Geo-Marine Letters (1987) 6:241–246

Geo-Marine Letters

Sea Level Measurements for Inferring Ground Deformations in Rabaul Caldera

J. Mori, C. McKee, I. Itikarai, P. de Saint Ours, and B. Talai

Rabaul Volcanological Observatory, Rabaul, Papua New Guinea

Abstract

Rabaul tide gauge records from 1968 through 1985 give the amount of vertical movement in the northern part of Rabaul Caldera. Monthly mean sea level data were compared with other regional tide gauge stations to remove large scale oceanographic effects. No large vertical movements (> 0.3 cm/yr) were noted in this portion of the caldera. The results of sea level measurements at other points around the caldera, from 1981 through 1983 are consistent with the 1 to 10 cm of uplift observed on Matupit Island from optical leveling surveys. There was relatively little vertical movement (~ 0.1 cm/yr) in the Vulcan area.

Introduction

Rabaul Caldera, at the northeastern end of New Britain Island, Papua New Guinea, is the eastern-most volcano of the Bismarck Volcanic Arc (Fig. 1). The volcanoes of New Britain Island are associated with the current subduction of the Solomon Sea plate beneath the Bismarck Sea Plate along the New Britain Trench. Rabaul has a geologic history of major ignimbrite eruptions [1,2] and a historical record of small to moderate eruptions from sites within the caldera [3,4]. The most recent eruptive period occurred from 1937 to 1943.

Since 1971 there has been an increase in the seismicity and ground deformation within the caldera. The most dramatic seismic activity occurred from late 1983 till mid 1984 during which time hundreds of earthquakes were often recorded daily [5]. Also, large ground tilts and substantial changes in ground elevation were measured (up to 8 cm/month of uplift), indicating localized inflations at two points within the caldera [6]. From late 1983 measurements from a network of stations gave a reasonable coverage of the ground deformation. However, before this time the measurements were not as extensive and patterns of deformation within the caldera were not as clear.

To estimate the absolute magnitude and detailed time sequence of vertical ground movement before late 1983, we have analyzed two sets of sea level measurements to see how points near the shore have changed with respect to sea level. The first set of data is from the Rabaul tide gauge which has been operating reliably since 1966 (Fig.2). The second set of data consists of sea level measurements that were read at weekly to monthly intervals from mid 1981 to mid 1983 from "tidesticks" located at various points around the caldera.

The Rabaul tide gauge data show that the vertical movements on the northern edge of the caldera have been relatively small from 1968 through 1985. Using the Rabaul tide gauge as a stable reference point, the tidestick data show that there was significant uplift near Matupit Island and relatively little uplift near the Vulcan volcanic cone from mid 1981 to mid 1983 (Fig. 2).

Rabaul Tide Gauge

Since 1966 there has been almost continuous recording of the sea level at the Rabaul main wharf on a Stevens A35 analog recorder. The wharf is located at the northern edge of the caldera (Fig. 2) about 6 to 8 km from the areas of uplift [6]. Unfortunately, because the responsibility for maintaining the tide gauge changed hands several times, there were considerable losses of data, particularly from 1971 through 1973.

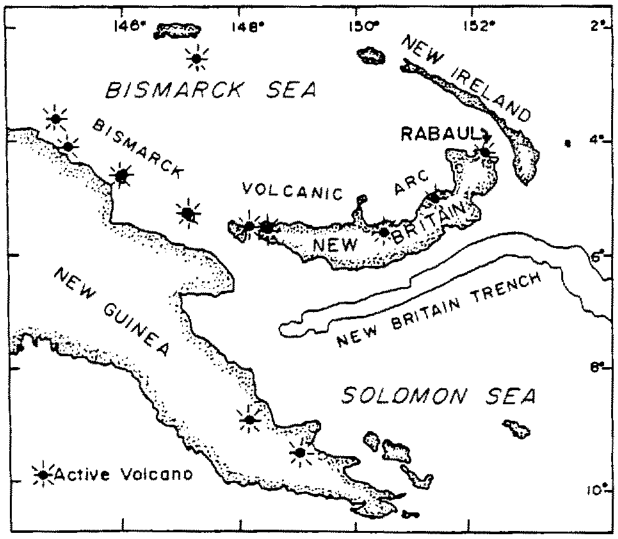

Figure 1. Map showing the location of Rabaul and other volcanoes in the Solomon Sea region of Papua New Guinea.

