

Seismo-Deformational Event of 20 May 1993, at Rabaul, Papua New Guinea

PAPER THREE

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Abstract

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• SEISMO - DEFORMATIONAL EVENT OF MAY 20, 1993 AT RABAU CALERA, PNG •

This paper will present the data recorded on 20 May and contrast this event with the normal pattern of uplift at Rabaul. The systems and techniques used to collect the ground deformation data will be described.

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Introduction

A swarm of felt but not damaging earthquakes occurred from 08.00 to 14.00 hours on 20 May 1993. The earthquakes had magnitudes of M_L 3.8 - 4.5. The earthquakes were located at the entrance to Green Harbour near Sulphur Point (Fig. 2). The earthquakes were associated with slipping of a ring fault. This paper will contrast this deformation with non-seismic uplift that usually occurs at the Rabaul Caldera; describe the uplift monitoring systems, and present the results obtained.

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Rabaul Caldera is located on the northeastern end of New Britain Island. It is a complex volcano associated with the subduction of the Solomon Sea plate beneath the South Bismarck Sea plate. The caldera measures 9 kilometres east to west and 14 kilometres north to south. The present shape has resulted from at least six huge caldera forming eruptions (the latest occurred 1400 years before present (BP)) and over 65 eruptions have occurred in total. More than 74 cubic kilometres of eruptive material has been produced over the last 500,000 years (Naim et al, 1983).

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Abstract

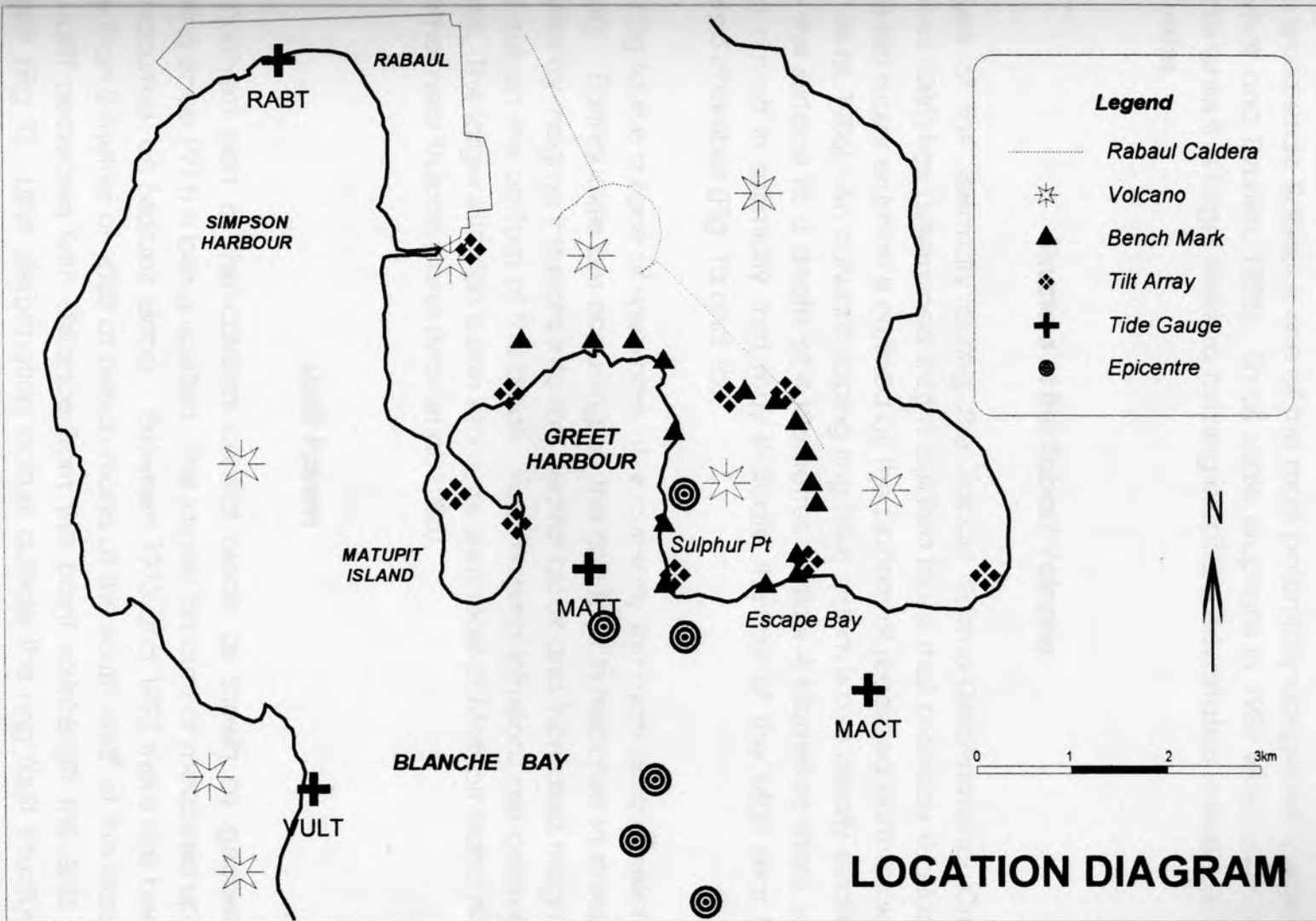
On 20 May 1993, a swarm of earthquakes occurred near Sulphur Point in Rabaul Harbour. For the first time at Rabaul ground deformation associated with a fault movement was recorded by the electronic tide gauge network in near real time. Geodetic and single set-up levelling confirmed the deformation. This paper will present the data recorded on 20 May and contrast this event with the normal pattern of uplift at Rabaul. The systems and techniques used to collect the ground deformation data will be described.

