7

Geophysical Unrest: Build-Up to Another Eruption, 1970–94

7.1. Demanding Times, 1970–83

The outstanding amount of geoscience-related work on Rabaul undertaken in the 1960s continued resolutely into the 1970s and beyond. The 1970s, in fact, were a particularly demanding time for the staff of both the Rabaul Volcanological Observatory (RVO) and the Geophysical Observatory in Port Moresby (Figure 7.1). The decade began with a large eruption at Ulawun volcano south-west of Rabaul in January–February 1970 (Figure 0.2). Then a magnitude 7.1 tectonic earthquake in October of the same year beneath the coastal ranges of mainland New Guinea—further west along the Bismarck Volcanic Arc—shook the Madang District, causing fatalities and building damage (ACSEE 1973). The seismic energy from two large earthquakes of magnitude 7.9 was released beneath the northern Solomon Sea in July 1971, generating ground-shaking and tsunamis that severely affected the north-eastern Gazelle Peninsula including the Rabaul area. Next, another earthquake series was recorded in January 1972 beneath the coastal ranges of mainland New Guinea, onshore from Manam volcano. Port Moresby–based Tony Taylor visited Manam volcano to inspect its condition in August 1972 but he collapsed and died while undertaking the field work (Fisher 1976a).

Figure 7.1. Rob Cooke and Elias Ravian at a Rabaul Volcanological Observatory staff gathering.

RVO staff are seen in this photograph, which was taken probably in 1977 or 1978 (R.W.J. Collection 14, Folder 2, Folio 13). Rob Cooke is second from the left in the back row with his arms folded. Elias Ravian is in the middle of the back row, standing behind Lesley Topue who is third from the left in the front row. The photographer is unknown.

Six volcanoes in the Bismarck Volcanic Arc—Manam, Karkar, Long, Ritter, Langila and Ulawun (Figure 0.2)—broke out in eruptive activity in 1972–75, constituting what can be considered another eruption 'time-cluster', like the one in the 1950s (Cooke et al. 1976). The long-inactive Kadovar volcano in the extreme west of the arc in 1976 showed signs of volcanic unrest but no eruption took place, and Bagana volcano on Bougainville Island was also in eruption during the same period. However, volcanoes in the Rabaul area were not part of this time-cluster. Karkar was in eruptive activity again in 1979, producing violent explosions that killed RVO staff members R.S.J. 'Rob' Cooke, the senior government volcanologist at Rabaul (Davies 1981), and Elias Ravian, a Tolai from Tavui no. 1 village who worked as a volcano observer (Talai and Pue 1981; Figure 7.1).

The first of the two magnitude 7.9 earthquakes that affected the Blanche Bay area in 1971 struck in the late afternoon of 14 July. Its epicentre was beneath the floor of the northern Solomon Sea, south-west of Buka Island and north-west of Bougainville (Braddock 1973; Everingham 1975; Figure 6.10). This epicentre is remarkably close to a large-magnitude earthquake of 6 May 1919 that was also felt strongly in Rabaul. A large

tsunami that reached Blanche Bay just before dusk was generated by the 1971 event. It became trapped in the harbours, slopping back and forth from shore to shore. One of us recalled:

> Buildings shook and shuddered, their timber frames creaked and groaned, trees swayed, water tanks rocked off their stands and burst open. Cupboards fell and the contents of shelves cascaded to the floor. Parked cars rocked on their springs and drivers halted as the roads heaved under them. People running out of buildings found it hard to keep on their feet as successive shock waves made the ground appear to rise and fall under their feet like the deck of a ship in rough seas.
>
> In other parts of the Gazelle Peninsula there were damaged buildings, burst tanks and roads blocked by landslides. The worst hit area was the United Church centre at Gaulim where sloping land slipped downhill, toppling buildings off their stumps or leaving them standing at a crazy angle.
>
> Then at about 5.40 pm … [the] waters of Simpson Harbour and Matupit Harbour receded until the seabed was exposed far below the low-tide mark. Suddenly the sea rushed back and moved over the land to a height of about two metres above the normal waterline. The waters fell and then rose again every few minutes for over an hour, with the height of each rise gradually growing less. (Threlfall 2012, 478–9; see also Threlfall 2021b)

Moderately large earthquakes of magnitude 7.9–8.1 are rare enough in the New Guinea region: those in 1906 and 1919 and referred to above (after Brooks 1965) are probable examples (Figure 6.10). As one of us (R.W.J.) recalls, there was surprise at the Rabaul observatory when another tsunamigenic magnitude 7.9 earthquake took place only 12 days later, on 26 July 1971, this time under the sea off the south-eastern coast of New Ireland and hence closer to Rabaul. More damage was sustained by ground-shaking in the Rabaul area. A notable feature is that the epicentres for the two earthquakes of 1971, as well as for those of 1916 and 1919, are all south-east or east of New Ireland, just to the north of where the New Britain submarine trench changes its north-easterly trend strongly to south-eastwards, down the south-western side of Bougainville Island (Figure 6.10). The implication is that this region must be one of particularly strong seismic-energy release related to lateral bending of the subducting Solomon Sea plate. Further, both of the July 1971 earthquakes were followed by numerous aftershocks that defined in plan a broad, composite arcuate zone

in the northern Solomon Sea and mainly to the north of the submarine trench (Everingham 1975). The aftershocks of the main 26 July earthquake in the western half of this aftershock zone contribute to the definition of a down-going subducted slab beneath Rabaul volcano (Figure 7.2).

The tsunamis, or seiches, of 26 July 1971 did further damage to the causeway at Matupit Island already affected by the earlier tsunami, as well as flooding homes on the island's shores and at Rapindik (Threlfall 2012). Matupit islanders were evacuated and those who could not find accommodation elsewhere were sheltered in a tent camp set up by the administration on the edge of the golf course near the Lakunai Airfield (Figure 7.3). Little wonder, therefore, that after this 'double' impact of natural forces there was some talk yet again of abandoning Rabaul and moving to Kokopo (Threlfall 2012).

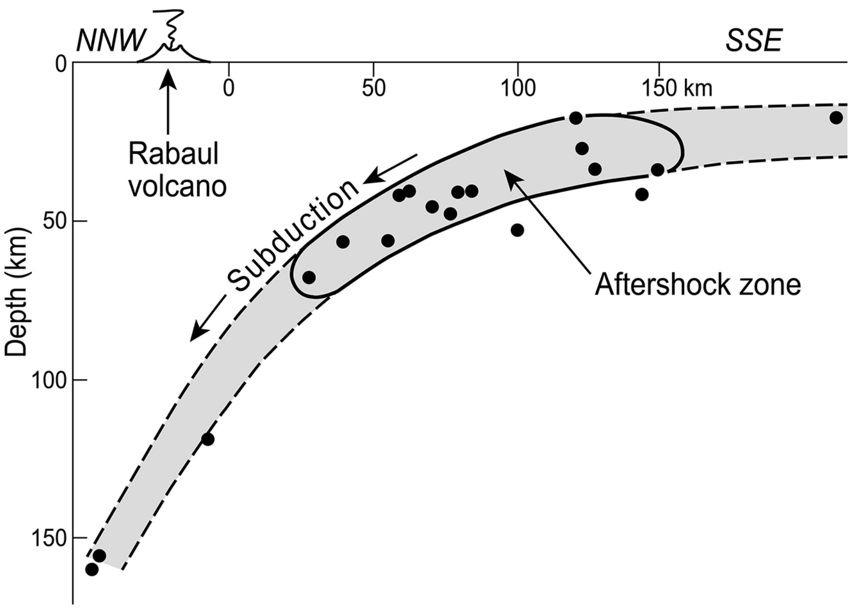

Figure 7.2. Subducting plate beneath the Rabaul area.

The upper part of a northward-dipping, subducting Solomon plate is shown in this schematic cross-section running from the Rabaul area in the north-north-west to the New Britain submarine trench in the south-south-east (adapted from Everingham 1975, Figure 5). The filled circles represent earthquakes that took place between August 1971 and May 1972, and were recorded by more than 10 seismograph stations. The 'aftershock zone' includes numerous events for the two days after the magnitude 7.9 earthquake of 26 July 1971. The shaded area represents only the seismically active upper part of the down-going plate; its base is not shown (see also Figure 9.5).

Figure 7.3. Aerial-photograph mosaic of the north-eastern Blanche Bay area.

Principal features of the north-eastern area of Blanche Bay are shown in this computer-enhanced aerial-photograph mosaic compiled in the early 1980s. The original photographs were taken before uplift of the south-eastern end of Matupit Island became strongly noticeable. The sea is coloured synthetically. Rabaul in the north-east extends down to the golf course and Lakunai Airfield.

The 1970s were a decade of great social and political change in the Territory of Papua and New Guinea, not least in the north-eastern Gazelle Peninsula where the demands for change were more strident, if not more threatening, than elsewhere in the territory (Threlfall 2012). The Gazelle Peninsula Local Government Council seemed to be one of the success stories of the territory but there were Tolai people who opposed its policies and planning, so much so that an opposition Mataungan Association was created in 1969. Protests and street marches ensued. The situation deteriorated considerably when, in August 1971, District Commissioner Jack Emanuel was stabbed and killed. There had been ongoing discussions in Canberra and Port Moresby about the Australian-administered territory achieving independence as a new nation-state, and those New Guineans anxious to see some form of release from expatriate-dominated control did not have too long to wait. Papua New Guinea achieved self-government in 1973 and full independence in 1975. Expatriates continued to lead the scientific and technical work of the RVO after 1975, but a measure of change was evident when Benjamin Talai, from the Duke of York Islands, graduated with a degree in geology from the University of Papua New Guinea, Port Moresby, in 1973, the first local staff member to do so. Talai had joined the RVO staff in 1967.

