Assessment of the Port Vila Earthquake Vanuatu 2nd January 2002

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CONTENTS

SUMMARY

The largest earthquake recorded to date in the vicinity of Port Vila occurred on 2nd January 2002 at 17:22 universal time. The shock measured Ms 7.3 and was initially located 50 km west of Efate at a depth of 21 km. A tsunami generated by the event struck Port Vila Harbour about 15 minutes later.

SOPAC and IRD teams intervened in the week following the earthquake to assist the Department of Geology, Mines & Water Resources of Vanuatu (DGMWR) to study and assess the effects of the earthquake. The combined team ensured the smooth running of the seismic network of Port Vila to record the seismic crisis, investigated the earthquake intensity distribution on the island, evaluated the damage caused by the earthquake and investigated the changes of relative sea level during the earthquake and tsunami.

As a result of the more accurate determinations from the 16 stations of the IRD networks in Vanuatu and New Caledonia, the Port Vila earthquake was later relocated to 45 km west of Port Vila at a depth of 18 km. The earthquake was caused by a slip on a fault of about 20 x 40 km resulting in an elastic vertical displacement of several centimetres of subsidence of the western coast of Efate.

The intensity distribution according to the Modified Mercalli scale varied across the island, ranging from a maximum of MM 10 in the west to MM 6 in the east. However, the averaged value of intensity by district in the rural areas of Efate generally ranged from MM 7.5 in the west to MM 6 in the east. The highest intensity from the earthquake, MM 10, was felt in Port Vila, but averaged values by district in the city area ranged from MM 8.5 to 6.5.

A comparison of the distribution of felt intensities in Port Vila and an earthquake microzoning scheme recently developed for the city indicated that the microzonation scheme was generally successful in discriminating the areas more severely affected. In general, areas zoned as high risk experienced an increase in felt intensity to MM 8 from a background level in the city area of MM 7. Anomalous results were generally related to topographical effects which were not resolved well in the earlier work.

The main shock was followed by thousands of aftershocks in the first fortnight with a few significant ones having magnitudes ranging from Ms 4.7 to Ms 6.4. The locations and magnitudes of the aftershocks reported by USGS NEIC placed epicentres on a northwest-southeast line to the west of Efate, but the more precise IRD network grouped the aftershocks on a slightly more northerly-oriented line.

The tsunami generated with the earthquake was recorded by the National Tidal Facility gauge Port Vila Harbour with a peak-trough height of 0.8 m. However, eyewitnesses reported a maximum effect up to about 3 m in other parts of the harbour. The wave was large enough to have caused serious flooding of the central business district if it had not coincided with one of the lowest tides of the year. Modelling of the tsunami characteristics suggested that faulting occurred on the steeper west-dipping nodal plane.

Despite its magnitude, the earthquake was sufficiently far enough from Efate to cause only moderate damage. Direct earthquake effects caused structural damage to the extent where several public buildings were condemned. Foundation failure damaged several structures on reclaimed areas of the city waterfront, and severely damaged several bridges around Port Vila. Slope failures caused large landslides that blocked access to the country's main wharf, cut road access to the west of Port Vila and caused damage to a coastal resort.

BACKGROUND

The day following the earthquake, the Director of SOPAC made a plea for international co-operation in bringing together scientific and engineering assessments of the event, and volunteered SOPAC to provide coordination of these activities. The UK Department For International Development (DFID), Suva, responded rapidly and favourably to an approach for assistance and provided funding for the post-disaster technical assessment, and for training activities related to the assessment.

The SOPAC assessment team reached Port Vila on the 8th of January and remained there until 24th January to obtain details on the earthquake damage and the tsunami event, and to assist the DGMWR in the investigation of the earthquake intensity in Port Vila city area.

IRD was also directly concerned as it, in cooperation with the DGMWR, runs a program of earthquake monitoring in Vanuatu. The IRD scientific team arrived in Port Vila on the 6th of January and stayed for a week. Their main objective was to ensure the smooth running of the local seismic network around Efate for the recording of aftershock data, and downloading the recorded seismic data for analysis of the main shock and the first aftershocks (magnitude and location). The IRD team also performed direct observations in the field on static displacements caused by the earthquake.

In this way, the Government of Vanuatu gained valuable assistance from two recognised international organisations in assessing the effects of the Port Vila earthquake. The three organisations have brought together their joint findings on the seismicity of the region, the earthquake of 2 January 2002 and related aftershocks, as well as the results of assessment of the effects of the main shock including the consequent tsunami.

The team was fortunate to be able to build on recent studies by Regnier et al. (2000), Shorten et al. (2001) and collations of data onto GIS database by Biukoto et al. (2001). The extent of this recent work is summarised in Shorten (2001).

The production of this report, in particular the support for the principal author to carry out research and report writing in Suva, was funded both by DFID through SOPAC (South Pacific Applied Geoscience Commission), and by DEPAC through IRD (Institut de Recherche pour le Developpement, ex-ORSTOM). The report is a joint effort including the Vanuatu Department of Geology, Mines and Water Resources (DGMWR), SOPAC, and IRD.

INTRODUCTION

On 2 January 2002 at 17:22 Universal time (3rd January 2002 at 4:22 am local time), a powerful earthquake struck Port Vila on Efate island in Vanuatu. It was the largest earthquake ever located by the worldwide seismic network in the vicinity of the city. Occurring in the small hours of the morning, it woke nearly the whole population of the Island. No severe injuries or deaths were reported, but a small amount of damage occurred in buildings and infrastructure and significant landslides were recorded.

Several teams were mobilised in Port Vila city during the morning to assess the damage. These included the Department of Geology, Mines and Water Resources (DGMWR), the National Disaster Management Office (NDMO), the Departments of Public Works (PWD), Health and Education and other organisations such as UNELCO, TELECOM Vanuatu Limited and the Vanuatu Red Cross Society.

Within ten hours of the main shock, NEIC (United States National Earthquake Information Centre) reported a magnitude of Ms 7.3 on the Richter scale, and a location 50 km west of Efate at the shallow depth of 21 km. Efate Island was shaken all through the day of 3rd January by minor aftershocks. Late in the same evening (UTC 2002/01/03) a large aftershock occurred at 9:17pm local time (UTC 10:17). NEIC reported its magnitude as Ms 6.4 . The aftershock was felt across the island, as well as in some neighbouring islands.

Tsunamis occurred after both of these seismic events; the first one arriving in Port Vila 15 minutes after the main shock, while the magnitude Ms 6.4 aftershock induced a second tsunami with a much smaller amplitude.

Aftershocks continued to hit Vanuatu – especially the island of Efate – for several weeks after the main shock. Some of these aftershocks were significant with magnitudes ranging from 4.7 to 5.8.

A few days after the earthquake, the Vanuatu government requested two recognised international organisations, IRD and SOPAC to assist the Department of Geology, Mines and Water Resources and the other government entities involved in assessing the details of the earthquake effects.

Both the IRD and SOPAC teams worked closely with the Department of Lands & Survey to obtain GPS data as soon as possible. On this occasion, officers and materials of this Department were mobilised to check as many GPS sites as possible in order to help locate observations in the field.

The initial results of the surveys carried out by the DGMWR, IRD and SOPAC which are compiled in this report, include the seismic data of the main earthquake and the first significant aftershocks, the details of damage induced, and the data on tsunami observations.

These results will be important in determining the origin of the earthquake, and its intensity distribution in Port Vila city and in the rural areas of Efate. Also, the details of damage incurred outline the areas prone to geotechnical failure and highlight unsuitable construction practices in buildings and infrastructure. The investigations also answer the question as to why no major tsunami flooding occurred on the coast of Efate island despite the fact that this was the largest magnitude shallow earthquake ever recorded in the vicinity of the city.

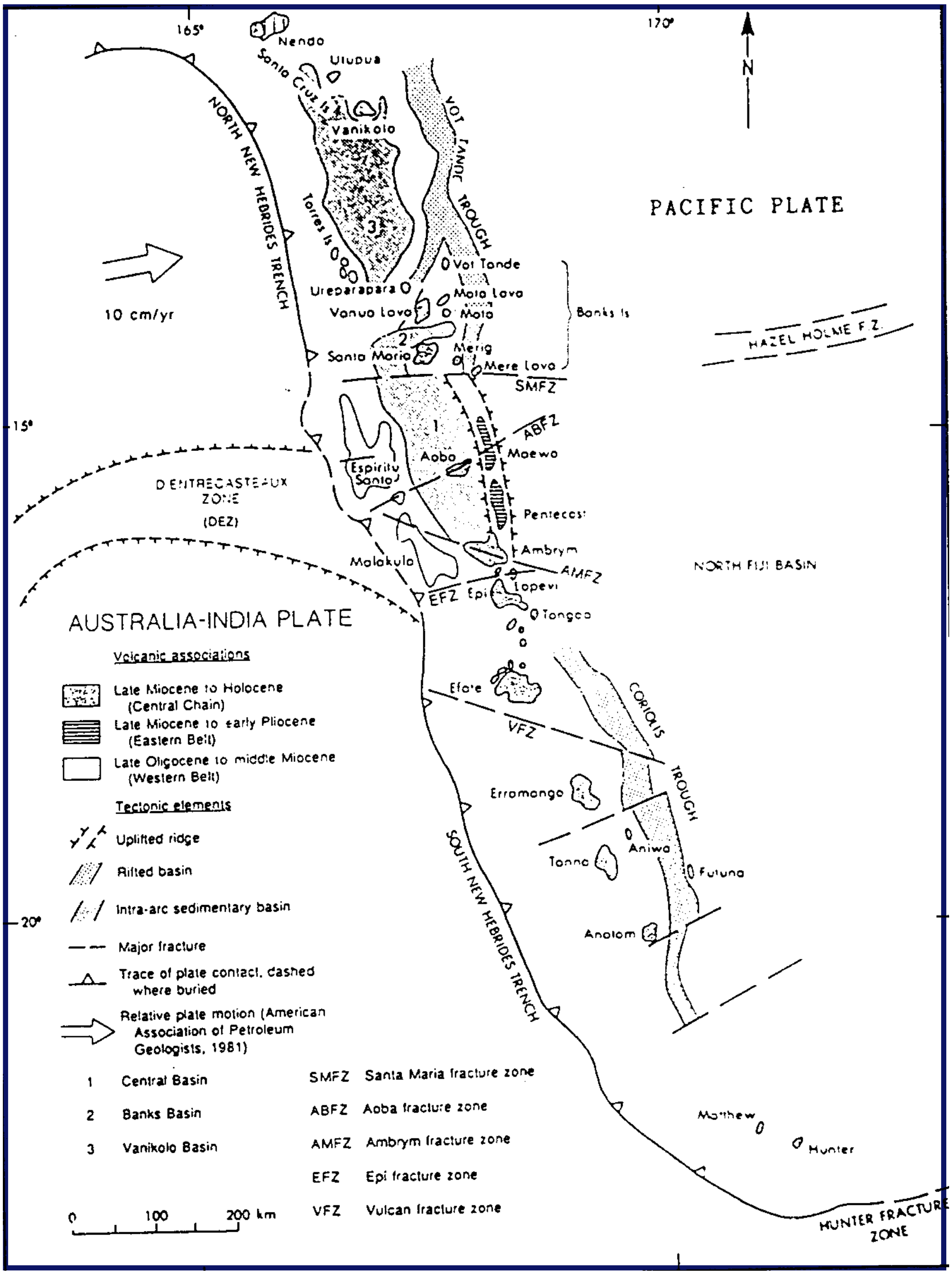

Figure 1: The principal tectonic and geological features of the New Hebrides Island Arc.

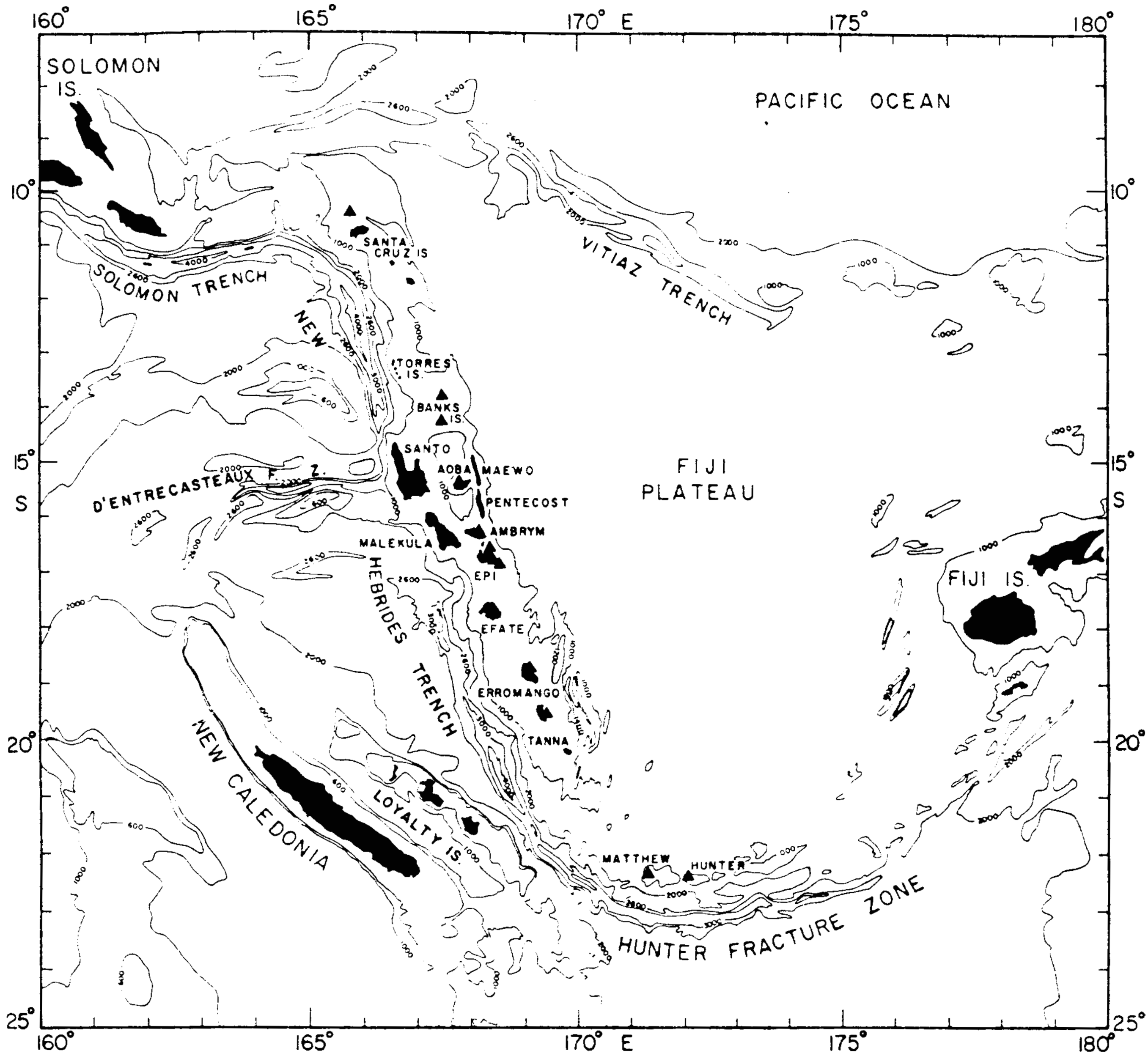

Figure 2: Bathymetric map of New Hebrides Island Arc and surrounding region.

PORT VILA EARTHQUAKE

1.0 Tectonics of the New Hebrides Island Arc

The New Hebrides Island Arc (Figure 1) is composed of several physiographic elements:

- Tectonic plates, including the Australia-India Plate and the Pacific Plate.
- Trenches, the North New Hebrides trench and the South New Hebrides trench.
- Arc platform supporting the islands.
- Back-arc rifts on the east of the arc.
- D'Entrecasteaux Fracture Zone (DFZ).

The New Hebrides island arc is composed of three volcanic chains (Carney et al. 1985): a western belt (late Oligocene to mid Miocene) forming the islands of Torres Group, Malekula and Santo; an eastern belt (late Miocene to early Pliocene), including the Islands of Pentecost and Maewo; and a central chain (late Miocene to Holocene) and the rest of the islands, from the Banks Group in the north to Aneitium Island in the south. This island arc extends for a distance of more than 1500 km from Tinakula-Nendo (Santa Cruz Islands) in the north to Matthew and Hunter volcanoes in the south (Figure 1).

The eastern belt of coral reefs represents an uplifted ridge at the eastern edge of the arc. The western belt consists of a limestone plateau resulting from uplift due to the subduction of the d'Entrecasteaux Fracture zone.

The central chain displays active volcanism related to the subduction of the Australian Plate beneath the Pacific Plate. The tropical latitude of the islands favoured important Quaternary growth of coral reefs in some of the islands of the central chain, including Efate island. During periodic uplifts due to the subduction, and intervening eustasy, several emergent reef terraces have developed on the lava flows, forming a characteristic landscape (Lecolle et al. 1990).

Overlying the New Hebrides subduction zone, the New Hebrides island arc is one of the few island arcs on Earth to display remarkable variation in structure in correlation with seismicity along the arc.

Various authors have shown that, following a late Miocene disruption of an ancestral Solomon-New Hebrides-Fiji-Tonga subduction zone, the New Hebrides arc reversed subduction polarity, moved to its present position and left the newly-created North Fiji Basin in its wake (Figure 2) (Karig & Mammerickx 1972; Gill & Gorton 1973; Falvey 1978; and Carney & Macfalane 1978).

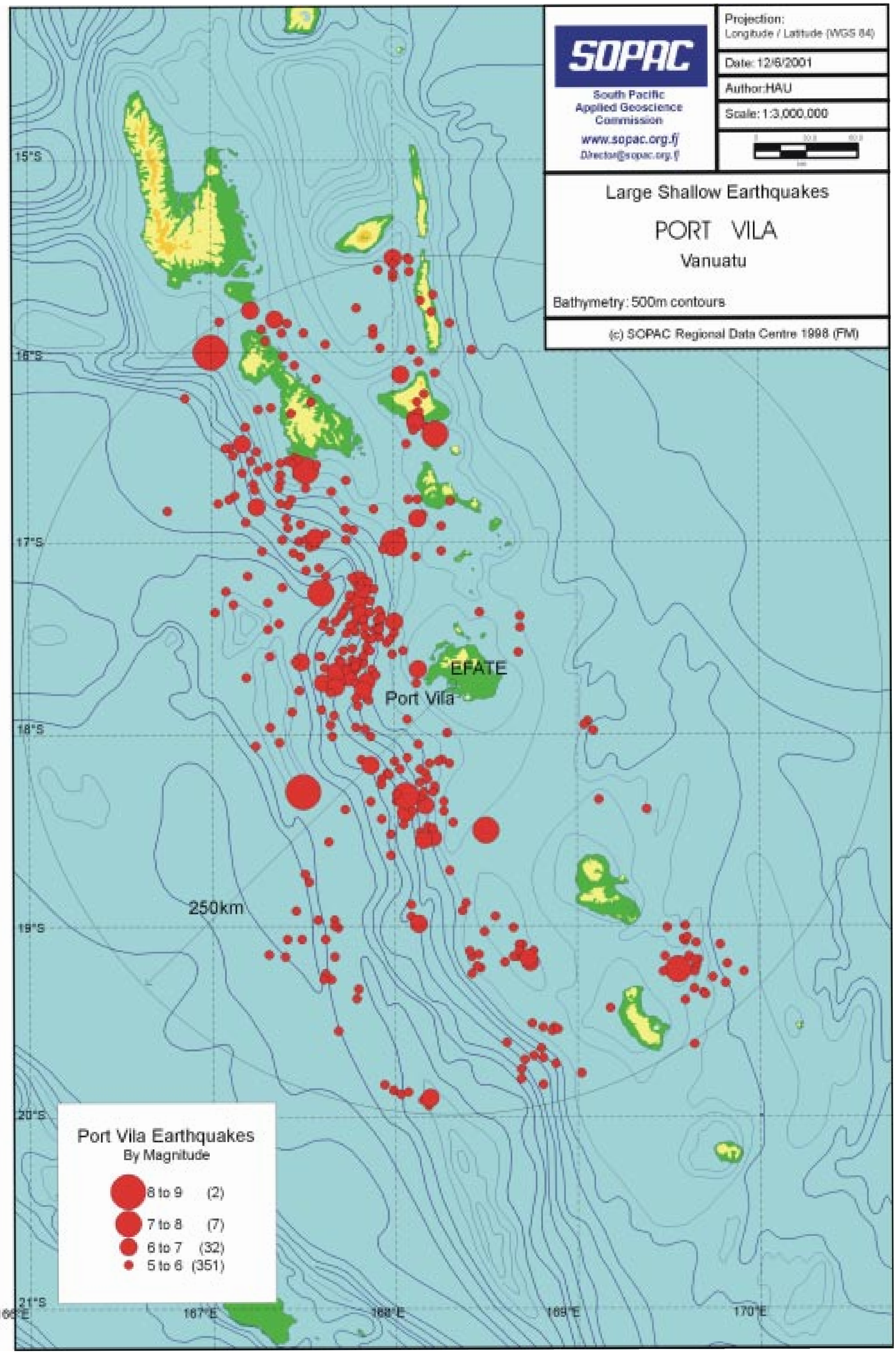

Figure 3: Historical seismicity map of Port Vila, 1973-2001 (M>5; d<70 km).