Introduction

A swarm of felt but not damaging earthquakes occurred from 06.00 (Universal Time) hours on 20 May 1993. Four large events were recorded, all with magnitudes of $M_L 3.8$. A total of 680 events occurred. The earthquakes were located at the entrance to Greet Harbour near Sulphur Point (Fig. 2). The earthquakes were associated with slipping of a ring fault. This paper will contrast this deformation with non-seismic uplift that usually occurs at the Rabaul Caldera; describe the uplift monitoring systems; and present the results obtained.

Rabaul Caldera is located on the northeastern end of New Britain Island. It is a complex volcano associated with the subduction of the Solomon Sea plate beneath the South Bismarck Sea plate. The caldera measures 9 kilometres east to west and 14 kilometres north to south. The present shape has resulted from at least six huge caldera forming eruptions (the latest occurred 1400 years before present (BP)) and over 66 eruptions have occurred in total. More than 74 cubic kilometres of eruptive material has been produced over the last 500,000 years (Nairn et al, 1989).

Figure 2. Location diagram showing survey bench marks, single set up levelling arrays, electronic tide gauges and earthquake epicentres on the 20th May, 1993.



On a world scale Rabaul is one of the most potentially dangerous calderas (Newhall and Dzurisin, 1988). Small scale eruptions in 1937 killed over 500 people while the larger caldera forming eruptions devastated a radius of 50 kilometres.

Structure of the Rabaul Volcano

Analysis of the seismicity during the Rabaul Seismo-Deformational Crisis (1983 to 1985) has determined that a caldera block that probably subsided in the last major eruption is outlined by the pattern of recorded earthquakes (Mori et al, 1986). An outward sloping ring fault system is also clearly evident from the surface to a depth of 4 kilometres. Below 4 kilometres there is a sharp cut-off in seismicity that may indicate the top of the 1400 year BP magma chamber (Fig. 1a and 1b).

The ring fault is a zone of weakness. It is currently the main area of seismic activity. Earthquakes are occurring on the ring fault in response to stresses created by magma intrusions into the central block and increased magma pressures on the bottom of the block. Two magma intrusions are believed to exist. The larger intrusion is one kilometre southeast of Matupit Island and the other near Vulcan Cone (Mori et al, 1986).

Uplift Pattern

The northern part of the caldera central block, as shown by geodetic levelling since 1971, is being uplifted. The largest amount of measured uplift has occurred on Matupit Island. Between 1973 and 1993 there has been more than 2 metres of uplift at bench marks at the south end of the island. The uplift decreases with distance from the point source off the end of Matupit (Fig 3). Little deformation occurs outside the ring fault structure, that is, off the central block. This pattern is consistent with uplift caused by the general stressing of the central caldera block (non seismic uplift). ring fault movement or slip. However, as the events of 20 May show, the stress on the ring fault is occasionally released by fault slip. Ring fault slip is much