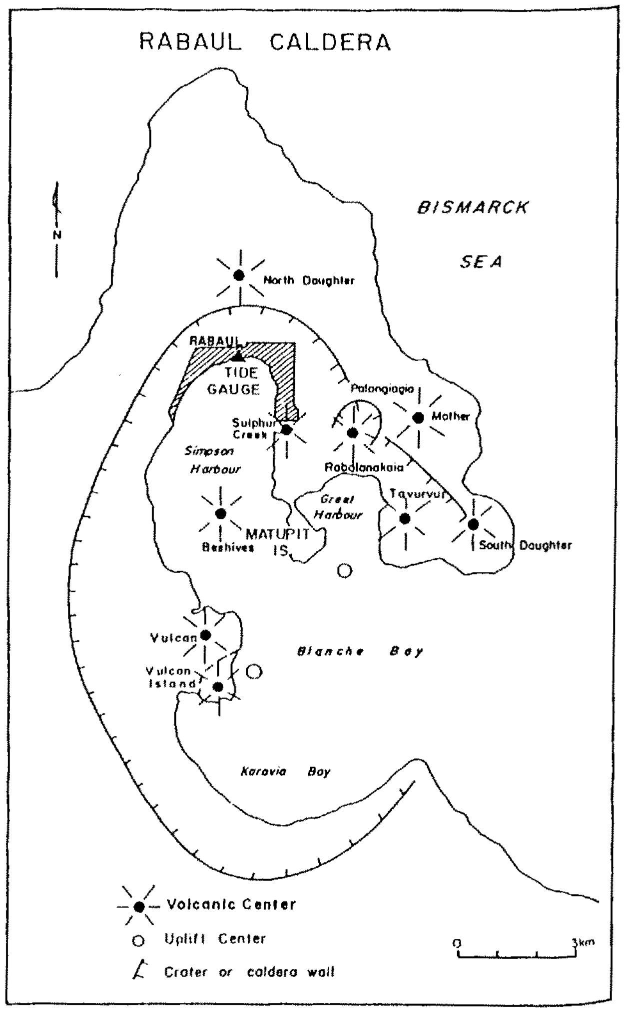

Figure 2. Map of Rabaul Caldera presenting the locations of the uplift sources and the Rabaul tide gauge.

Flinders University of South Australia digitized available records from 1966 through 1974 and computed the monthly averages of sea level height (SLH) for this period. In 1974 an additional tide guage, a Stevens M7000 digital recorder, was installed and referenced to the same datum level by the University of Hawaii. The monthly averages of SLH from 1974 through 1977 were calculated by Flinders University for the analog records and the University of Hawaii for the digital records. Generally, the values for the monthly averages differed by less than 0.16 cm. In this study, we have used the values produced by the University of Hawaii for the time period from 1974 through 1985 because of the continuity of the data.