The central region of the arc shows outstanding features of anomalous morphology indicating that the normal elements of physiography, including the trench, island arc and back arc rifts, found in the northern and southern part of the New Hebrides arc are replaced respectively by the island blocks of Santo and Malekula, the Aoba basin, and the uplifted horst-like ridge upon which the islands of Maewo and Pentecost emerged (Figure 1 and 2). The d'Entrecasteaux Fracture Zone (DFZ) intersects the arc in this region but appears to be subducted along with the rest of the oceanic plate (Isacks & Barazangi 1977; Pascal et al. 1978; Chung & Kanamori 1978).

Two mechanisms are invoked to explain this morphological anomaly of the New Hebrides arc (Isacks et al. 1981):

- A late Miocene episode of intra-arc rifting, which produced a major seaward protrusion of the upper plate as the Santo and Malekula blocks moved outboard of the main arc and in doing so, creating the Aoba basin (Karig & Mammerickx 1972).
- A Quaternary interaction with the DFZ that affected the uplift and tilting of Santo and Malekula as well as influencing the seismicity (Taylor et al. 1980).

The d'Entrecasteaux Fracture Zone (DFZ) is thus characterized as an aseismic ridge located on the subducting oceanic plate that abuts the central part of the Vanuatu islands.

The cross-sectional shape of the Benioff zone, which represents the dip of the subducting plate and is defined by seismicity along the island arc, is among the most sharply down-bent and steepest on Earth, with a dip of around 70° (Isacks et al. 1981).

Convergence between the Australia-India Plate and the Pacific Plate along the arc occurs at the rate of 12 cm/yr at 20°S in the southern, and 15 cm/yr at 11°S in the northern part of the archipelago, and in a direction approximately E-NE (Louat & Pelletier 1989).

Thus, the island arc of the New Hebrides is continuously subjected to high seismic activity related to faulting due to the sudden slip of the Australian Plate beneath the Pacific Plate

2.0 Historical seismic activity in the vicinity of Port Vila

Over the length of the New Hebrides archipelago, a belt of high seismic activity extends from north to south, associated with active volcanism. Seismicity in the central New Hebrides convergent plate boundary is broken into three classes: large earthquakes (Ms > 6.9), moderate-sized earthquakes (mb > 4.5 and Ms < 7.0) and small earthquakes (mb = 2.5 to 4.5). The seismicity is dominated by shallow events (focal depth < 70 km).

The epicentres of large shallow earthquakes with magnitude greater than 5 for the period of 1973-2001 are plotted in Figure 3 and catalogued in Appendix 1. The data was taken from both the NEIC database and the local ORSTOM/Cornell network.

Magnitude-frequency relationships for the region were outlined in Hoffstetter et al. (2000).

The Vanuatu islands have experienced a number of major earthquakes (Wong & Green 1988), but the great majority of earthquakes recorded in Vanuatu are of small magnitude (magnitude < 4.5). Louat & Baldassari (1989) reported few cases of damage to buildings over a 100-year period:

1880: The event of 1880 generated a seiche in the harbour that inundated extensive areas of the harbour islands and stranded large number of fish in the vegetated areas well above sea level.

1927: Eyewitness accounts from Port Vila suggest that the largest tsunami experienced there was as a result of the 24th January 1927 event of Ms 7.1 located on South Malekula. The tsunami entered the harbour and apparently caused seiching and flooding of the shoreline up to several metres above the normal tide levels. Its origin and magnitude are uncertain.

1950: An event with a magnitude near 7 occurred about 100 km southwest of Efate.

Between 1961 and 1978, a series of large earthquakes (Ms > 5.5) recorded in the vicinity of Efate ranged up to magnitude 6.0 with an isolated example of Ms 6.5.

1961: A small tsunami was recorded in Port Vila harbour after the 23rd July 1961 (Ms 6.0) event 100 km south of Port Vila.

1965: On 12th August 1965, an Ms 6.3 earthquake in the north of the group was felt with intensity MM 7 in Efate.

1974: The 30th June 1974 a Ms 5.7 earthquake occurred about 25 km south of Port Vila, resulted in cracks in newly-constructed multi-storey buildings and rock-falls from cliffs in the city.

The ORSTOM-Cornell network began operating in 1978. According to Prevot & Chatelain (1984), only four earthquakes of large magnitude had been recorded in the archipelago since the inception of the network. The largest one was the Mere Lava event near Santo.

1979: Three events occurred to the west of Efate. The first on the 17th of August (Ms 6.1) occurred 35 km off Efate. It was followed nine days later by a second shock (Ms 6.0), some 20 km to the north of the first one.

1980: The largest, 12th May 1980 (Ms 6.1), was the Mere Lava event near Santo that caused relatively major damage but no casualties.

1981: The earthquake of 15th July 1981 (Ms 7.0) occurred approximately 85 km northwest of Efate and was reported to have caused damage in Port Vila. This earthquake is notable for having occurred in an area that had not experienced any large earthquakes in the preceding 75 years.

According to Prevot & Chatelain (1984), each of the earthquakes was preceded by swarms around the zone where the aftershocks occurred, in areas of characteristically low seismicity, and even to the rear of the arc, east of Efate. The swarms occurred up to eight hours before the main shock, and the aftershock zone expanded quickly over the following days to cover areas 5 to 10 times greater than normal earthquakes of such magnitude. Thus, even though an earthquake of 7th July 1981 was centred some distance offshore of Efate, the region of aftershocks spread onto the island itself.

Prevot & Chatelain estimated that the greatest possible magnitude for the archipelago is 7.6 on the basis of calculated energy release in earthquakes since the beginning of the century. Based on this, they estimated that the maximum likely predicted intensity for Efate (and Port Vila region in particular) would be MM 8, and in places up to MM 9. They did not however, discount the possibility of intensities as high as MM 12 in the archipelago (Shorten et al. 2001).

1999: On November 26th, the Mw 7.5 earthquake occurred between the northern tip of Ambrym Island and the south of Pentecost. It was the largest known earthquake to be recorded in that area. Located at the depth of 18 km, it induced a maximum uplift of over 1.2 m at the easternmost tip of the island near Pamal and Ulei. This earthquake caused felt intensities of MM 6 to 7 on the Mercalli scale, and was the origin of a tsunami which struck Baie Martelli in South Pentecost and causing much damage, ten deaths, two lost and several injuries in both Pentecost and Ambrym islands.

3.0 Event of 2nd January 2002

The earthquake that hit Port Vila in the dawn of 3rd January 2002 local time was first located by the United States Geological Survey (USGS) worldwide seismologic network with a magnitude of Ms 7.3 and the location was published in the nine hours after the earthquake. The magnitude and epicentre were most recently shown as Ms 7.5 and placed at 17.590 S and 167.829 E, and the best nodal plane orientations as 15º/105º and 75º/285º.

Further details on the location were reported later by IRD and the DGMWR, after analysing the data of the main shock collected from the IRD telemetric network stations based in Vanuatu and New Caledonia.

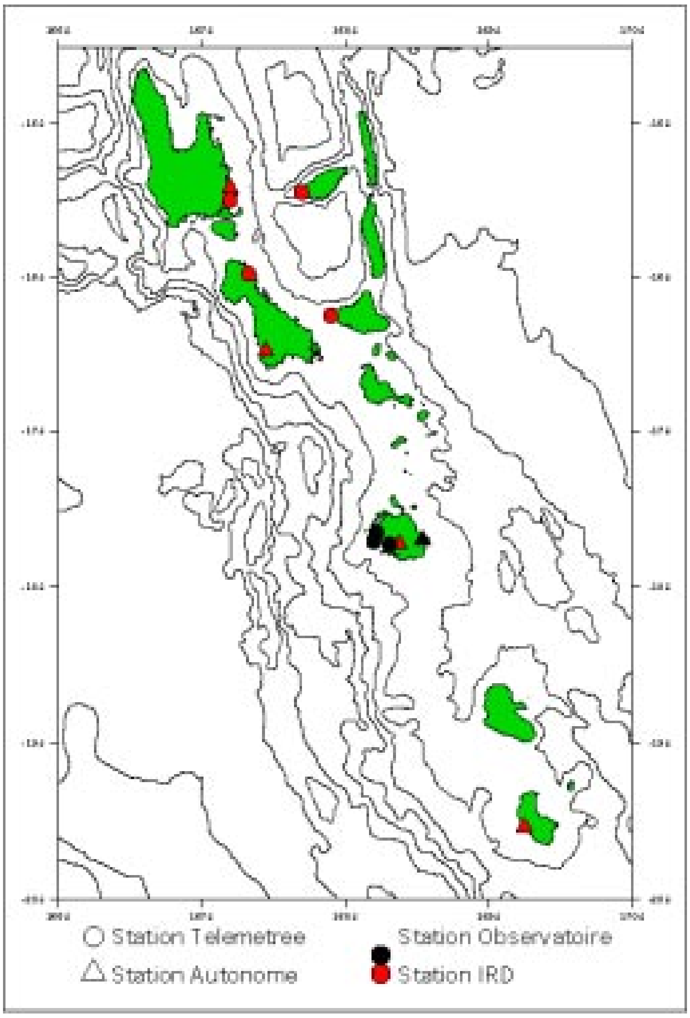

Figure 4: Map of seismic stations of Vanuatu.

The GEOSCOPE stations are located in Port Vila and Santo and are included in the CAVASCOPE network. They contain 3-component seismometers with long period acquisition, using Guralp CMG-3EP type for Santo and STS1 type for Port Vila as part of the IRD autonomous stations.

The rest of the autonomous stations are of different types, but all have three component seismometers. At South West Bay (Malekula) (SWB), and Tanna (TAN) the seismologic stations are of Guralp CMG-3EP type whereas the semi-permanent station of Forari (FOR) is of type Hathor 3.

Two seismologic stations were recently installed at Lalinda (LAL), southwest Ambrym and at Tasmalum (TAS), southwest Santo.

3.2 Seismicity

The Ms 7.3 Port Vila earthquake of the 3rd January 2002 at 4:22 am local time was located by NEIC at 17.59 S and 167.83 E, which is about 50 km west of Efate, at a depth of 21 km below the sea floor (Figure 5).

The IRD network in the Southwest Pacific (16 stations) located the hypocentre of the quake at latitude 17.763S and longitude 167.850E, and at a depth of 18 km below the sea floor. This places the epicentre of the earthquake at a distance of 19 km southeast of the location given by NEIC. The earthquake was thus relocated to about 45 km west of Port Vila by IRD.

Table 1 shows the details of the location of each seismic station in the IRD Southwest Pacific network.

The hypocentre of the earthquake was closest to the Devil's Point station. The first seismic wave reached the seismic sensor in only 1.843 seconds. The Noumea seismic station was the farthest from the Port Vila earthquake source; sensing the quake almost a minute later than the Devil's Point station.

During the first week after the earthquake, some temporary GPS stations were added to the permanent one located in Port Vila to complete the IRD seismologic network set up for a better recording of the seismic crisis. Data from these stations will be indispensable in determining the coseismal displacement related to the main shock.

3.1 Seismologic network in Vanuatu

The acquisition of data in Vanuatu is centred at the Department of Geology, Mines and Water Resources (DGMWR). The network includes:

- A800 accelerometer.
- Telemetric stations
- GEOSCOPE stations

The earthquake monitoring stations are distributed throughout the islands of Vanuatu as shown in Figure 4.

The A800 accelerometer is located at the DGMWR in Port Vila. It is used to record ground motion in times of earthquake.

Telemetric stations are short period and are comprised of Lennartz seismometers with three components: north-south, east-west and the vertical component. They are divided into two networks. One is based in Port Vila; with the stations of Port Vila (PVC), Klem's Hill (BKM) and Devil's Point (DVP). The Santo telemetric network is formed by four telemetric stations, which are based in the islands of Santo (SAN), Ambrym (AMB), Aoba (AOB) and Malekula at Walarano (WAL). Data is directly recorded on computer in the seismic observatories of Santo and Port Vila.

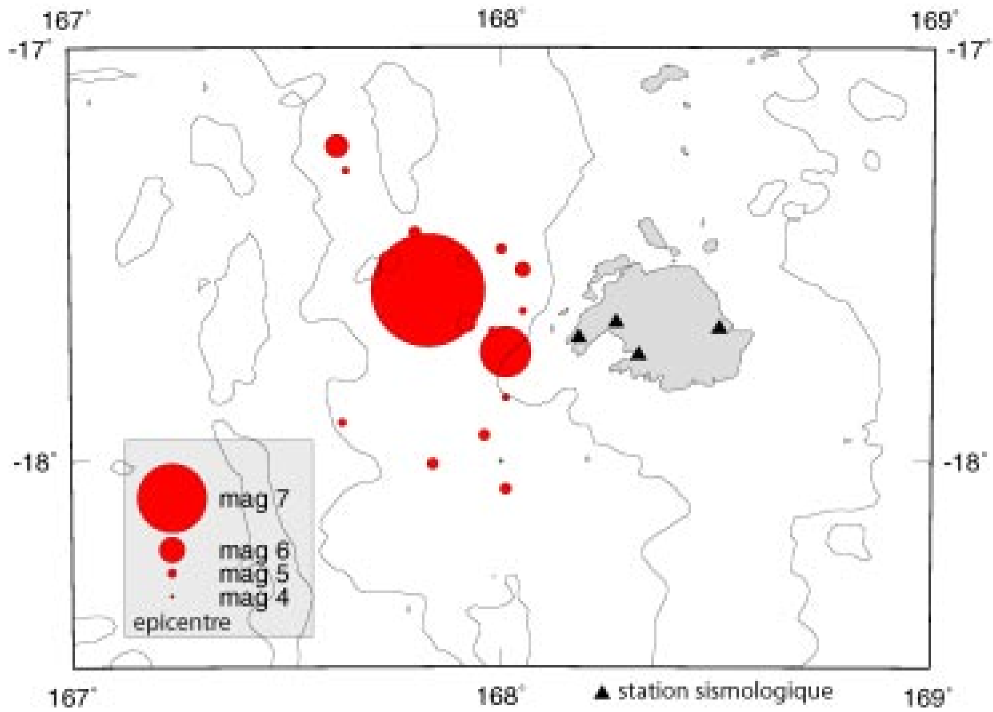

Figure 5: Location of the main Port Vila earthquake and aftershocks by USGS.

Table 1. Location of IRD seismic stations, Southwest Pacific Network.

Station	Distance	Azimuth	Emergence	W	Obs. P wave	P wave Calc.	Residual	W	Obs. S wave	S wave calc
DVP C	35.93	83.3	114.8	4	2.387	1.843	0.544	5		7.202
BKM D	42.94	75.9	50.6	3	3.034	2.76	0.274	5		8.717
PVC D	48.99	87.1	50.6	3	3.860	3.501	0.359	5		9.977
FOR D	73.73	83.6	50.6	0	6.445	6.538	-0.093	5		15.139
SWB	147.77	343.2	50.6	4		15.622		4		30.582
LAL	161.35	7.8	50.6	4		17.289		4		33.416
AMB D	172.40	2.9	50.6	0	18.751	18.644	0.107	5		35.720
WAL U	203.72	344.6	50.6	4	22.690	22.487	0.203	5		42.252
TAN U	248.31	142.5	50.6	0	27.999	27.958	0.041	5		51.553
AOB	259.18	356.9	50.6	4	29.283	29.292	-0.009	5		53.821
TAS	261.04	337.1	50.6	4		29.52		4		54.209
SAN D	266.42	345.1	50.6	1	29.813	30.18	-0.367	5		55.331
LIF	341.36	190.9	50.6	4		39.376		4		70.964
KOU	489.63	230.5	50.6	4		57.568		4		101.891
DZM	501.69	197.3	50.6	4		59.047		4		104.405
NOU	509.48	198.8	50.6	3	60.252	60.003	0.249	5		106.030

Using the earthquake mechanism published by the USGS in the first hours after the earthquake on the 3rd January 2002, IRD created the following model of vertical elastic displacement generated by a slip on the fault of about 40 x 20 km in the region west of Efate island (Figure 6).

The fault is represented by the rectangle inscrib0ed in the red zone of uplift. The slip on the fault is about 2 meters. The four square symbols represent the GPS stations (one is permanent and three were temporarily reoccupied after the earthquake). Note that the western coast of the Efate Island sank elastically by a few centimetres during the earthquake (M. Regnier pers. comm.).

A more precise model will be obtained after the complete seismological analysis of the whole earthquake crisis and the calculation of coseismal displacement occurring at the different GPS sites. This will eventually add further detail on the nature and the geometry of the fault

3.3 Intensity

The intensity measures the strength of shaking produced by the earthquake at a certain location. It is determined from effects on people, human structures, and the natural environment, and measured according to the Mercalli scale.

For the Port Vila earthquake, the field intensity investigation was conducted by the DGMWR with a mixed team from SOPAC and IRD to perform the questionnaire survey in order to determine earthquake intensity: SOPAC hired and trained three groups of students to help cover the Port Vila city area while the DGMWR and IRD took charge of the rural and coastal areas around Efate, as well as some areas in the city that displayed serious effects.

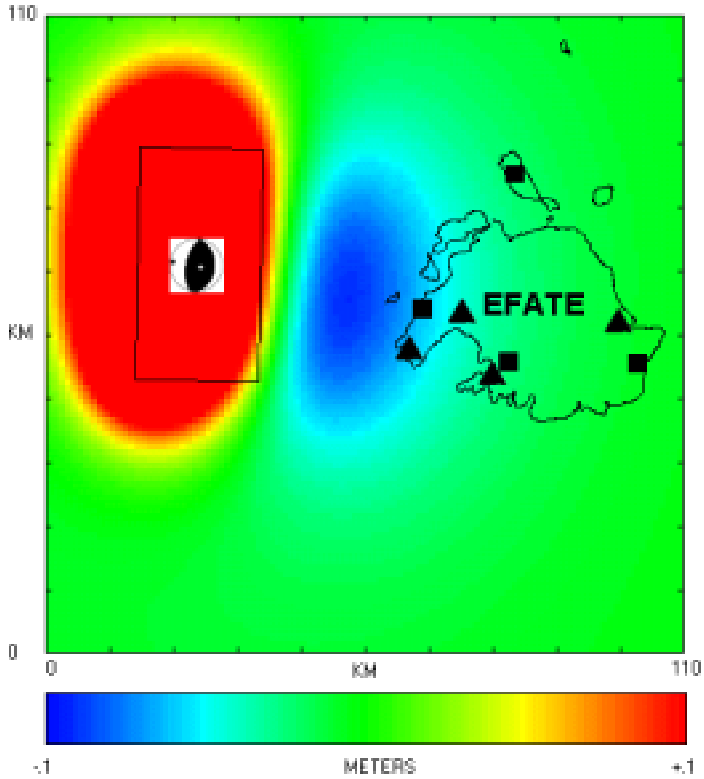

Figure 6: Simulation of vertical elastic displacements due to the Port Vila earthquake.

3.3.1 Modified Mercalli scale (1956 version)

A description of the 12 levels of the modified Mercalli scale (1956 version) is shown on the next page.

3.3.2 Questionnaire

The questionnaire survey normally should be taken down as soon as possible after the earthquake. This investigation of field intensities consisted of examining seismic effects on a site and interviewing several persons on that particular locality. The interview is based on a series of questions as presented on the next page; the person being questioned should complete or circle the right answer. The questionnaire is shown on page 14.

For each locality, the report given by people on the description of the earthquake and the way they react to the shaking is fundamental for the determina-

MODIFIED MERCALLI SCALE (1956 Version)

I. Not felt except by a very few under especially favourable conditions.

II. Felt only by a few persons at rest, especially on upper floors of buildings.

III. Felt by persons indoors. Many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibrations similar to the passing of a truck. Duration could be estimated.

IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Hanging objects swing. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. Wooden walls and beams could sometimes crack.

V. Felt by nearly everyone; many awakened. Direction of the arrival waves could be estimated. Liquids resonate, some overflow. Some dishes, windows are broken. Unstable objects overturned. Pendulum clocks may stop, restart, and change their rhythm. Curtains may flap, paintings move.

VI. Felt by all, many frightened and run outside. Pedestrians stagger. Glasses dishes are broken. Books are drawn out from their shelves. Paintings are pulled out from walls. Some heavy furniture moved; a few instances of fallen plaster. Masonry of type D split. Small bells started to ring. Trees and bushes shake or vibrate. Damage slight.

VII. It is hard to stand. Drivers feel the earthquake. Hanging objects tremble. Furniture is broken. Type D masonry is damaged or cracked. Less solid chimneys are destroyed at the roof level. Loose plasters, bricks, stones, tiles, cornices, and parapets fall off. Some fissures in type C masonry. Waves in the lakes, the water becomes muddy. Small slips on embankments, sands and gravel. Large bells began to ring. Irrigation trenches are damaged.

VIII. Driving is disturbed. Damage in type C masonry: partial collapses. Few damages in type B masonry, and nothing to type A. Plasters and some walls in masonry could fall. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Unbolted house frames jump out of their foundations. Branches are broken. Cracks appear on humid soils and on high slope areas. *(Damage slight in specially designed structures. Considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures).*

IX. General panic. type D masonry destroyed; type C masonry damaged with sometimes complete collapse and type B seriously damaged. Damage to all foundations. If the frames are not anchored, they shift off their foundations and are damaged. Considerable damage to water tanks, underground pipes are broken. Clear visible cracks on the ground surface. In alluvial zones, outbursts of saturated sands, splashing of water and mud. *(Damage considerable in specially designed structures. Well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations).*

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. Serious damage on dams, breakwater and embankment. Large land sliding. Water overflows the riverbanks, canals, lakes. Sands and mud move horizontally on flat land.

XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

PS: Masonry A, B, C, D: To avoid imprecision of language, the masonry quality, bricks or others, is specified by the use of the following letters:

Type A masonry : serious workmanship, mortar and conception of high quality. Reinforced, conceived to resist lateral forces.

Type B masonry : serious workmanship and good mortar. Reinforced but not conceived to resist lateral forces.

Type C masonry : workmanship and mortar of average quality. Not reinforced, not conceived to resist lateral forces.

Type D : weak materials, workmanship of bad quality, little or no horizontal resistance.

tion of the earthquake intensity on that site.

In the city area, SOPAC utilised its GPS facilities to locate each place where the questionnaire was applied. This technique of data collection enabled the rapid creation of an isoseismal map for Port Vila and its easy incorporation into the GIS database for Port Vila.

3.3.3 Results

The originals of the 280 questionnaire sheets are filed at the Department of Geology, Mines and Water Resources of Vanuatu. The summary table of all the intensity data for Port Vila city and the rural areas of Efate are catalogued in Appendix 2.

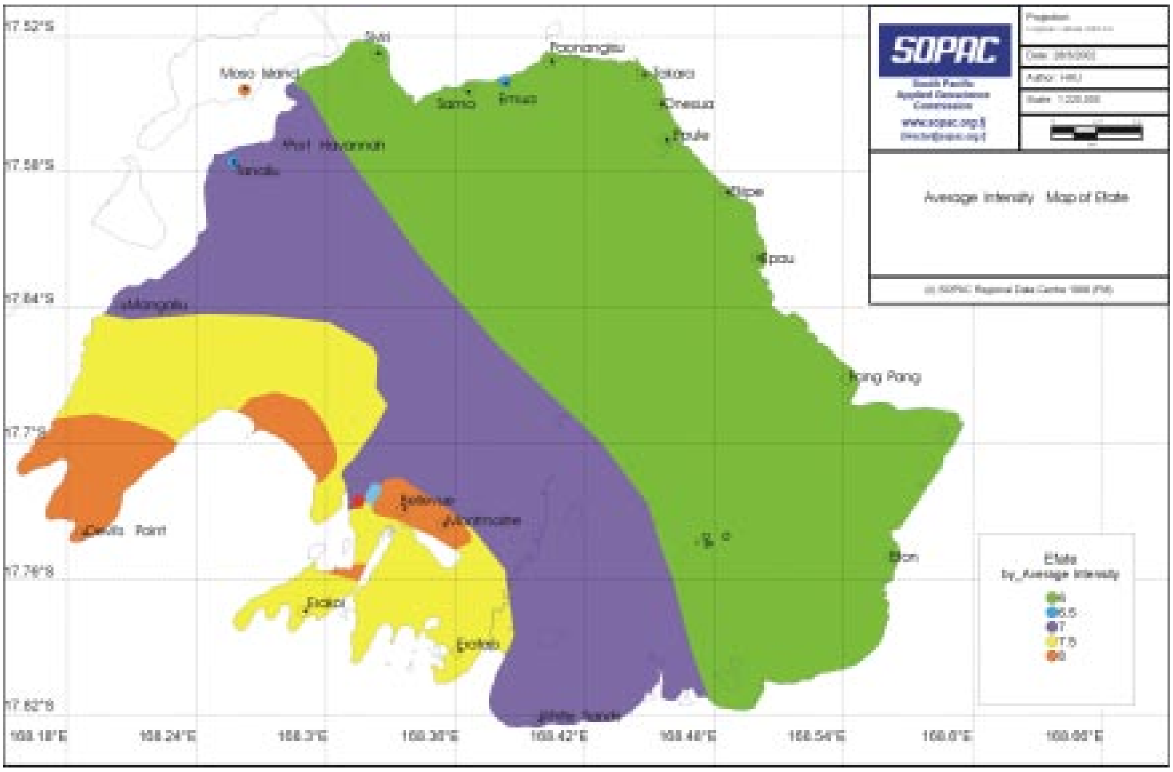

Figure 7: Averaged intensity map of Efate.

Intensity in the rural areas

Only the average values of intensities were considered on this chapter. The intensity shown for each village is the average value of intensity felt by the different persons interviewed.

The intensity distribution in the whole Efate Island is summarized in Table 2 and illustrated in Figure 7.

QUESTIONNAIRE.

Date of the quake.

Time (as precise as possible).

Approximate duration of the quake.

The position of the person when he perceives the quake.

- Lying down	- Standing	- sitting
- In the open air	- In the house	- at which floor
- In a boat/ship	- in a car	

Was the earthquake felt by:

- Few people - every body

Were there any other quakes felt?

- yes - no - how many

If many quakes were felt in a short period

At which approximate intervals?

Which one was stronger?

From which direction did the quake come?

- north	- northeast	- east	- southeast	- south
- southwest	- west	- northwest		

What was the nature of the movement?

- lateral	- vibration	- slow	- rapid	- sudden shock

The effects of the earthquake in the house.

- Vibration of dishes	- glasses
- Furniture cracks	- floor
- Cracks on the ceiling	- walls
- Furniture displacement	- objects fall
- Other damages	- which one?

Effects on land/natural features

Could we observe:

- broken branches	- fallen trees	- landslide	- riverbank sliding
- boulders fall	- faults	- fissures	

Indicate as precisely as possible the place of the observed phenomenon (*).

Type of soil at the locality

- hard rock (limestone, coral, basalt)	- loose soil (sand, clay)
- hard rock and loose soil	- nature of soil unknown

Did the observer remark the effects on the sea level?

- Abnormal tide	- at what time
- Big waves	- at what time
- The sea withdraws	- at what time

In the spring water, the wells and the rivers

- Did the water level change? yes/no	- at what time	
- If it did: did it rise?	- drop	- at which height?
- Did it vary: - a certain time?	- Definitely?	
- Did the water temperature change?	- yes	- no
- Did it become	- colder	- warmer?
- Were the river ways modified?		

Indicate the intensity of the quake according to the Mercalli scale.

Force

Indicate the name of the localities where the earthquake was felt.

Name of the person filling the questionnaire - profession

- Address

The rural areas of Efate island felt intensities ranging from MM 6 to 7. The lowest intensity of MM 6 was felt along the northeast coast, from Enam in the southeast to Siviri in the northwest of Efate. Areas near the town experienced intensity 7 on the Mercalli scale; these include the villages from Mangaliu to Port Havannah in the northwest, and from White Sands to Rentapao in the southeast.

Intensity in the urban and peri-urban area

The detailed intensity distribution of the earthquake in Port Vila is illustrated in Figure 8.

The recorded intensities range from MM 6 to MM 10. The lowest intensity is

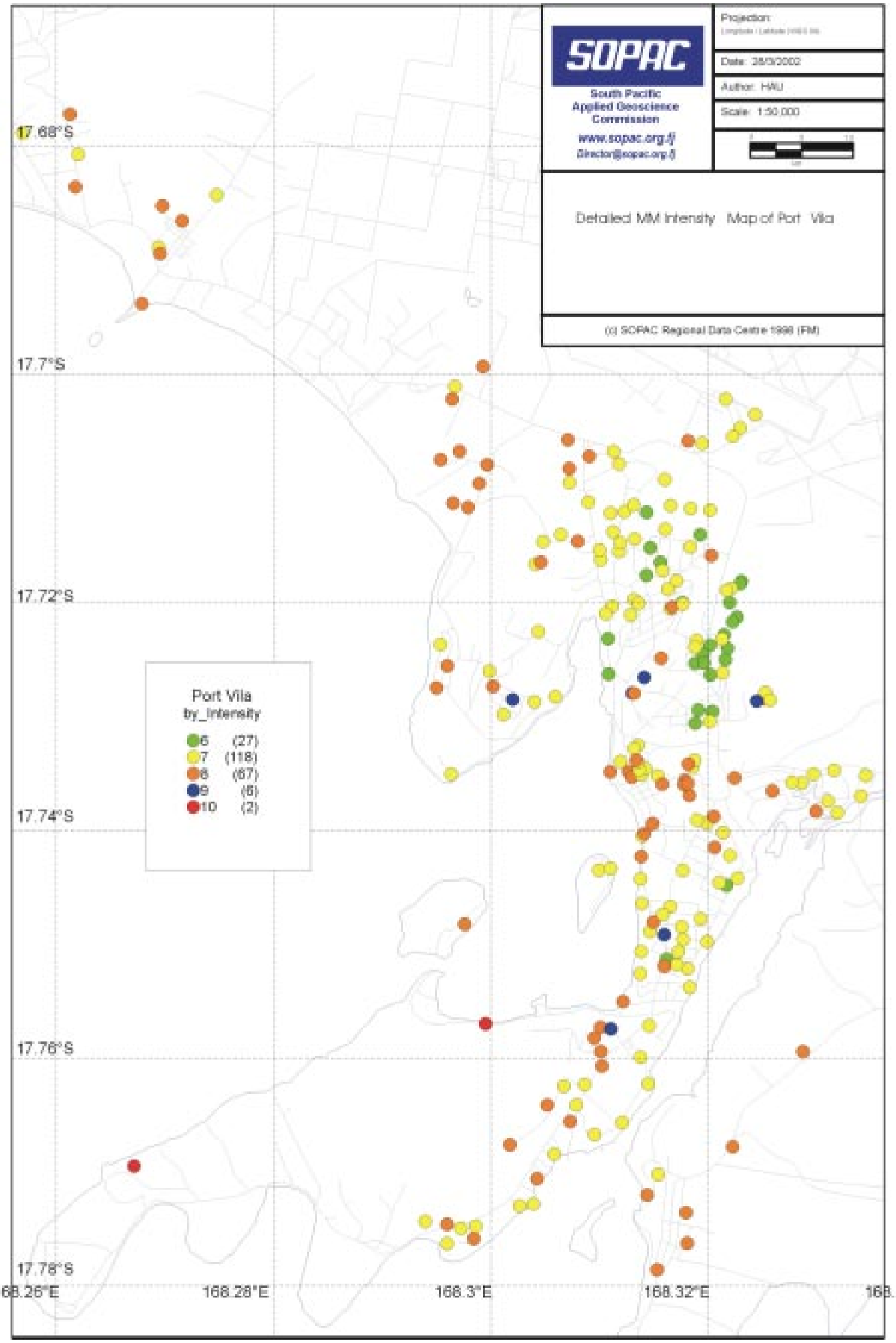

Figure 8: Detailed MM intensity map of Port Vila.

Table 2: Averaged MM intensity by residential district.

Residential district	Intensity	Residential district	Intensity
Mele maat	7.5	Bellevue	8
Mele	8	Montmartre	8
Blacksand	8	Erakor	7.5
Tagabe	7.5	Eratap	7.5
Manples	7	White Sands	7
Smett	7	Eton	6
Agathis	7	Pang Pang	6
Malapoa	7.5	Epau	6
Tebakor	7	Ekipe	6
Namburu	7	Epule	6
Lycee/VMF	8.5	Onesua	6
Iririki	7	Paunagnisu	6
Ohlen	7	Emua	6.5
Fresh Water	6.5	Sama	6
Town	7.5	Siviri	6
Ind. Park	7.5	Port Havanah	7
Sea side	7	Tanaliu	6.5
Nambatu	7.5	Mangaliu	7
Nambatri	8	Devil's point	8
Elluk	7.5	takara	6
Pango	7.5	Moso Island	8
Tassiriki	7.5	Beverly hills	8
Lagoon area	7		

found at Fresh Water. The localities with considerable damage to buildings such as Au Bon Marche Nambatu, Bougainville Lycee school and the Ministry of Education office suggest a felt intensity of MM 9. Large landslides in Pango and at Star Wharf represent an intensity of MM 10.

To obtain a global intensity of an area, the average of the intensity value is calculated for each separate district in the city (see Appendix 2 and Table 2).

As a result, the average intensity in the city ranges from MM 6.5 in the Fresh Water area to MM 8 along the cost at Mele/Blacksand, Devil's Point, Nambatri, and in the interior of the island from Beverly Hills to Montmartre (Figure 9).

The areas of Tagabe, Malapoa, Nambatu, Elluk, Pango, Namburu, Tassiriki and along the coast from Erakor to Eratap felt an averaged intensity of MM 7.5.

Note that the intensity felt in Montmartre was the same as Mele and Nambatri.

Various explanations could be suggested for these remarkable variations of earthquake intensities in a small area:

- They might be due to lateral change of soil type.
- Different structures in different areas respond to the earthquakes in different ways.
- The answers to the questionnaire are not precise enough. Sometimes people couldn't express exactly what they have actually felt.
- People did not understand the questions or the questions are not asked properly.
- As there were several strong aftershocks during the period of investigation, people might be confused about the real facts of the main shock.

Comparative analysis of intensity in Port Vila city area

Earlier studies employing the Nakamura technique defined a potential earthquake microzoning scheme for Port Vila which is based on the analysis of micro-seismicity (Regnier et al. 2000; Shorten et al. 2001). In this scheme, ground conditions in Zone A (thick sediment deposits) are broadly considered to be more likely to cause amplification of earthquake shaking and, at the other end, Zone D (limestone bedrock), least likely. In the final analysis, the amplifications are also strongly frequency-related.

Of the 220 assessments of intensity carried out in the city and peri-urban areas alone for the current earthquake, 199 were able to be cross-correlated with the four major earthquake microzones developed in the earlier work.

Given the reservations expressed above concerning the accuracy of assigned MM intensity levels, the matrices in Tables 3a-c attempt to demonstrate the broad correlation of observed intensities with the pre-existing earthquake microzones.

In Table 3a, the data is tabulated to show the number of MM intensity observations (all lying between MM 6-10) of each size in each of the four main microzones (Zones A-D).

In Table 3b, these data are represented as a percent of the total survey. It is obvious that there is strong bias caused by the uneven numbers of intensity observations in each microzone. This effect is largely a function of the relative areas of the city lying within each microzonation category.

In Table 3c, the data are reduced and normalised to show the relative proportion of observations of each level of intensity recorded in each of the Zones A-D.

This final table highlights, for each microzone, the most frequently recorded level of intensity. In Zones C-D the most frequently occurring intensity level is MM 7, which is regarded as the general background level of intensity felt in Port Vila during the current earthquake. There is a clear shift however in Zone A where the most frequent level of felt intensity is MM 8. This shift may also be recorded in Zone B but the results are equivocal due to the small number of observations in this particular microzone.

Given the particular characteristics of the earthquake under study here, it appears that the microzoning scheme developed earlier for Port Vila is able to clearly predict an amplification of earthquake effects in Zone A. The earlier studies characterised Zone A (generally in the Bauerfield-Mele area to the north and west of the city) as a zone of weak sediments having a thickness of at least 20 m, with a resonant period of around 0.8 seconds, and an amplification factor of at least 2 times. Medium to high-rise buildings constructed on this zone would be most at risk from resonant amplification of earthquake effects. This zone also represents the highest risk of geotechnical/foundation failure.

The same argument, but with the qualifications indicated above, may possibly

Table 3: Correlation between observed intensities and earthquake microzones.

Surveyed MM Intensity	Port Vila Microzone Categories A	B	C	D	*Total*
a. Number of MM intensity level in each microzone					
6	0	1	11	16	*28*
7	10	3	27	72	*112*
8	17	2	10	23	*52*
9	0	0	1	5	*6*
10	0	1	0	0	*1*
	27	*7*	*49*	*116*	*199*
b. Percent of total MM intensity level in each microzone					
6	0	1	6	8	*14*
7	5	2	14	36	*56*
8	9	1	5	12	*26*
9	0	0	1	3	*3*
10	0	1	0	0	*1*
	14	*4*	*25*	*58*	*100*
c. Proportion of MM intensity level in each microzone					
6	0.00	0.14	0.22	0.14	*0.51*
7	0.37	0.43	0.55	0.62	*1.97*
8	0.63	0.29	0.20	0.20	*1.32*
9	0.00	0.00	0.02	0.04	*0.06*
10	0.00	0.14	0.00	0.00	*0.14*
	1.00	*1.00*	*1.00*	*1.00*	*4.00*

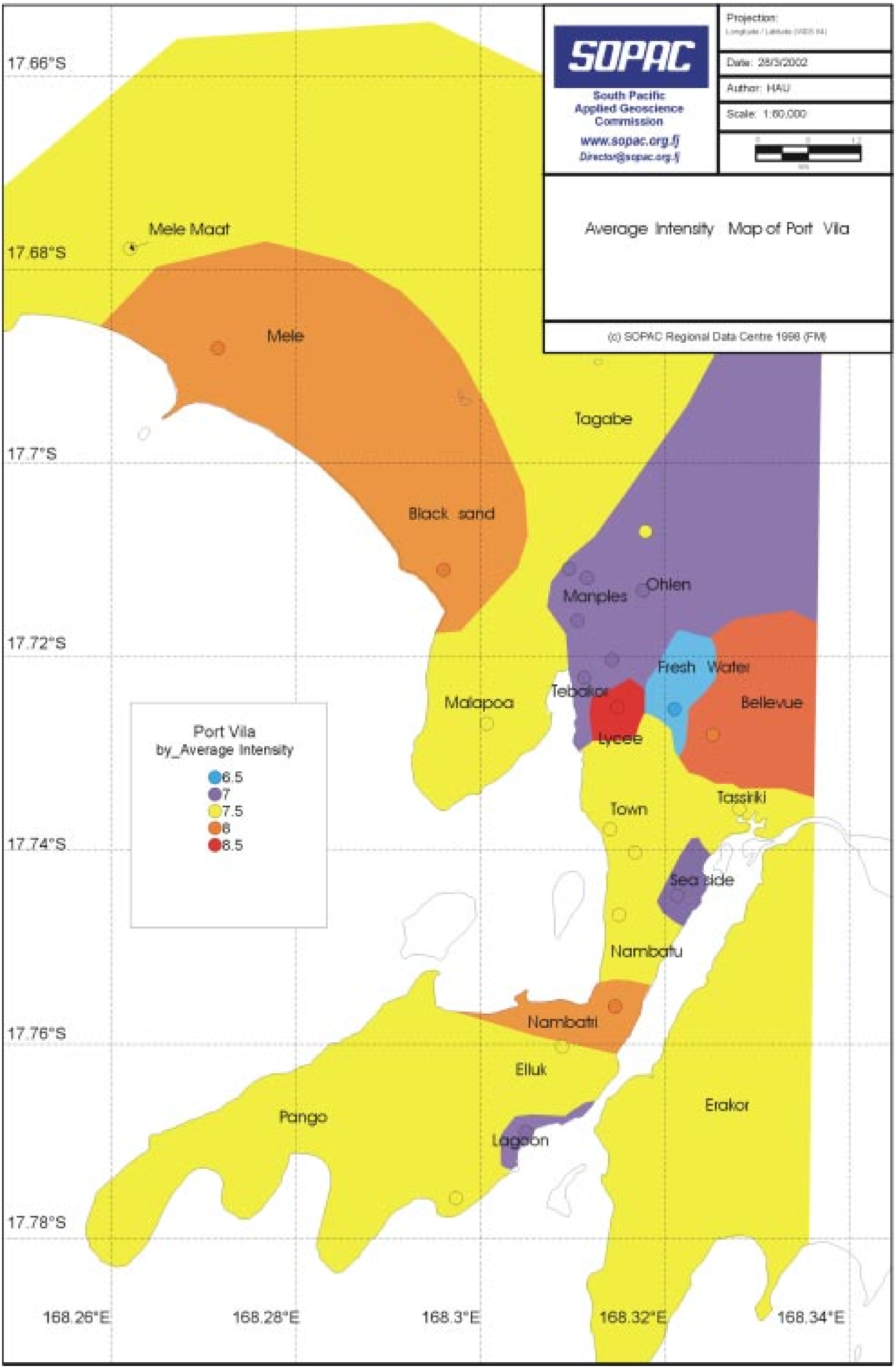

Figure 9: Averaged intensity map of Port Vila.

apply to Zone B (generally reclamations on the edge of Port Vila Harbour) which represents areas of the city reclaimed over somewhat thinner deposits of sediment, having a resonant period of around 0.3 seconds and a potential amplification factor of about 1.5 times. Shorten et al. believed that this might have important implications for the safety of low to medium-rise buildings; most of the multi-storey buildings of Port Vila lie within this zone. Regnier et al. however, considered that amplification due to resonance would only occur in Zone A, based on micro-seismicity measurements. This prediction was apparently supported by the survey following the recent earthquake which found no excessive damage in Zone B buildings.