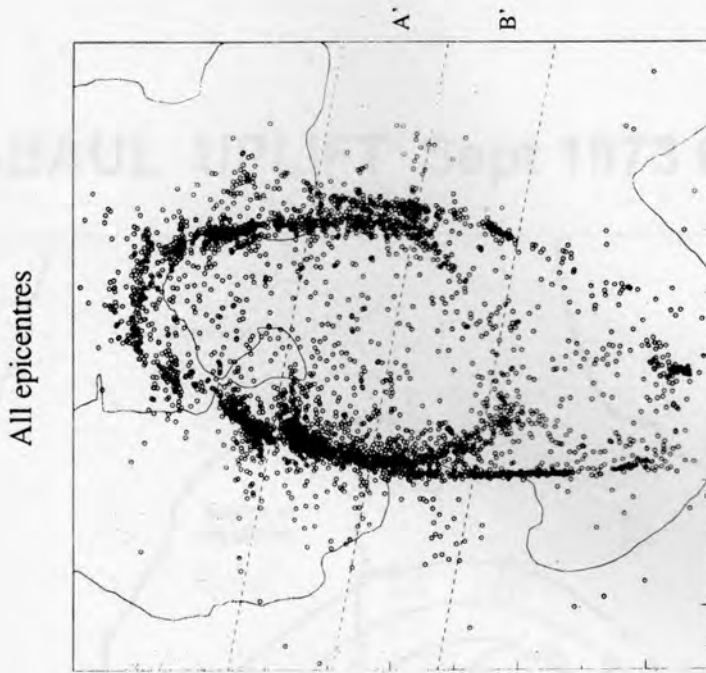


Fig. 1a.

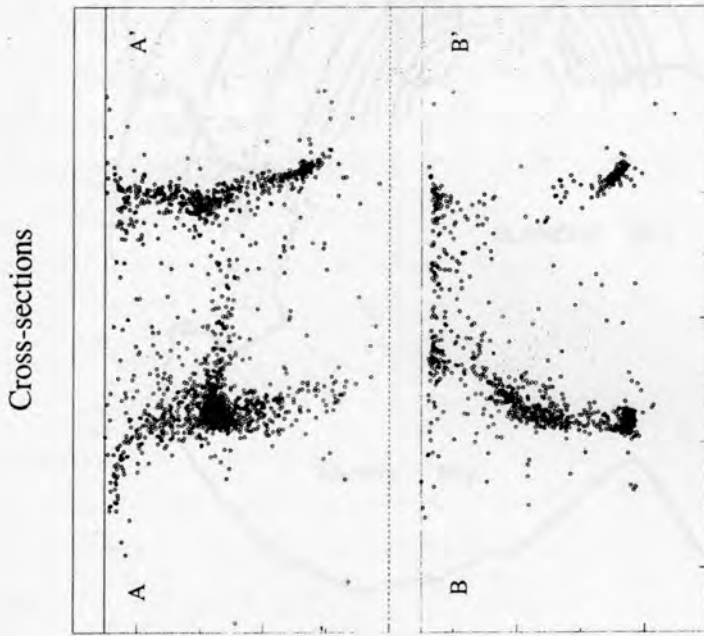


Fig. 1b.

Figure 1. Earthquake locations at Rabaul Volcano.

(a) The elliptical pattern shows the outline of the central block of the last caldera formed at Rabaul 1400 Before Present.

(b) Section through the above plan showing earthquakes to a depth of 4 km and outlining the outward dipping ring-fault structure.

Note: The locations used for these diagrams have undergone an image enhancement process and are unpublished at present.

RABAU UPLIFT Sept 1973 to July 1985

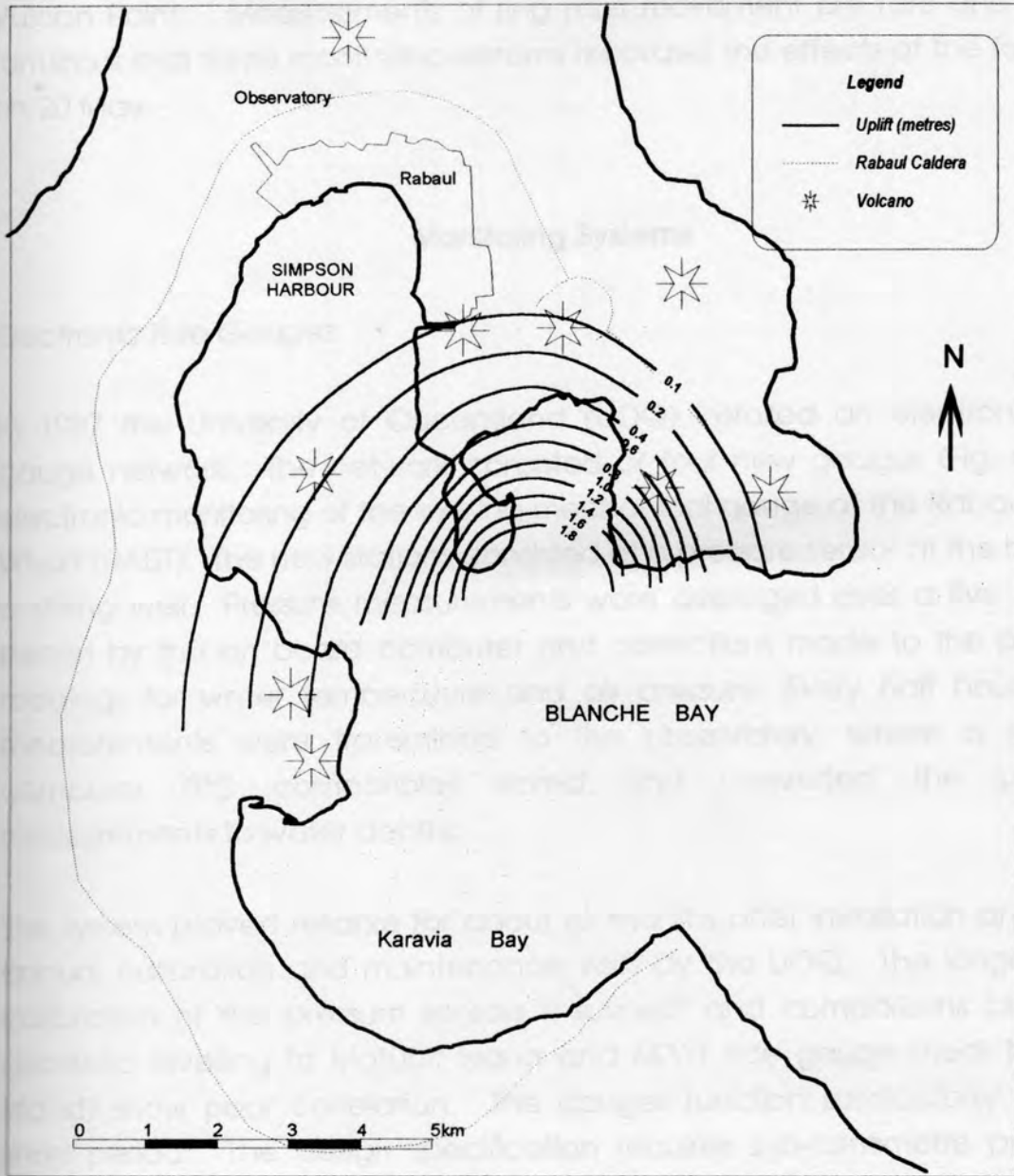


Figure 3. Uplift contours at Rabaul Volcano. Uplift from Sept 1973 to July 1985 is plotted and includes the Crisis period of 1983-85. Post 1985 uplift has conformed to the same pattern. Contour interval is 0.2 m with an additional contour at 0.1 m shown.

less than the uplift near the point source and has resulted from the inability of the faults to immediately accommodate the uplift forces.

Unfortunately only a small part of the ring fault system is accessible by geodetic levelling. The access areas are Matupit Island, Talwat Road and Vulcan Point. Measurements of ring fault movement are rare and it was fortuitous that three monitoring systems recorded the effects of the fault slip on 20 May.

Monitoring Systems

Electronic Tide Gauges.

In 1987 the University of Queensland (UOQ) installed an electronic tide gauge network. The network consisted of four new gauges (Fig. 4) and electronic monitoring of the existing mechanical gauge at the Rabaul Main Wharf (RABT). The new stations consisted of a pressure sensor at the base of a stilling well. Pressure measurements were averaged over a five minute period by the on board computer and corrections made to the pressure readings for water temperature and air pressure. Every half hour these measurements were transmitted to the observatory, where a second computer (PC compatible) stored and converted the pressure measurements to water depths.

The system proved reliable for about six months after installation and after annual calibration and maintenance visits by the UOQ. The longer term calibration of the pressure sensors is suspect and comparisons between geodetic levelling to Matupit Island and MATT tide gauge (near Matupit Island) show poor correlation. The gauges function satisfactorily over a short period. The design specification requires sub-centimetre precision when pressures are averaged over 24 hours. The effect of tides are removed by calculating differences in water level between two gauges in the network.

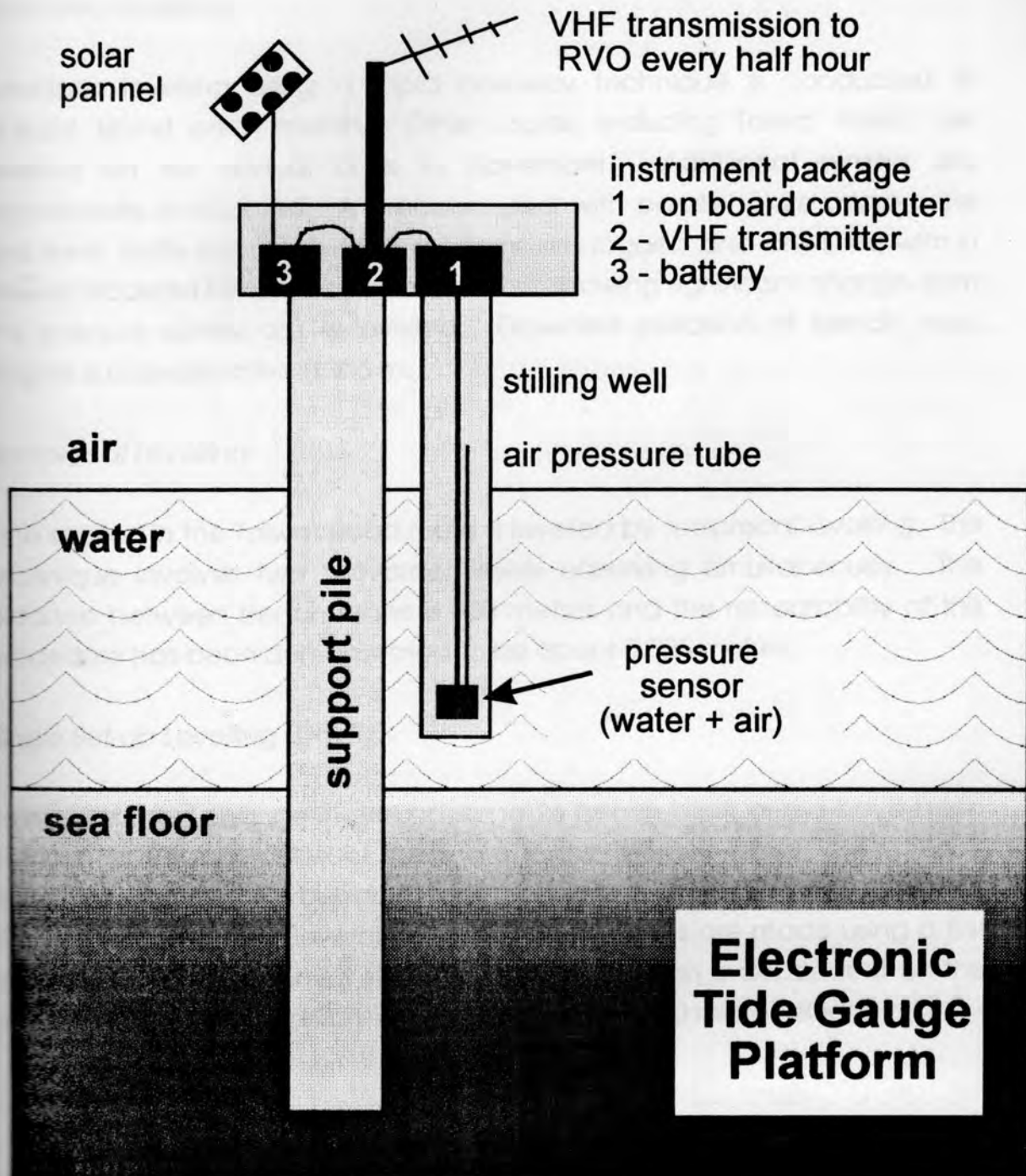


Figure 4. Diagram of a typical electronic tide gauge platform. Some detail has been deleted to simplify the diagram.

Geodetic Levelling

Geodetic levelling using a rapid one-way technique is conducted to Matupit Island each month. Other routes, including Talwat Road, are levelled on an annual basis in November. Additional surveys are occasionally conducted. A precision level with parallel plate micrometer and invar staffs are used. Staff readings are logged and checked with a Hewlett Packard HP48 calculator. Sections showing significant change from the previous survey are re-levelled. Expected precision of bench mark heights is approximately 0.005 m.

Reciprocal Levelling.

One section in the Talwat Road route is levelled by reciprocal levelling. This technique involves two first order levels observing simultaneously. The distance between bench marks is 750 metres and the repeatability of this procedure has been demonstrated to be about 0.005 metres.

Single Set-up Levelling (Dry Tilt).

To measure the change in ground slope 26 bench mark arrays have been installed at Rabaul. Nine of these are in the Matupit-Talwat area. Each array consists of three bench marks forming a triangle with sides ranging from 28 to 40 metres. Several rounds of observations are made using a first order level to a single invar staff. Expected precision is dependent on the prevailing climatic conditions and is in the order of 10 micro radians.

Effects of 20 May Earthquakes

Electronic Tide Gauges Results

Differences in water depths between MATT and VULT tide gauges were calculated at the minimum recording period of five minutes. Changes in height start almost simultaneously with the arrival of the first earthquakes. Accelerated deformation occurs with the occurrence of the two of the larger magnitude events. Total deformation was approximately 0.050

metres (Fig. 5). Following the initial deformation there is a slow subsidence (rebound) over the next few hours of 0.010 metres.

Geodetic Levelling Results.

Levelling on 18 May, along the Talwat Road route, indicated a small subsidence from the previous survey in August, 1992. The survey of 7 June recorded an uplift of more than 0.100 metres on the reciprocal levelled section across Escape Bay (Fig 6). Re-levelling on 6 Sept confirmed the uplift. The fault slip apparently occurred between the terminal bench marks across Escape Bay. Levelling to Matupit Island after 20th, recorded an uplift of 0.020 metres at the southern end of the island. Little deformation occurred outside the ring fault structure.