The values for the monthly average SLH from the Rabaul tide gauge are shown in Figure 3 along with similar data from Honiara (Solomon Islands) and Anewa Bay (Bougainville Island) which were also produced by the University of Hawaii. Anewa Bay and Honiara are 450 km and 1080 km, respectively, southeast of Rabaul. There are large fluctuations in the SLH (10 to 20 cm) which correlate between the three stations. These fluctuations are presumably due to large scale ocean flows [7]. If we assume that these large scale oceanographic effects occur simultaneously (when using a time increment of one month) at all the stations and with the same amplitude, they can be eliminated by subtracting the record of one station from the record of a nearby station. Figure 4 shows the resultant traces of subtracting the Honiara record from the Rabaul record (Rab-Hon) and subtracting the Anewa Bay record from the Rabaul record (Rab-Ane). Since Anewa Bay was operating only between 1968 and 1977 and Honiara was not operating before 1975, neither the Rab-Ane nor the Rab-Hon record covers the entire period from 1968 through 1985. To produce one trace covering the entire duration we have combined the two traces of Figure 4. Assuming that the only difference between the two traces is a difference in baselines (i.e., there are no systematic sea level changes occuring at Anewa Bay or Honiara), we combined the two traces by constraining the baselines to be the same during the period from 1975 through 1977 when there are data from both sources. This was done by the following procedure:

1. Calculating an average value for the two traces for the period from 1975 through 1977.

2. Calculating the difference between the average value and each of the two trace values for each point during the period from 1975 through 1977.

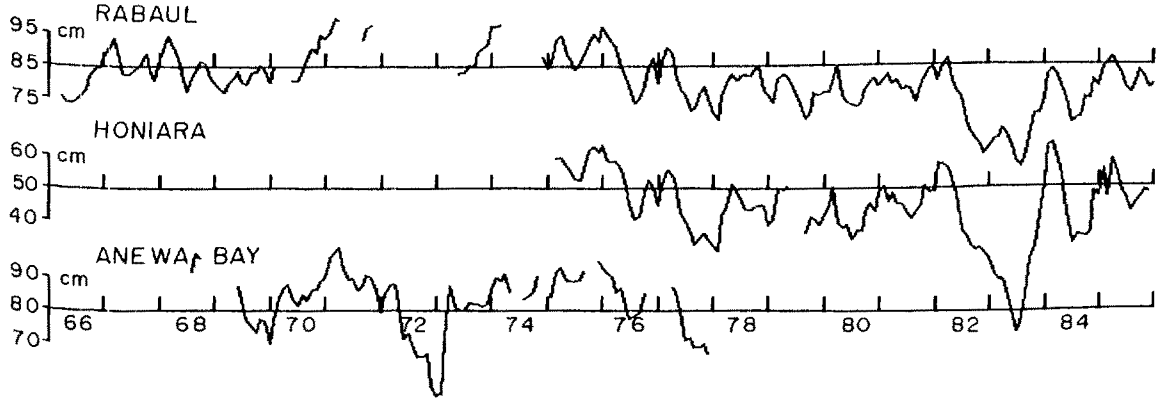

Figure 3. Monthly mean sea level values recorded at Rabaul and two stations in the Solomon Islands.

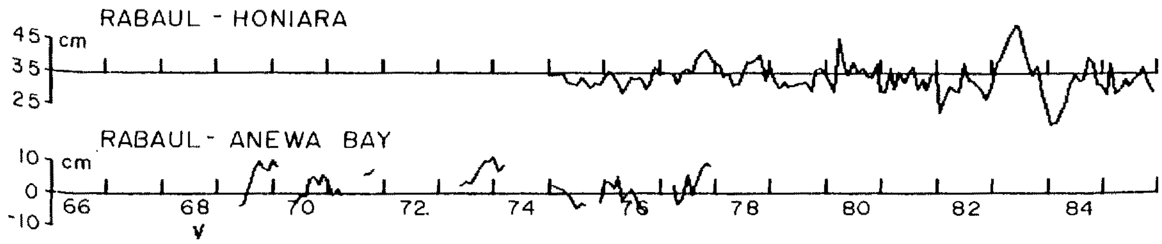

Figure 4. Differences of sea level measurements between Rabaul and Honiara, and between Rabaul and Anewa Bay.

3. Taking the mean of the values obtained in #2 and using that as the offset to correct the baselines for the two traces. The resultant monthly mean SLH record for 1968 through 1985 is shown in Figure 5.