Considering that the whole of the relatively small Port Vila city area can be viewed as being equidistant from an earthquake some 45 km to the west, the general level (56% of the surveys analysed above) of felt intensity in the city can be considered to be MM 7. While there are a number of factors discussed earlier that preclude the rigid interpretation of intensity levels, reports of MM 8 and MM 6 intensities in Port Vila, especially if grouped in particular areas, might be considered respectively to be anomalously high or low (with regard to the mean value).

The areal distribution of the results of the MM intensity survey is shown in Figure 10, overlaid on the pre-existing earthquake microzoning scheme.

The intensity levels above or below intensity MM 7 are grouped in Figure 11 as anomalously-high and anomalously-low areas respectively, set against a general background of intensity MM 7. These areas are draped over a digital terrain model to demonstrate their relationship to the physiography of Port Vila.

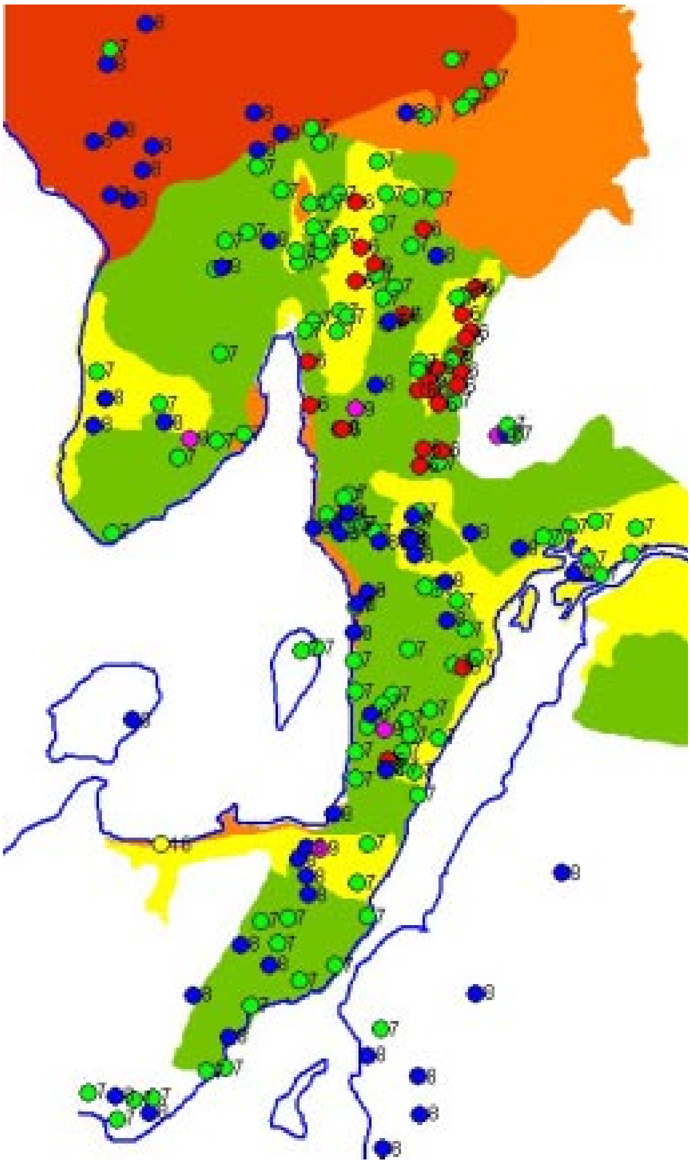

Figure 10: Distribution of detailed intensity surveys in Port Vila overlain on earthquake microzonation scheme.

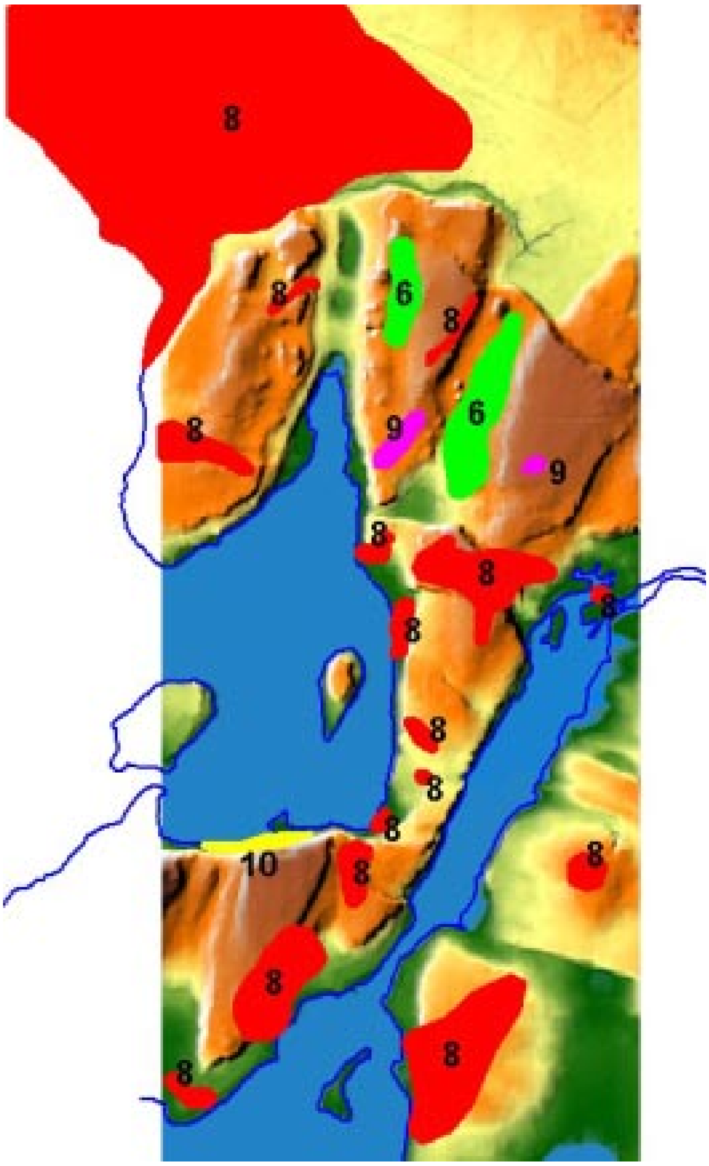

Figure 11: Zones of anomalous intensity overlain on digital terrain model of Port Vila.

Only two anomalously-low (MM 6) areas have been delineated and these lie in the northern part of the city, both matching closely with deeply weathered physiographic troughs developed on grabens in the limestone bedrock.

A large, anomalously-high (MM 8) area lies, as expected from earlier investigations, north of the city in the Bauerfield-Mele plain. Other MM 8 highs lie, also as expected, over low-lying reclaimed areas and deeply weathered fault zones throughout the city.

Less expected perhaps are the MM 8 high anomalies observed on steep topography and plateau-tops throughout the city which were not anticipated by the results derived from the earlier microzoning study, even though topographic effects have been long recognised as influencing the resonant amplification of earthquake effects. Two small MM 9 highs lie on the plateau tops between the MM 6 lows discussed above.

An area of MM 10 effects was recorded around the access road to the main wharf and the high ground above the road. These should be viewed in the light of the reservations expressed earlier on the limitations of the MM intensity scheme. The large slope failures that occurred here were strongly influenced by specific geological factors; in particular, the fact that in this area, weak volcanic tuffs were exposed in the high slopes above the road to the main wharf.

The broad interpretation of the earthquake microzonation map published by Shorten et al. is that all of the delineated zones apart from the bedrock zone would be expected to show some level of frequency-dependent amplification relative to the effects felt on bedrock. As a rough test of the predictive capability of the earlier microzonation map, the anomalously-high (red dots; MM 8-10) observations, anomalously-low (yellow dots; MM 6) observations, and background level intensity (green dots; MM 7) observations, are plotted against the microzonation scheme in which Zone D bedrock (green zones) represents areas where no amplification above the background level was foreseen, and Zones A-C (red zones) where some amplification was expected (Figure 12).

Anomalously-high (red zones) and anomalously-low (green zones) zones of observed intensities are plotted for ready reference against the road map of Port Vila in Figure 13 as basis for further investigations of the city area.

4.0 Aftershocks

Although the local seismologic network in Port Vila continues to record aftershocks of the earthquake as this report is written, only the aftershocks that occurred in the first fortnight of January 2002 are taken into account here.

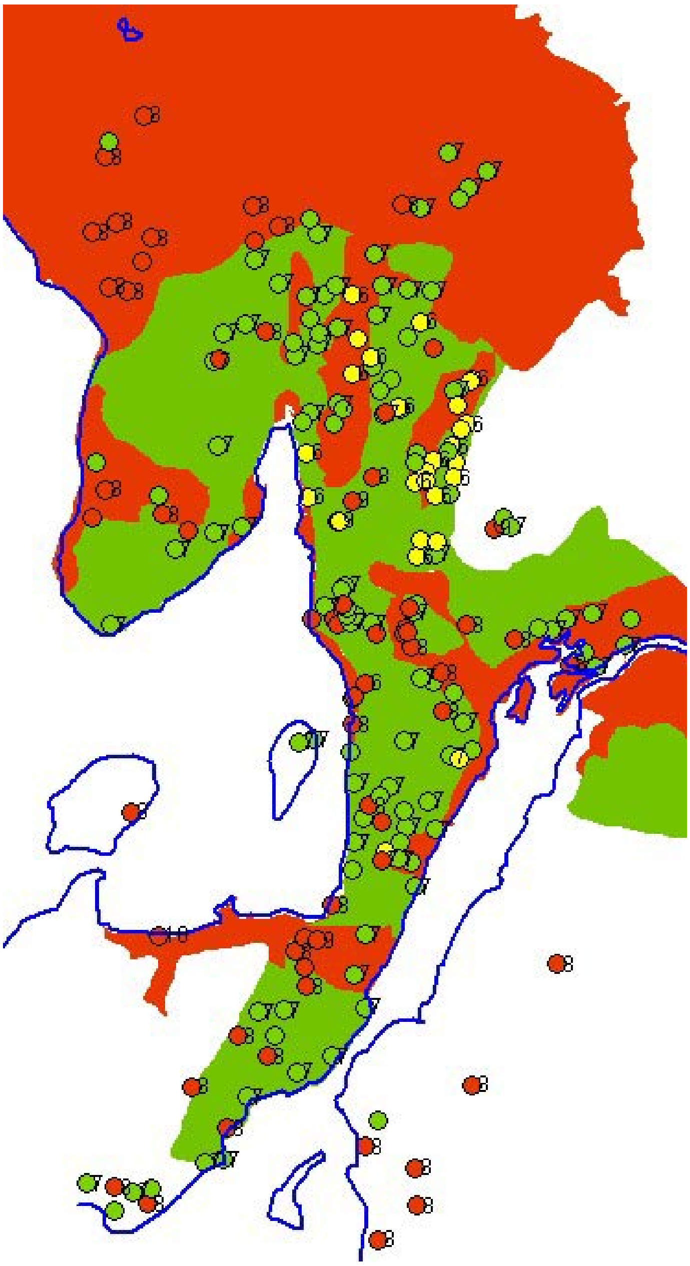

Figure 12: Comparison of zones of under-prediction and over-prediction of intensity. The results should then be interpreted as:

Yellow dots on Green or Red zones	:	Under-prediction of recent earthquake effects
Red dots on Green zones	:	Under-prediction of recent earthquake effects
Red dots on Red zones	:	Accurate prediction of recent earthquake effects
Green dots on Green zones	:	Accurate prediction of recent earthquake effects
Green dots on Red zones	:	Over-prediction of recent earthquake effects

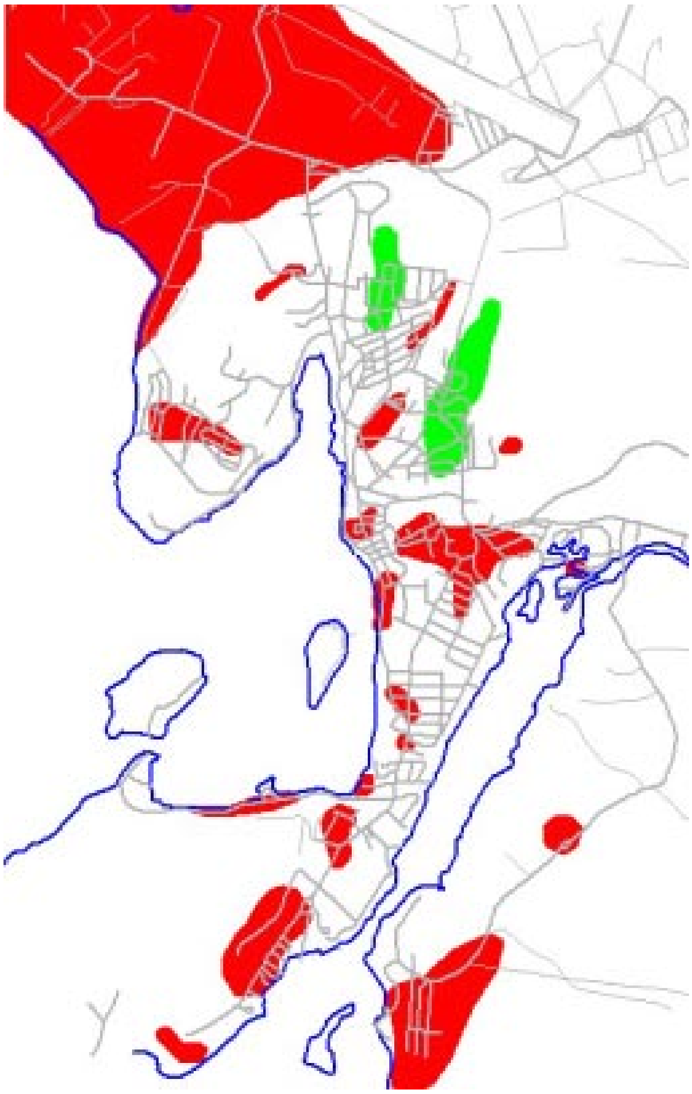

Figure 13: Map of anomalously-high (red) and anomalously-low (green) zones of intensity.

Within this period, the local seismologic network recorded 3289 seismic events, of which 16 were significant. The magnitudes of these significant events were defined by the USGS, and range from Ms 4.7 to Ms 6.4.

The largest with magnitude Mw 6.4 occurred on the 3rd January 2002 at 9.17pm local time (UTC 2002/01/03, 10:17). Its location and magnitude were defined within the first ten hours after the quake by the USGS worldwide network that place the epicentre of the earthquake at latitude 17.740°S and longitude 168.010°E, 47 km southwest of Port Vila. The depth of the hypocentre was 33 km below sea floor.

During this period of seismic crisis, the magnitude and locations of all significant aftershocks were first reported by USGS and then confirmed by IRD. Details of locations by USGS are shown in Table 4.

After analysing the data collected from the local seismologic network in the Southwest Pacific, IRD reported the locations of these significant aftershocks as shown in Table 5.

The Mw 6.4 aftershock is relocated by IRD at latitude 17.79°S and longitude 167.92°E at a depth of 27 km below sea floor. Its epicentre is then repositioned at 50 km south-southwest of Port Vila.

The magnitude and the frequency of the aftershocks generally decreased in the days after the main shock. The aftershocks are centred round the main shock and define an extended band about 81 km long (from 17.340°S to 18.025°S) and 33 km wide (from 167.740°E to 168.111°E) oriented in a north-northwest direction. Further details on the geometry and nature of this plane will be reported at the end of the earthquake crisis.

A comparison of locations plotted by IRD and USGS is drawn in Figure 14.

Table 4: Location and magnitude of aftershocks (USGS).

Date/Time USGS	Latitude	Longitude	Depth	Magnitude
201021722	–17.59	167.83	21	7.3
201022243	–18.07	168.01	33	
201031017	–17.74	168.01	33	6.4
201031135	–17.94	167.96	33	5.2
201040713	–18.01	167.84	33	5.1
*201042240	–17.85	168.01	33	4.8
201042329	–17.91	167.63	33	4.7
201060741	–17.30	167.64	33	
*201061531	–17.52	167.91	33	5.1
*201061638	–17.54	168.05	33	5.5
*201061707	–17.64	168.05	33	4.8
201061709	–17.49	168.00	33	5.1
201090846	–17.69	167.98	33	4.7
*201100556	–17.67	167.92	33	5.7
*201131632	–17.52	167.74	33	5.8
*201150448	–17.24	167.62	33	5.9
*201150456	–17.45	167.80	33	5.3

(*): Accelerogram data is available in the Department of Geology, Mines and Water Resources of Vanuatu.

Table 5: Location and magnitude of aftershocks (IRD).

Date/Time IRD	Latitude	Longitude	Depth	Magnitude (NEIC)
0201021723	–17.763	167.850	18.75	7.3
0201022243	–17.997	167.963	30.92	
0201031017	–17.790	167.920	27.01	6.4
0201031135	–18.025	167.923	18.80	5.2
0201040713	–17.943	167.761	10.79	5.1
*0201042240	–17.810	167.892	19.05	4.8
0201042329	–18.012	167.740	9.43	4.7
0201060741	–17.340	167.667	9.97	
*0201061532	–17.504	168.023	17.86	5.1
*0201061639	–17.722	167.951	45.39	5.5
*0201061708	–17.513	168.078	17.96	4.8
0201061712	–17.538	168.115	0.60	5.1
0201090846	–17.734	167.920	52.40	4.7
*0201100556	–17.637	167.915	18.50	5.7
*0201131633	–17.469	167.983	17.75	5.8
*0201150448	–17.409	167.827	13.86	5.9
*0201150456	–17.418	167.922	13.62	5.3

(*): Accelerogram data is available in the Department of Geology Mines and Water Resources of Vanuatu.