Small earthquakes in the Blanche Bay area began to be noticed and measured, starting in November 1971 (Mori et al. 1989), just four months after the two magnitude 7.9 earthquakes. The harbour's seismic network of five stations began recording them, but the earthquakes were found to be mainly in the Karavia Bay and Matupit Island area rather than beneath the Simpson Harbour area to the north. Three additional stations therefore were added to the network south of the bay to improve the mapping of the epicentres (Myers 1976; Cooke 1977; McKee et al. 1984). The initial results were quite surprising as the epicentres defined a continuous zone of points between two roughly concentric lines, or what became known informally as the 'seismic annulus', stretching across the entrance of Blanche Bay (Figure 7.4). Different shapes for the annulus would be mapped in the years ahead.

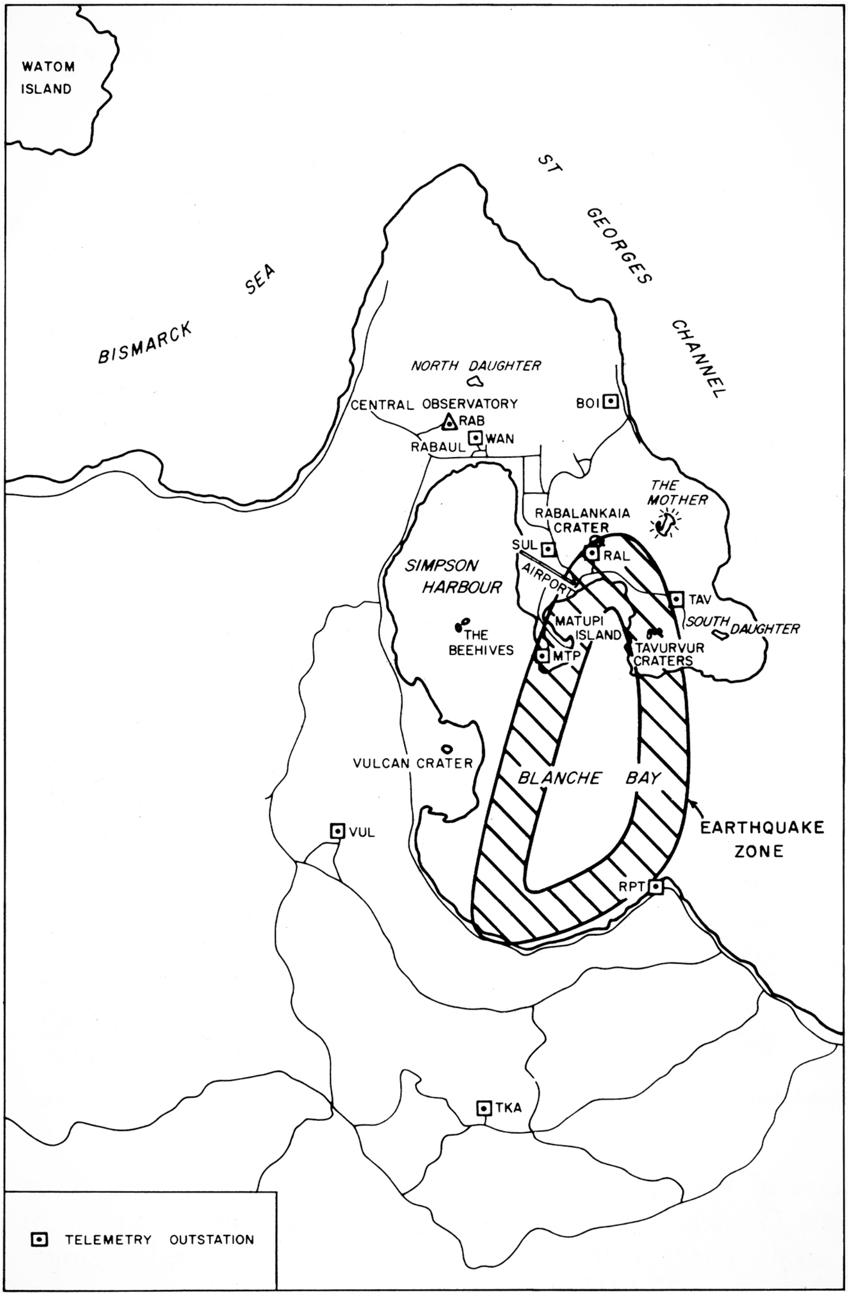

Figure 7.4. Early version of the 'seismic annulus' at Rabaul.

The 'seismic annulus' is seen here in its earliest published version (Myers 1976, Figure 1; see also Cooke 1977, Figure 1). Note that the hachured earthquake zone is 'flattened' on its western side, and that the annulus includes Tavurvur volcano but not Vulcan.

Another feature of the harbour earthquakes was that over the next 10 years or so they defined a series of time-clusters or seismic 'swarms' apparently triggered in some way by the two large earthquakes of July 1971 (Figure 7.5). Further, the largest number of monthly earthquakes in each swarm tended to increase over the same period (McKee et al. 1984). This increase was of concern, particularly as there was growing evidence too that the southern end of Matupit was slowly rising. This rise was in some ways welcome to the islanders who, one of us (N.A.T.) recalls, were gravely concerned about the loss of land caused by wave erosion at the southern end of the island. Some coastal scrub had died, apparently from flooding by seawater caused by subsidence of the south-western tip of the island during the 1971 earthquakes. This evidence for subsidence of Matupit has some similarities to that noted by George Brown in 1875 (see Section 1.2).

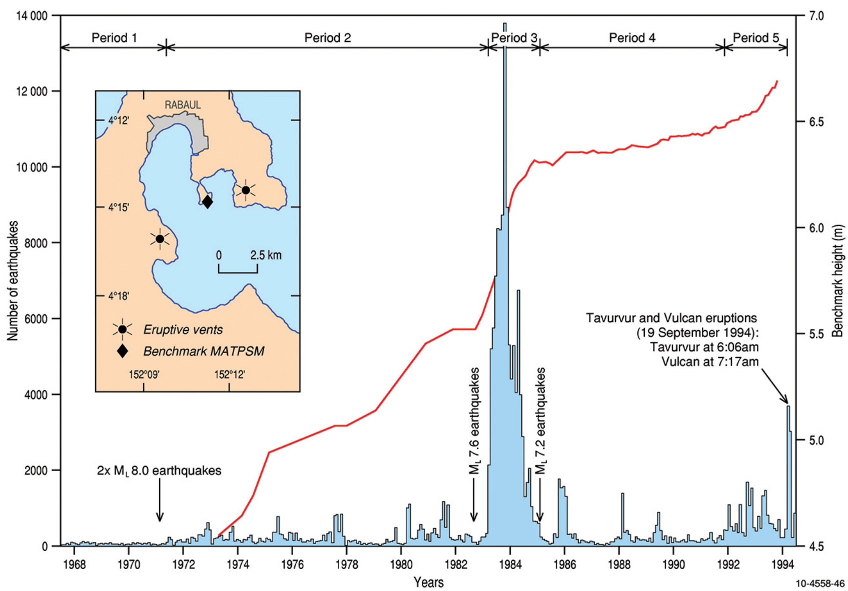

Figure 7.5. Graph of monthly earthquake counts between 1968 and 1994.

The monthly number of caldera earthquakes recorded between 1968 and 1994 on two or more stations of the Rabaul Harbour network are shown in this time series diagram adapted from the one presented by Itikarai (2008, Figure 2.9; see also Mori et al. 1989, Figure 2). Also shown is the progressive increase in height of the benchmark at the southern end of Matupit Island (see MATPSM in inset). Itikarai has here divided the 1968–94 time series into five periods.

Recognition of Matupit Island uplift led the RVO to instigate a new program of geodetic monitoring of height changes throughout the Blanche Bay area (de Saint Ours et al. 1991). The program began in 1973 using the normal optical-levelling methods deployed by surveyors, but other techniques were added, including portable tiltmeters ('dry tilt'); measurements of the changing gravity field; the monitoring of sea level using tide gauges and graduated rods (or 'tide sticks'); comparing bathymetric results from different marine surveys; and even measuring the heights of raised, stranded barnacles. Electronic (laser) horizontal-distance measurements were introduced in 1983 when Norm Banks of the United States Geological Survey (USGS) came with equipment donated to the RVO (Archbold et al. 1988). These geodetic data were used in conjunction with the earthquake datasets and ongoing temperature measurements to investigate the possible meaning of this growing geophysical unrest.

One question that emerged from the geodetic results collected throughout the 1970s and early 1980s concerned the nature of two centres, or foci, of sea floor uplift possibly caused by bodies of magma at shallow depths (McKee et al. 1984). In particular: what was pushing up and tilting Matupit Island towards the north and was there any additional evidence that might be obtained by studying the sea floor south and south-east of the island? A research vessel of the USGS, the RV *S.P. Lee*, was invited to undertake a bathymetric and seismic-reflection survey of Blanche Bay. The ship's survey in 1982 included tracks in and out of Greet Harbour and then south-westwards across the area south-east of Matupit (Greene, Tiffin and McKee 1986). A 'bulge' and associated active fault zones in the sea floor were detected (Figure 7.6), which

> are a result of emplacement of magma at a shallow depth. Contorted sediments and slumps adjacent to the bulge are probably the result of uplift and seismic activity. The pattern of activity appears to reflect increased magma pressure at depth beneath the caldera floor. This activity may eventually lead to an eruption. (Greene, Tiffin and McKee 1986, 327–9)

The possibility of such a submarine eruption taking place from a centre of uplift south-east of Matupit Island had already been considered, with concern, by RVO volcanologists: specifically, that a 'period of potentially very dangerous phreatomagmatic activity could occur in the early stage of the next eruption if a vent was established directly above the magma body' unless magma was channelled obliquely to one of the nearby subaerial volcanoes, such as Tavurvur (McKee et al. 1984, 408).

