22	15	13	1-50	7.51°
	eS	22	18	19							
WAU				No reading							
HNR				No reading							
ESA	iP	22	16	30.2	1-00.2	1-18	22	15	11.9	1-20	5.38°
	i(S)		17	30							
AGE	iP	22	16	39	1-10.5	1-30.7	22	15	08.2	1-31	6.16°
	i(S)²		17	49½							
GRK	eP	22	17	01						1-53	7.73°
CTA	iP	22	19	03.8	3-07.2	4-01	22	15	03	3-56	16¼°
	iS		22	11							
BRS	iP	22	20	13.2	4-05	5-05	22	15	08	5-05	23°
	iS		24	18							

RABAUL OBSERVATORY ADOPTED ORIGIN TIME: 22 15 08 EPICENTRE: Not Determined

NO AZIMUTH OBTAINABLE

U.S.C.G.S.	ORIGIN TIME	22 15 09.6 (36 stns)
	EPICENTRE	4.37S 152.51E
	DEPTH	29 kms ± 4.9 kms
	MAGNITUDE	MB 5.3 (8 Stns)
P.M.G.	MAGNITUDE	ML 6.4

NOTES

1.	Only records from horizontal instruments available.
2.	Read from Willmore vertical instrument.
*	Used to determine epicentre
+	For near stations Eiby and Muir's Travel Time Curves were used, and Jeffrey and Bullen Seismological Tables for stations over 10° from Rabaul viz. Charters Towers and Brisbane.

List of Station Abbreviations:-

RAB	RABAUL	
RAL	RABALANAKAIA	RABAUL HARBOUR NETWORK
SUL	SULPHUR CREEK	RABAUL HARBOUR NETWORK
WAN	WANLISS STREET	RABAUL HARBOUR NETWORK
PMG	PORT MORESBY	
WAU	WAU	
HNR	HONIARA	
ESA	ESA'ALA, D'ENTRECASTEAUX ISLANDS	
AGE	AGENAHAMBO, POPONDETTA	
GRK	GOROKA	
CTA	CHARTERS TOWERS	
BRS	BRISBANE	

WAU and GRK were temporary seismic stations and are no longer occupied.

U.S.C.G.S. United States Coast and Geoldetic Survey.

Information on the major earthquakes was obtained from EDR 51-67, 54-67 and 59-67.

APPENDIX 2

LIST OF REPORTED INTENSITIES, DIRECTION AND OTHER NOTABLE FEATURES OF THE KOKOPO EARTHQUAKES, AUGUST 14TH, 1967

EARTHQUAKE AT 1654 G.M.T. (0254 E.S.T.)

Locality	Modified Mercalli	Direction	Nature of Motion and Duration	Extent of Damage	Sounds	Other Features	Comments
RABAUL	V	SE-NW	Rapid motion (25 secs)	Some water tanks and ornaments damaged and broken	Rumbling like thunder	-	Many houses escaped without any damage or ornaments falling over.
KOKOPO	VI	-	Rapid	-	From north	-	-
KOKOPO PRIMARY SCHOOL	VI	E-W	Rapid	Furniture overturned	-	-	-
VUNADIDIR LOCAL GOVERNMENT CENTRE	VI	-	Rapid	Moved heavy furniture, split water tank	Like heavy trucks from SE	-	-
VUNADIDIR MISSION	V	-	Rapid	Knocked some books over	-	-	Large number of unstable objects were not knocked over.
RUM JUNGLE PLANTATION, UPPER WARANGOI	V or VI	-	Rapid (10 secs)	Ornaments and books knocked over	-	Difficulty in standing	-
BUBUANA PLANTATION, UPPER WARANGOI	VI	-	Rapid	Overturned furniture, cracked an uncompleted wall	Like galvanised iron tank rolling. Sound came from below	-	-
KRAKENBAK PLANTATION, UPPER WARANGOI	V	-	Rapid (120 secs)	None	Like thunder	Reported slight ground waves	-
RONGAMATANE PLANTATION, UPPER WARANGOI	V	Circular	Slow (35 secs)	Small objects overturned	Underground rumble from N lasted for 10 secs prior to shaking	-	-
MALABUNGA, KERAVAT VALLEY	V	(E-W)?	Rapid (60 secs)	Some leaking tanks	-	-	-
MALAKUNA T SCHOOL	VI	(E-W)?	Rapid	Slight damage	Slow like rolling thunder	-	-
C.B. PLANTATION	VI	-	Slow	-	-	Some damage. No mention of when it occurred	-
TOMARINGA POLICE STATION	V	SE-NW?	Rapid	One pipe broken	(Noise like bomb at 5am)	Walked with difficulty	-
KERAVAT HIGH SCHOOL	V	-	Rapid (120 secs)?	Damaged some water pipes	-	-	-
VARZIN PLANTATION	V or VI	-	Rapid	Wardrobes knocked over	-	-	-
CLIFTON PLANTATION, UPPER WARANGOI	V or VI	SW-NE	-	(Old tanks broken, pipes snapped off)	-	-	Damage was not discovered until after 8.15 earthquake
GILALUM PLANTATION, WARANGOI	VI	SW-NE	-	Refrigerator and glassware knocked over	-	-	-