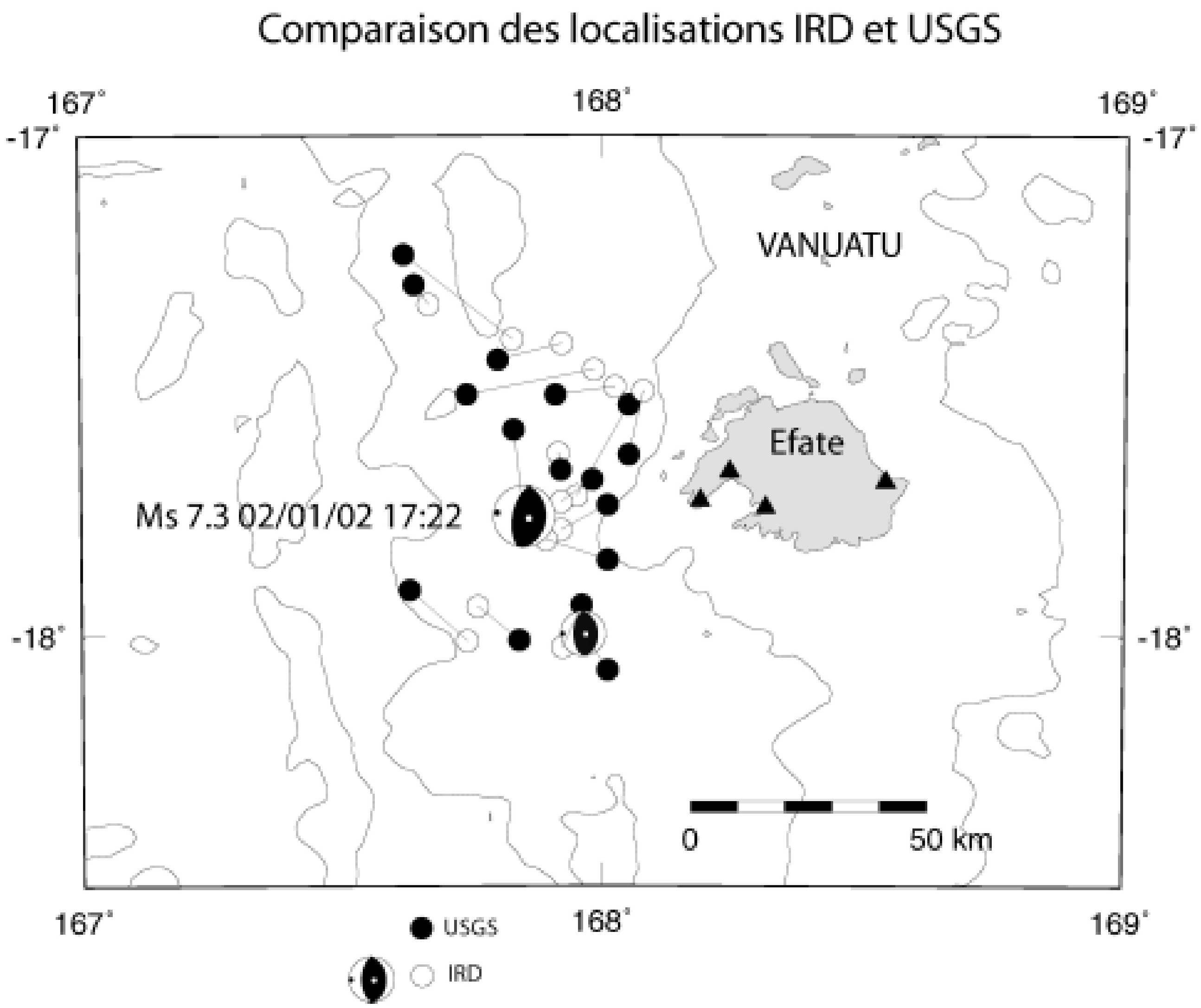

Figure 14: Comparison of IRD and USGS locations of main Port Vila earthquake and aftershocks.

5.0 Tsunami observations

5.1 Tsunami Event

A tsunami generated with the earthquake struck Port Vila Harbour some 15 minutes later, at 4:37 am on 3rd January 2002 (local time), according to records of the National Tidal Facility Australia supplied by Bill Mitchell through the Acting Director of the Vanuatu Meteorological Office (Figure 15). The first event was followed that same night by another large aftershock of magnitude Mw 6.4 which also produced a tsunami at 9.17pm local time, although with much smaller amplitude.

The rapid changes of water level associated with the main tsunami were mostly unnoticed by residents at a distance from the seashore for two reasons. Firstly, the event occurred in the dark, and secondly the tsunami arrival time coincided with an extremely low tide. However residents of Ifira island and the Blacksands and Mele areas were acutely aware of the tsunami and its potential dangers.

Approximately 500 people fled from low-lying areas along the coast to highlands during January. In fact, it is reported that some of the chiefs of villages in these areas encouraged a total migration of the people to highlands following the tsunami.

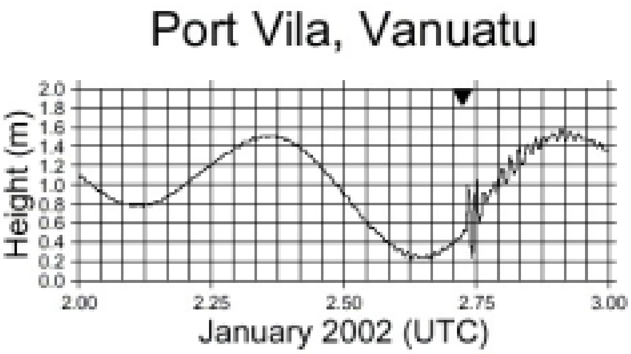

Figure 15: NTF Tide gauge record at Port Vila Star Wharf showing tsunami event.

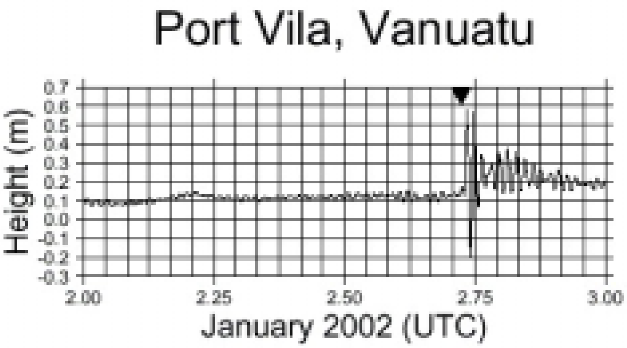

Figure 16: Tsunami record, Port Vila Star Wharf – differences between observed and predicted sea level.

Although the tsunami only registered on the tide gauge as having a crest to trough amplitude of 0.8 m (Figure 16), eyewitness accounts in different parts of the harbour put the maximum effect at around 3.0 m several times that of the recorded height, making it large enough to cause significant damage.

Fortunately the tsunami occurred at a time close to one of the very lowest spring tides of the year (predicted CD+0.15 m), when the tide was close to Chart Datum. If the earthquake had occurred four hours later at high tide (CD+1.35 m), flooding would have reached up to 1 metre over the top of the sea wall in the CBD area. A much smaller tsunami occurred following the major aftershock that night, but passed unnoticed.

5.2 Reports of Interviews

Good eyewitness accounts were obtained for seven locations around Port Vila Harbour (Figure 17) for the Port Vila tsunami UTC 2002/01/02/17:37, and measurements were made relative to predicted tide levels on the day of

Figure 17: Location of tsunami eyewitness accounts, Port Vila Harbour.

measurement. The results of the measurements are summarised and displayed together in Figure 18.

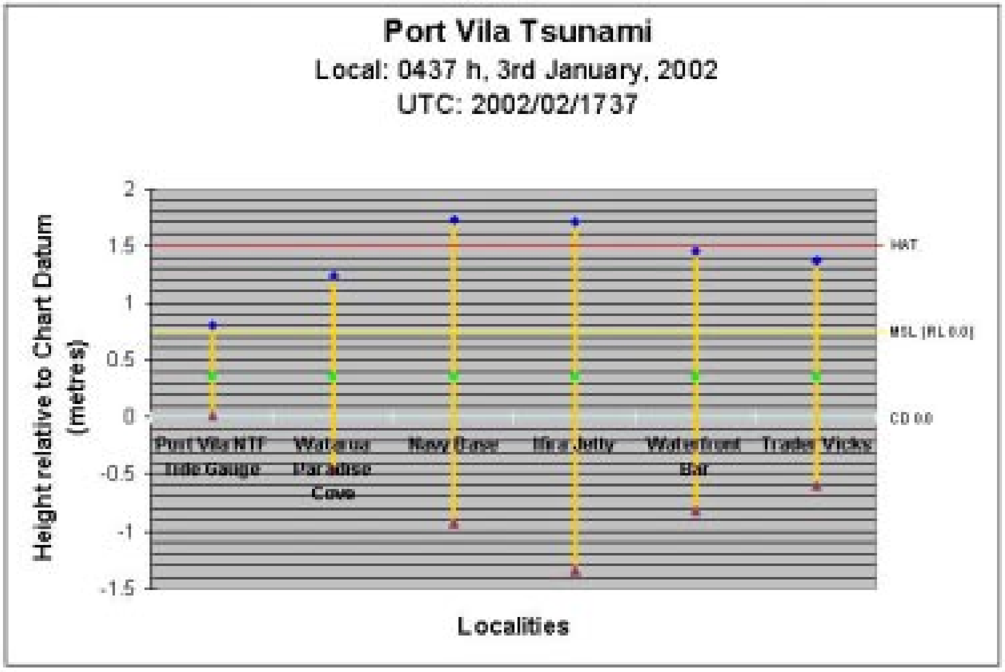

Figure 18: Eyewitness accounts of the tsunami effects around Port Vila Harbour.

1. Watarua/Paradise Cove: On 12/1/2002, interviewed Leising Hughes on the Mele Bay side of the peninsula (outside of Port Vila Harbour) at Watarua/Paradise Cove. She related how some 5 minutes after the earthquake the water first receded quickly and then returned quickly about 5 minutes after the first low. The lowest negative wave (the second) exposed the base of the shipping channel marker pole and then returned, without any wave action, to the level of the high tide mark on the beach. Measurements were made relative to those features and predicted tide heights.

2. Navy Base: On 10/1/2002, interviewed Colin Ioan, Vanuatu Navy, on his observations while on watch at the Navy Base in the southeastern corner of Port Vila Harbour. He indicated the heights of the highest and lowest surge in that area. Colin recalled three in-out surges, the first movement being a receding wave. He estimated the time between the earthquake and the receding wave to be about 2 minutes, and that the water level was lowered for about 4-5 minutes. The time between the first and second wave was estimated to be about 3-4 minutes, and between the second and third wave about 3-4 minutes as well. He indicated that a mud plume developed across the harbour towards the wharf access road to the southwest and suspected a submarine slump (massive on-land slides occurred above the wharf access road in this vicinity). Colin indicated that the second negative wave was the lowest observed, and significantly lower than the first. Measurements were taken on observed points beside the BBQ hut on the water's edge near the Navy wharf and on the adjacent concrete-geotextile blanket sea wall.

3. Ifira Spit: On 10/1/2002, interviewed John Jacob, resident on Efate mainland just south of Ifira Island. Related how he was at his house above the main wharf at 04:30 h local time when his relatives came running up from the spit south of the Ifira passage to tell him that the sea was coming up and going down repeatedly. He claimed that others said that the water oscillation started immediately after the earthquake and then continued until early afternoon. He could see the sand beach below him being covered and uncovered only until full tide (09:12 h) when it stopped altogether. He also noted that whirlpool activity also continued until high tide. One large whirlpool (he indicated roughly some 200-300 m across) began offshore from the main wharf and moved gradually towards the Ifira passage.

4. Ifira Island: On 12/1/2002, interviewed Esau and Harry (with the assistance of Michael Mangawai) who live near the concrete jetty on Ifira Island. They claimed that the first effects of the tsunami came some 5 minutes after the earthquake was felt. Their account had the water receding slowly down to a white mooring buoy offshore, and then returning slowly. Large whirlpools formed within some 50 m of the shore and these currents persisted for a few hours after the earthquake. Measurements were taken relative to the features on the concrete jetty and water depth at the white mooring buoy.

5. Ifira Island: On 12/1/2002, interviewed Kalchichi Sope, the oldest man in Ifira village at 84 years of age. He remembered the effects of an earthquake and tsunami on January 24th 1927 as being similar to, but worse than, the recent event. (A 1984 interview with Ifira village Chief Graham Kalsaku on the 1927 event is also on record). Again, as in the recent event, no coastal houses on the island were affected but the turbidity in the water, and the degree of fish stranding he remembered as being much worse in the 1927 event. During the current event he too noticed the whirlpools that formed off shore and then progressed around the northern end of the island.

6. Waterfront Bar: On 10/1/2002, interviewed the bartender at the Waterfront Bar who related the story of the night watchman Joseph Manamoan. Joseph initially saw the water retreat so that the boats moored at the sea wall

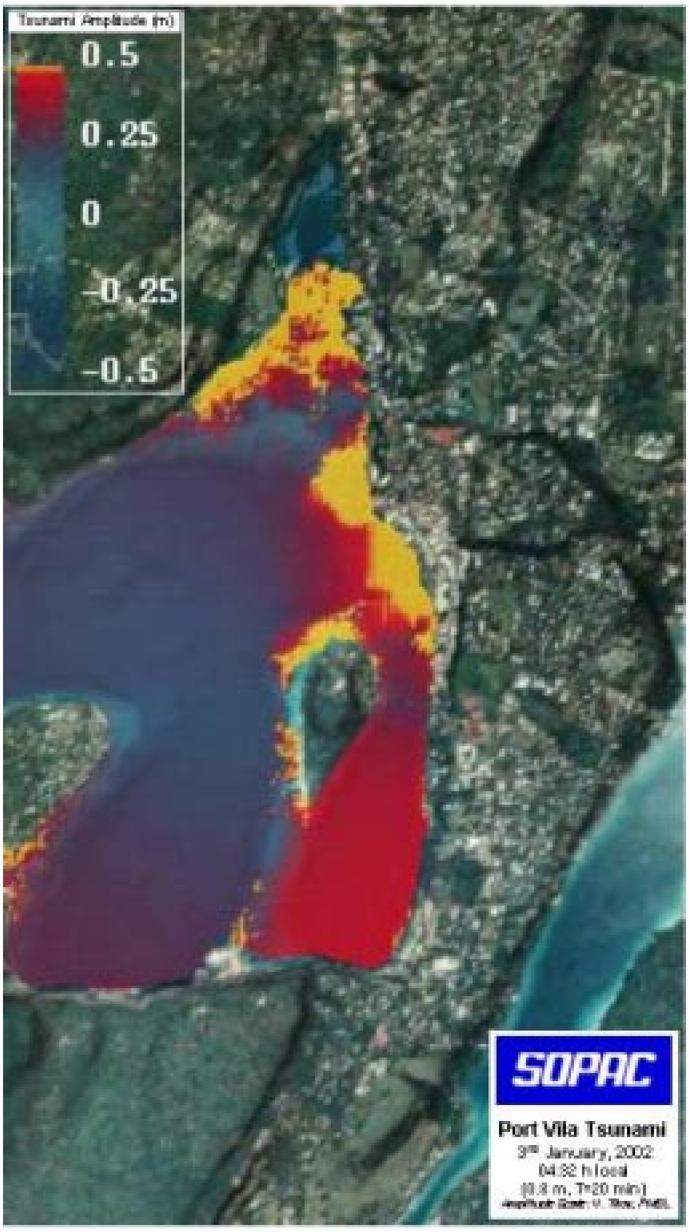

Figure 19: Model of tsunami heights in Port Vila Harbour based on tide gauge record.

directly outside the bar/restaurant almost touched the bottom of the mooring for about 20 minutes before the water came back again, appearing to him very much like a full tide. Apparently the water reached, but did not splash over, the top of the sea wall. Measurements were taken on the height of the sea wall and depth of mooring and dimensions of one of the boats affected.

7. Trader Vick's: On 12/1/2002, interviewed a taxi driver living in the green-roofed ex-boathouse on the shore immediately north of the old Trader Vick's bar. He remembered that about 3 minutes after the earthquake, the water level dropped to about 0.75 m below the low tide mark, and about 3 minutes later, came back up to high tide level. This effect happened several times, with degenerating amplitude on each occasion. Continued small wave action distributed coral rubble across his taxi-parking ramp just above HAT level.

Summary:

The common points in the interviews were:

1. The first effect noticed was a receding wave, as opposed to the positive wave on record at the NTF Tide Gauge.
2. Estimates of the time between the earthquake and the first tsunami effects range from 2-5 minutes; well under the 15 minutes measured at the NTF Tide Gauge.
3. The maximum reach of the tsunami was usually put at close to highest tide level, and the minimum markedly below lowest tide level.
4. Most observations made reference to several waves, some 3-5 minutes apart. The Waterfront Bar observation is an exception.
5. The tsunami was generally reported as having around 2-4 times the amplitude and the frequency recorded on the NTF Tide Gauge.
6. Persistent whirlpools tracking around the east and north of Ifira Island were widely reported.
7. The tsunami was always characterised as a slow, tide-like surge rather than a wave.
8. Measurements were made on fixed points where possible, relative to predicted tide levels at the times of the interviews. Summary diagrams and NTF tidal predictions are available. Differences between observed and predicted sea levels on the gauge have not been incorporated.
9. Most of the people interviewed weren't wearing watches.

5.3 Tsunami Predictions

Predictive tsunami modelling carried out by Vasily Titov, in conjunction with Stan Goosby of the Pacific Disaster Center, Hawaii, USA, as part of the Port Vila Pacific Cities project prior to the actual event, confirms that the observed amplifications are likely to occur due to resonance and interference effects within the harbour. A video-animation of the simulated tsunami in Port Vila harbour produced by Vasily Titov, but based on the scenario of a larger, M 8.2 earthquake occurring in a similar location, is available from SOPAC.

The tsunami model appears, on the face of it, to have successfully predicted the amplification effects of the latest tsunami (Figure 19) and is currently being re-checked using the actual earthquake parameters and the eyewitness accounts for verification.

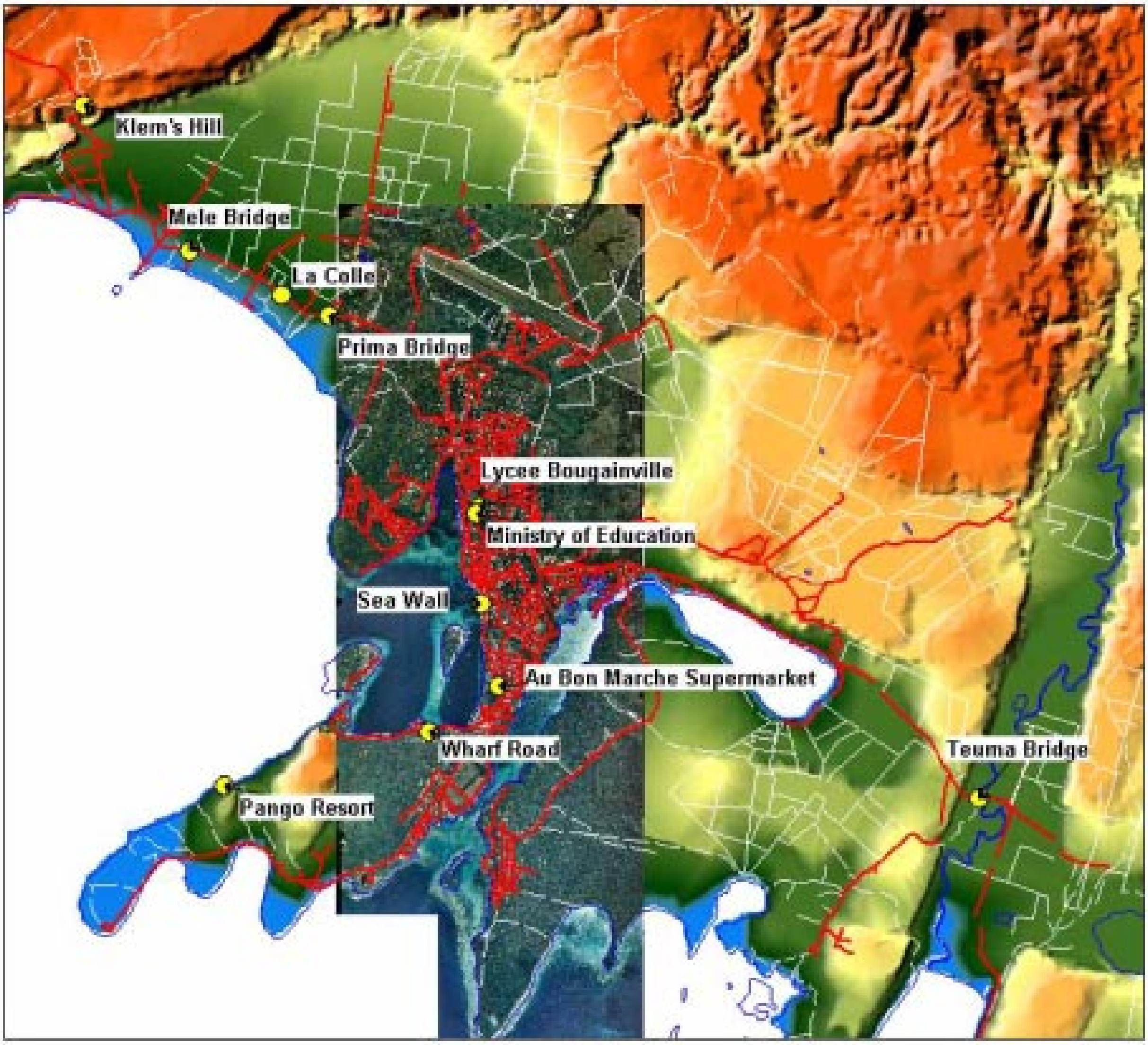

Figure 20: Sites of major earthquake damage.