Single Set-up Levelling (Dry Tilt) Results.

Tilt vectors calculated between April and May 1993 show a more complex picture (Fig. 7). The largest vectors (57 and 55 micro radians) occurred closest to the fault slip. Vectors on the east side of Greet Harbour are mostly to the east and north. Vectors on the Matupit Island side are to the north and northwest. This vector pattern is consistent with tilting of the central caldera block in an east to northwest direction.

Conclusions

Two processes are present in the uplift at the Rabaul Caldera. A non-seismic deformation at the centre of the northern part of the caldera central block and slip on the ring fault. Near real time electronic tide gauge results show the slip that occurred on 20 May coincided with a swarm of local earthquakes. The deformation was accelerated when the two larger events occurred. Sea floor deformation measured by the tide gauge network was confirmed by geodetic levelling. The area of greatest uplift was across Escape Bay. Single set up levelling also indicates a tilting of the central block of the caldera. Deformation was mostly contained to the northern part of the central block as defined by the ring fault structure.

Rabaul Tide Gauge Data

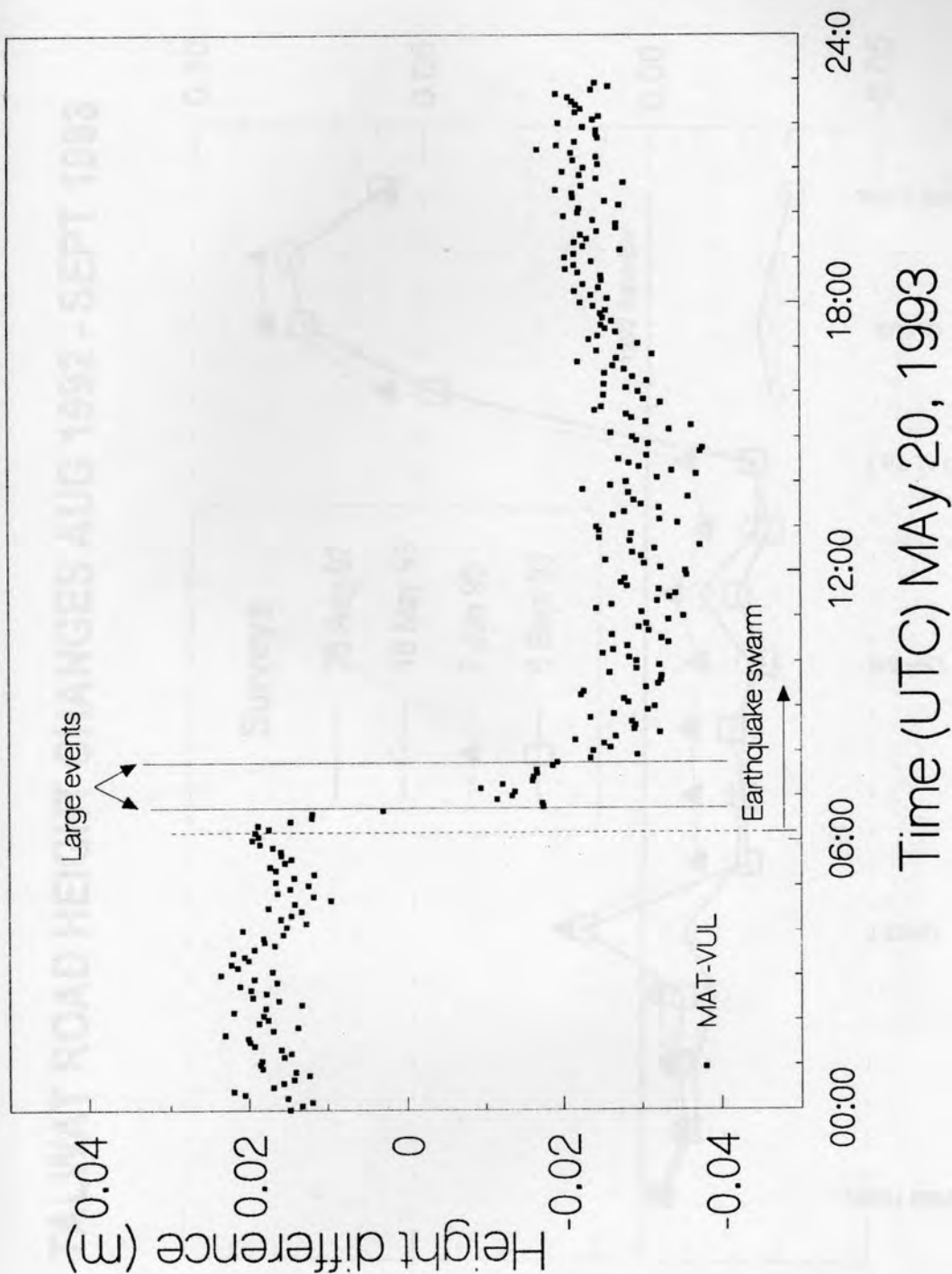


Figure 5. A plot of differences in sea level height between VULT and MATT electronic tide gauges. The deformation starts almost simultaneously with the 20th May earthquake swarm and is accelerated by the effect of two ML3.8 earthquakes. Total height change is about 0.05 m with a rebound of .01 m over the following few hours. Note a lowering of sea level as shown in the plot indicates a rise in the sea floor. Each point plotted is an average of water depth over a five minute interval.

TALWAT ROAD HEIGHT CHANGES AUG 1992 - SEPT 1993

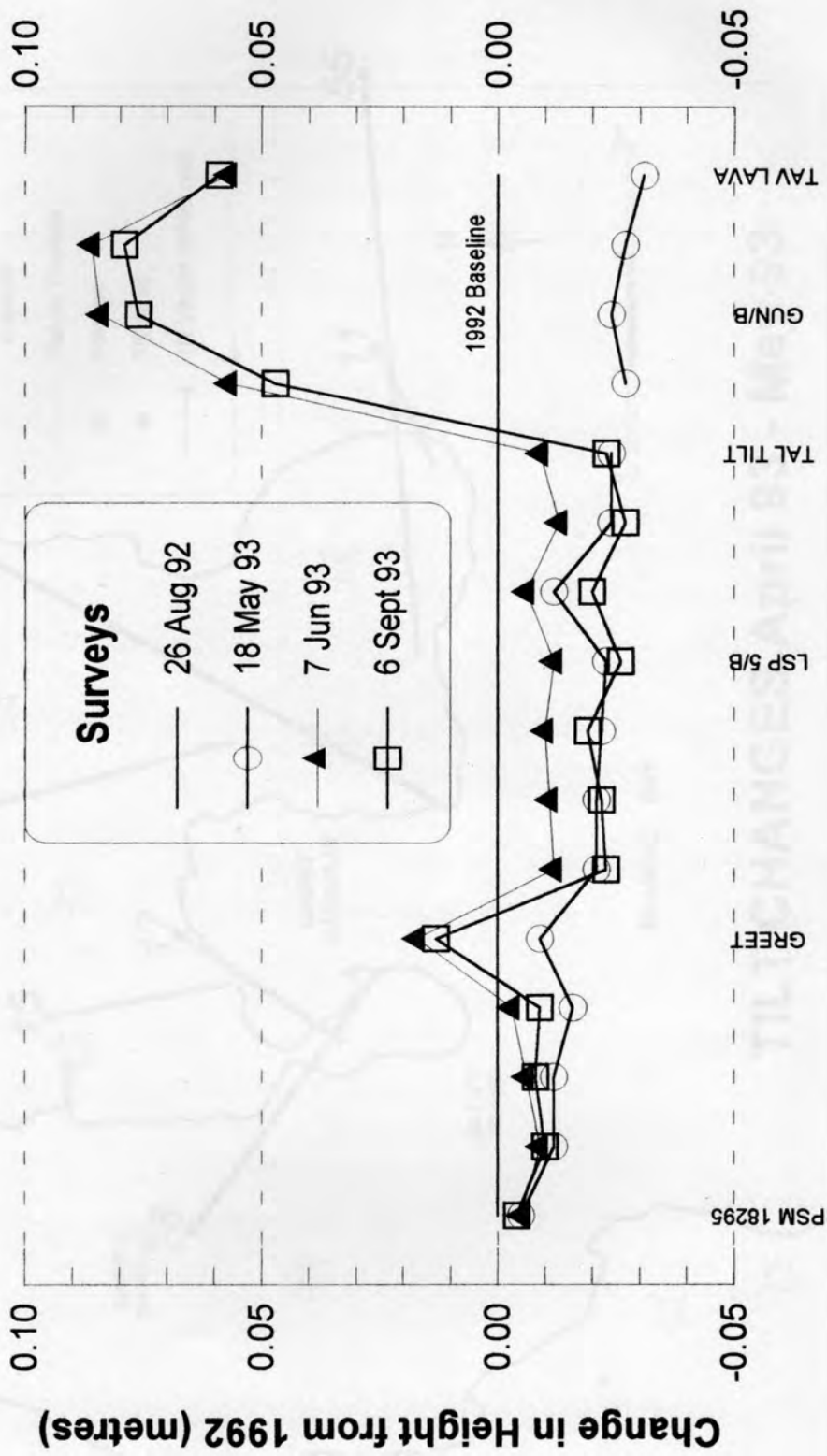
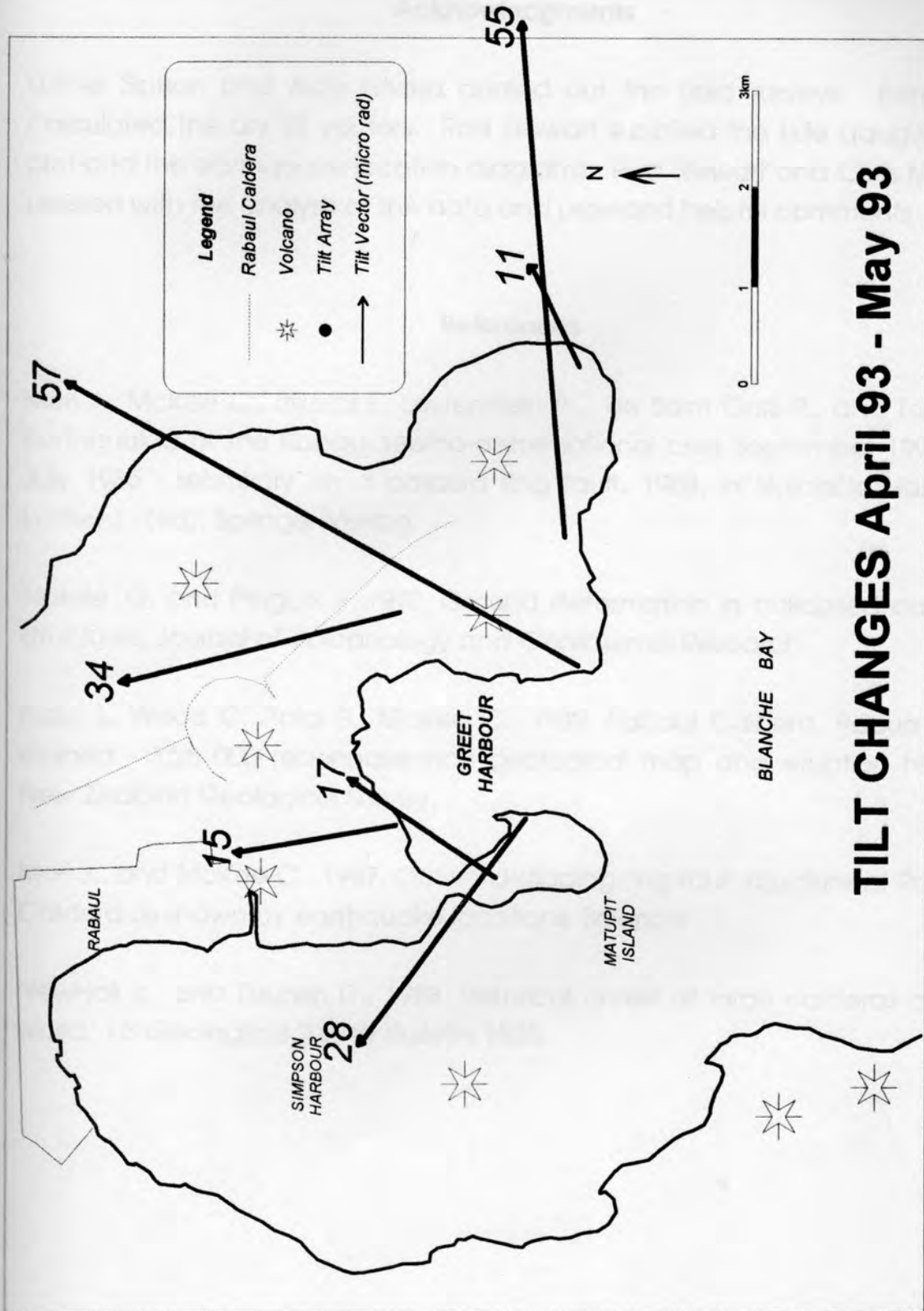


Figure 6. A plot of geodetic levelling results for four surveys along the Talwat Road route. Note the significant change in height between bench marks TALTILT and GUN/B. The slip associated with the 20th May 1993 earthquake swarm (an uplift of 0.10 m) was at a maximum between these marks.



TILT CHANGES April 93 - May 93

Figure 7. Diagram showing single set up levelling tilt vectors for selected stations near the 20th May, 1993 earthquake epicentres. The pattern of vectors indicates a tilting of the central Caldera block from east to northwest. Note the largest vectors are near the point of maximum vertical deformation as determined by geodetic levelling.

Acknowledgments

Luther Sipison and Alois Giwisa carried out the field surveys. Ben Talai calculated the dry tilt vectors. Rod Stewart supplied the tide gauge data plot and the earthquake location diagrams. Rod Stewart and Chris McKee assisted with the analysis of the data and provided helpful comments.

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