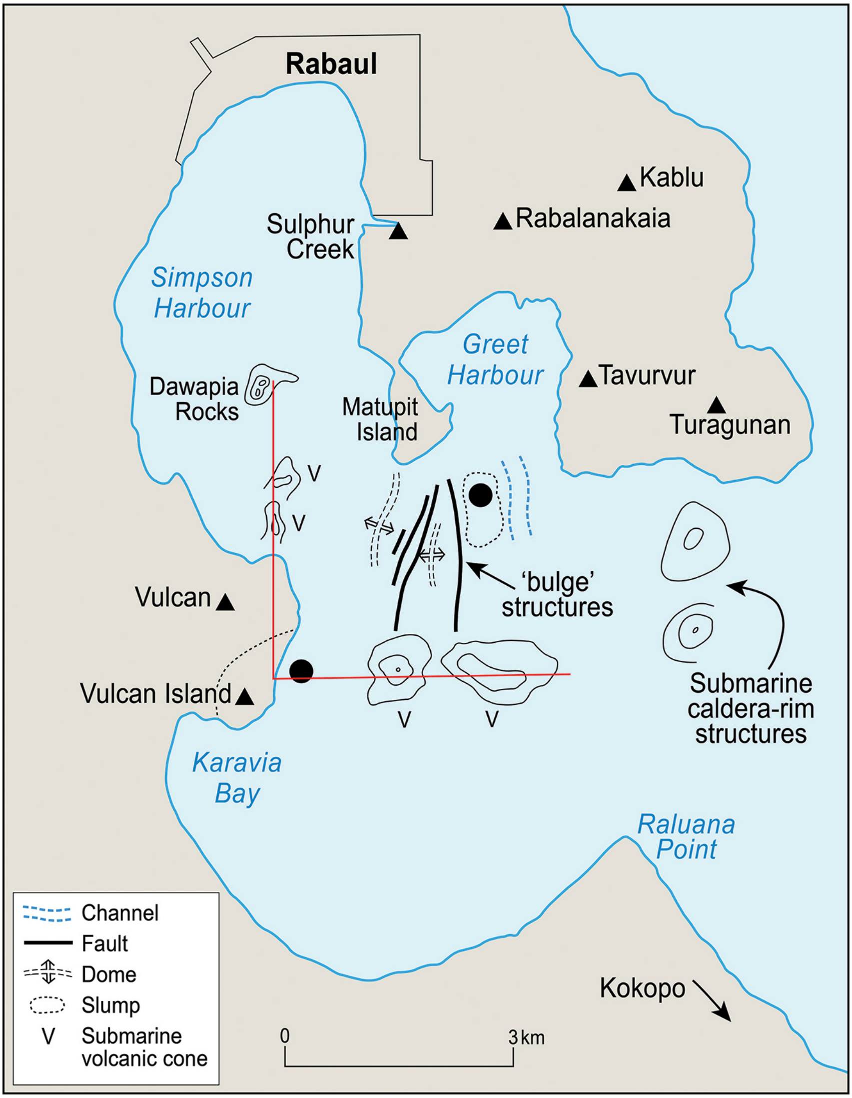

Figure 7.6. Centres of uplift and bulge structures in Blanche Bay.

This map of the 'bulge' structures south and south-east of Matupit Island is adapted from diagrams published by Greene, Tiffin and McKee (1986, Figure 16) and de Saint Ours et al. (1991, Figure 10). The filled circle south-east of Matupit Island represents the approximate position of the centre of uplift calculated from geodetic measurements (McKee et al. 1984). The other filled circle representing the centre of uplift near Vulcan Island to the south-west was mapped later using dry-tilt measurements (McKee et al. 1984). The RV S.P. Lee also mapped four sea floor cones of probable volcanic origin: two are in line with and east of Vulcan Island as well as with the centre of uplift there, and the other two are on a south–north line between Vulcan Island and Dawapia Rocks. The two lines intersect at right angles to each other.

7.2. A Time of Crisis, 1983–85

The seismic swarms continued into the early 1980s (Figure 7.5), as did the concerns of people throughout north-eastern Gazelle Peninsula, and a Volcanic Contingency Plan was completed for East New Britain Province by mid-1983. The content of the plan was guided by a disaster-management specialist, Brian Ward, from the United Nations Disaster Relief Organization, and was undertaken in consultation with national and provincial government authorities, the RVO and the private sector (McKee, Itikarai and Davies 2018). This contingency plan would be updated periodically in the years ahead and was part of an overall Provincial Disaster Plan managed by a Provincial Disaster Committee (PDC) and chaired by Nason Paulius, secretary of the Department of East New Britain (East New Britain PDC 1988).

The Provincial Disaster Plan was informed by the results of an assessment made by a volcanological team—mainly RVO staff—of volcanic hazards at Rabaul (McKee et al. 1985), thus updating the volcano-related hazard assessments made by N.H. Fisher 40 years previously (Fisher 1946b; Figure 6.1). McKee and his co-workers reported on the wide range of volcanic hazards accompanying different scales of eruption at Rabaul in the context of both eruption contingency planning and ongoing instrumental surveillance of the volcanoes at Rabaul. This study also included consideration, for the first time, of the impact of pyroclastic flows and involved a reinterpretation of photographs of pyroclastic flows from 1937 (Figures 3.11–3.13 and 3.17). The Provincial Disaster Plan assumed eruptions only of the scale of those in 1937 and 1878. Importantly, the plan also included a scheme of four stages of volcanic alert: Stage 1, in which a volcanic eruption was expected within years to months, up to Stage 4, in which one was expected within just hours to days.

The situation in Blanche Bay changed dramatically in September 1983 when many more earthquakes and a stronger period of uplift began to be detected (McKee et al. 1984; Mori et al. 1989). A magnitude 7.6 earthquake had taken place in March 1983 in the same region as the two large earthquakes of July 1971, possibly triggering the new period of enhanced unrest (Itikarai 2008; Figure 7.5). Monthly earthquake totals reached a maximum in April 1984 after which they declined gradually to July 1985, defining what became known as the 'Rabaul Seismo-Deformational Crisis'. This period of almost two years caused great concern and uncertainty among the wider

community, including businesses, villages, crop-growing property owners, subsistence farmers and service providers—as well as insurance companies. It would demand virtually the sole attention of RVO staff, led by Englishman Dr Peter L. Lowenstein, who had taken over leadership of the observatory after Cooke's death in 1979 (Lowenstein 1988). A key question was: Are there now stronger precursory signs that a volcanic eruption would soon take place? If so, when would it occur, how big would it be and how long would it last?

The East New Britain PDC held its inaugural meeting on 13 April 1983 (Lowenstein 1988), and the first of several evacuation exercises was practised in late May and early June by government authorities. Hazardous and safe areas were shown on coloured posters that were displayed on public notice boards, together with the localities of key facilities such as evacuation pick-up points and care centres (McKee, Itikarai and Davies 2018). Film Australia in 1983 released a documentary by Bob Kingsbury appropriately entitled *Waiting for the Big Bang* (Kingsbury 1983). A range of other public awareness-raising activities were initiated, including—in the background in Canberra—preparation of the first edition of *Volcano Town* (Johnson and Threlfall 1985). Publication of the book was sponsored by the Insurance Underwriters' Association of Papua New Guinea and was aimed at illustrating how the previous eruptions had affected the Rabaul area.

A Stage 2 volcanic alert indicative of a possible volcanic eruption within only weeks to months was declared on 29 October 1983 following further intense earthquake swarms. The number of recorded earthquakes in April had reached a monthly maximum of more than 13,000, and the southern end of Matupit Island had risen a total of about 1.6 metres above its 1973 height. These events caused even greater concern among the communities of Rabaul town and the surrounding region. Peter Lowenstein was quoted on the front page of the *Sydney Morning Herald* newspaper for 26 January 1984 as saying that

> evidence is accumulating to suggest that the [Rabaul] volcano has embarked on an irreversible course towards the next eruption and that it is only a matter of time before this occurs … within the next few months. (Hastings 1974, 1)

The headline was: 'Volcano Set to Blow: 20,000 Plan Island Escape. Rabaul Fears Repeat of the 1937 Disaster'.

There was a partial and voluntary evacuation of the town itself, including businesses (Lowenstein 1988; Blong and Aislabie 1988; Neumann 1996). Many villagers moved to land outside the caldera area, including perhaps as many as 40 per cent of those people living in the perceived highest-risk areas south of the main business district. Blocks of government-owned land south of the Warangoi River were made available for settlement. Other people left the province altogether—for West New Britain, for example—and some expatriates departed for Australia.

An inevitable topic of debate in the community and media, as well as at different levels of government, concerned the suitability of Rabaul as a place for a town and provincial capital—a repetition of discussions that had taken place after the 1937–43 eruptions and after WWII. Prime Minister of Papua New Guinea Michael Somare entered the debate by announcing in mid-February 1984 that, should an eruption take place, Kokopo would be developed as a new administrative centre, and that Rabaul had insufficient land for expansion anyway (Darius 1984). The crisis was a local one, but it nevertheless prompted development of eight new national Acts of disaster-related legislation, which were passed by the National Parliament of Papua New Guinea in March 1984 (Davies 1995b). The national government also provided funds for an emergency airport at Tokua, 15 kilometres east of Kokopo, which was opened by Prime Minister Somare in November 1984. The airport for normal commercial aviation in the province, however, remained at Lakunai, south of Rabaul and north-west of nearby Tavurvur volcano.

There was increasing concern in the community about the limited flow of authoritative and up-to-date information from the provincial government and the RVO about the state of the volcanoes. The provincial government therefore established a Public Information Unit in early February 1984 to disseminate as much relevant information about the crisis as possible (McKee, Itikarai and Davies 2018). The unit was assisted for a time by the well-known Australian Government geologist Hugh L. Davies, who had many years of experience working in Papua New Guinea and who was based in Port Moresby. Town meetings and meetings with special-interest groups were arranged, and a local newspaper was produced that was supported by a local businessman (Davies 1995a). Its name was *The Rabaul Gourier*—a word combination of the English 'courier' and 'guria', which is Tok Pisin for earthquake (Davies 1984). Two other expatriates involved with the work

of the Public Information Unit attempted to obtain information about community disaster preparedness through distribution of a questionnaire, but afterwards were dissatisfied by the way they had designed the questions (Kuester and Forsyth 1985).

A great deal of international interest was generated by the 1983–85 crisis at Rabaul, especially in Australia, the US, New Zealand and Japan. Overseas technical and professional assistance was provided to the RVO through international development-assistance agencies including, particularly, partnership collaborations involving staff of the USGS, Bureau of Mineral Resources, Geology and Geophysics (BMR), and RVO. The crisis also triggered a dramatic increase in the number of investigative geoscience publications on Rabaul volcano, a publication surge that continued well into the twenty-first century.

One reason for the overseas interest in Rabaul was because of geophysical unrest and concerns about volcanic outbreaks at caldera systems in two other countries. Alarming earthquake activity, ground deformation and new gas emissions (in one case) were also being reported in the early 1980s from the large active calderas at Long Valley, eastern California, US, and at Campi Flegrei ('burning fields') or Phlegrean Fields, west of Naples in Italy. This concurrent restlessness at three caldera systems in different parts of the world was quite coincidental, but the three were compared with considerable interest by volcanologists internationally. The three calderas also featured prominently in a major scientific literature review in the 1980s by two USGS volcanologists. These authors summarised almost 1,300 episodes of historical 'unrest' at 138 large calderas worldwide. Their conclusions included the following: 'The remarkable unrest at Rabaul Caldera that began in 1971 is perhaps the most threatening example in this compilation' (Newhall and Dzurisin 1988, 227).

The 1980s were also a time when there was global concern about aviation safety and dangerous encounters of aircraft—and jet-aircraft in particular—with volcanic ash clouds. High-rising eruptions at Galunggung volcano in Indonesia in 1982 caused the engines on a British Airways flight to cut out (Tootel 1985). The Australian Bureau of Meteorology in 1982 began using images from the Japanese geostationary meteorological satellite for the detection of ash clouds, and then issuing 'volcanic ash advisories' through an aeronautical telecommunications network. A Qantas aircraft sustained damage caused by high-rising ash clouds from Soputan in 1985.

International conferences were held on the subject (Casadevall 1994) and a worldwide network of Volcanic Ash Advisory Centers (VAACs) was set up in the early 1990s by the International Civil Aviation Organization, an agency of the United Nations, as part of the International Airways Volcano Watch. The Australian Bureau of Meteorology became responsible for running a VAAC in Darwin that covered the region encompassing Papua New Guinea, Indonesia and Australia.

Meanwhile, the 1983–85 crisis at Rabaul provided RVO scientists with even more seismological and geodetic data for interpretations of what might be happening geophysically beneath Blanche Bay. Attention was focused on the seismic annulus that, by this time, had become much better defined, although there was still considerable scatter in the map of epicentres caused by uncertainties in recording each individual earthquake (Mori et al. 1989). The annulus appeared to be mainly two long arcuate zones that faced each other but were linked in the north and south (Figure 7.7). Tavurvur and Vulcan volcanoes lay just outside the limits of the annulus. Another striking result was that the earthquakes were found to be mainly less than 4–5 kilometres deep—depths that apparently defined the top, or roof, of a large underlying reservoir of magma probably left over from the last period of caldera formation (Figure 7.8).

Further insights into the nature of the seismic annulus beneath Blanche Bay would be provided by seismologists in later years, using improved techniques and leading to a refinement of its likely structure (Jones and Stewart 1997; Itikarai 2008). The study by Jones and Stewart (1997), which recalculated or 'relocated' the original epicentres of 4,442 events recorded by the RVO between 1971 and early 1992, was particularly innovative. The method involved 'collapsing' two or more epicentres that were sufficiently close to one another and treating them as if they were just one event. This had the effect of reducing the number of epicentres *and* changing the previous scattering of epicentres (Figure 7.7) to a more focused configuration that appeared to define new structures within the zone of seismicity (Figure 7.9). In particular, a smaller inner ellipse of earthquakes in the north appeared to be younger than an incomplete but still seismically active and deeper one in the south.

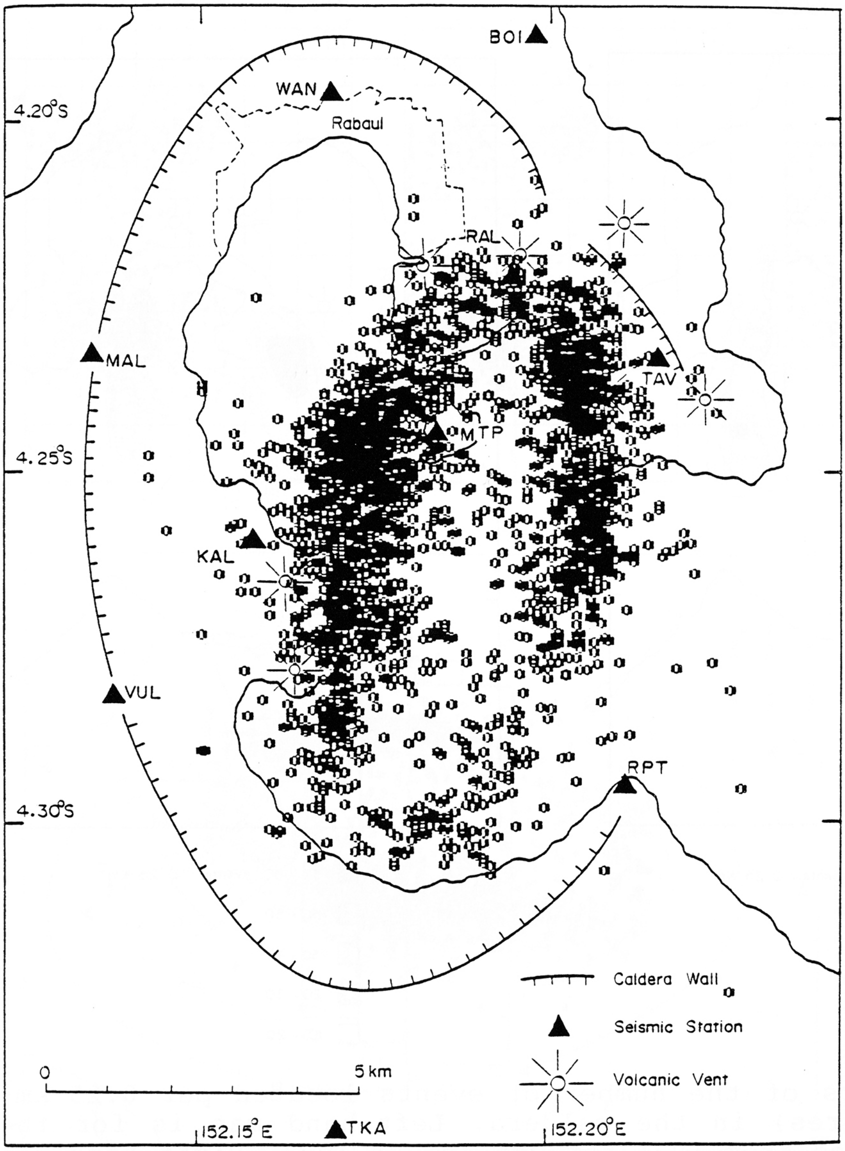

Figure 7.7. Map of earthquake epicentres defining the seismic annulus in 1983–85.

This map of earthquake epicentres is adapted from the one presented by Mori et al. (1989, Figure 7). These are the epicentres for over 2,500 earthquakes for the crisis period of September 1983 – July 1985. All plotted events were recorded by seven or more stations and had horizontal errors of less than 1 kilometre.

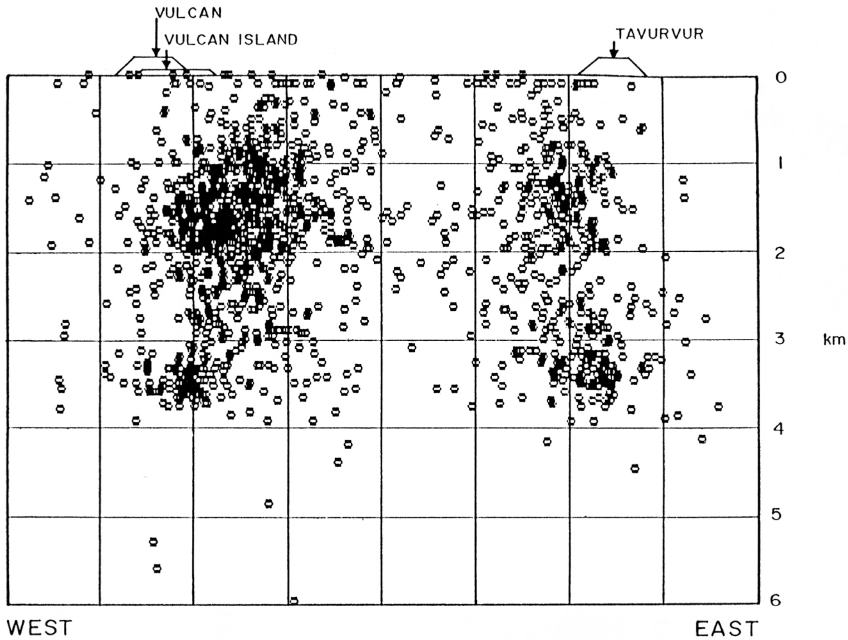

Figure 7.8. East–west cross-section through the seismic annulus shown in Figure 7.7.

This is a composite of three east–west cross-sections adapted from Mori et al. (1989, their Figures 9 and 10; see Figure 7.6). The plot includes all the well-located events between 4.24°S and 4.28°S.

The significance of the inner ellipse volcanologically is that the young eruptive centres within Blanche Bay generally have locations that are just outside the limits of the northern ellipse (McKee et al. 2020). An exception is the 1878 centre for Vulcan, which is close to the western margin of the older structure and in line with the two Karavia Bay centres, whereas its 1937 and 1994 centres are closer to the younger inner one. More importantly, however, an implication of the relationships shown in Figure 7.9 is that the distribution and growth of the young volcanoes appear to depend on the existence of the inner ellipse, meaning that there may have been earthquake activity on it prior to the 1937 and 1878 eruptions even though its existence at that time was unknown because of the absence of seismograph networks. Note also that the three Vulcan centres in Figure 7.9 may correspond to a northward progression between 1878 and 1994.

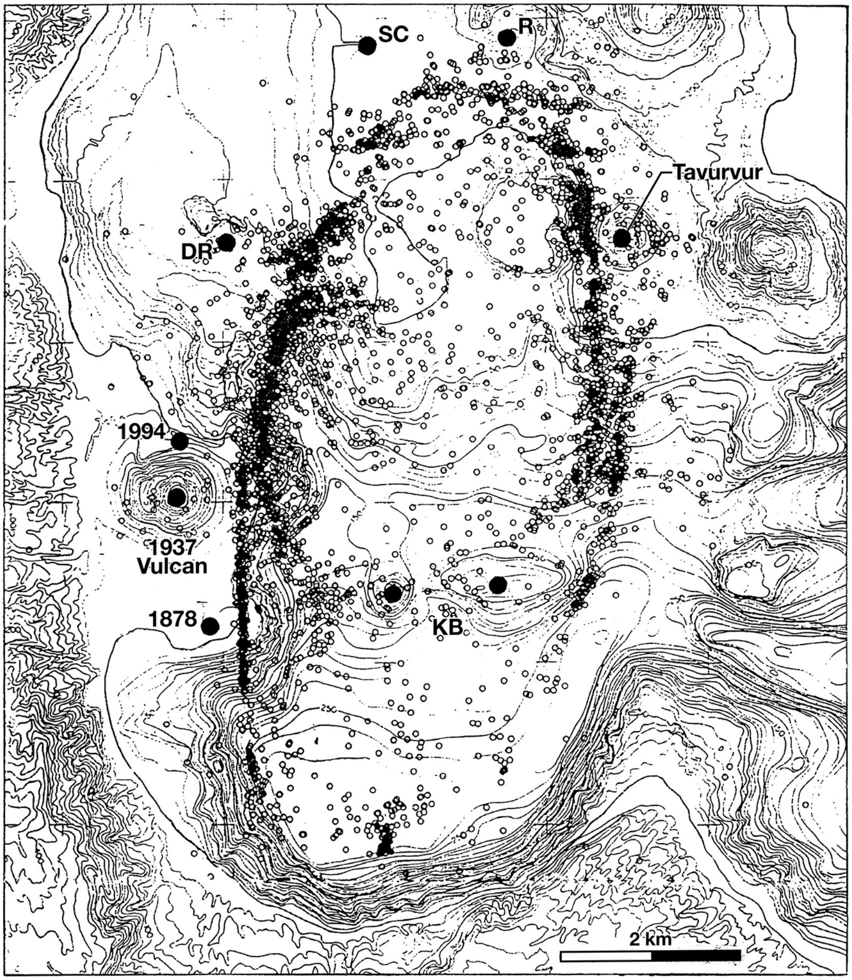

Figure 7.9. Ellipses formed by earthquake epicentres in Blanche Bay.

This map is adapted from ones published by Jones and Stewart (1997, Figure 7) and McKee et al. (2020, Figure 23). Abbreviations are as follows: DR, Dawapia Rocks; SC, Sulphur Creek; R, Rabalanakaia; KB, the two submarine cones in Karavia Bay. Only the initial outbreak point of the Vulcan 1994 eruption is shown here. Dawapia Rocks has not been in eruption historically and may have formed before creation of the northern ellipse of earthquakes (McKee et al. 2020). Itikarai (2008) showed that earthquakes in the northern earthquake ellipse are shallower than those in the south.

There was recognition by the early 1990s that the annulus earthquakes were not of the type expected from magma rising to the surface, and no volcanic tremor was recorded (McKee et al. 1984), meaning that there was uncertainty about whether magma was actually rising from below and how long the Stage 2 alert should be kept in place, or whether the level should

be reduced or increased. The earthquakes were classified technically as being of 'volcano-tectonic' or 'V-T' type. An eruption may have been expected imminently during 1982–84, but the monthly totals of earthquakes dropped off after peak values in April 1984 and the Stage 2 alert was called off in November 1984. The monthly totals then declined further to pre-crisis levels (Figure 7.5). There was a feeling in the community that the crisis had been a volcanic 'false alarm', but this did not reduce overall safety concerns. The RVO continued its instrumental monitoring, and many more investigations would take place over the following years, some of which are highlighted below.

7.3. Ongoing Investigations and Uncertainty, 1986–94

Earth science staff members of UNESCO (Paris) promoted an international focus on volcanic disasters during the 1970s. Initially, interest focused on support for studies on the scientific prediction of volcanic eruptions (UNESCO 1972), but the emphasis changed during the decade towards how best the scientific results of volcano monitoring during volcanic crises could be integrated with social needs such as crisis management and evacuation decisions in a 'risk' context. This change was encapsulated by a simple but influential 'multiplication' formula (Fournier d'Albe 1979, 321):

> Risk = Value or 'Exposure' (human lives, capital investment, agricultural land)
>
> x Vulnerability (the proportion of the value likely to be lost)
>
> x Hazard (the probability of different threats affecting an area).

There is no volcanic risk or disaster if any of these three factors is zero. Further, the expression 'natural disaster' becomes somewhat misleading as a disaster must also involve loss of, or in, a community caused by its own vulnerability, should a natural hazard strike. Therefore, a vulnerable community, such as the Rabaul one, is as much a cause of its own demise as any volcanic eruption that might overwhelm it. In this way, a community itself decides what level of risk it is prepared to accept, assuming it has a clear idea of what is at risk in the first place.

Another important clarification of terminology at this time centred on the meaning of eruption 'prediction'. Fournier d'Albe, for example, wrote:

> [W]e must face the fact that we do not have at present, nor are we likely to have in the foreseeable future, sufficient data or knowledge of the eruptive process to make predictions on a deterministic basis. (Fournier d'Albe 1979, 323)

The best that could be achieved would be to identify reliable precursors of eruptions empirically—such as earthquakes and ground-tilt—with the aim of making general forecasts rather than accurate predictions. This matter was highlighted by reflections on the prediction-versus-forecast problem in the case of other eruptions worldwide at this time (Opinion 1983). Scientific uncertainty and, therefore, lack of accurate predictions were unavoidable for volcanologists at the RVO, even though Rabaul people might have wanted otherwise. The best that could be done, using the accepted four-stage alert system, was to make general forecasts in the hope that a Stage 4 alert could be announced in good time.

Three studies on Rabaul were influenced by the overriding concept of disaster-risk reduction and were undertaken in response to the 1983–85 crisis. Two of these were sponsored by the Insurance Underwriters' Association of Papua New Guinea and were completed by consultants from New Zealand and Australia. The first of three, following Fournier d'Albe (1979), was produced by former RVO seismologist John Latter, who, with co-author A.W. Hurst, considered earthquake and tsunami threats as well as volcanic hazards (Latter and Hurst 1987). Both investigators were geophysicists from the New Zealand Department of Scientific and Industrial Research. Latter and Hurst (1987) concentrated on the hazards and the risk to human life.

The second, even more comprehensive, study of the Rabaul area, its volcanic hazards, vulnerabilities and likely damage impacts used more or less the same 'risk' principles as Latter and Hurst. The investigators in this study were Australian academics, physical geographer Russell J. Blong and economist Colin Aislabie. They considered much more 'exposure' information than did Latter and Hurst—on the built environment, agricultural investment and human life—as well as describing the contemporary disaster-management activities of the 1983–85 crisis (Blong and Aislabie 1988). Three eruption 'scenarios' were presented, together with assessments of their respective impacts. The first two cases were based on eruptions of the same scale as those of 1937, and for two different wind regimes corresponding to the changes

of season in any one year. Most attention was directed towards the impact of a damaging eruption from a new volcano, named 'New Matupit', at the submarine centre of uplift south-east of Matupit and starting with sea floor phreatomagmatic eruptions. A much smaller but simultaneous eruption was considered for 'Liklik Vulcan' near the site of the 1878 eruption. Pyroclastic flows from New Matupit would inundate Matupit Island in either season and would create a new volcanic island to the south-east. The third scenario considered by Blong and Aislabie was a major eruption similar in scale to the one that took place in 1400 CE. They concentrated on the devastating and widespread effects of major pyroclastic flows out to distances of more than 50 kilometres.

A third risk-related and groundbreaking study dealing with disaster management at Rabaul was begun in 1983 by another Australian geographer, K.J. 'Ken' Granger. This research led to a master's thesis that was submitted to The Australian National University under the title, 'The Rabaul Volcanoes: An Application of Geographical Information Systems [GIS] to Crisis Management' (Granger 1988). This contribution, perhaps more than any other up to that time, provided a reminder that the 'Digital Age', including personal computers, had arrived and that computer-based processing of digital images taken by aircraft and from space could be coupled with spatial modelling and relational databases to produce a valuable information tool for use by crisis managers at Rabaul. The 1983–85 crisis was over, but volcanic eruptions could still be expected, meaning that 'the present period of remission from volcanic activity' could be used to good effect (Granger 1988, 135). Granger also wrote, somewhat famously:

> There is nothing more certain in the disaster management business than the fact that once a disaster starts to unfold, it is too late to start looking for the information to manage it. (Granger 2000, 20)

These results do not represent the only studies of value and relevance to emerge in the late 1980s. The surge of interest in Rabaul from researchers eager to work with RVO staff was ongoing, even though the current crisis had ended. A major contribution of lasting significance resulting from field work in 1985–86 was the production of a new geological map of the Rabaul area and an accompanying report by two geologists from the New Zealand Geological Survey and two staff from the RVO (Nairn et al. 1989, 1995). This work added greatly to the earlier geological achievements of Heming (1973, 1974) and Walker et al. (1981). The research accomplished on the many ignimbrites in the area, and how the major explosive eruptions that produced them were related to different phases of caldera formation

at Rabaul, were among the highlights (Figure 7.10; see also Section 4.2). These eruptions were many times more powerful and voluminous than the eruptions of 1937 and 1878.

Another conclusion reached from this more modern geological mapping was that Matupit Island was different from the other young volcanic centres in Blanche Bay (Nairn et al. 1989, 1995). The raised, flat-topped island, which has no visible crater, was found to consist of water-sorted sediments of sea-rafted pumice and ash of unknown thickness comprising the 'Matupit Pumice Sediments'. These pumice and ash sediments were overlaid by sands, gravels and coral, and shell fragments that were radiocarbon-dated at about 750 BP. The Matupit Pumice Sediments were laid down shortly before this time and were then raised above sea level, possibly episodically. They may have been produced from a sea floor volcanic centre to the west—that is, by an eruption similar to the one at Vulcan in 1878. The deposits of Dawapia Rocks are thought to have a similar age to those of the Matupit Island sediments, so this post-caldera volcano may have been the eruption source for the Matupit pumice and ash (Nairn et al. 1989, 1995).

Figure 7.10. Pyroclastic deposits in a road cut near Kabakada.

The volcanic deposits exposed in this new road cut near Kabakada, Rabaul, and photographed in 1969 by R.F. Heming, consist of thick grey ignimbrite deposits (the Rabaul Ignimbrite and the Kulau Ignimbrite) overlying the eroded surface or 'unconformity' of the near-horizontal brown and yellow pyroclastic deposits of the older Kabakada Subgroup in the lower centre and right (Nairn et al. 1989, Figure 4). This road cut soon became shrouded in vegetation and the geology concealed.

Scientific interest continued in trying to understand the nature of the 'bulge' south-east of Matupit Island, and postwar technologies were used to investigate if the sea floor in that area was any warmer than elsewhere in Blanche Bay. First, a remotely operated vehicle equipped with a video camera and temperature sensor undertook dives at 11 different places on or near the sea floor bulge. No evidence of elevated water temperatures, hot springs, upward streaming of gas bubbles or submarine craters was found (Johnson 1986). These results led to major heat-flow surveys being undertaken in 1990 and 1992 when 4-metre-long probes equipped with thermistors down their lengths were used to map what turned out to be a complex pattern of heat discharge from the floor of Blanche Bay (Graham et al. 1993). The highest heat-flow values were found in Greet Harbour—and, surprisingly, at one point north-east of Dawapia Rocks—but the area south of Greet Harbour, including the uplift area south of Matupit Island, had much lower values than those to the north. The earlier interpretation that a new volcano might be created at this sea floor–uplift area looked less certain. Neither were high heat-flow values found in the Vulcan area.

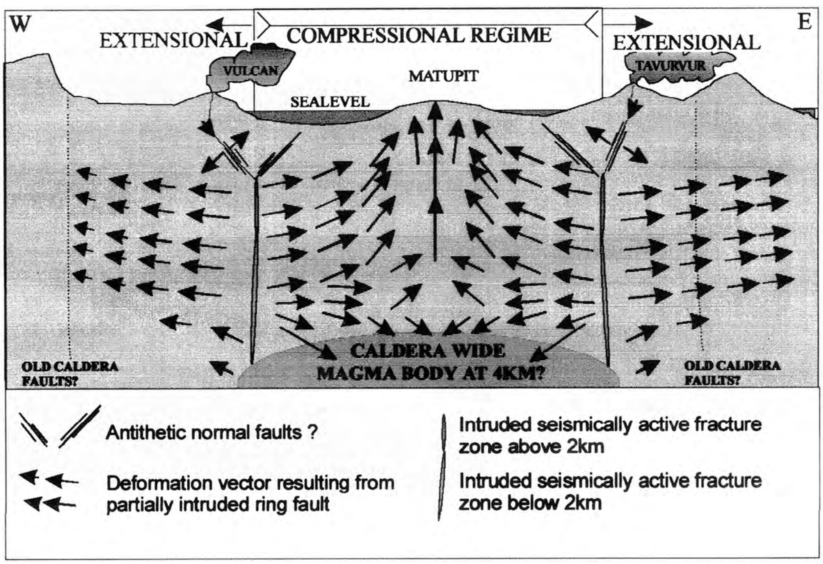

Figure 7.11. Intrusion of magma up ring fault and its resulting deformation of the central block.

Magma is shown rising in two stages from the large magma reservoir below (Saunders 2001, Figure 11) resulting in the eruptions at Vulcan and Tavurvur in 1994 (see also Roggensack et al. 1996, Figure 4). An 'antithetic' fault in geology refers to a minor secondary fault, commonly one of a set, whose sense of displacement is opposite to that of its associated major normal faults. Saunders has used the concept here as a way of explaining the slight outward displacement of the sites of the two volcanoes away from the seismic annulus (see Figure 7.9).

RVO geodesist Steve Saunders published the cross-section in Figure 7.11, showing both Vulcan and Tavurvur in eruption and the magma rising in underlying ring fractures. The injected magma is shown squeezing the central caldera block such that the area south-east of Matupit is up-bowed, thus explaining the doming up of the sea floor and the creation of the 'bulge' (Figure 7.6). Robertson and Kilburn (2016), however, promoted a different interpretation in which the surface up-doming was produced by the 4–5-kilometre-deep magma body, but was followed by a change in stress state from elastic to inelastic after 1991–92. In this interpretation, ascending magma does not utilise the fractures of the seismic annulus until one to two days before eruption.

The amount of financial support that could be provided to the RVO by the national government declined following the end of the 1983–85 crisis. Peter Lowenstein resigned from the RVO in January 1989 largely because of this reduced support. An Australian, C.O. 'Chris' McKee, who had joined the RVO as a geophysicist/geologist in 1973, took over as head of the Rabaul observatory, assisted by Ben Talai as deputy. By the late 1980s, the observatory was finding it difficult to keep all the monitoring instruments up-to-date and operational. The routine and manual measurement of temperatures on the volcanoes was labour intensive, and such work declined during and after the crisis period, mainly because of other work demands. Neither was the monitoring of changes in volcanic gas emissions at Tavurvur possible. Six villagers were in fact killed by gas asphyxiation in a crater on the southern side of the volcano (Figure 6.8) on 24 June 1990 when three people who had been collecting megapode eggs in the crater were overcome by carbon dioxide, and another three villagers were killed the day after when they tried to rescue them (RVO 1990).

The year 1990 was also when the scientific crew of the *Sonne*, a German research vessel, produced a bathymetric map of the sea floor immediately off the north-eastern coast in St Georges Channel confirming the existence of a large, mainly submarine caldera that impinged on the coastline (Tiffin et al. 1990; Figure 7.12). The caldera had been identified earlier, but not fully mapped, on a marine-research cruise of the research vessel *Moana Wave* in 1985–86, and its on-land, curved south-western side had been mapped previously as the Tavui Fault (Nairn et al. 1989). Tavui caldera is a major volcanic centre and the likely source of some of the volcanic deposits mapped on the land within the Rabaul volcanic complex. These deposits probably include the voluminous, 6,900-year-old Raluan Ignimbrite, which has been described as the 'penultimate major eruption deposit in the Rabaul area' (McKee 2015, 1).

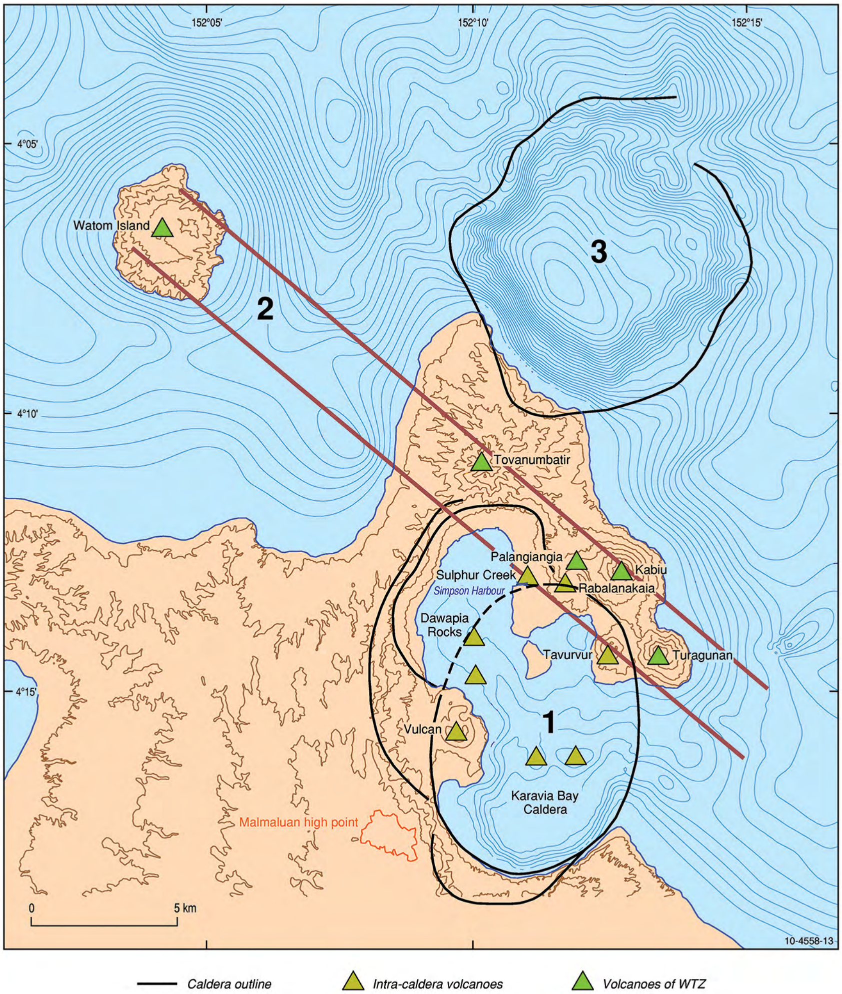

Figure 7.12. Map of proposed volcanic systems of the Rabaul area.

Three volcanic systems of the north-eastern Gazelle Peninsula are shown in this map: (1) Blanche Bay caldera complex; (2) Watom–Turagunan Zone; and (3) Tavui caldera (Johnson et al. 2010, Figure 13).

Tavui caldera is generally regarded as a neighbouring volcano to the main Rabaul volcanic complex and, accordingly, they have been considered separately by the Smithsonian Institution (Siebert, Simkin and Kimberly 2010; see Figure 0.2). There remains the possibility, however, that both centres are interrelated and are fed by common, albeit complex, conduit systems at depth—that is, they can be regarded as a single Rabaul–Tavui complex. Further, the 'Rabaul volcanic complex' itself may consist of

two main parts, and a total of three interlinked components may make up the overall geological structure of the north-eastern Gazelle Peninsula (Figure 7.12).

Vulcan and Tavurvur are set just inside the youngest and most complete of the calderas of the Blanche Bay caldera complex (number 1 in Figure 7.12). This was the area that Norm Fisher (1939a) suggested was the former site of a large volcano perhaps more than 2,700 metres high that had exploded outwards leaving Blanche Bay as a giant, now water-filled depression (see Section 4.2). The second of the three components is the line of stratovolcanoes running north-westwards from Turagunan in the south-east to Watom Island that Fisher regarded as secondary satellite or parasitic volcanoes to the main ancestral volcano that had collapsed. Fisher stated, however, that this Watom–Turagunan Zone (WTZ) (Figure 7.12) was parallel to New Ireland and, therefore, tectonically controlled. Magmas of the WTZ and Blanche Bay caldera complex are considered here to have interacted prior to the eruptions of both 1937 and 1994, as discussed below in Section 9.4.

7.4. Future Prospects for Much Larger Disastrous Eruptions

The historical eruptions at Rabaul in 1937 and 1994 are classified at the lower end of the 'large' category on the volcanic explosivity index (VEI) (Siebert, Simkin and Kimberly 2010). There is evidence, however, in the exposed geology of the Rabaul area for explosive eruptions many times larger than this, as introduced above (in Section 6.4 on 'ignimbrites') and, in particular, with reference to the geological work of Ian Nairn and colleagues, who presented mainly radiocarbon dates for many of these deposits. At least five, and possibly as many as nine, ignimbrite-producing eruptions may have taken place in the past 20,000 years or so, each perhaps accompanied by a collapse forming a caldera (Nairn et al. 1989, 1995). Serial collapses are thought to have formed the nested caldera escarpments in the Blanche Bay caldera complex (Figure 7.12), the more recent collapses being the best preserved, and the older ones hardly preserved at all.

These results provided average return intervals for major explosive eruptions at Rabaul of between 2,600 and 6,000 years. A similar range of intervals was found later for the earlier part of the pyroclastic sequence at Rabaul

using an 'argon–argon' ($^{40}Ar/^{39}Ar$) isotopic method on additional samples (McKee and Duncan 2016). These more recent results have emerged from a considerable amount of new geological and geochronological work that has been completed in the Rabaul area since the 1994 eruption, undertaken primarily by Chris McKee and RVO colleagues (McKee et al. 2020; McKee 2021). The tephra volumes for most of the larger explosive eruptions at Rabaul are between about 5 and more than 11 cubic kilometres, corresponding to the 'very large' (VEI 5–6) classification on the VEI scale.

The range of 2,600 to 6,000 years is wide, meaning that there is no reliable evidence for a constant eruption periodicity for the largest known eruptions at Rabaul. Further, there are many uncertainties in the geochronological record, including some imprecise radiometric dates. Perhaps the greatest uncertainty, however, is in mapping the stratigraphy of the tephra sequences. Exposures are generally poor or ephemeral and typically quite unlike the one illustrated in Figure 7.10. Also, tephras of different ages may look similar in the field, and making correlations between exposures over large distances can be challenging or not possible at all. In addition, the tephras expected at some exposures may have been removed by erosion from the sequence being examined.

Another complication is evidence of large eruptions at Rabaul that fall between the upper size limit of the small 1937–43 eruptions and the lower limit of the large caldera-forming, ignimbrite-producing ones. The best studied of these is the Talili Pyroclastics eruption sequence (Nairn et al. 1989, 1995; McKee and Fabbro 2018). These deposits are sandwiched stratigraphically between the two youngest of the larger caldera-forming ones. Their age range is given as 4200–1400 BP, and their total volume as 5 cubic kilometres or more (VEI 5). Part of the sequence consists of fine-grained pumice thought to have been derived from sea floor vents in Simpson and Greet harbours, whereas the remainder are the deposits of eruptions from WTZ volcanoes of Kabiu and Palangiangia. These prehistoric eruptions would have had an impact on Rabaul town far greater than those in either 1937 or 1994. Good outcrops of the Talili Pyroclastics are seen at Adelaide Street on the south-eastern edge of the now-destroyed town, and in road cuts on Namanula Hill, which was used as a major evacuation route for townspeople and others in 1937.

The best studied of the large, caldera-forming eruptions at Rabaul is the most recent one (Heming 1973, 1974; Walker et al. 1981; Nairn et al. 1989; McKee 2021). These deposits are referred to as the 'Rabaul Pyroclastics'.

They have an estimated volume of more than 11 cubic kilometres, meaning a VEI value of 6, and they consist of an upper ignimbrite layer (at least 8 cubic kilometres) and a lower plinian ash fall layer. The eruption led to formation of the most recent and best-preserved caldera escarpment in the Blanche Bay area, located mainly in Karavia Bay (Figure 7.12). The eruption is known, conveniently, as the '1400 BP' event, based on conventional radiocarbon-dating methods (Heming 1973, 1974), but a more recent age of 667–699 CE has been determined using a so-called wiggle-match radiocarbon-dating technique on a large charcoalised log from the ignimbrite (McKee, Baillie and Reimer 2015). Note that a seventh-century eruption is only a little more than 1,300 years ago. This value is less than the 2,600–6,000-year range of intervals between the earlier dated large eruptions and, on face value, could be taken as an indication that another major eruption is not due yet for quite some time. Such prognostications, however, need to be treated with considerable caution, bearing in mind the uncertainties in the record of geochronological results.

The seventh-century ignimbrite is found widely throughout the north-eastern Gazelle Peninsula. For example, it is known to be more than 40 centimetres thick more than 40 kilometres south of Blanche Bay (McKee 2021, Figure 10). Kokopo and other present-day settlements in the region are built on the deposit. The ignimbrite has been described as having a 'low-aspect ratio', meaning the pyroclastic flow that deposited it was energetic enough to roll over wide tracts of countryside, depositing ash thinly relative to the distance travelled, but filling some valleys during its passage (Walker et al. 1981). The eruption destroyed much of the environment and presumably was a major disruption to human life and settlement throughout the north-eastern Gazelle Peninsula. Afterwards, however, the revegetated area would have provided an opportunity for reoccupation for those migrants quick enough to take advantage of any newly recovered volcanic land.

An illustration of the hazard impact of larger eruptions in the north-eastern Gazelle Peninsula, including Rabaul and Kokopo, is presented in Figure 7.13 where the dashed line represents the area expected to be affected by a large ignimbrite-producing, pyroclastic-flow eruption. Note that this area includes Watom Island where the seventh-century ignimbrite can be identified but excludes the Duke of York Islands where it cannot.

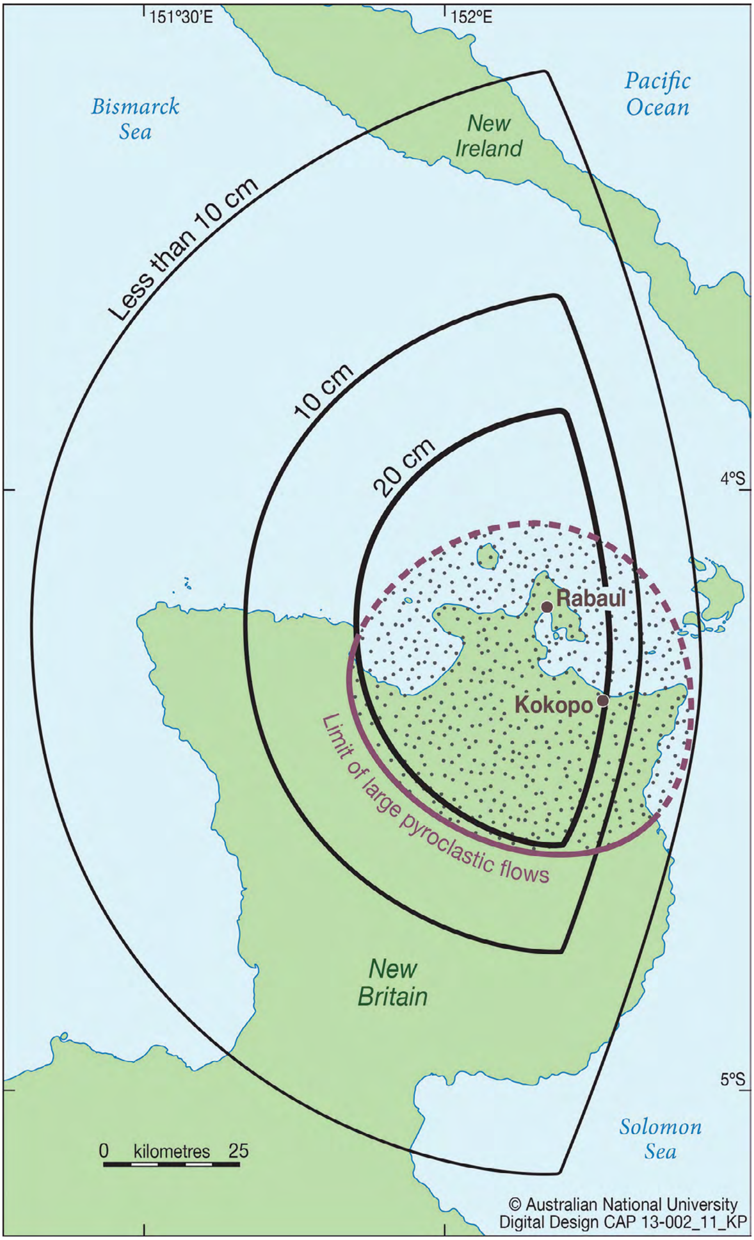

Figure 7.13. Anticipated extents of large pyroclastic flows and heavy ash falls in Gazelle Peninsula.

The dashed and solid line and the stippling (all in red) represent the area expected to be affected by large ignimbrite-producing pyroclastic flows across the north-eastern Gazelle Peninsula (adapted from McKee et al. 1985, Figure 13). The solid black lines signify the anticipated thickness of air fall ash. Bear-Crozier et al. (2013) provide a more detailed and recent assessment of the ash fall hazard in this area.

7.5. A Prepared Community Amid Scientific Uncertainty

A significant degree of uncertainty pervaded the Blanche Bay area in the years after the 1983–85 crisis. There was, perhaps superficially, some reduction of community interest in the state of Rabaul volcano and in the work of the RVO after the crisis; however, awareness of the threat of volcanic eruptions and concern about the future still existed. The community as a whole was 'volcano aware' not only as the result of the 1983–85 crisis and its accompanying awareness-raising activities, but also owing to the fact that some elders were still able to recall the volcanic disaster of 1937. This point was brought out very clearly on the occasion of the fiftieth anniversary of the 1937 eruption when a high-profile commemoration ceremony was held at Tavana (Figure 7.14).

Figure 7.14. Fiftieth anniversary ceremony of the 1937 volcanic disaster.

A *matamatanai* or commemorative ceremony was held on 29 May 1987 by villagers from Tavana, Valaur, Karavia and Latlat in memory of those who had perished in the Vulcan eruption 50 years previously (Neumann 1996). Prominent Papua New Guineans, including the governor-general, gave speeches and the large assembled crowd listened to choirs. The old monument shown here was erected shortly after the 1937 disaster and was the focus of the 1987 ceremony. Death tolls for each of seven villages are inscribed on the monument, totalling 352 people. The words at the foot of the inscription are: 'The earth covered them up at 4 o'clock 29th May 1937.' Photograph by R.W.J.

RVO staff also had the advantage of being more knowledgeable about the nature of the Blanche Bay volcanic complex as the result of post-WWII scientific advances. They were clearly in a much better state of preparation for an eventuality than were people in May 1937 when no volcanological observatory existed at all. Nevertheless, the RVO had declared in 1983 that the volcano was on an 'irreversible course' to an eruption 'within the next few months'. They had had to call off the Stage 2 alert in 1984 and there had been no volcanic eruption in the 10 years since then. In fact, the RVO, like many other volcano observatories worldwide, had the capacity to make only general volcanic forecasts and, as considered above, living with 'false alarms' was part of the responsibility of managing uncertain risk in the area.

Monthly earthquake totals had declined to pre-crisis levels by July 1985, but two magnitude 7.2 earthquakes within about 100 kilometres of Rabaul were recorded in May and July 1985, possibly marking the recommencement of higher monthly values in the following months (Itikarai 2008). Earthquake swarms from the seismic annulus were again recorded, and uplift continued at the southern end of Matupit Island, although at lower rates than before the crisis period (Figure 7.5). May 1992 marked the beginning of an increase in seismicity that was maintained for about two years, and the rate of uplift increased somewhat. A new feature of the seismic activity during this time were earthquakes in a well-defined zone running north-east of the caldera and well away from the seismic annulus (Itikarai 2008).

Friday 16 September 1994 was a national holiday, celebrating the anniversary of Papua New Guinea's Independence. Then, early on Sunday 18 September, two strong caldera earthquakes were felt at 2.51 am: one was located in Greet Harbour near Tavurvur volcano and the other appeared to be beneath the southern part of the Vulcan headland (McKee, Itikarai and Davies 2018; McKee et al. 2018). These events triggered an intense period of ongoing earthquake activity throughout the day that naturally gave rise to fears in the community and to uncertainties at the RVO. Some seismographs at the RVO 'were a mass of almost unreadable black scribble and the recording pens were having difficulty holding up with the constant movement' (Lauer 1995, 19, including a photograph of the seismograms). This was unlike the more 'normal' earthquakes of the 'swarms' recorded previously from the seismic annulus. People from the Vulcan area who visited the RVO later that morning were told they should not be too concerned (Neumann 1996); however, at about 6 pm a recommendation was made by the RVO to the PDC, and passed onto the National Emergency Disaster

Centre in Port Moresby, that a Stage 2 alert—signifying an eruption within months or weeks—should be declared, as in 1983 (Davies 1995a, 1995b, 1995c; McKee, Itikarai and Davies 2018).

A spontaneous evacuation of villagers from the Vulcan area had already started in the late afternoon, and by dusk most people on Matupit Island and in the southern end of town were resolutely evacuating along the road northwards towards an assembly place at Queen Elizabeth Park sportsground in Rabaul. People did not wait for any official recommendation from the authorities to do so. At least some listened to the advice of older people, their *patuana*, who recalled the 1937 eruption (Neumann 1995, 1996). Other Matupit people remained on the island. The unexpected night-time departure of aircraft from Lakunai appears to have confirmed in people's minds that evacuations should be continued if not hastened. By the early hours of 19 September, people from Rabaul town and villages within the caldera had evacuated by land and sea to safer villages, towns and missions in the south. Temporary camps, soon to be called 'care centres', were erected. The self-evacuation of people on the western slopes of Vulcan cone, including Tavana and Valaur villages, contrasts sharply to May 1937 when hundreds did not evacuate and so perished in the eruption, particularly in those two villages.

Meanwhile, the RVO advised the PDC at around midnight on the Sunday night that 'Rabaul was on an irreversible course towards an eruption' and that a Stage 3 alert—meaning an outbreak within weeks or days—should be declared (McKee, Itikarai and Davies 2018, 221). The PDC held off announcing this for the time being because of their concern that undue anxiety, even panic, might be caused in the community, which was already evacuating steadily. However, the National Disaster Emergency Services in Port Moresby was informed and its director, Leith Anderson, passed on the information about the Stage 3 alert to the prime minister, Sir Julius Chan, as well as to aviation authorities and the media. News about the Stage 3 alert was broadcast by ABC and NBC radio nationally, including in Rabaul, even though the alert had not been officially declared by the PDC itself.

There had been remarkable periods of uplift and exposure of the sea floor during the night of 18–19 September that were not seen fully until daybreak. The eastern shore of the Vulcan headland had risen about 6 metres and the southern shoreline of Matupit Island had migrated about 70 metres southwards (McKee, Itikarai and Davies 2018; McKee et al. 2018). Tavurvur broke out in eruptive activity at 6.06 am on Monday 19 September and was

joined by Vulcan at 7.17 am in another 'twin' eruption at Rabaul like those of both January 1878 and May 1937 (Itikarai 2008; McKee, Itikarai and Davies 2018; McKee et al. 2018). There was no eruption from the area of the 'bulge' south-east of Matupit Island—the anticipated 'New Matupit'.

The Stage 2 alert was still being broadcast by the local radio station early on the morning of 19 September advising people to stay home and remain calm. Stages 3 and 4 were declared, belatedly, after the Tavurvur eruption had started; Stage 4 meant that an eruption could be expected within hours to days. This anomaly clearly illustrated the unsuitability of the four-stage system of alert, which was based, at least in part, on the expected time before an eruption. The RVO later abandoned the system.

About 17,000–18,000 people lived in the Rabaul town area in September 1994 and a further 27,000 had homes in immediately adjacent villages, including those on the north-east coast (Davies 1995a, 1995b, 1995c; Lindley 1995). Many thousands of other people lived outside the limits of Blanche Bay, all of whom would be affected in one way or another by the unfolding eruption. Probably as many as 105,000 displaced people would require assistance, including the provision of rations by the provincial government. Evacuees were accommodated in more than 270 care centres, ranging from large camps like the one at the Kokopo Showground, to numerous smaller ones scattered throughout the region.

This text is taken from *Return to Volcano Town: Reassessing the 1937–1943 Volcanic Eruptions at Rabaul*, by R. Wally Johnson and Neville A. Threlfall, published 2023 by ANU Press, The Australian National University, Canberra, Australia.

doi.org/10.22459/RVT.2023.07