6.0 Earthquake damage

For a magnitude of Ms 7.3, the damage due to the 3rd January 2002 earthquake was, in general, surprisingly light. Though neither loss of life nor severe injury was reported after the earthquake, several bridges and roads were damaged and the landscape transformed by landslides. The majority of engineered structures fared well in the earthquake, and most of the damage appears to be the result of either ground failure or inadequate structural design. SOPAC carried out a rapid assessment of damage in the Port Vila area, which was reported in Shorten (2002) and largely reiterated here, while the Public Works Department produced an infrastructure assessment report on the earthquake soon after the event. A map of the sites of major damage is shown in Figure 20.

Figure 21: Short columns spalled and failed, ground floor, Lycee Bougainville.

Figure 22: Differential damage between upper and lower floors of the Lycee Bougainville.

Earthquake damage to structures and disruption to lifelines fell into several categories:

- Direct earthquake effects
- Foundation failure
- Slope failure

6.1 Direct Earthquake Effects

Significant structural damage occurred to the Lycee Bouganville where a 3-storey school classroom building was severely damaged, displaying short-column failure concentrated at the top of the infill walls throughout the entire ground floor level (Figure 21). An adjacent dormitory block suffered similar, significant structural damage, and a 2-storey classroom block reached the stage of incipient failure. The school buildings are built on a cut and filled slope. Damage consistently increases from upper to lower floors (Figure 22).

The pattern of failure suggests that the fixity of the ground-floor infill walls has concentrated stresses and promoted shear failure in the short, lower-floor columns (Figure 23). The design strength of the concrete has been exceeded, possibly due to poor concrete mix characteristics.

A retrofitting program should be undertaken without delay for this particular design (where not already condemned) especially in the case where they are used as public school buildings.

Unreinforced concrete blocks set in a checkerboard pattern in the stairwell spaces of the Lycee buildings (Figure 24) have failed catastrophically, highlighting a dangerous and unnecessary construction practice. The blocks should be removed immediately and replaced with alternative materials.

The neighbouring 3-storey section of the Ministry of Education building was also badly damaged in a very similar fashion to the 3-storey classroom block at the Lycee.

The 3-storey Au Bon Marche in No.2 district was badly damaged (Figure 25) through column failure, probably due to inadequate foundation floor beams.

Figure 23: Damage to ground-floor classrooms of the Lycee Bougainville.

Figure 24: Infill block-work in stairwells of the Lycee Bougainville sheared and collapsed.

Figure 25: Damage around ground-floor columns at Au Bon Marche.

The building housing the Australian and British High Commissions suffered thoroughgoing cracks in piers on the eastern side, as well as significant distress in internal infill walls. The degradation of concrete in the under surface of the lower floor due to the placement of reinforcing too close to that surface does not engender confidence in the construction practices used in that building. Eyewitnesses in this same building reported the toppling of shelves during some of the larger aftershocks; a feature not reported elsewhere.

A large number of buildings suffered minor structural damage, including shearing of infill walls and window breakage.

According to Public Works Department reports, the Forestry Department building and the Department of Health and Department of Lands offices in the George Pompidou Building suffered minor cracks and shear failure in some elements, and the Imford Museum at Nambatu suffered similar structural failure (Figure 26).

Although still occupied, several buildings in town were severely cracked and fissured. These included the Health Department building and the Lands & Survey Department at George Pompidou, the Government Building, the building housing the Australian High Commission and others.

Figure 26: Damage at the Imford Museum.

Figure 27: Fissuring in back-fill behind sea wall, north of Market.

Figure 28: Detached Market toilet block.

6.2 Foundation Failures

Movement of the sea wall during the main shock has led to some permanent deformation to seaward and subsidence of the foreshore in reclaimed areas around the Central Business District. The worst affected area runs for some 150 m from the open park area north of the main public Market (Figure 27), southward through the seaward end of the Market building and car park and then through the seaward end of the Sea View Restaurant/Bon Marche in a 25 m-wide zone adjacent to the sea wall.

This has led to the subsidence and tilting of the Sea View Restaurant, detaching it away and rotating it to seawards from the main Bon Marche building, and causing significant distress and cracking to structural columns and beams throughout the restaurant. Similarly, the toilet block on the seaward end of the Market (Figure 28) has detached 150 mm away from the main structure. It is likely that both structures are founded directly on fill in an inherently unstable area.

The ground distress also extends into the floor slab up to the first row of columns of the main market where the first (westernmost) slab construction joint has opened up. Between the public Market and the restaurant, the concrete slabs of the car park have also opened up some 50-100 mm on construction joints (Figure 29) due to the same cause.

Subsidence and rotation of the sea wall has also occurred further south in the vicinity of the Waterfront Bar (Figure 30). Fissures that opened in filled ground behind the sea wall there reportedly issued water under high pressure.

A gap of around 20 mm is present between the concrete sea wall and backfill in areas of the reclaimed area around the CBD (Figure 31). In fact the extent of damage to the sea wall is defined in Figure 32. It can be seen from this figure that the area of reclamation and sea wall that failed (yellow lines) is closely related to the encroachment of reclamation into the deeper areas of the harbour (blue lines) where presumably thicker sediment and/or landfill is present.

The Teouma Bridge to the southeast of the city has suffered significant structural damage as a result of the shearing of the eastern pier set/pile cap due to a rotational soil failure in the eastern abutment (Figure 33). The bridge superstructure has shifted eastward and tilted down to the east, causing some tilting of the western pier set as well (Figure 34). Soil failure due to liquefaction is also apparent in the western approach. The PWD has plans in hand to drive new piles, re-establish the level of the superstructure and repair the piers.

Both the Mele (Figure 35) and Prima Bridges to the northwest of Port Vila have been affected by failure of their approach embankments and abutments due to liquefaction in the underlying alluvial soils (Figure 36), although the main bridge structure in both cases is considered by the PWD to be sound. Fissures

Figure 29: Car park slabs opened on construction joints south of Market.

Figure 30: Ground fissures and tilted sea wall near Waterfront Bar.

Figure 32: Areal extent of damage to sea wall in Port Vila.

Figure 31: Gap between sea wall and back-fill..

Figure 33: Damaged Teouma Bridge, eastern abutment.

in the roadway and underlying embankment fill (Figure 37) opened up to 500 mm wide with depths in excess of a metre in places.

The Rentapao Bridge southeast of Teouma also suffered damage.

A few power poles and water supply systems in some areas were damaged but were restored at the end of the first day by UNELCO teams deployed to ensure power supply in the capital.

6.3 Slope Failures

A number of very large landslides occurred on the access road to the main Star Wharf at the southern end of Port Vila Harbour (Figure 38). Failure reportedly occurred about five to ten minutes after the main earthquake.

The geology of Port Vila is characterised by a thick series of weak volcanic tuffs capped by a cemented limestone some tens of metres thick. The underlying tuffs are exposed only in limited number of localities in the city area; the principal exposure being in the high slopes above the access road to the main Star Wharf. The slope failures in the wharf road were principally within the weaker tuffs, although undercutting of the top of the cliff has brought down significant blocks of limestone as well (Figure 39). Failures in the tuff have been variously initiated on wide shear zones and areas where the layering dips out of the cliff face, as well as within fossil gullies containing weak colluvial material.

Whereas the interface between the tuff and overlying limestone lies high in the cliff face on the city side of the harbour, it dips towards the west so that it lies within several metres of sea level on the western margin of the peninsula.

Figure 34: Damaged Teouma Bridge, western abutment.

Figure 35: Embankment failure, Mele Bridge.

Figure 36: Slumping due to liquefaction, Prima Bridge.

Figure 37: Embankment failure, Prima Bridge.

Figure 38: Blockage of Star Wharf access road by landslide.

Figure 39: Toppled limestone boulder puncturing surface of the main Star Wharf access road.

Accordingly, the slope failures have been concentrated in the tuff composing the cliff face above the southeastern part of the harbour with very few in the southwest where the cliff face is almost entirely composed of limestone (Figure 40).

The fill in the roadway to the wharf has fissured and failed in numerous places (Figure 41). The security of the wharf access road is a key issue requiring further geotechnical investigation and remedial work.

Significantly, the one catastrophic slope failure that did occur in the west of the peninsula (Figure 42) was in the area between Pango and Watarua-Paradise Cove where prior paleo-erosion of the tuff had undercut the overlying limestone. According to eyewitness reports, the limestone overhang fell from the face onto the road some twenty to thirty minutes after the main shock.

The section of the cantilevered limestone, including one still-intact house-sized block of limestone of 300-400 m^3, toppled from the 10 m-high cliff line to partially demolish a modern concrete bungalow used as a reception area for the Pango Resort and block the road to the resort (Figure 43 & Figure 44). It was estimated by PWD that the total volume of rock to be removed from the road was about 2000 m^3.

At Klem's Hill, a significant slope failure occurred both within the Efate Ring Road roadway fill (Figure 45) and in the tuff forming the cut slope above.

Figure 42: Toppling failure from the cliff face near Pango Resort.

Figure 40: Massive slope failure in tuff above Star Wharf access road.

Figure 41: Road embankment collapse, Star Wharf road.

Figure 43: Rock debris behind Pango resort.

Figure 44: Bungalow damaged by rock-fall at Pango resort.

Inspection of other, smaller failures nearby suggest that shear planes dipping out of the face may have led to the failure in this area. The road is excessively steep and remains vulnerable to such failures in the future. Transverse and longitudinal cracks in the roadway were related to collapse of the main embankment (Figure 46). The length of the damaged area on this road is about 200 km.

The short-term fix of cutting the roadway deeper into the hillside may not prove a long-term solution. Apparently a less precipitous route to the west around Devil's Point is under consideration.

In the rest of the island, the earthquake caused several landslides in the highland areas on volcanic hillsides. There were several reported incidences of natural dam formation, major disturbance in drainage pattern, deviation of streams, and spring waters drying up.

Figure 45: Transverse fissures on Efate ring road at Klem's Hill.

Figure 46: Landslide on Efate ring road at Klem's Hill.

CONCLUSIONS

The Ms 7.3 earthquake of 3rd January 2002 was the largest ever recorded in the vicinity of Port Vila. The event brought different government departments and Non-Government Organisations together for the assessment of the earthquake damage. The Department of Geology, Mines and Water Resources (DGMWR), which is responsible of the earthquake monitoring in Vanuatu, has been ably supported by international organisations such as SOPAC and IRD in assessing the earthquake effects.

Located as it is on a plate boundary near a subduction zone, Vanuatu is continuously subject to tectonic earthquakes due to faulting. The large earthquake that hit Port Vila in the dawn of 3rd January originated through a sudden slip of the Australian Plate beneath the Pacific Plate.

The earthquake was first located by the USGS worldwide network at latitude 17.59 S and longitude 167.83 E, about 50 km west of Efate, at a depth of 21 km. The local seismologic network, IRD and the DGMWR, relocated the main shock more precisely to latitude 17.763 S and longitude 167.850 E, at a depth of 18 km below the sea floor, about 45 km west of Efate.

The investigations of the field intensity carried out after the earthquake show a high variation of intensity across the island of Efate. Port Vila city localities suffered the worst effects with intensities ranging from MM 6 to MM 10. Using a global intensity value for each district of Port Vila, the intensity can be seen to have ranged from MM 6.5 (in the Fresh Water area) to MM 8 (along the coast from Mele to Black Sands, and at Nambatri). In the rural areas, the intensity range of the earthquake was lower; from MM 6 along the eastern coast to MM 7 in the northwest and south of Efate.

A large number of Modified Mercalli intensity surveys were carried out in Port Vila city area in order to test the veracity of the earthquake microzoning scheme developed recently for the city. The existing scheme was generally successful in predicting areas of above-background felt-intensities where values of MM 8 were generally observed in low-lying areas of thick sediment in contrast to the general background of MM 7 on rock in the city area. Areas of anomalous intensity have been singled out for further investigation, eventually leading to some modification of predicted earthquake effects in Port Vila.

This large earthquake led to series of aftershocks that shook the island for a number of weeks. The intensity of the aftershocks ranged from Ms 4.7 to Ms 6.4; the largest one occurring on the same day as the main shock. The local seismologic network located this event at latitude 17.79 S and longitude 167.92 E at a depth of 27 km below sea floor, about 25 km from the main shock.

According to the local network location scheme, the distribution of the hypocentre of the aftershocks determined so far defines an extended band of about 81 km long (from 17.340 S to 18.025 S) and 33 km wide (from 167.740 E to 168.111 E) running in a north-northwest direction.

The National Tidal Facility Australia gauge registered a tsunami that accompanied the Ms 7.3 earthquake. According to the recordings, the tsunami struck Port Vila some 15 minutes later at 4:37 am of 3rd January 2002 (local time). It was registered on the gauge as having the crest at 0.8 m

As the time of its occurrence was that of the lowest tide of the year, the majority of the people living away from the coast did not notice major water level anomaly. However, eyewitnesses reports in the harbour put the tsunami at heights up to more than 3 m.

Though neither death nor serious injury was reported, the earthquake caused significant damage on Efate island, especially in buildings and infrastructure in Port Vila.

The majority of buildings suffered from inadequate structural failures to the extent where some are earmarked for possible demolition, such as the 3-storey Bougainville Lycee school classroom and dormitory, and the Ministry of Education building.

Bridges and their approach embankments suffered structural and foundation failure, generally due to liquefaction of fine-grained alluvial deposits. The Rentapao and the Teouma bridges will need major repairs.

Damage to roads was generally due to embankment collapse and slope failures that led to several landslides blocking access to important facilities.

Data analysis of the whole seismic crisis recorded by the seismic network of Port Vila will be used to increase the knowledge of the geometry and nature of the fault that caused the Ms 7.3 Port Vila earthquake and provide clues as to future earthquake activity.

During this seismic crisis IRD and SOPAC have provided the Geohazard Mitigation section of the DGMWR the benefit of their experience in geohazard assessment and management in times of crisis.

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APPENDIX 1: HISTORICAL SEISMICITY DATA FOR PORT VILA (M>5, d<70 km)

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
9-Aug-01		-16.00	167.00		8.4	Ms		239
13-May-03	063400.00	-17.00	168.00	60	7.9	Ms		88
22-Mar-25	084100.00	-18.50	168.50	50	7.6	Ms		85
2-Dec-50	195100.00	-18.30	167.50	60	8.1	Ms		105
24-Feb-73	073827.00	-19.19	168.74	59	6.0	mb	GS	166
8-Apr-73	124102.00	-15.78	167.22	35	6.4	Ms	GS	246
21-Apr-73	203035.70	-15.88	167.28	33	5.3	mb	GS	233
5-Jun-73	020712.50	-17.30	167.80	12	5.2	mb	GS	73
5-Jun-73	031225.80	-17.19	167.81	24	6.5	UK	PAS	80
5-Jun-73	090432.90	-17.34	167.79	21	5.0	mb	GS	71
8-Jun-73	010111.40	-17.47	167.74	21	5.9	UK	BRK	68
9-Jun-73	042702.80	-17.46	167.65	27	5.0	mb	GS	76
13-Jun-73	094825.20	-19.18	169.66	24	5.7	mb	GS	213
19-Jul-73	162531.20	-15.79	168.21	28	5.5	mb	GS	215
27-Jul-73	160832.60	-17.22	167.85	15	5.1	mb	GS	75
9-Aug-73	193329.80	-19.01	168.65	45	5.0	mb	GS	144
27-Aug-73	134831.60	-15.99	168.10	11	5.7	mb	GS	195
2-Sep-73	160633.50	-19.25	167.62	33	5.2	mb	GS	182
27-Oct-73	075338.20	-17.98	169.09	29	5.3	mb	GS	86
10-Nov-73	092116.50	-19.07	167.41	12	5.4	mb	GS	174
4-Dec-73	153039.00	-16.50	167.10	9	5.3	mb	GS	188
15-Dec-73	225702.90	-16.77	168.13	7	5.6	mb	GS	109
16-Jan-74	104510.90	-17.45	167.89	30	5.3	mb	GS	54
28-Feb-74	125929.70	-19.20	169.82	14	5.5	mb	GS	226
14-Mar-74	213523.00	-19.16	167.67	33	5.2	mb	GS	170
5-May-74	081750.30	-17.45	167.91	33	5.6	Ms	GS	53
26-May-74	013211.20	-17.70	167.75	13	6.1	UK	PAS	59
26-May-74	021526.40	-17.77	167.48	31	5.2	mb	GS	88
26-May-74	055240.20	-17.32	167.12	53	5.5	mb	GS	134
26-May-74	081450.00	-17.72	167.68	8	5.1	mb	GS	67
26-May-74	100242.10	-17.73	167.79	27	5.0	mb	GS	55
26-May-74	152424.00	-17.62	167.49	7	6.2	mb	GS	88
28-Jun-74	180635.20	-17.97	167.84	26	5.1	mb	GS	56
30-Jun-74	083346.50	-17.99	168.29	61	5.7	mb	GS	27
30-Jun-74	125001.60	-19.16	168.67	32	5.7	mb	GS	161
5-Aug-74	141301.30	-16.59	167.58	42	5.1	mb	GS	149
19-Nov-74	065029.00	-16.07	167.46	42	5.2	mb	GS	205
4-Jan-75	020039.40	-17.07	168.12	62	5.0	mb	GS	76
5-Mar-75	102709.80	-19.53	168.87	55	5.6	mb	GS	205
25-Mar-75	210528.90	-16.55	167.46	14	5.1	mb	GS	160
10-Jun-75	071911.50	-17.36	167.02	33	5.1	mb	GS	143

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
1-Jan-76	184338.20	-16.79	167.25	25	5.5	Ms	GS	154
25-May-76	003908.40	-19.77	169.02	70	5.1	mb	GS	235
25-May-76	180117.90	-17.36	167.79	20	5.5	mb	GS	70
6-Jun-76	205345.50	-16.29	167.33	18	5.1	mb	GS	191
8-Jun-76	092217.60	-16.30	167.26	13	5.6	Ms	GS	194
5-Jul-76	024252.90	-16.39	167.19	22	5.4	mb	GS	191
4-Sep-76	161554.70	-19.21	169.65	38	5.0	mb	GS	214
9-Nov-76	012536.70	-18.13	168.26	32	5.0	mb	GS	42
30-Nov-76	075617.20	-19.19	168.60	53	5.0	mb	GS	162
20-Dec-76	100419.90	-17.41	167.83	33	5.1	mb	GS	62
24-Jan-77	144117.60	-17.35	167.92	38	5.0	mb	GS	59
27-Jan-77	045053.30	-17.36	167.87	25	5.0	mb	GS	63
28-Jan-77	180051.80	-17.44	168.69	14	5.6	Ms	GS	52
28-Jan-77	235451.20	-17.38	168.69	16	5.0	mb	GS	56
9-Apr-77	211614.60	-19.08	169.59	25	5.5	UK	BRK	199
9-Apr-77	215108.10	-19.09	169.65	15	5.0	mb	GS	205
10-Apr-77	005416.50	-19.00	169.59	18	5.0	Ms	GS	193
11-Apr-77	052820.90	-19.25	169.56	39	5.0	mb	GS	212
16-May-77	111430.70	-17.42	167.92	30	5.3	Ms	GS	54
23-May-77	120909.20	-17.65	167.62	11	5.0	mb	GS	74
25-May-77	191853.80	-17.73	167.61	13	5.2	mb	GS	74
10-Jul-77	023714.60	-19.13	168.41	12	5.5	mb	GS	153
10-Jul-77	031108.10	-19.22	168.47	21	5.1	mb	GS	163
11-Jul-77	191051.20	-19.15	168.46	20	5.3	mb	GS	155
25-Jul-77	224104.50	-19.16	168.42	30	5.1	mb	GS	156
16-Aug-77	061516.70	-19.28	167.65	12	5.5	mb	GS	183
16-Aug-77	070301.30	-18.97	167.58	33	5.1	mb	GS	155
22-Sep-77	234144.40	-15.94	167.30	25	5.1	mb	GS	226
9-Nov-77	084439.70	-16.24	166.86	27	5.2	mb	GS	227
3-Dec-77	163526.40	-17.59	167.32	10	5.4	mb	GS	106
14-Feb-78	231648.00	-15.58	168.09	33	5.4	mb	GS	240
21-Mar-78	175307.90	-17.50	167.88	27	5.2	mb	GS	52
21-Mar-78	191405.90	-17.61	167.77	23	5.4	mb	GS	59
8-May-78	163538.00	-17.02	167.54	33	5.4	mb	GS	115
8-May-78	190539.40	-16.98	167.59	33	5.1	mb	GS	114
13-May-78	040726.20	-16.99	167.48	15	5.3	mb	GS	120
23-May-78	050347.70	-16.14	167.58	47	5.2	mb	GS	193
3-Jul-78	030533.10	-18.25	168.14	33	5.3	mb	GS	58
1-Sep-78	041642.10	-17.41	168.00	32	6.2	UK	BRK	49
8-Sep-78	060248.60	-15.96	167.63	39	5.3	mb	GS	209
9-Sep-78	122333.70	-17.49	167.92	27	5.0	mb	GS	50