The data from 1982 through 1984 was recorded during a very strong El Nino [8]. During this period there were large fluctuations of sea level that moved over the region and simple subtraction of the records does not remove the effect. This portion of the data was not used in our analysis. There was another El Nino identified in 1976 [9], but during this period the correlation of the large fluctuations in SLH is still quite good between the stations and its effect can be eliminated in the station subtraction process. A third El Nino in 1972 [10] does not affect our study because we have little data from that time period.

In Figure 5 the monthly average SLH is stable within about 4 cm for the period from 1974 through 1985, excluding the time of the El Nino. If one fits a least-squares straight line to the SLH data for this time period, the change comes out to be an apparent drop in sea level of 0.11 cm/yr. Assuming uncorrelated errors, the 95% confidence limits are ± 0.27 cm/yr for the slope. Before 1974 the data appear more scattered and are not as complete, but fitting a straight line to the entire period from 1968 through 1985, again indicates a drop in sea level of 0.11 cm/yr with 95% confidence limits of ± 0.21 cm/yr. Even though the data are more scattered in this case, the longer time period reduces the error in estimating the magnitude of any long-term trend.

Within the uncertainties of the data it is difficult to determine if there is significance in the slight changes that are observed. If there is a real change, it may be due to vertical movements at Rabaul, vertical movements in the Solomon Islands and Bougainville, geographical variations in the sea level changes, or a

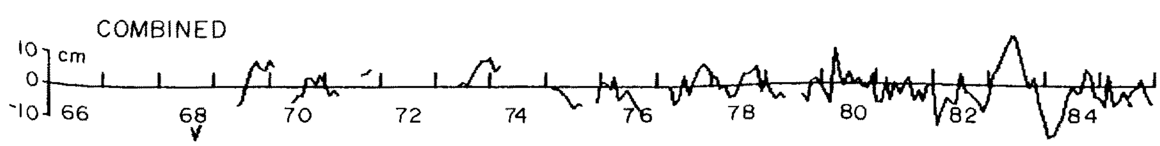

Figure 5. The data of Figure 4 combined to a common baseline. This plot shows the changes in sea level at Rabaul from 1968 to 1985 with the regional oceanographic effects removed.

combination of these factors. However, it is concluded that any changes that may have been recorded by the Rabaul tide gauge are less than a few mm per year.

The relative stability of the monthly averaged SLH is interpreted to reflect the stability of the ground elevation at the northern edge of the caldera. Establishing this reference point is important for three reasons:

1. The results of the tidestick data described in the next section are based on the assumption that the Rabaul tide gauge is an acceptable reference point.

2. The reference point of the level line which began in 1973 is located in this area. Previously, it was unclear if this point was far enough away from the areas of uplift to be considered a stable benchmark. From this analysis, it appears that the area in which the benchmark is located has been stable to within a few cm from 1973 through 1985.

3. The stability of the ground at the Rabaul main wharf suggests that the areas of uplift identified within the caldera are local features and that there has not been a large caldera-wide uplift during this period.

Tidestick Data

Sea level measurements were made at various points around the caldera by simply noting the water level on graduated rods (secured to stable) positioned immediately offshore. These measurements were made

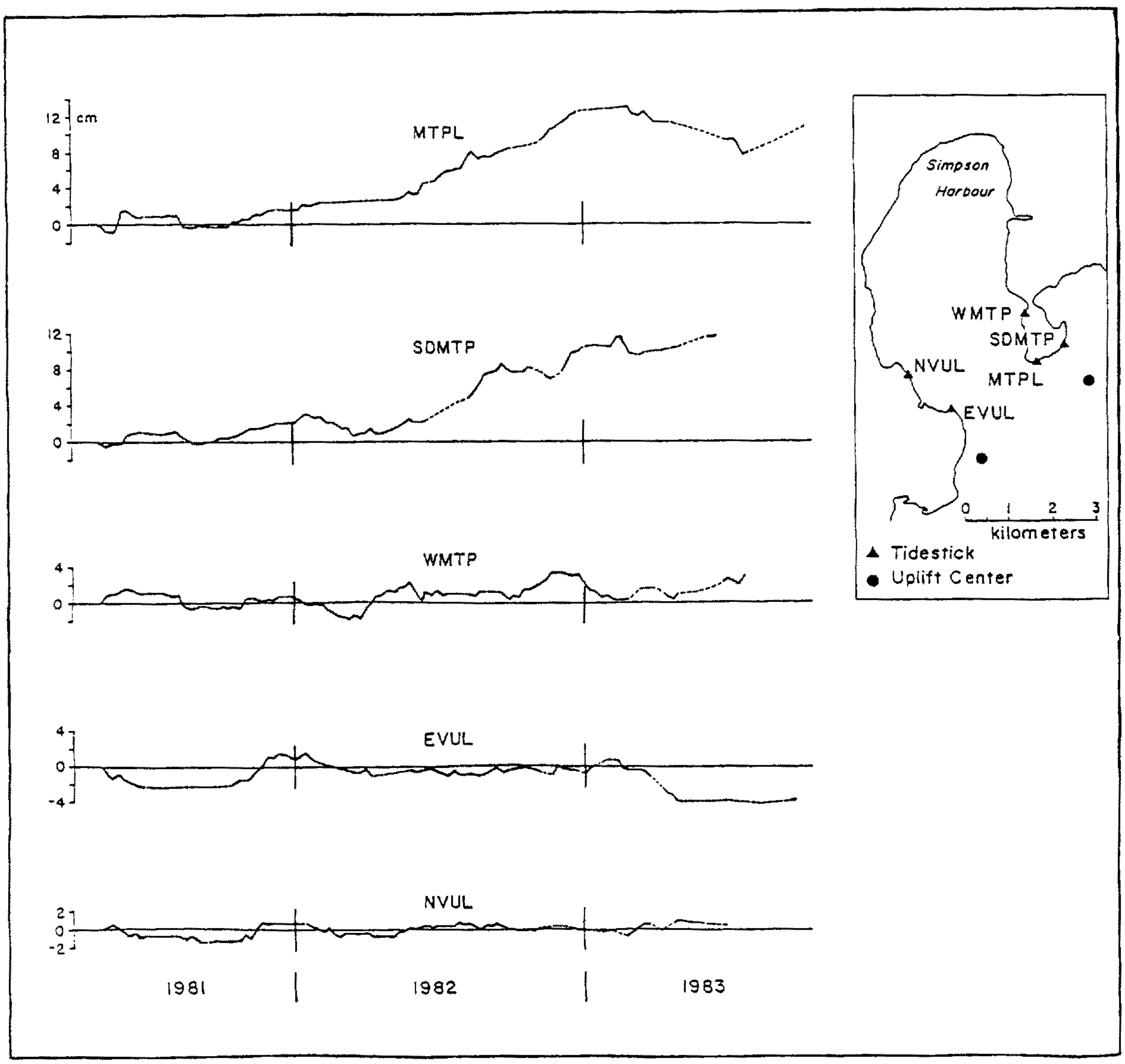

Figure 6. Reduced tidestick data for five stations around the caldera.

at weekly to monthly intervals over the time period from mid 1981 to mid 1983. On calm days the accuracy of the readings was within 0.5 cm, however, when the water was rougher the uncertainty of the readings could be much larger, 5 to 10 cm. There were originally 11 tidesticks but some of these stations were apparently located on unstable sites or were physically disturbed, since the measured water levels varied greatly and had large offsets. The five sites shown in Figure 6 were judged to be stable sites which remained undisturbed on the basis of the consistency of the readings.

To remove the periodic effects due to the lunar and solar tides, the sea level measurements were referenced to the tide gauge at the Rabaul main wharf. The values plotted in Figure 6 are the measurements from the Rabaul tide gauge minus the measurements read at the tidesticks. These values represent the change in elevation of the tidestick site with respect to sea level. Since there was a considerable amount of scatter from point to point, a 9-point running mean was applied to the data. The result of this filtering is that we are looking at only the longer period components (> 2 months) in the data. The zero levels of the plots in Figure 6 are arbitrarily set to the value of the first reading.

A comparison of the tidestick data on Matupit Island and the elevation change of nearby points measured by optical leveling is shown in Figure 7. The leveling was done in May to April 1981, May 1982, and May to June 1983 (benchmark 16 was established in 1982 so there is no reading for 1981). The leveling was referenced to the point marked BM 21 in Figure 7. Note that there is a reasonably good correlation between the elevation changes obtained from the two different methods. A comparison of the tidestick data at NVUL and leveling data from a nearby benchmark in July 1981, September 1982 and July 1983 also shows consistent results. The similarity of the results from the tidestick measurements and the leveling gives us confidence that the tidestick results are reliable estimates of the ground deformation, within a few cm.

The data from Matupit Island show approximately the same uplift as the leveling data but with more time resolution. For example, the tidestick data appear to show an increase in the uplift rate in late 1982, which cannot be resolved from the annual leveling measurements. In contrast to the Matupit Island region, the tidestick data from around Vulcan show only a small amount of uplift. During 1983 and 1984 there was substantial ground deformation in this area as evidenced by the large tilts recorded [6], but from 1981

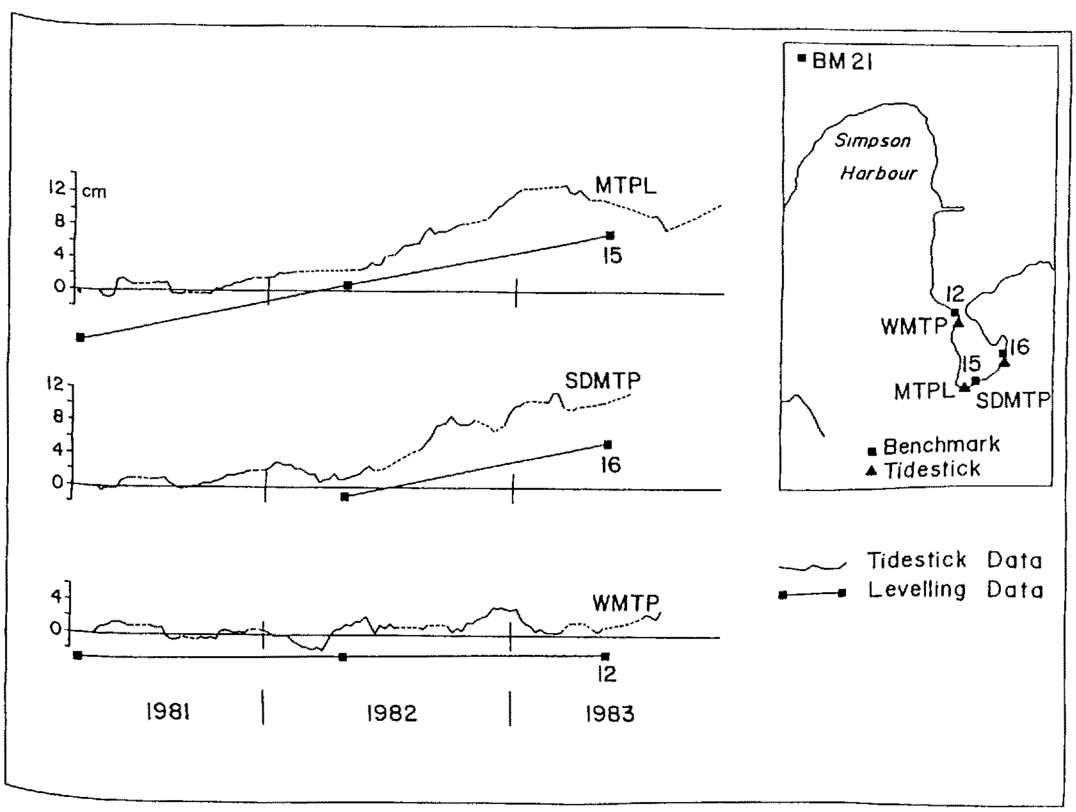

Figure 7. Comparison of tidestick data with leveling measurements for three areas on Matupit Island. There is an arbitrary offset between the tidestick data and the leveling data.

to 1983 the elevation change measured on the tidesticks and a nearby leveling benchmark were small. Fitting a least-squares line to the data gives a slope of 0.09 ± 0.10 cm/yr for EVUL and 0.13 ± 0.07 cm/yr for NVUL, where the uncertainities are the 95% confidence limits. These small uplift rates may be reflecting inflation of the magma body near Vulcan although the changes are not well resolved.

Conclusions

Examination of 18 years of data from the Rabaul tide gauge in the northern part of the caldera shows that there has been relatively little vertical movement in that area, less than a few mm per year. The stability of this reference point is important for several of the crustal deformation measurements used to monitor activity throughout the caldera. The relative stability of this point also indicates that there has not been a large caldera-wide uplift in the period 1968 through 1985.

The tidestick data recorded from mid 1981 to mid 1983 show uplift occuring in the Matupit Island area, a result that was previously recognized from leveling data. During the same period, the tidestick data show that there was only a small amount of uplift (~ 1 mm/yr) occurring in the Vulcan area.

Acknowledgments

K. Wyrtki kindly provided the processed sea level data from Rabaul, Anewa Bay, and Honiara. The tidestick data were collected by A. Pidik, R. Pakat, C. Matupit, P. Daimbari, and V. Kaita. The authors publish with permission of the Secretary of the Department of Minerals and Energy, Papua New Guinea.

References

1. Heming RF (1974) Geology and petrology of Rabaul Caldera, Papua New Guinea. Geological Society America Bulletin 85:1253–1264
2. Walker GPL, Heming RF, Sprod TJ, Walker HR (1981) Latest major eruptions of Rabaul volcano. In: Johnson RW (ed) Cooke-Ravian Volume of Volcanological Papers. Geological Survey Papua New Guinea Memoir 10, pp 181–194
3. Fisher NH (1939) Geology and vulcanology of Blanche Bay and the surrounding area, New Britain. Territory of New Guinea Geological Bulletin No. 1, pp 1–68
4. Fisher NH (1976) 1941–1942 eruption of Tavurvur volcano, Rabaul Papua New Guinea. In: Johnson RW (ed) Volcanism in Australia. Elsevier, Amsterdam, pp 201–219
5. Mori J, McKee CO, Itikarai I, Lowenstein PL, de Saint Ours P, Talai B (1987) Earthquakes of the Rabaul seismo-deformational crisis, September 1983 to July 1985: Seismicity on a caldera ring-fault. Bulletin Volcanology (in press)
6. McKee CO, Lowenstein PL, de Saint Ours P, Talai B, Itikarai I, Mori JJ (1984) Seismic and ground deformation crises at Rabaul Caldera: Prelude to an Eruption? Bulletin Volcanologique 47:397–411
7. Hickey B (1975) The relationship between fluctuations in sea level, wind stress and sea surface temperatures in the equatorial Pacific. Journal Physical Oceanography 5:460–475
8. Wyrtki K (1984) The slope of sea level along the equator during the 1982/1983 El Nino. Journal Geophysical Research 89:10419–10424
9. Wyrtki K (1979) The response of sea surface topography to the 1976 El Nino. Journal Physical Oceanography 9:1223–1231
10. Wyrtki K (1977) Sea level during the 1972 El Nino. Journal Physical Oceanography 7:779–787

Manuscript received 10 November 1986; revision received 11 February 1987.