EARTHQUAKE AT 1654 G.M.T. (0254 E.S.T.) Continued

Locality	Modified Mercalli Intensity	Direction	Nature of Motion and Duration	Extent of Damage	Sounds	Other Features	Comments
KIEP PLANTATION, WIDE BAY	II	-	-	-	-	-	-
ULAMONA MISSION	II	N-S	30-40 secs	-	-	-	-
POMIO S.D.O.	III?	N-S	-	-	-	-	-
TALASEA	Not felt						
CAPE HOSKINS	Not felt						
MOLOT, DUKE OF YORK ISLANDS	IV or V	-	15-20 secs	-	-	-	-
NAMATANAI, NEW IRELAND	IV	-	Rapid 20 secs	-	-	-	-
SURSURONGA P.T.S. NEW IRELAND	IV or V	E-W	15 secs	Books knocked over	Thunder noise from E	-	-
LAMBON P.T.S., NEW IRELAND	IV	-	Rapid	-	Sound heard	-	-
TUBUWANA P.T.S., NEW IRELAND	III	E-W	Slow 3 secs	-	Rolling noise like galvanised iron tank	-	-
METLIK PLANTATION, NEW IRELAND	V	-	-	Nil	-	-	-
SOHUN, NEW IRELAND	IV	N-S	Rapid (150 secs)?	Nil	Noise like rolling of galvanised iron tank	-	-
LONDOLOVIT, LIHIR ISLAND	II or III	S-N	127 secs ?	-	-	-	-
NOIPUOS P.T.S., NEW HANOVER	Not felt						
TASKUL, NEW HANOVER	Not felt						
TINPUTZ, BOUGAINVILLE	Not felt						
BOKU, BOUGAINVILE	Not felt						
BUIN, S.D.O., BOUGAINVILLE	Not felt						
MAKUNAI	Not felt						
HIRE VILLAGE, BOUGAINVILLE	II or III	E-W	Slow 60 secs	Nil	Sounds like rolling of galvanised iron tank	-	-
SOHANO, BOUGAINVILLE	IV	N-S	Rapid (150 secs)?	Nil	Noise from S like rolling of galvanised iron tank		

EARTHQUAKES AT 2211 AND 2215 G.M.T. (0811 AND 0815 E.S.T.)

Locality	Modified Mercalli Intensity	Direction	Nature of Motion and Duration	Extent of Damage	Sounds	Other Features	Comments
RABAUL (0811)	IV	E-W	Rapid	-	-	-	-
RABAUL (0815)	VI or VII	E-W	Rapid	Unstable objects knocked over, tanks broken	-	-	-
MOLOT, DUKE OF YORK ISLANDS	VI	-	10 secs	Damage to Molot Wharf and Rakanda Wharf, structural damage to copra dryer shed	-	-	-
BUTLIVUAN, DUKE OF YORK ISL.	V or VI	SE-NW	Rapid 10 secs	Unstable objects and water tanks, knocked over	Sounds like thunder SE-NW	-	-
KOKOPO PRIMARY SCHOOL	VII	-	Rapid 30 secs	Overturned furniture	Souns like rolling galvanised iron tank from E.	-	-
KOKOPO S.D.O.	VII	N-S	Violent 30 secs	Considerable structural damage to some buildings	Sounds like rolling galvanised iron tank from N.	-	Reported ground waves knocked over some trees and bushes.
RUM JUNGLE PLANTATION, UPPER WARANGOI	V	NE-SW	Rapid	Unstable objects overturned	Noise like goods train approaching from north	-	-
RONGAMATANE (0811)	V	-	Slow 12 secs	-	-	-	-
RONGAMATANE (0815)	V or VI	N-S	Slow 20 secs	Unstable objects overturned	-	Reported trees fell over in forest	-
VUNADIDIR LOCAL GOVERNMENT CENTRE	VII	-	Slow 30 secs	Tanks and windows broken	Sounds like truck 10 secs	Ground waves reported. Difficulty in standing.	-
MALABUNGA	V or VI	Some vertical movement	Rapid (60 secs)	Overturned unstable objects	Subdued rumble from E.	-	-
CLIFTON PLANTATION, UPPER WARANGOI	-	-	-	-	-	-	-
GILALUM, WARANGOI (0811)	VII	-	-	Damaged structure of copra dryer	-	-	Did not differentiate between 0811 and 0815 shocks. Reported bigger shock at 0830.
C.B. PLANTATION, WARANGOI	VII	-	Rapid	Slight structural damage, pipes broken, overturned furniture	Like heavy rain storm	Seiche in pond - NE-SW, difficulty in walking	-
KERAVAT HIGH SCHOOL	V	-	Rapid 30 secs	Underground pipes broken	-	-	-
TOMARINGA POLICE STATION	V - VI	SE-NW	Rapid	Water pipes broken	-	People walked with difficulty	-
NAPAPAR, KERAVAT ROAD	V	-	Rapid 30 secs	-	-	-	-
VARZIN PLANTATION	VI	E-W	Rapid	Furniture overturned	-	Difficult to keep balance	-
POMIO S.D.O. (0815)	IV	N-S	20 secs	-	-	-	-

EARTHQUAKES AT 2211 AND 2215 G.M.T. (0811 AND 0815 E.S.T.) Continued

Locality	Modified Mercalli Intensity	Direction	Nature of Motion and Duration	Extent of Damage	Sounds	Other Features	Comments
ULAMONA MISSION (0811)	II	N-S	2-3 secs	-	-	-	-
ULAMONA MISSION (0815)	III	N-S	20 secs	-	-	-	-
LODOLOVIT (0811)	III	S-N	,(140 secs)	-	-	-	-
LODOLOVIT (0815)	III or IV	S-N	(225 secs)	-	-	-	-
METLIK PLANTATION, (0811) NEW IRELAND	III or IV	-	-	-	-	-	-
METLIK PLANTATION, (0815) NEW IRELAND	VI	-	-	-	-	-	-
SURSURUNGA P.TS., NEW IRELAND	IV or V	E-W	Rapid	Books fell over	Thunder sound from east	-	Mentions 2.56 and 8.15 earthquake, does not differentiate effects.
NAMATANAI	No report						
KIEP PLANTATION	III	-	-	-	-	-	-
TINPUTZ, BOUGAINVILLE	Not felt						
NOIPUOUS, P.T.S., NEW HANOVER	Not felt						
TASKUL, NEW HANOVER	Not felt						
TALASEA	Not felt						
CAPE HOSKINS	Not felt						

APPENDIX 3

INSTRUMENTATION AT RABAUL (as at August 1967)

	Comp.	To	Tg	Trace Speed mm/min	Approximate Relative Magnification	Approximate Damping
World-Wide	Z	1.0	0.74	60	12,500	critical
Standard Set	N,E	1.0	0.74	60	6,250	critical
	Z/N/E/	15.0	110.0	15	750	critical
Benioff VR 14.7Kg*	Zhr	1.0	0.02	180+	4,000	critical
Omori 15Kg	No	3.6	-	24	12	10:1 air
Omori 15Kg	Eo	3.8	-	24	10	10:1 air

RABAUL HARBOUR NETWORK Signals Telemetred by land line to Helicorders at the Rabaul Observatory.

	To	Tg	Trace Speed	Magnification	Damping
WAN Benioff VR 14.7Kg	1.0	0.02	60	24,000 at 4Hz	critical
SUL " "	1.0	0.02	60	6,000 at 4Hz	critical
RAL " "	1.0	0.02	60	24,000 at 4Hz	critical

STATION CO-ORDINATES

	Latitude	Longitude	Elevation (Metres)	Foundation
RABAUL	04°11'28.6"	152°10'11.4"	183.5	Basalt Flow
WANLISS	04°11'39.6"	152°10'32.5"	25.0	Basalt Flow
SULPHUR CREEK	04°13'09.8"	152°10'33.3"	08.5	(Unconsolidated (Volcanic Ash
RABALANAKAIA	04°13'13.0"	152°12'07.0"	91.0	

* The recorder is triggered by the onset of any earthquake with a predetermined minimum amplitude, and stopped automatically on reaching the hour break.

APPENDIX 4
MAINSHOCK AND AFTERSHOCK CHARACTERISTICS
KOKOPO EARTHQUAKES 14TH AUGUST, 1967

Time of Earthquake G.M.T.	S-P Interval	Period of P waves	Double trace amplitude of P waves	Ground Motion
13.8.67				
165453.0	4.0	0.5	23.0	d
1702	-	-	-	-
170340.4	-	-	-	c
171009.0	-	0.4	2.0	c
1713	-	-	-	-
171734.0	-	-	-	c
1719	-	-	-	-
172814.6	3.0	0.3	5.0	c
173252.7	4.0	-	-	d
173633.0	4.2	0.3	2.0	c
173928.6	4.4	0.3	4.0	c
174150.0	-	-	-	c
174357.5	-	-	!	d
174520.4	(2.6)	0.5	11.6	c
174823.5	3.9	0.4	1.5	c
175155.0	-	-	!	d
180405.5	4.5	0.4	8.0	c
180846.0	-	-	-	c
181204.2	4.8	0.4	2.0	c
181628.3	3.9	0.3	5.2	d
181727.6	4.8	0.4	5.7	c
182540.0	-	-	!	c
184445.5	4.0	0.5	5.0	c
190413.7	5.2	0.5	4.4	c
1916	-	-	-	-
192047.9	4.3	0.5	2.8	c
192702.8	-	0.5	1.8	d
1935	-	-	-	c
193938.3	4.7	0.5	2.4	c
1959	-	-	-	-
200354.8	-	0.5	2.1	c
200727.0	4.9	0.5	1.8	d
201414.4	3.6	-	!	d
202820.4	-	-	!	c
203442.2	(2.7)	0.4	1.8	c
2042	-	-	-	-
204303.4	-	-	!	c
204619.0	-	0.5	19.5	c
204904.4	-	0.3	18.4	c
205059.9	-	-	!	c
205707.4	-	0.4	3.8	d
210106.0	-	0.3	7.4	c
210229.4	4.2	0.4	13.8	c
211435.4	-	0.6	3.8	d
211540.5	4.5	0.5	7.0	d
212514.8	-	0.4	2.8	d
212930.2	4.4	0.4	1.8	c
213408.5	4.0	0.5	10.4	c
214951.0	4.4	0.4	4.0	c

Time of Earthquake G.M.T.	S - P Interval	Period of P waves	Double trace amplitude of P waves	Ground Motion
13.8.67				
220903.2	-	0.4	2.6	d
211120.0	4.5	-	-	c
2115	-	-	-	c
2220	-	-	-	c
2222	-	-	-	c
2223	-	-	-	c
2224	-	-	-	-
2226	-	-	-	c
2227	-	-	-	c
2228	-	-	-	c
2230	-	-	-	d
2241	-	-	-	-
2243	-	-	-	-
224959.0	5.0	0.5	27.0	c
225423.0	-	0.4	6.0	c
2257	-	-	-	-
230255.6	4.4	0.4	5.9	c
232740.5	(4.0)	-	-	c
2329	-	-	-	c
233008.5	4.4	0.4	18.0	c
233445.8	4.7	0.4	9.7	c
233745.0	-	0.4	21.8	d
233933.0	-	0.4	9.0	d
234205.2	3.8	0.4	2.7	d
234244.8	-	-	-	c
234545.0	3.5	0.3	8.1	c
234831.4	4.1	0.5	2.8	d
235128.8	4.2	0.3	4.2	c
235247.0	-	-	-	c
235725.0	5.0	0.5	5.5	c
235917.8	(5.2)	0.4	3.2	c
000255.9	-	-	-	d
0011	-	-	-	-
001419.0	-	-	-	c
002229.0	4.5	0.3	1.8	c
002742.2	3.6	-	-	d
003134.7	-	0.4	4.8	d
003501.5	-	-	!	c
0041	-	-	-	-
005131.5	-	-	-	c
005454.9	4.7	0.5	7.3	c
0058	-	-	-	c
14.8.67				
010721.0	5.4	0.4	4.5	c
011413.5	-	-	-	(d)
011850.8	-	0.3	3.8	c
0128	-	-	-	c
013206.9	5.1	0.3	5.1	c
0146	-	0.2	2.1	c
0147	-	-	-	d
020502	-	-	!	c
021341.7	5.1	0.5	2.0	d
021748.9	3.9	0.3	11.9	c

Time of Earthquake G.M.T.	S- P Interval	Period of P Waves	Double trace amplitude of P waves	Ground Motion
022736.6	5.4	0.5	9.0	c
023607.0	-	-	-	c
024035.2	5.4	0.3	4.3	c
024605.2	3.7	0.4	6.2	c
030551.4	-	0.3	3.3	c
031302.0	-	-	-	c
031532.0	-	0.4	13.6	c
031935.3	6.7	0.3	13.4	c
032649.1	3.4	0.4	2.5	d
033353.4	3.6	0.4	2.7	c
033558.4	-	0.4	7.3	c
034537.3	-	-	-	c
035808.0	-	-	-	c
040428.8	4.7	0.5	3.3	c
0413	-	-	-	-
042718.0	-	0.4	38.0	c
0437	-	-	-	c
044419.5	4.9	0.4	5.0	c
044720.4	6.6	0.5	16.8	c
045115.1	(3.9)	0.5	1.0	c
045224.8	-	-	!	c
050243.0	-	-	-	c
051526.8	5.5	0.3	10.2	c
053359.6	-	-	!	c
054815.5	-	-	!	c
055250.0	3.7	0.4	32.0	c
061457.4	3.6	0.4	9.8	c
063501.0	-	-	!	c
070114.9	4.8	0.5	4.0	c
074619.5	-	0.4	3.0	c
081101.2	-	0.4	2.2	c
0815	-	-	-	-
0847	-	-	-	c
090206.2	5.8	0.4	2.8	c
100428.9	4.7	0.4	4.3	c
1007	-	-	-	-
101859.5	-	0.4	20.0	c
103418.0	-	0.5	3.6	c
105242.0	3.2	0.4	2.2	c
110040.3	3.9	0.4	2.0	c
110203.0	-	0.5	1.6	c
110443.2	4.6	0.3	2.2	c
111301.0	5.0	0.5	1.0	c
120521.0	4.2	0.3	1.2	d
122338.0	4.4	0.3	3.0	c
122812.2	4.8	0.3	4.0	c
122901.6	4.4	0.3	2.4	c
124824.0	4.6	0.5	5.5	c

Time of Earthquake G.M.T.	S-P Interval	Period of P waves	Double amplitude of P waves	Ground Motion
131535.0	3.4	0.3	12.2	c
131816.8	8.0	0.3	3.4	c
1341	-	-	-	-
134221.6	5.2	0.5	4.2	d
152832.7	4.9	0.4	6.2	c
153554.1	4.8	0.4	2.2	c
154422.1	4.2	0.3	2.8	c
155737.1	4.8	0.4	1.4	c
161842.0	4.0	0.3	17.4	c
162242.2	4.8	0.4	3.0	c
162805.2	5.2	0.3	2.4	c
164811.4	-	0.3	5.0	c
173858.4	-	0.4	13.6	c
174510.5	4.9	0.4	2.0	c
175359.4	-	-	-	d
180747.4	4.8	0.4	2.2	d
181505.2	-	-	-	d
1849	-	-	-	c
185859.6	6.1	0.4	2.8	c
193721.0	8.1	0.4	5.5	c
200811.6	-	0.5	3.4	d
204127.9	3.7	0.5	2.2	c
204356.9	3.9	0.4	1.2	d
205134.4	-	0.3	4.8	c
205707.6	4.5	0.3	1.7	c
212048.4	3.8	0.3	5.8	c
222931.4	-	-	7.1	c

( ) Uncertain reading

! Large amplitude

- Information not available due to overlapping traces, faint traces or microseismic background.

Most of the information in this Appendix is shown graphically in Figure 4.

The central column in the diagram shows the time in GMT and covers the period from 1600 GMT on the 13.8.67 to 2200 G.M.T. on the 14.8.67. All information for earthquakes with compressional arrivals is shown on the right hand side and for dilatational arrivals on the left. Double trace amplitude is expressed in millimetres and plotted on a logarithmic scale. The dotted line symbol is used for an earthquake with an unknown amplitude, while earthquakes with a large amplitude which was impossible to measure (due to overlapping or fading traces) are shown by a line 20 mm in length with an exclamation mark at the extremity.

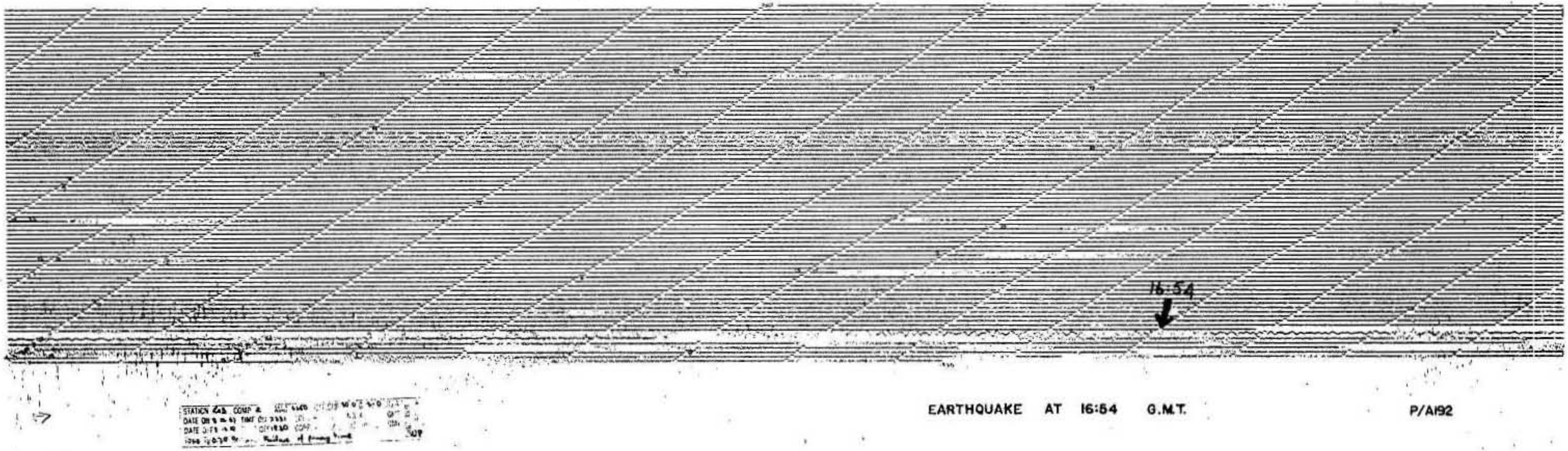
The second column has a scale in tenths of a second and in it are plotted the period of the P waves, while the last column shows the S - P interval in seconds.

The incidence of compressional arrivals is very much larger than dilatational ones, especially after 0400 GMT when they stop occurring until 1200 GMT.

The S-P interval for earthquakes with compressional arrivals vary between 3 and 5 seconds until 0300 GMT after which they begin to spread. A faint cyclical pattern is discernible during the first eleven hours. Each cycle has an amplitude range of two seconds and a period of about three hours. No corresponding pattern is found in the amplitudes, but the larger S - P intervals do sometimes correspond with periods of 0.5 seconds.

No clear pattern exists among the dilatational arrivals. The majority of S-P intervals are 5 seconds. Compared with the compressional arrivals whose period varies from 0.3 to 0.5 seconds, most of the dilatational ones have a period of 0.4 seconds.

PLATE I



EARTHQUAKE AT 16:54 G.M.T.

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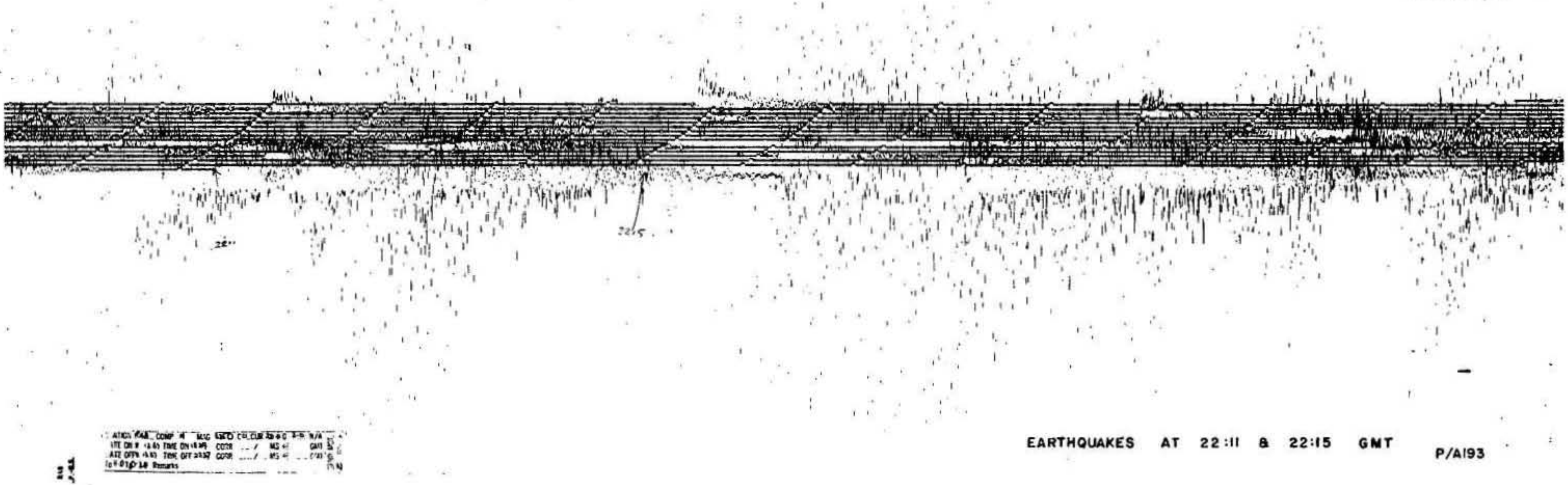
PLATE II



EARTHQUAKES AT 22:11 & 22:15 GMT

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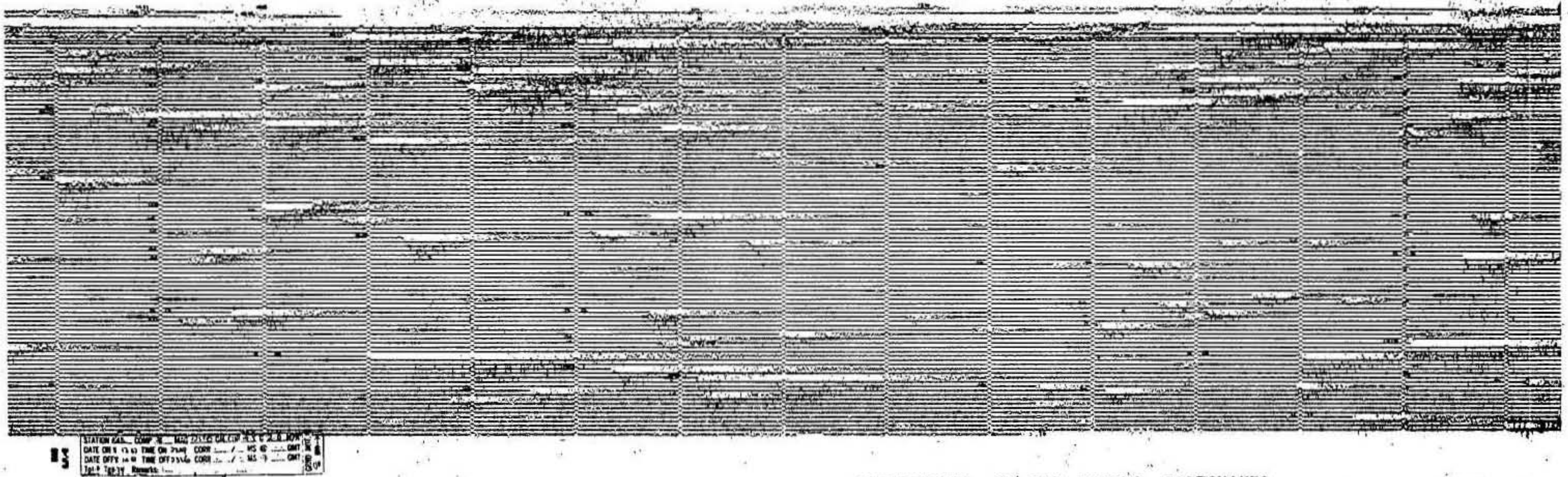
PLATE III



AFTERSHOCKS OF THE KOKOPO EARTQUAKES

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Plate 4: Collapsed timber stacks, Vunapope.

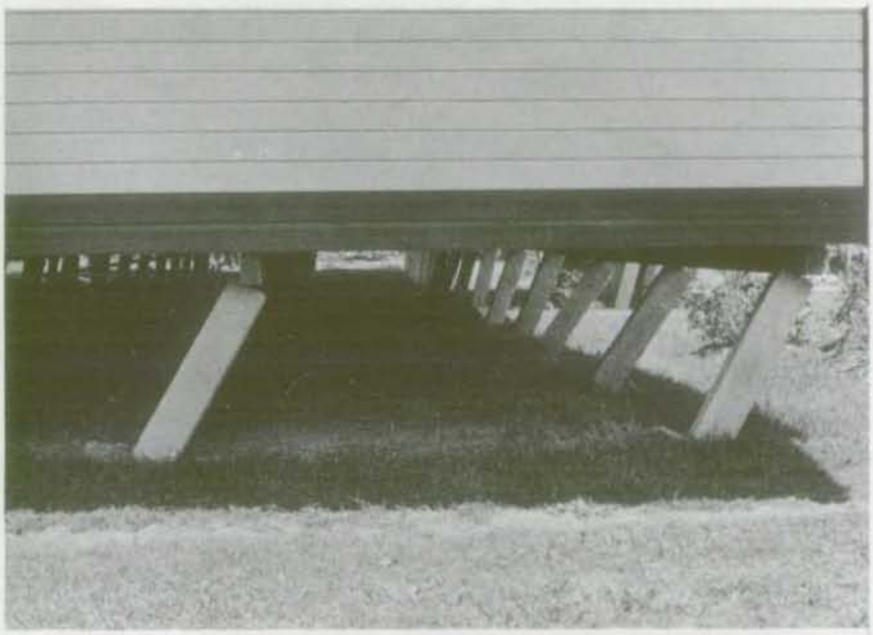

Plate 5: Damage to sister's house, Kabaleo

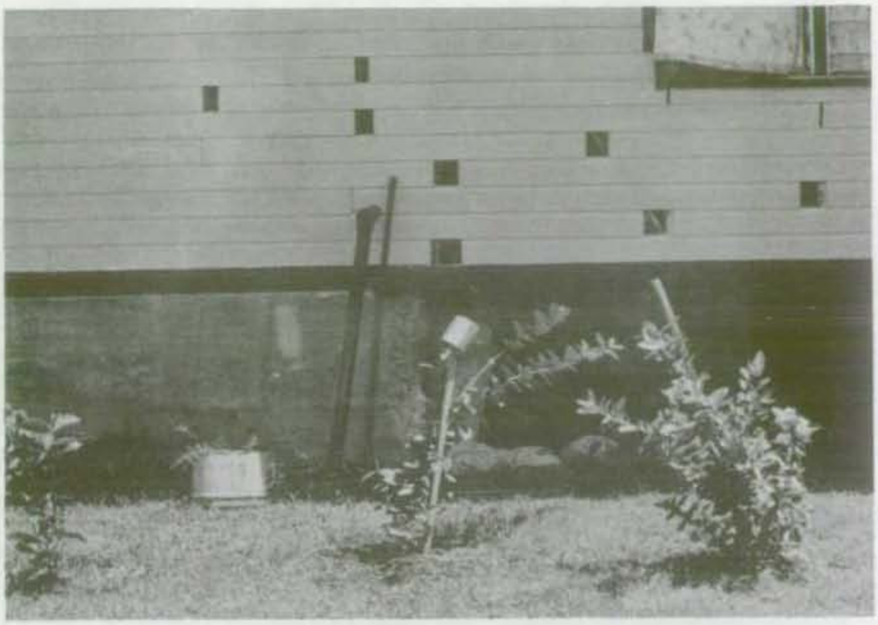

Plate 6: Detail showing how sister's house is held by concrete pier beneath rear wing.

Plate 7: Shifting of frame from foundations in dormitory block, Kabaleo. Note method of construction and fixing of frame to the foundation.

Plate 8: Shifting of wooden frame from foundation dormitory block, Kabaleo. Note warping and distortion of the building.

Plate 9: Collapse of village house, Livuan.

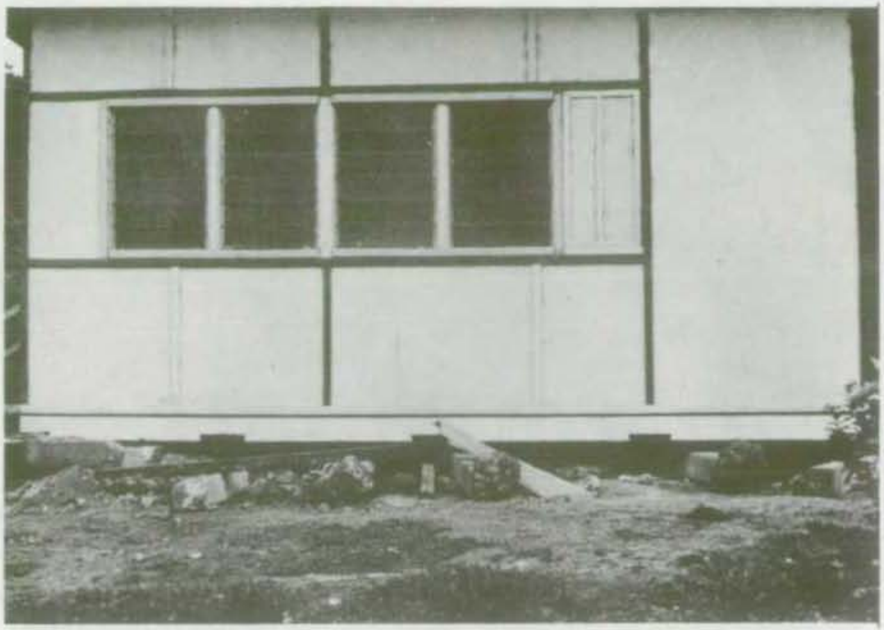

Plate 10: Collapse of piers under house, Livuan.
Note depth of burial of piers.

Plate 11: Early stage in failure of concrete walls built by unit method. Note the absence of reinforcing, Makurapau.

Plate 12: Collapse of concrete walls in half timbered building, Rainau.

Plate 13: Same as above showing how the poor quality concrete has crumbled.

Plate 14: Complete collapse of same type of concrete structure seen in Plate 11.

Plate 15: Clearing operations at one of the bigger landslides at Keravia Bay.

Plate 16: Burst 10,000 gallon water tank,
Makurapau.