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
28-Sep-78	132232.20	-17.46	167.91	33	5.0	mb	GS	52
22-Nov-78	050257.80	-19.61	168.61	33	5.1	mb	GS	208
29-Nov-78	111050.80	-15.51	168.08	33	5.5	mb	GS	248
6-Dec-78	095234.70	-19.33	167.80	22	5.3	mb	GS	183
23-Jan-79	214320.20	-17.50	167.86	33	5.3	mb	GS	55
27-Jan-79	001815.00	-18.54	168.21	25	6.3	Ms	GS	89
8-Apr-79	053839.30	-18.48	168.18	32	5.3	mb	GS	82
10-May-79	145725.80	-19.91	168.15	33	5.1	mb	GS	239
29-May-79	054600.10	-16.93	167.78	39	5.3	mb	GS	105
14-Jun-79	215716.30	-17.66	167.79	27	5.2	mb	GS	56
21-Jun-79	145741.80	-15.61	168.00	33	5.1	mb	GS	238
10-Jul-79	162508.00	-18.95	168.55	56	5.3	mb	GS	136
15-Jul-79	183947.00	-19.10	168.70	55	5.4	mb	GS	155
9-Aug-79	144418.20	-19.94	168.18	42	5.1	mb	GS	243
14-Aug-79	105703.80	-18.53	168.20	39	5.3	mb	GS	88
17-Aug-79	125907.40	-17.72	167.85	17	6.2	UK	BRK	49
17-Aug-79	141834.70	-17.72	167.71	23	5.4	mb	GS	63
17-Aug-79	151826.50	-17.65	167.75	39	5.7	Ms	GS	60
17-Aug-79	181716.30	-17.90	167.67	15	5.0	Ms	GS	70
26-Aug-79	114724.50	-17.67	167.68	10	6.2	UK	PAS	67
26-Aug-79	165612.20	-17.29	167.76	33	5.1	mb	GS	77
2-Sep-79	183747.20	-17.59	167.59	33	5.3	mb	GS	78
19-Sep-79	184420.00	-17.36	168.47	33	5.0	mb	GS	45
5-Dec-79	085354.80	-18.15	168.30	48	5.1	mb	GS	44
8-Dec-79	083133.70	-15.85	168.31	34	5.6	mb	GS	209
11-Dec-79	052819.50	-19.10	168.68	51	5.1	mb	GS	155
16-Dec-79	063347.70	-17.46	167.79	19	5.2	mb	GS	63
24-Dec-79	120549.30	-18.23	167.93	26	5.0	mb	GS	67
12-Jun-80	175553.50	-17.31	167.81	32	5.1	mb	GS	71
6-Jul-80	051843.20	-18.35	168.27	43	5.1	mb	GS	66
9-Oct-80	061137.00	-19.24	169.64	33	5.2	Ms	GS	217
9-Oct-80	104413.20	-19.18	169.64	33	5.2	Ms	GS	211
9-Oct-80	113256.40	-19.27	169.74	33	5.9	UK	BRK	226
3-Dec-80	203643.00	-17.95	169.04	33	5.2	mb	GS	79
5-Dec-80	173933.90	-16.50	167.08	35	5.0	mb	GS	189
15-Jul-81	075908.47	-17.26	167.60	30	7.1	Ms	BRK	92
15-Jul-81	090043.61	-17.07	167.49	35	5.2	mb	GS	115
15-Jul-81	100120.17	-16.92	167.42	33	5.0	mb	GS	131
15-Jul-81	165126.12	-17.62	167.46	38	5.0	mb	GS	91
15-Jul-81	221052.79	-17.56	167.72	32	5.2	mb	GS	66
15-Jul-81	232041.77	-17.59	167.60	31	5.5	Ms	GS	77

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
17-Jul-81	005734.69	-17.17	167.63	33	5.1	mb	GS	95
17-Jul-81	101915.44	-17.42	167.37	33	5.0	mb	GS	106
19-Jul-81	044259.36	-17.14	167.52	46	5.5	Ms	GS	106
19-Jul-81	153046.79	-17.25	167.08	27	5.1	mb	GS	141
29-Jul-81	050913.10	-16.75	167.13	33	5.0	mb	GS	166
31-Jul-81	000103.76	-16.87	167.41	33	5.0	mb	GS	136
9-Aug-81	202442.21	-17.04	167.28	33	5.0	mb	GS	134
18-Jan-82	042337.75	-17.29	167.81	44	6.0	Ms	BRK	73
27-Jan-82	010401.75	-17.47	168.00	33	5.1	mb	GS	44
26-Feb-82	211801.88	-18.01	167.87	44	5.0	mb	GS	55
27-Feb-82	052838.95	-16.11	168.23	25	5.0	mb	GS	180
1-May-82	174649.59	-15.85	167.42	33	5.3	Ms	GS	229
19-Aug-82	044048.22	-19.07	169.58	38	5.6	mb	GS	197
5-Oct-82	091432.51	-15.59	168.00	17	5.8	mb	GS	240
12-Mar-83	084946.35	-18.12	168.07	35	5.8	Ms	GS	48
26-Apr-83	111537.43	-15.99	168.43	33	5.5	mb	GS	193
26-Jun-83	155419.03	-17.87	167.60	13	5.1	mb	GS	77
27-Jun-83	082510.42	-18.13	167.82	32	5.0	mb	GS	67
15-Jul-83	031804.73	-18.95	168.09	33	5.0	mb	GS	135
3-Aug-83	181742.23	-17.40	167.91	33	5.6	Ms	GS	57
5-Aug-83	052543.44	-17.30	167.87	33	5.7	Ms	GS	67
5-Aug-83	070238.81	-17.24	167.84	15	5.3	mb	GS	75
11-Dec-83	130252.88	-18.36	168.05	54	5.5	mb	GS	73
5-Mar-84	044804.37	-17.04	168.26	33	5.2	mb	GS	78
5-Mar-84	114233.25	-16.94	168.04	33	5.1	mb	GS	93
21-Mar-84	170447.04	-17.17	167.20	32	5.3	mb	GS	134
1-Apr-84	212809.63	-17.64	167.80	33	5.0	mb	GS	55
29-Apr-84	223400.44	-18.06	167.24	33	5.2	mb	GS	118
18-May-84	095505.19	-17.73	168.12	43	5.2	mb	GS	20
28-May-84	174726.84	-15.84	167.05	33	5.2	Ms	GS	249
16-Jul-84	181630.58	-18.49	168.21	24	5.2	mb	GS	83
25-Jul-84	130928.48	-16.67	167.74	40	5.0	mb	GS	133
18-Aug-84	132458.30	-17.62	167.83	23	5.1	mb	GS	53
2-Oct-84	013708.12	-18.63	167.98	6	5.9	Ms	GS	104
2-Oct-84	132240.97	-18.52	167.98	14	5.5	mb	GS	93
2-Oct-84	194149.19	-18.51	168.14	24	5.5	mb	GS	86
3-Oct-84	143043.18	-18.44	167.93	37	5.0	mb	GS	87
3-Dec-84	131313.43	-19.16	168.65	38	5.3	Ms	GS	160
5-Dec-84	120229.72	-15.70	168.22	33	5.3	Ms	GS	226
17-Feb-85	194048.00	-19.25	168.42	33	5.0	mb	GS	166
28-Feb-85	111016.83	-19.16	168.74	48	5.5	mb	GS	163

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
1-Apr-85	010453.00	-16.69	167.23	42	5.0	mb	GS	163
12-May-85	152342.18	-17.01	167.57	32	5.1	mb	GS	112
25-Jun-85	141757.81	-19.51	168.75	61	5.0	mb	GS	200
3-Jul-85	155548.77	-17.24	167.83	28	6.7	Ms	BRK	75
1-Aug-85	080129.35	-18.88	168.39	38	5.1	mb	GS	125
7-Aug-85	132146.56	-18.92	168.37	33	5.2	mb	GS	130
8-Sep-85	180740.05	-17.62	167.71	10	5.3	mb	GS	65
4-Jan-86	095253.34	-17.55	167.77	23	5.1	mb	GS	61
4-Jan-86	133633.73	-17.56	167.85	26	5.3	Ms	GS	53
5-Jan-86	212804.95	-19.83	168.81	47	5.3	mb	GS	236
7-Jan-86	080846.56	-17.43	167.61	25	5.3	Ms	GS	82
31-Mar-86	070850.00	-17.23	167.39	33	5.0	mb	GS	113
12-Apr-86	121246.19	-17.54	167.85	22	5.2	mb	GS	54
14-Jun-86	232923.38	-19.10	169.78	15	5.9	Ms	BRK	214
14-Jun-86	233741.80	-19.06	169.60	16	5.3	mb	GS	199
7-Jul-86	163306.10	-17.33	167.74	27	5.1	mb	GS	75
2-Aug-86	111852.07	-18.20	167.96	33	5.0	mb	GS	62
23-Sep-86	133015.37	-16.62	167.26	19	5.7	Ms	GS	166
7-Oct-86	140344.57	-16.60	167.31	10	5.7	mb	GS	165
25-Oct-86	204701.80	-17.66	168.13	30	6.2	Ms	BRK	20
19-Nov-86	115237.18	-19.55	167.69	33	5.3	mb	GS	210
19-Nov-86	171155.36	-18.89	168.09	47	5.3	mb	GS	128
20-Nov-86	131424.95	-16.26	167.55	60	5.7	mb	GS	182
13-Dec-86	183152.46	-17.95	167.65	17	5.6	Ms	GS	73
14-Dec-86	112252.76	-17.96	167.79	10	5.0	mb	GS	60
16-Dec-86	081827.75	-18.01	167.66	10	5.2	mb	GS	75
28-Dec-86	114733.85	-19.21	168.45	50	5.2	mb	GS	162
11-Feb-87	075612.91	-15.83	167.35	23	6.6	Ms	BRK	234
17-Feb-87	041957.65	-19.68	168.76	33	5.6	mb	GS	218
17-Feb-87	051743.39	-19.69	168.81	33	5.3	mb	GS	221
26-Feb-87	043035.82	-19.70	168.71	43	5.2	mb	GS	220
26-Feb-87	043608.41	-19.80	168.69	49	5.4	mb	GS	230
7-Mar-87	061117.02	-16.02	167.40	35	5.6	mb	GS	213
29-Mar-87	091734.93	-17.24	167.89	21	5.4	Ms	GS	71
16-Jul-87	002305.62	-17.66	167.88	37	5.0	mb	GS	46
28-Sep-87	071538.24	-18.40	168.27	31	5.9	Ms	GS	73
28-Sep-87	114708.61	-18.41	168.06	30	6.8	Ms	GS	78
28-Sep-87	121651.98	-18.40	168.10	31	5.3	mb	GS	75
28-Sep-87	134613.95	-18.55	168.16	25	6.5	Ms	GS	90
28-Sep-87	150102.22	-18.14	168.00	54	5.0	mb	GS	54
28-Sep-87	230937.10	-18.34	168.12	31	5.2	mb	GS	69

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
30-Sep-87	013928.09	-18.16	167.87	51	6.3	Ms	GS	66
8-Nov-87	060604.72	-18.35	167.87	23	5.3	mb	GS	81
18-Nov-87	122758.97	-19.24	169.91	49	5.0	mb	GS	236
26-Nov-87	172854.73	-16.35	168.12	18	6.3	Ms	GS	155
27-Nov-87	130552.62	-16.26	168.13	32	5.5	mb	GS	164
27-Nov-87	131122.61	-16.31	168.14	28	5.3	Ms	GS	159
27-Nov-87	133318.05	-16.37	168.12	28	6.4	Ms	GS	152
27-Nov-87	173536.04	-16.22	168.17	30	5.0	mb	GS	168
21-Jan-88	082222.93	-18.18	168.14	44	5.9	Ms	GS	51
22-Jan-88	231329.13	-19.55	168.86	42	5.0	mb	GS	207
7-Feb-88	033316.48	-17.66	167.74	10	5.4	mb	GS	61
7-Feb-88	040531.33	-17.56	167.87	22	5.3	mb	GS	50
16-Feb-88	214230.16	-18.46	168.32	38	5.1	mb	GS	78
5-Mar-88	120649.63	-18.14	168.24	47	5.4	Ms	GS	44
26-Mar-88	094239.39	-18.26	167.93	17	5.1	mb	GS	70
30-Apr-88	065010.64	-17.05	167.45	47	5.2	mb	GS	118
5-May-88	075750.03	-18.20	168.17	35	5.3	Ms	GS	53
17-Jul-88	131211.58	-17.82	167.86	33	5.1	mb	GS	49
13-Aug-88	123621.62	-16.52	167.25	33	5.3	mb	GS	176
20-Aug-88	081937.64	-16.48	167.17	21	6.1	Ms	PAS	184
20-Aug-88	083101.34	-16.54	167.12	12	5.1	mb	GS	183
22-Aug-88	023538.32	-16.63	167.17	10	5.1	mb	GS	172
16-Sep-88	062729.76	-17.93	169.06	33	5.5	Ms	BRK	81
14-Feb-89	145306.21	-17.45	167.31	33	5.1	Ms	GS	111
8-Mar-89	035721.57	-19.13	168.68	65	5.2	mb	GS	157
24-Apr-89	203255.84	-17.48	167.84	27	5.1	mb	GS	58
24-Apr-89	204111.54	-17.40	167.83	34	5.7	Ms	BRK	64
25-Apr-89	031117.46	-17.42	167.78	15	5.0	mb	GS	67
18-Jul-89	235239.48	-17.57	168.68	41	5.2	mb	GS	43
20-Jul-89	172221.24	-17.41	167.83	33	5.1	mb	GS	63
11-Aug-89	011219.96	-18.71	168.30	42	5.0	mb	GS	106
17-Aug-89	110310.64	-17.70	167.19	10	5.2	mb	GS	119
17-Nov-89	153557.89	-17.39	167.93	27	5.7	Ms	BRK	56
29-Nov-89	155955.39	-18.32	168.15	23	5.1	mb	GS	66
1-Jan-90	172138.88	-19.15	167.31	10	5.2	mb	GS	188
9-Jan-90	184354.45	-19.88	168.03	33	5.0	Ms	GS	237
28-Jan-90	111530.32	-16.73	167.66	26	5.1	mb	GS	131
5-Mar-90	163812.57	-18.32	168.06	20	7.0	Ms	GS	68
5-Mar-90	171039.57	-18.35	168.01	33	5.4	mb	GS	74
8-Mar-90	101514.57	-18.47	168.05	17	5.2	mb	GS	84
7-Apr-90	182556.39	-18.05	168.13	36	5.2	mb	GS	39

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
7-Jul-90	203557.24	-15.52	168.09	33	5.2	mb	GS	247
22-Jul-90	012609.44	-19.13	168.76	45	5.0	mb	GS	160
17-Sep-90	000524.58	-18.34	169.12	41	5.1	mb	GS	107
17-Sep-90	020914.07	-18.39	169.38	33	5.4	mb	GS	133
23-Sep-90	175402.96	-17.73	167.61	10	6.2	Ms	GS	74
24-Sep-90	014420.25	-17.61	167.70	20	5.1	mb	GS	67
24-Sep-90	015801.92	-17.59	167.83	25	5.5	Ms	GS	53
2-Oct-90	074827.97	-17.63	167.83	26	5.3	mb	GS	52
2-Oct-90	080826.37	-17.62	167.80	19	5.5	Ms	GS	56
5-Nov-90	132254.53	-17.50	167.98	33	5.3	mb	GS	44
14-Dec-90	150002.78	-15.90	167.39	55	5.0	Ms	GS	226
27-Dec-90	180141.73	-19.53	168.81	59	5.2	mb	GS	204
18-Feb-91	161506.59	-19.03	168.49	39	5.7	mb	GS	143
14-Mar-91	135049.05	-19.38	167.79	33	5.0	mb	GS	189
28-Mar-91	072236.86	-18.31	168.01	29	5.2	mb	GS	69
28-Mar-91	075831.94	-18.21	167.97	26	5.3	Ms	GS	62
5-Jun-91	144713.11	-19.01	169.49	27	5.0	mb	GS	186
6-Jul-91	190012.56	-16.71	167.52	26	5.2	Ms	GS	141
11-Jul-91	020228.21	-16.77	167.44	28	5.1	mb	GS	142
3-Oct-91	202010.21	-17.03	167.94	10	5.7	Ms	GS	88
3-Oct-91	202417.38	-16.82	167.89	10	5.9	Ms	BRK	111
3-Oct-91	204331.16	-16.85	168.16	15	5.6	Ms	GS	99
6-Oct-91	075133.67	-16.77	168.08	22	5.2	Ms	GS	109
12-Dec-91	061301.23	-18.18	168.03	33	5.0	mb	GS	56
4-Mar-92	125525.01	-17.38	167.71	43	5.0	mb	GS	76
17-Mar-92	003809.38	-18.39	167.73	33	5.3	mb	GS	94
20-Mar-92	081646.66	-18.29	168.22	42	5.0	mb	GS	61
22-Mar-92	204520.64	-17.45	167.92	33	5.3	mb	GS	53
7-Apr-92	224729.45	-16.87	168.13	16	6.0	Ms	BRK	98
8-Apr-92	030127.59	-16.91	168.26	18	5.6	Ms	GS	92
8-Apr-92	133656.43	-16.78	168.31	14	5.8	Ms	GS	105
10-Apr-92	030142.52	-17.58	167.99	34	5.3	mb	GS	39
13-Aug-92	005750.67	-16.64	167.48	33	5.2	mb	GS	150
10-Sep-92	201057.09	-17.22	167.82	20	5.5	mb	GS	78
11-Sep-92	065353.15	-17.36	167.72	23	5.4	Ms	GS	75
19-Sep-92	232809.33	-15.73	168.15	20	5.1	mb	GS	222
15-Oct-92	144023.31	-19.16	169.61	20	5.3	mb	GS	207
17-Oct-92	020601.99	-19.35	169.69	57	5.3	mb	GS	229
17-Oct-92	025150.92	-19.23	169.55	11	7.0	Ms	BRK	209
17-Oct-92	054758.11	-19.24	169.47	33	5.2	mb	GS	205
17-Oct-92	114103.30	-19.16	169.48	33	5.3	mb	GS	199

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
17-Oct-92	141233.13	-19.36	169.70	39	5.1	mb	GS	230
17-Oct-92	181023.88	-19.33	169.64	36	5.3	mb	GS	224
19-Oct-92	120330.13	-19.39	169.59	20	5.8	Ms	GS	226
18-Nov-92	163645.19	-16.77	167.10	22	5.3	Ms	GS	167
11-Dec-92	022251.84	-17.52	167.96	33	5.4	mb	GS	44
17-Jan-93	053606.35	-19.72	168.88	30	5.2	Mw	HRV	226
10-Feb-93	001632.33	-19.43	169.18	10	5.2	mb	GS	207
22-Apr-93	180340.79	-16.32	167.44	33	5.0	mb	GS	182
3-May-93	232756.51	-19.64	168.80	33	5.1	mb	GS	215
9-Jul-93	130309.51	-17.37	167.93	16	5.9	Mw	GS	58
9-Jul-93	130849.33	-17.44	167.84	23	5.0	mb	GS	60
9-Jul-93	163706.33	-17.45	167.78	10	5.0	mb	GS	65
9-Jul-93	231747.95	-17.55	167.77	28	5.1	mb	GS	61
25-Jul-93	053746.39	-16.83	167.73	33	5.3	Mw	HRV	118
29-Sep-93	093920.67	-18.97	167.67	34	5.5	mb	GS	151
29-Sep-93	094848.27	-18.92	167.46	34	5.4	mb	GS	157
29-Sep-93	100920.04	-18.77	167.53	34	5.1	mb	GS	140
29-Sep-93	120708.08	-19.07	167.49	35	5.4	mb	GS	170
29-Sep-93	125029.90	-18.73	167.51	33	5.0	mb	GS	138
29-Sep-93	140748.80	-19.07	167.62	42	5.4	mb	GS	163
29-Sep-93	144427.73	-19.01	167.69	34	5.2	mb	GS	154
30-Sep-93	223620.88	-19.28	167.61	44	5.0	mb	GS	185
2-Oct-93	042340.61	-19.00	167.67	10	5.0	mb	GS	154
15-Nov-93	224519.35	-18.56	167.64	48	5.2	mb	GS	115
22-Jan-94	053701.12	-17.69	167.90	33	5.0	mb	GS	43
16-Feb-94	064858.04	-18.99	168.13	13	6.5	Ms	BRK	139
26-Feb-94	174550.37	-17.65	167.78	28	5.4	Mw	HRV	57
6-Apr-94	121344.97	-17.37	167.82	17	6.2	Mw	HRV	66
6-Apr-94	121958.39	-17.43	167.76	10	5.2	mb	GS	68
10-Apr-94	051826.90	-17.41	167.68	29	5.4	Mw	HRV	77
17-Apr-94	061439.17	-15.90	167.51	39	5.7	Mw	HRV	220
7-Jul-94	001925.41	-19.30	169.81	33	5.2	mb	GS	233
13-Jul-94	002514.43	-16.64	167.47	33	5.4	mb	GS	150
13-Jul-94	023556.02	-16.62	167.52	33	7.3	Ms	GS	150
13-Jul-94	024347.10	-16.64	167.38	33	5.6	mb	GS	156
13-Jul-94	031319.31	-16.81	167.25	33	6.7	Mw	HRV	152
13-Jul-94	080951.75	-16.57	167.22	29	5.3	mb	GS	173
13-Jul-94	090156.67	-16.90	167.49	23	5.2	mb	GS	127
13-Jul-94	134807.93	-16.57	167.42	25	5.3	mb	GS	160
14-Jul-94	000924.70	-16.58	167.45	19	5.9	Ms	GS	157
14-Jul-94	075306.32	-17.13	167.59	36	5.2	Ms	GS	102

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
14-Jul-94	082538.77	-16.71	167.37	30	5.7	Mw	HRV	152
14-Jul-94	112633.47	-16.80	167.42	21	5.3	Mw	HRV	140
15-Jul-94	131149.60	-16.58	167.38	28	5.0	mb	GS	161
15-Jul-94	160430.49	-16.56	167.48	33	5.2	mb	GS	158
15-Jul-94	192043.38	-16.72	167.24	33	5.0	mb	GS	160
17-Jul-94	220458.06	-16.68	167.38	33	5.6	Mw	HRV	153
23-Jul-94	133956.46	-16.79	167.04	33	5.2	Ms	GS	171
23-Jul-94	195306.81	-16.79	167.38	33	5.0	mb	GS	144
24-Jul-94	175540.38	-16.97	167.57	20	6.6	Ms	BRK	116
24-Jul-94	203752.43	-16.98	167.39	33	5.3	Mw	HRV	129
25-Jul-94	215208.72	-16.98	167.52	33	5.1	mb	GS	118
29-Jul-94	075328.47	-16.98	167.74	13	5.9	Mw	GS	103
29-Jul-94	124224.06	-16.95	167.63	33	5.3	mb	GS	113
29-Jul-94	131251.23	-16.92	167.74	36	5.4	Mw	HRV	109
3-Aug-94	182401.16	-17.31	167.31	40	5.2	Mw	HRV	116
10-Aug-94	140657.03	-16.89	167.19	33	5.5	Mw	HRV	152
15-Aug-94	105853.87	-17.62	167.79	33	5.4	mb	GS	56
1-Oct-94	150331.31	-17.85	167.80	25	5.7	Mw	HRV	55
1-Oct-94	163520.79	-17.75	167.68	16	6.5	Ms	GS	66
1-Oct-94	174637.58	-17.77	167.83	33	6.3	Ms	GS	51
1-Oct-94	175416.71	-17.96	167.32	33	5.1	mb	GS	107
1-Oct-94	181622.20	-18.04	167.37	33	5.4	Ms	GS	105
1-Oct-94	210128.36	-17.81	167.79	24	5.3	mb	GS	55
1-Oct-94	232856.24	-17.64	167.79	18	5.4	Mw	HRV	57
1-Oct-94	235359.40	-17.88	167.44	33	5.4	Mw	HRV	94
2-Oct-94	101432.38	-17.56	168.05	10	5.4	Mw	HRV	34
2-Oct-94	103545.48	-17.78	167.65	33	5.2	mb	GS	70
18-Jan-95	121437.12	-19.16	167.40	36	5.5	mb	GS	183
22-Jun-95	075710.92	-16.41	168.11	33	5.8	Mw	GS	148
7-Nov-95	160810.18	-17.92	168.07	33	5.2	Mw	HRV	32
13-Jan-96	000723.94	-19.54	168.89	33	5.3	Mw	HRV	207
11-Feb-96	205025.48	-16.39	168.18	18	5.4	mb	GS	149
18-Sep-96	041144.40	-19.75	168.69	31	5.7	Mw	HRV	225
26-Jan-97	144116.64	-17.18	167.77	37	5.4	Mw	HRV	84
23-Mar-97	154939.68	-19.17	168.74	33	5.5	Mw	HRV	163
3-Apr-97	004441.52	-16.05	168.14	50	5.0	mb	GS	188
27-Apr-97	003132.54	-19.17	168.73	41	6.1	Mw	GS	163
9-Jun-97	012131.77	-19.62	169.64	33	5.2	Mw	HRV	249
21-Jul-97	123029.98	-17.41	167.62	33	5.3	Mw	HRV	82
28-Aug-97	214207.61	-17.40	167.91	33	5.5	Mw	HRV	57
18-Oct-98	031538.42	-16.86	166.79	33	5.0	mb	GS	188

Date	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Solution	Recorder	Epicentral Distance from Port Vila (km)
19-Oct-98	012501.20	-17.30	167.72	33	6.0	Mw	HRV	79
19-Oct-98	022334.68	-17.24	167.84	33	5.1	Ms	GS	75
14-Feb-99	211224.58	-15.51	168.00	10	6.0	Mw	GS	249
15-Feb-99	051907.37	-15.54	168.00	33	5.4	Ms	GS	245
2-Apr-99	170547.11	-19.90	168.19	10	6.2	Mw	GS	238
2-Apr-99	183816.97	-19.86	167.99	10	5.2	mb	GS	236
2-Apr-99	195610.81	-19.83	167.94	10	5.0	mb	GS	233
6-Apr-99	003313.36	-19.87	168.07	10	5.0	mb	GS	236
15-Jul-99	142625.76	-18.23	168.18	33	5.2	mb	GS	55
15-Jul-99	154459.24	-18.15	168.19	43	5.0	mb	GS	47
22-Aug-99	124045.96	-16.12	168.04	33	6.5	Mw	GS	182
26-Nov-99	132115.42	-16.43	168.23	33	7.5	Mw	HRV	144
26-Nov-99	133834.26	-15.98	167.93	33	5.7	mb	GS	199
26-Nov-99	134643.54	-15.88	167.89	33	5.3	mb	GS	210
26-Nov-99	144120.86	-15.77	167.80	33	5.5	mb	GS	225
26-Nov-99	152529.86	-15.91	167.89	33	5.0	mb	GS	208
26-Nov-99	193609.40	-16.48	168.07	33	5.5	mb	GS	141
26-Nov-99	220320.01	-15.57	167.92	33	5.9	Mw	Gs	243
25-Fev-00	014358.60	-19.52	173.81	33	7.0	Mw	Gs	420
4-Oct-00	165844.30	-15.42	166.91	23	6.7	Mw	Gs	270
9-Jan-01	164928.00	-14.93	167.17	103	7.1	Mw	Gs	360

APPENDIX 2: DETAILED INTENSITY DATA FOR EFATE (INCLUDING PORT VILA)

Area/Aire	Latitude	Longitude	Intensity/ Intensite	Average per area/Moyenne par aire	Corrected av./moy. arrondi	Questionnaire/Questionnaire N0-
Mele maat	-17.6772	168.261	8	7.33	7.5	205
	-17.6788	168.257	7			206
	-17.6807	168.262	7			207
Mele	-17.6843	168.275	7	7.88	8	208
	-17.6852	168.27	8			209
	-17.6835	168.262	8			211
	-17.6894	168.27	8			212
	-17.6938	168.268	8			213
	-17.6889	168.269	7			221
	-17.702	168.289	9			235
	-17.6865	168.272	8			222
Blacksand	-17.7075	168.295	8	8.00	8	51
	-17.7068	168.297	8			52
	-17.7022	168.296	8			53
	-17.6993	168.299	8			54
	-17.7642	168.305	8			77
	-17.7096	168.299	8			95
	-17.7117	168.298	8			128
	-17.7079	168.3	8			129
	-17.7165	168.305	8			152
	-17.7113	168.297	8			153
Tagabe	-17.7072	168.309	8	7.31	7.5	2
	-17.7054	168.322	7			9
	-17.7022	168.322	7			10
	-17.7061	168.319	7			11
	-17.7068	168.311	7			12
	-17.7573	168.31	8			22
	-17.7047	168.323	7			33
	168.324	-17.7035	7			34
	168.307	-17.7057	8			35
	-17.7083	168.307	8			36
	-17.7011	168.297	7			37
	-17.7095	168.307	7			66
	-17.7465	168.314	7			135
	-17.7058	168.318	8			190
Manples	-17.7138	168.311	7	7.13	7	68
	-17.7122	168.311	7			69
	-17.7154	168.31	7			70
	-17.7147	168.308	8			126
	-17.7163	168.31	7			127
	-17.7141	168.306	7			149
	-17.7147	168.305	7			150
	-17.7166	168.304	7			151
Smett	-17.7079	168.312	7	7.00	7	65
	-17.7112	168.309	7			67
Agathis	-17.7115	168.313	7	6.80	7	71
	-17.7121	168.312	7			72
	-17.7148	168.312	7			73
	-17.7092	168.316	7			157
	-17.7121	168.314	6			158

Area/Aire	Latitude	Longitude	Intensity/ Intensite	Average per area/Moyenne par aire	Corrected av./moy. arrondi	Questionnaire/ Questionnaire N0-
Malapoa	-17.7237	168.295	7			55
	-17.7256	168.296	8			56
	-17.7275	168.295	8			57
	-17.7261	168.3	7			58
	-17.7286	168.302	9			101
	-17.7274	168.3	8	7.45	7.5	124
	-17.7283	168.306	7			125
	-17.7299	168.301	7			145
	-17.7287	168.304	7			146
	-17.7351	168.296	7			147
	-17.7226	168.304	7			148
Tebakor	-17.721	168.311	7			175
	-17.7232	168.311	6			176
	-17.7263	168.311	6	6.83	7	177
	-17.7395	168.315	6			218
	-17.7395	168.315	8			219
	-17.7395	168.315	8			220
Namburu	-17.7201	168.318	7			167
	-17.7206	168.317	7			168
	-17.7181	168.317	7			169
	-17.7188	168.316	7			170
	-17.7198	168.313	7	7.00	7	171
	-17.7201	168.314	7			172
	-17.7211	168.313	7			173
	-17.7204	168.311	7			174
	-17.72	168.318	6			214
	-17.7204	168.317	8			215
Lycée/VMF	-17.728	168.313	9			216
	-17.7266	168.314	9	8.67	8.5	235
	-17.7249	168.316	8			234
	-17.728	168.313	8			217
Ohlen	-17.7118	168.318	7			23
	-17.7119	168.32	7			154
	-17.7115	168.317	7			155
	-17.7136	168.316	7			156
	-17.7141	168.319	6			159
	-17.7152	168.318	7			160
	-17.7165	168.316	6	6.77	7	161
	-17.7172	168.316	7			162
	-17.7176	168.314	6			163
	-17.7152	168.315	6			164
	-17.7145	168.313	7			165
	-17.7155	168.312	7			166
	-17.7159	168.32	8			232

Area/Aire	Latitude	Longitude	Intensity/ Intensite	Average per area/Moyenne par aire	Corrected av./moy. arrondi	Questionnaire/ Questionnaire N0-
Fresh Water	-17.724	168.319	7			13
	-17.7234	168.319	7			14
	-17.7182	168.323	6			103
	-17.7184	168.323	6			104
	-17.7188	168.322	7	6.30	6.5	105
	-17.719	168.322	7			106
	-17.72	168.322	6			107
	-17.7213	168.323	6			108
	-17.7217	168.322	6			109
	-17.7229	168.321	6			110
	-17.7232	168.321	7			111
	-17.7241	168.322	6			112
	-17.7238	168.32	6			113
	-17.7254	168.319	6			114
Fresh Water	-17.7246	168.32	6			115
(continue/suite)	-17.7253	168.32	6			116
	-17.7262	168.321	7			117
	-17.7251	168.322	6			118
	-17.7264	168.32	6			119
	-17.7295	168.319	6			120
	-17.7296	168.32	6			121
	-17.7305	168.32	7			122
	-17.7306	168.319	6			123
Town	-17.7349	168.311	8			1
	-17.7403	168.314	8			3
	-17.7345	168.319	7			38
(George	-17.7339	168.319	7			39
Pompidou,	-17.7342	168.318	8			40
cathedrale, joint	-17.7356	168.318	8			41
court/Shefa).	-17.7359	168.318	8			42
	-17.736	168.318	8			43
	-17.7369	168.318	8			44
	-17.736	168.316	8			45
	-17.7353	168.315	7			46
	-17.7346	168.314	7	7.50	7.5	47
	-17.7347	168.314	7			48
	-17.7341	168.314	7			49
	-17.7339	168.313	8			50
	-17.7326	168.314	7			59
	-17.7328	168.313	7			60
	-17.734	168.312	7			61
	-17.7349	168.313	8			62
	-17.7354	168.313	8			63
	-17.7352	168.314	7			64
	-17.7405	168.314	7			130
	-17.7423	168.314	8			133
	-17.7443	168.314	7			134

Area/Aire	Latitude	Longitude	Intensity/ Intensite	Average per area/Moyenne par aire	Corrected av./moy. arrondi	Questionnaire/ Questionnaire N0-
Independance Park	-17.7402	168.321	7	7.33	7.5	91
	-17.7391	168.319	7			92
	-17.7436	168.318	7			93
	-17.7415	168.321	8			96
	-17.7388	168.32	8			97
	-17.7394	168.32	7			98
Seaside	-17.7442	168.323	7	6.80	7	88
	-17.7446	168.321	7			89
	-17.7422	168.322	7			90
	-17.7538	168.318	7			94
	-17.7449	168.322	6			189
Nambatu	-17.7492	168.316	9	7.31	7.5	7
	-17.7474	168.316	7			15
	-17.7481	168.315	8			16
	-17.752	168.316	8			17
	-17.7551	168.312	8			18
	-17.7478	168.319	7			24
	-17.7485	168.318	7			25
	-17.7496	168.318	7			26
	-17.7507	168.317	7			27
Nambatu (continue/suite)	-17.7518	168.317	7			28
	-17.7522	168.318	7			29
	-17.7467	168.317	7			30
	-17.7513	168.316	7			31
	-17.7519	168.316	7			32
	-17.7489	168.315	7			136
	-17.7507	168.314	7			137
	-17.7526	168.314	7			138
Nambatri	-17.757	168.3	10	8.20	8	5
	-17.7594	168.31				20
	-17.7582	168.31	8			21
	-17.7599	168.314	7			84
	-17.7572	168.315	7			85
	-17.7575	168.311	9			102
Elluk	-17.7607	168.31	8	7.50	7.5	19
	-17.7676	168.302	8			76
	-17.7625	168.307	7			78
	-17.7623	168.309	7			79
Pango	-17.7695	168.267	10	7.64	7.5	6
	-17.7657	168.312	8			81
	-17.7744	168.294	7			139
	-17.7763	168.296	7			140
	-17.7746	168.296	8			141
	-17.775	168.297	7			142
	-17.7759	168.298	8			143
	-17.7748	168.299	7			144
	-17.7706	168.304	8			193
	-17.773	168.303	7			194
	-17.7685	168.306	7			195

Area/Aire	Latitude	Longitude	Intensity/ Intensite	Average per area/Moyenne par aire	Corrected av./moy. arrondi	Questionnaire/ Questionnaire N0-
Beverly hills	-17.7286	168.326	7	7.75	8	82
	-17.7285	168.325	8			203
	-17.7279	168.325	7			204
	-17.7287	168.324	9			210
Tassiriki	-17.7359	168.329	7	7.30	7.5	99
	-17.7358	168.328	7			100
	-17.7384	168.33	8			182
	-17.7385	168.332	7			183
	-17.7375	168.331	7			184
	-17.7352	168.334	7			186
	-17.7348	168.332	7			187
	-17.7351	168.33	7			188
	-17.7366	168.326	8			191
	-17.7354	168.322	8			192
Bellevue			7	8.00	8	200
			8			201
			9			202
Montmartre			8	8.00	8	181
Lagoon area	-17.7656	168.307	8	7.17	7	74
	-17.7641	168.308	7			75
	-17.7667	168.31	7			80
	-17.7623	168.314	7			83
	-17.7498	168.32	7			87
			7			233
Iririki ressort	-17.7434	168.311	7	7.00	7	131
	-17.7435	168.31	7			132
Erakor			8	7.67	7.5	4
	-17.7702	168.315	7			178
	-17.7736	168.318	8			179
	-17.7678	168.322	8			180
	-17.737	168.334	7			185
	-17.772	168.314	8			196
	-17.7786	168.315	8			197
	-17.7763	168.318	8			198
	-17.7594	168.329	8			199
	-17.7727	168.302	8			236
	-17.7699	168.303	7			237
	-17.7745	168.299	7			238
	-17.7736	168.315	7			239
	-17.7704	168.315	8			240
	-17.7772	168.316	8			241
Eratap	-17.7938	168.362	7	168.36	7.5	242
	-17.7913	168.364	7			243
	-17.797	168.361	8			244
	-17.7881	168.368	8			245
White sands	-17.8222	168.399	7	7.00	7	246
	-17.8216	168.395	7			247
Eton			6	6.00	6	248
	-17.7491	168.564	6			249
	-17.7524	168.562	6			250
	-17.7459	168.563	6			251

Area/Aire	Latitude	Longitude	Intensity/ Intensite	Average per area/Moyenne par aire	Corrected av./moy. arrondi	Questionnaire/ Questionnaire N0-
Pang Pang			6	6.00	6	252
			6			253
			6			254
			6			255
			6			256
Epau	-17.6213	168.499	6	6.00	6	257
	-17.6197	168.499	6			258
	-17.6237	168.499	6			259
Ekipe	-17.5883	168.484	6	6.00	6	260
	-17.5895	168.485	6			261
	-17.5903	168.486	6			262
Epule	-17.565	168.46	6	6.00	6	263
	-17.5674	168.458	6			264
Onesua	-17.5513	168.456	6	6.00	6	265
Paunagnisu	-17.5305	168.405	6	6.00	6	224
	-17.5333	168.408	6			225
	-17.5351	168.404	6			226
	-17.5337	168.406	6			266
	-17.532	168.408	6			267
	-17.5357	168.407	6			268
Emua	-17.5369	168.389	6	6.33	6.5	227
	-17.5387	168.385	7			228
	-17.5401	168.388	6			269
Sama	-17.541	168.366	6	6.00	6	229
	-17.5417	168.366	6			270
Siviri	-17.5252	168.324	6	6.00	6	271
Port Havannah	-17.5686	168.27	7	7.00	7	272
Tanaliu	-17.5731	168.253	6	6.50	6.5	273
"	-17.5735	168.255	7			274
Mangaliu	-17.6369	168.203	7	7.00	7	275
"	-17.6362	168.204	7			276
"	-17.6388	168.205	7			277
"	-17.6391	168.202	7			278
"	-17.6404	168.202	7			279
Devil's point	-17.7409	168.187	8	8.00	8	231
	-17.7412	168.186	8			280
Takara	-17.5335	168.446	6	6.00	6	223
Moso island	-17.5437	168.263	8	8.00	8	230
Forari	-17.6925	168.559	6	6.00	6	252
	-17.6957	168.562	6			253
	-17.6957	168.559	6			254
	-17.6925	168.562	6			255
	-17.6993	168.563	6			256
	-17.6973	168.565	6			257
Enam	-17.8047	168.517	6	6.00	6	282
	-17.8034	168.518	6			283

NOTES: