15. Reassessing Volcanic Risk in the North-eastern Gazelle Peninsula: 2000–2012

> 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 needed to manage it.
>
> K.J. Granger (2000)

Restructuring a Society

Rabaul town celebrated its centenary in 2010. The 100 years that have passed since German colonists established the town on Simpson Harbour in 1910, after draining the mangrove swamps, is brief in the context of archaeological and geological time frames. Yet the story is intimately interwoven with, and is a recurrent theme of, the larger history of volcanic disasters in Near Oceania, because of the drama of its high-risk location. The extraordinary history of Rabaul town is, of course, punctuated not only by the relatively small eruptions of 1937–1943 and the ongoing eruptive activity that started in 1994, but by military invasions by Australia in 1914 during the First World War and by Japan in 1942 during the Second World War. Thus, navies, too, have appreciated the strategic benefits of Simpson Harbour. Nevertheless, the volcanoes, their historical eruptions, and the threat of larger eruptions and even the catastrophic formation of a new caldera, form the major part of contemporary risk perceptions. The town's brief history, accordingly, is significant for the present day because of the tension that has been recorded between, on the one hand, the needs of economic development based on fertile volcanic soils and ideal rainfall, coupled with the export wharfs bordering the superb breached-caldera harbour at Blanche Bay and, on the other hand, an ongoing requirement for community safety and the need to reduce disaster risk from devastating volcanic eruptions in the future. A modern history of Rabaul and its environs is, therefore, a narrative of volcanic risk management, and the dramatic tension is an ongoing question of what level of risk is acceptable.

The Rabaul–Kokopo area, by the year 2000, had already undergone great socio-economic changes since the 1994 eruption. This included, especially, the withdrawal of many people from the Blanche Bay area to new settlements outside of the active caldera area, despite the nostalgia for and strong sentimental attachments to 'old Rabaul'. Urban development of the Kokopo, Baliora, Kenebot and Takubar areas was undertaken successfully. Furthermore, there has been, and continues to be, a determination by modern-day leaders in East New Britain Province to reduce volcanic risk in the north-eastern Gazelle Peninsula through planned resettlement in parallel with sensible policies for economic development. This ongoing commitment was reflected in the 2003 Provincial Development Plan and its 'growth centre' policy of encouraging development at four main centres in the north-eastern Gazelle — Kokopo, Kerevat, Vunakanau and Kurakakaul — but not at Rabaul or, indeed, anywhere within the caldera area of Blanche Bay, including Matupit Island. The ongoing eruptions at Tavurvur assisted this process of social change as they were, and are, a constant reminder that the decision to focus development away from Rabaul is a sensible one. Nevertheless, Rabaul itself clearly remains a volcanically vulnerable place. Furthermore, the challenges of economic growth in East New Britain Province are set against a difficult national backdrop of population growth, poor employment opportunities, and a wide range of developmental issues affecting the whole of Papua New Guinea — such as poverty, inadequate health services, law and order, education and governance issues. These challenges have continued up to the present day in East New Britain, even as the Gazelle Restoration Authority (GRA) closes down at the end of the formal, post-disaster, restoration and relocation program.

The major socio-economic restructuring in the rural areas of the north-eastern Gazelle has not all gone to plan, in part because of the absence of a thorough disaster-preparedness plan of land acquisition supported by rigorous socio-economic modelling in the years immediately after the 1983–1985 seismo-deformational crises.[1] Ian Scales, for example, in his report on roads in the post-eruption economic landscape of the province concluded that 'The bulk of resettlement has ultimately been unofficial, unplanned and unfacilitated … [and the] formal resettlement areas, their roads and other infrastructure are carrying much lower population than planned'.[2] Problems were compounded by some delays in post-disaster settlement construction and by the reluctance of some communities to resettle in the prescribed areas. Furthermore, upkeep of the existing road networks has not been possible, and the stretch of the economically important Kokopo–Rabaul trunk road, west of Vulcan, still remains unsealed. Economic development in recent years has also been affected adversely by much reduced cocoa harvests that were caused by a pod-borer infestation.

Many people after the 1994 eruption made their own resettlement arrangements by moving informally to the peri-urban area of Kokopo, or buying smallholdings from Baining people and other landowners in rural areas, thus contributing to the development of a settlement belt which covers the outermost parts of

1 Neumann (1996) and Scales (2010).

2 Scales (2010), p. 65.

the best agricultural land in the Rabaul area. Furthermore, some people in the early years, for any one of several reasons, moved back from the new, still poorly serviced, inland settlement areas to their original villages near Rabaul — including at Matupit Island, for example, where several hundred villagers still prefer to live on their traditional coastal land adjacent to Tavurvur, enduring living conditions that are substandard compared to other parts of the province.

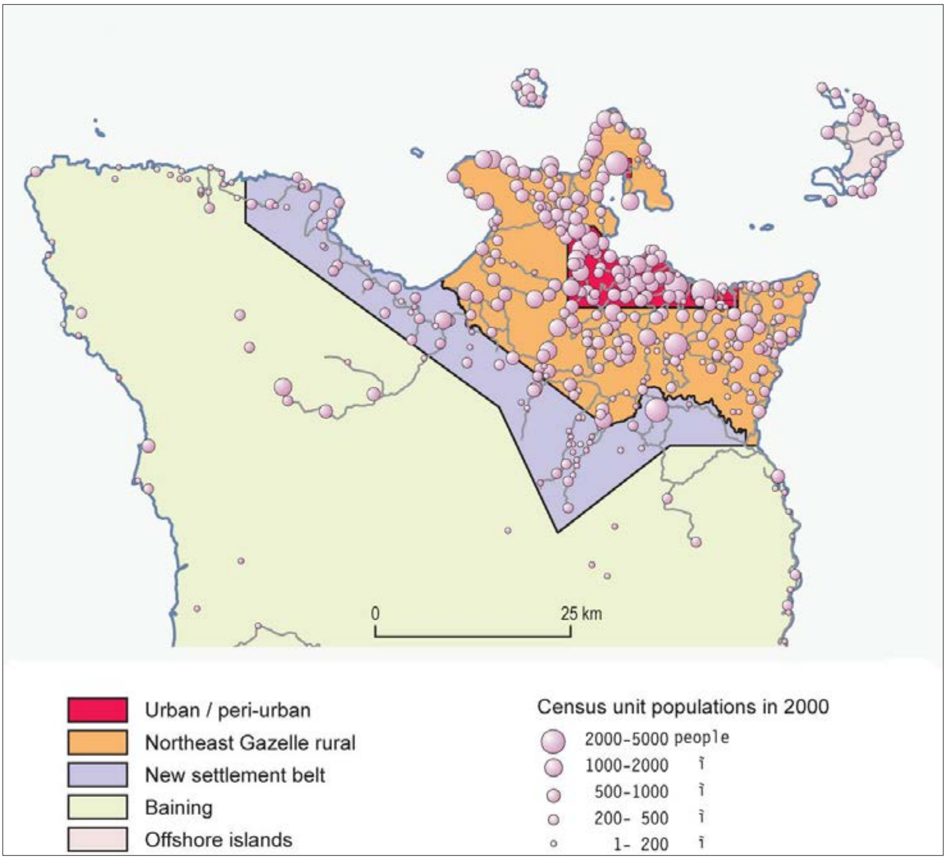

Figure 125. Economic zones, including the new settlement belt together with population distribution in 2000, are here mapped for the northern part of East New Britain Province.

Source: Provided courtesy of Ian Scales who adapted Figure 4 in his original account (Scales, 2010).

The 1994 eruption triggered a demographic shift to places away from the dangerous, volcanically active caldera area of Blanche Bay, but what is the current level of risk from natural hazards for the redistributed population? Are people today, together with their settlements and infrastructure, any safer? Sector 1 of Rabaul town, its economically crucial wharf on Simpson Harbour, and the Kokopo trunk road have survived, but what is the ongoing risk to their viability within the active caldera area? Answering these questions means that the 'risk formula' from the 1980s has had to be kept in mind — perhaps even more so than it was before the 1994 eruption. Formulaic 'risk' is a product of the following three factors and is 'zero' if any one factor is zero:

- The hazards (e.g. magnitudes, frequencies, early warning precursors)
- Elements of a society exposed to risk (e.g., people, homes, lifelines, etc.)
- The total of the separate vulnerabilities of each element.

This formula serves as a framework for important questions for the future. What is the range of the volcanic hazards that can now be identified and which threaten the communities? Is there an improved understanding of how the volcanic systems at Rabaul 'work' in a geophysical sense? Can volcanic risk be reduced through improved early warnings by the Rabaul Volcanological Observatory (RVO) of impending volcanic eruptions? Can community vulnerability be assessed more rigorously? And, overall, what is the current understanding of natural hazard risk, including volcanic risk, in the north-eastern Gazelle Peninsula, and can it be quantified?

Volcanic Hazards

A good deal is now known about the wide range of volcanic hazards in the north-eastern Gazelle Peninsula, based on the experiences of the 1878, 1937–1943, and ongoing 1994 eruptions at Vulcan and Tavurvur.[3] These eruptions are, however, generally regarded as only 'small' to 'moderately large' in volume and scale — that is, mainly 1–3 on the Volcanic Explosivity Index (VEI) scale, although the current eruptive period at Rabaul eventually may well classify up to VEI 4.[4] Different volcanic hazards, irrespective of the size of an eruption, affect the vulnerable Rabaul-Kokopo area differently, and therefore need to be treated separately where considering risk.

The main hazards from the small, intra-caldera volcanoes in Blanche Bay are from explosive eruptions. The main threat to life is within one or two kilometres of the active vents, from small pyroclastic flows and surges and from the impact of ballistic lava blocks and bombs flung out on parabolic trajectories. The most damaging hazard, even from small–moderate explosive eruptions, is from the widespread fall of ash from clouds driven over settlements and agricultural lands

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3 McKee et al. (1985), Blong & Aislabie (1988), Blong & McKee (1995) and McKee et al. (2012).

4 Siebert et al. (2010) tentatively classified the combined Vulcan and Tavurvur eruptions of both 1937 and 1994 as VEI '4?' (note the question mark) or 'large'. There is some debate amongst volcanologists about the appropriateness of adjectives such as 'large' for VEI 4 eruptions. These are considerably smaller than those having VEIs of 6–8, corresponding to tephra volumes with orders of magnitude smaller than for VEI 6–8 eruptions.

by prevailing winds. Ash clouds may also produce deadly lightning strikes, such as are believed to have caused one death at Ralalar village, south of Vulcan, in 1994. Clouds and lightning can be a threat to aviation and airport operations, including Tokua Airport, during north-west monsoon seasons, but even at great distances, to which ash may drift from the volcano. Ash falling on buildings may produce roof collapses that can kill any entrapped victims. A combination of heavy ash fall and pyroclastic flows and surges was probably responsible for the 500 deaths at Vulcan in 1937. Explosive eruptions also produce atmospheric shock waves that may rattle or break window glass.

Figure 126. Ash from Tavurvur falls on Rabaul and clogs the air on 6 September 2008. Piles of ash from previous eruptions, and which have been removed from the road, are seen in front of the Cathedral of St Francis Xavier on the left, but winds re-suspend the dry ash.

Source: J. McLean, Port Moresby.

Mudflows and floods contemporaneous with eruptive periods, and caused by heavy rain, can have serious consequences to property and, potentially, to life. Some Blanche Bay eruptions can entrain seawater and contribute to the severe run-off and resultant problems of rapid surface erosion. Other run-off and erosional problems are caused after eruptions, when normal rainfall degrades areas of vegetation stripped earlier during the eruptions, or through clearing by people for new, post-eruption, settlement areas outside of the caldera area. Mudflows and floods are still generated on the steep walls of the calderas in Blanche Bay, especially during the north-western monsoon. They cause problems in Rabaul town and periodically cut the Rabaul–Kokopo trunk road. In contrast, lava flows from Tavurvur during the ongoing 1994 eruption are localised, slow-moving, and are not nearly as much a threat to property as they are, for example, in the radial valleys on Manam Island.

A range of volcanic gases can be hazardous, even during non-eruption times when a volcano may be quietly degassing. Some gases are a severe irritant to eyes and the respiratory tract. Carbon dioxide is an asphyxiant in low-lying areas, such as at Tavurvur in 1990, when six people suffocated in gas-filled depressions. Sulphur dioxide and halogen gases can form aerosols and acid rain, which attack exposed metals and kill vegetation. Long-term exposure to the ingestion of fine ash particles may produce respiratory problems. Significant ingestion of silica minerals, such as crystobalite, could lead, in the longer term, to silicosis, although this has not been confirmed as a significant problem during and since the 1994 eruption. The long-term persistence of fine ash in the atmosphere, including ash re-suspended by winds or by traffic on busy roads, can also be psychologically wearing on the spirit of a community. Dust finds its way into homes, businesses, gutters, vehicles and the fabric of clothes. It enters ears, nostrils and eyes. Wearing goggles and wide-brimmed hats can be advantageous at such times.

Other volcanic hazards include tsunamis, which are formed where pyroclastic flows crash onto the waters of Blanche Bay, as in 1994, for example, or where part of a volcano collapses into water generating a debris avalanche and then a tsunami, such as happened on the northern flank of Tavurvur in 2006 when the rock avalanche ploughed into the waters of Greet Harbour. Pumice floating on water as rafts can be dangerous if the pumice surface is thought by pedestrians to be firm; or damaging to ships, if they are navigated by captains who do not recognise the abrasive properties of pumice on painted hulls; or to boats, when their water-cooling systems ingest pumice.

Evidence for past eruptions at Rabaul that were larger than those witnessed since 1878, has been found as a result of extensive geological fieldwork and study of the old volcanic deposits around Blanche Bay.[5] Such fieldwork is not without its challenges as exposure of the deposits and rocks is generally inferior because of the cover of tropical vegetation, and making stratigraphic correlations over large distances between one part of the area and another can be extremely difficult. Nevertheless, a general tephra-stratigraphy has been established, supported by isotopic dating on a range of samples. One important result is the identification of material from prehistoric explosive eruptions of

5 Nairn et al. (1995). C.O. McKee and RVO staff in recent years have undertaken extensive geological fieldwork and their largely unpublished results supplement and extend those provided by Nairn et al. (1995).

'intermediate' scale, corresponding to VEI values of 4 or 5.[6] These may not have been large enough to have been accompanied by formation of a caldera in every case, or at all, but nevertheless are thought to have been sourced within Blanche Bay and to be of a scale that, were they to recur today, would affect large tracts of landscape outside of the Blanche Bay area, as well as within, and likely would cause hazards and disasters much greater than anything experienced historically.

Evidence for even larger, catastrophic, VEI–6 eruptions is also found at Rabaul. The youngest and best-exposed deposits of these large-volume eruptions are the so-called 'Rabaul Pyroclastics', dated by the radiocarbon method and correlated to a calendar date of AD 720–750 ±20 years.[7] The Rabaul Pyroclastics have an estimated volume of 11 cubic kilometres and consist of thick, pumiceous, airfall deposits together with overlying ignimbrites laid down by pyroclastic flows and which can be traced up to 50 kilometres from their source in Blanche Bay, including over water to Watom Island. Kokopo is built on the deposits of the eruption, which most probably devastated the whole of the north-eastern Gazelle Peninsula and presumably made the area uninhabitable for quite some time. The eruption is thought to have been accompanied by a caldera-forming event, probably together with tsunamis. Whether this habitation 'vacuum' in the Rabaul area presented a subsequent opportunity for the ancestors of the present-day Tolai, who are thought to have come from New Ireland, to reoccupy a recovering and fertile landscape is unknown.

A key challenge concerning future volcanic risk in the north-eastern Gazelle Peninsula is determination of the frequency of occurrence of eruptions of different sizes at Rabaul. A general rule in applied volcanology is that larger eruptions are separated by longer time intervals than are smaller ones — or, in other words, eruption frequency decreases as eruption size increases.[8] This relationship could apply to Rabaul. The historical, intra-caldera, VEI 1–3 eruptive periods at Rabaul are separated roughly by decades of inactivity, whereas there may have been, according to one estimate, at least five and possibly nine 'significant ignimbrite eruptions' — say, VEI 6 — possibly together with accompanying caldera-forming events, over the last 20,000 years or so, thus giving a rough recurrence rate of between 2,000 and 3,600 years.[9] Intermediate-size and possibly non-caldera-forming eruptions presumably are somewhere between these two limits.

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6 McKee & De Saint Ours (1998). Latter & Hurst (1987) suggested that intermediate-scale eruptions may pose a greater 'annually apportioned risk' in the Rabaul–Kokopo area than do larger eruptions. This risk value is obtained by first estimating how many people are at risk for each size category of eruption, VEI 2–6, and then dividing these population numbers by the interval between eruptions of the same size category. Latter & Hurst considered that the larger eruptions at Rabaul were too infrequent to provide higher annually apportioned risk values, even though the field evidence for these frequencies was unknown at the time.

7 Walker et al. (1981), Nairn et al. (1995) and C.O. McKee (personal communication, 2011).

8 See, for example, Siebert et al. (2010).

9 Nairn et al. (1995).

The question that arises from such considerations of hazard types and eruption sizes and frequencies at Rabaul is not only whether eruptions can be forecast effectively, but whether their sizes and durations can be forecast too. In other words, can risk be reduced by effective early warnings, which are sufficiently accurate and early enough to permit effective evacuations of an appropriate scale? A starting point in attempting to answer such questions is to consider what is now known about the sub-surface geophysical structure at Rabaul, the location of magma reservoirs, how magmas reach the surface, and what kind of useful signals they provide as eruption precursors.

Early Warnings and a New Model for Rabaul Volcano

Eruptions at Tavurvur have continued up to 2013 — that is, 19 years after the start of the volcanic activity at Rabaul in 1994. Serious attempts over this time had been made by RVO scientists and their colleagues to reach a general consensus on how Rabaul volcano may 'work' in a geophysical sense. Professional volcanological work at Rabaul began in 1939 with publication of the report on the 1937 eruption by N.H. Fisher, while Ima Itikarai completed a seismological study of Rabaul for a postgraduate thesis in 2008. The years between have seen major contributions by dozens of other geoscientists based both in Papua New Guinea and abroad.

A workshop was held at the Rabaul Hotel in November 2009 in order to discuss the results of these 70 years of information gathering, and a report was published in 2010.[10] An overall conclusion of the workshop was that the feature known as 'Rabaul volcano' was best understood not as a single volcano but rather by the concept of *three* volcanic systems working together. These three are: (1) the Blanche Bay area, where there is evidence for the presence of several calderas of different ages; (2) the line of stratovolcanoes from Watom Island in the north-west to Turagunan volcano in the south-east; and (3) the largely submarine Tavui Caldera to the north-east. Thus, the old idea of 'Rabaul volcano' once being a towering ancestral mountain having smaller stratovolcanoes as satellites on its flanks, and which disappeared to form a single caldera at Blanche Bay, has been abandoned.

Another important aspect of the favoured model is the existence of two adjacent magma reservoirs about 4–5 kilometres deep beneath the Rabaul area. These reservoirs were identified as a result of the mapping of low seismic velocities, known as 'low-velocity anomalies' (LVA), during the RELACS geophysical

10 Johnson et al. (2010).

survey in 1996–1997. One reservoir is the Rabuana LVA, which is thought to underlie the north-eastern coast on St Georges Channel. Rising basalt magmas erupt from this magma reservoir, which together with its precursors in more distant times, have formed the volcanoes of the Watom–Turagunan Zone. Some of the basalt in the present-day reservoir is thought to have been injected south-westwards into a second magma reservoir beneath Rabaul Caldera, its lateral passage probably marked by the occurrence of the north-east earthquakes. This second reservoir corresponds to the Harbour LVA where the basaltic magma mixes and mingles with resident dacitic magma beneath Rabaul Harbour. The 'mixed' magmas then inject the lower parts of ring faults beneath Blanche Bay. This causes earthquakes which form the seismic annulus, as well as uplift at places such as Matupit Island. Such caldera-wide geophysical unrest is followed eventually by near-synchronous eruptions at Tavurvur and Vulcan.

This process is thought be a long-lived one, such that the reservoir beneath Blanche Bay has been replenished repeatedly with new magma over recent geological time. Furthermore, a key aspect of the sequence of events is that there are opportunities for RVO to track changes instrumentally at different stages and to assign new levels of volcanic alert. Thus, the north-east earthquakes can be detected and mapped by seismometers as the first stage of the progression of events. Formation of the seismic annulus, or geodetically measured uplift at Matupit and Vulcan, or both, can be detected, mapped, and interpreted as magma 'on the move' after mixing beneath the Greet Harbour area. Similarly, any measured increases in temperatures and changes to the chemistry of fumaroles in the Greet Harbour area, including at Rabalanakaia and Tavurvur, can be taken as a trigger for declaring a higher level of alert following magma-mixing beneath the area. But can provision of alerts be accomplished any better than they were in 1994?

The experience of the build-up to the 1994 eruption is that magma mixing, accompanied by magma intrusion up the ring faults of the seismic annulus, may have taken place over many years without leading to an immediate eruption. The magma system underlying Rabaul can remain inflated and unstable for a long time — somewhat analogous to a filled balloon or bladder waiting to burst. Thus, the 1994 eruption at Rabaul seems to have had 13 years of build-up time between 1971 and 1984, and then a further ten years of relative quiescence before an eruption finally took place 23 years later, after only 27 hours of immediate warning. RVO may have to affirm, and Rabaul people may have to accept, that 27 hours is the only time they may have in the future if eruptions similar to those in 1937 and 1994 happen again. Rabaul people will have to accept, too, that RVO will continue to struggle in understanding the workings of Rabaul volcano. RVO deals with scientific uncertainty, caldera complexity, and only generalised eruption forecasting, and not with precise prediction of geophysical events.

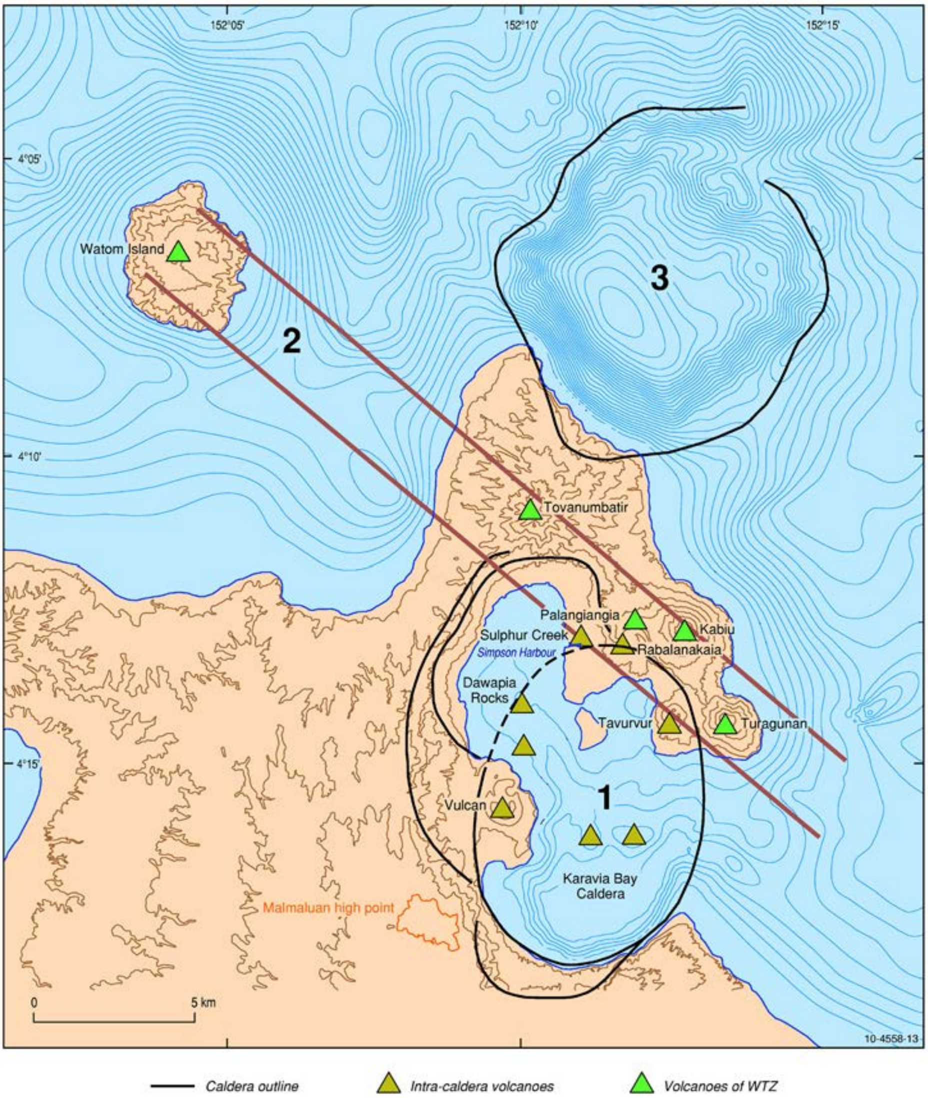

Figure 127. The three volcanic systems of Rabaul volcano are (1) the cluster of 'nested' caldera escarpments in the south, (2) the Watom-Turagunan Zone in the middle, and (3) Tavui Caldera in the north-east.

Source: Johnson et al. (2010, Figure 13).

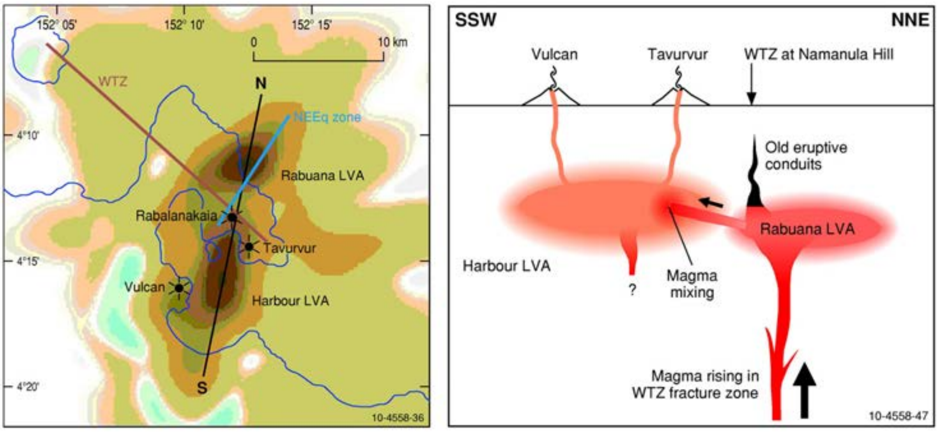

Figure 128. Two large reservoirs that are thought to contain magma are shown in the left-hand map of a horizontal slice, about five kilometres deep, beneath the Rabaul area. The different colours from black outwards to light green refer to rocks having increasing seismic velocities. Rabalanakaia volcano is near where the two 'low-velocity anomalies' or magma reservoirs connect, and where the trend of the north-east-earthquake zone or NEEq intersects the Watom to Turagunan Zone, or WTZ, of stratovolcanoes. The line N–S refers to the vertical cross section shown in the right-hand cartoon, where new magma from the more northerly reservoir, Rabuana, is injected into older magma of the Harbour reservoir, causing mixing or mingling of the different magma types. The magma then moves up the fractured seismic annulus and erupts from Vulcan and Tavurvur volcanoes.

Source: Itikarai (2008, adapted from Figure 6.3 by Johnson et al., 2010, Figures 36 and 47).

One remaining question is whether the 1994 eruption is typical of Rabaul eruptions. Eruptions are continuing at Tavurvur 19 years after the 1994 activity, whereas eruptive activity following the 1937 eruption was restricted only to 1941–1943. The current pattern is different, and so extreme care must be taken in assuming that the lessons learnt from 1994, and indeed from 1878 and 1937–1943, will necessarily apply in the future. This point, too, will have to be taken into consideration by those who continue to live in the Rabaul area and who may still retain the desire of restoring the town to what it was before 1994.

Determining Risk Today

More attention since the year 2000 has been focused both internationally and in the Rabaul–Kokopo area on defining the exposure and vulnerability factors of the 'risk formula' — especially the susceptibility to hazard impacts of populations, settlements, housing, commercial buildings, power supplies, critical infrastructure and transport facilities, including roads, ports and airports. Furthermore, since 2000, work that is aimed at reducing risks arising from natural hazards has involved a general trend towards undertaking more formal risk assessments — a trend that, in large part, was stimulated by the risk-reduction focus of the United Nation's International Decade for Natural Disaster Reduction (IDNDR) in the 1990s. The direct result of such assessments is evidence-based identification of the highest risk areas, which should lead in turn to key decisions about new economic development strategies and community safety. This may, in the case of East New Britain Province, result in further migration of people and investment to safer areas, but ultimately will require a determination of what risks are acceptable and why. East New Britain, like any at-risk society, will determine its own 'risk equilibrium' based on the best possible information and analysis.

Risk assessment of natural hazards, for many years before 1994, had been a general part of the work of the insurance and reinsurance industries in determining the costs of premiums, but now there is wider interest in the topic amongst members of the disaster management community, both locally and internationally. Two of the risk studies that were undertaken at Rabaul during the 1980s were commissioned by companies of the Insurance Underwriters' Association of Papua New Guinea,[11] thus providing the industry with some basis for reassessment of insurance premiums. The extent to which these results, and those of the other hazard and risk studies of the 1980s, had a direct impact on strategies for governmental policies on economic development and natural-hazard risk-reduction is not clear, but there is a possibility that results were largely forgotten, or at least put to one side, in the ten years after the 1983–1985 crisis when the expectation of an eruption declined.

The first attempt to address natural-hazard risk in East New Britain Province after the 1994 eruption was in 2001–2002, when the provincial administration, the GRA, and the Australian Agency for International Development (AusAID) collaborated in a multi-hazard risk assessment of the province. A trained disaster risk assessment adviser, Isolde Macatol, was contracted to join a team led by Levi Mano, advisor for the administration's Planning and Research Division. Macatol compiled and edited a final report, which included benchmark papers on individual hazards by RVO staff: volcanic hazards (Jonathan Kuduon), earthquakes (Itikarai), landslides (Felix Taranu), and tsunamis (Kila Mulina). Other natural hazards considered were active faults and floods and, to a lesser extent, land subsidence, sea level rise, coastal erosion and drought. The report also included development by Macatol of a 'hazard and vulnerability index' for

11 Latter & Hurst (1987) and Blong & Aislabie (1988).

the province, as well as a range of risk-reduction recommendations.[12] In addition, discussion papers on different aspects of risk — economic, social, political and cultural — arising from extreme natural hazard events were prepared by officers from the provincial administration and GRA.[13] A third report on community 'risk perceptions' was planned, but was not developed to production stage.

Figure 129. The artificial lights in this night-time photograph of strombolian activity at Tavurvur volcano, as seen from RVO on 16 April 2008, serve as a proxy to illustrate the closeness of settlements to the active volcanic centres of the Blanche Bay area. Rabaul town and the wharf area extend along the length of the foreground. The Rabaul Yacht Club and its marina, together with the Travelodge Hotel, are in the middle distance in front of Tavurvur. Kokopo town is in the far distance to the right of Tavurvur and outside Blanche Bay.

Source: S. V. Hohl, Freie Universitat Berlin.

The 'hazard and vulnerability index' for East New Britain Province consisted of 119 computer-drafted maps for a range of natural hazards that were classified

12 Macatol (2002).

13 Macatol (no date). A photocopy of this second report was kindly provided by Levi Mano, East New Britain Province Administration.

into groups of different severities, and shown in relation to settlement locations. These maps were supplemented by 24 tables of village population data based on the 2000 census, together with related statistics. Risk assessment was, therefore, focused largely on estimating the numbers of people living the different hazard zones. A significant conclusion was that settlements in the province as a whole were threatened by mainly geological hazards: volcanic eruptions, earthquakes, tsunamis, landslides and related flooding, and rapid shoreline loss. One other principal conclusion was that 85 per cent of people still living in the Rabaul district in 2000 — including Rabaul town and Matupit Island — occupied zones of high to very high risk. All of this population-based risk work contributed substantially to the information base required for ongoing risk-reduction and development strategies in East New Britain.[14]

Risk perceptions in any multicultural society, such as that found in the north-eastern Gazelle Peninsula, are wide-ranging, commonly subjective, even conflicting, and not always based on the best factual evidence. A major, but complex, challenge in disaster management, then, is to provide an objective assessment of risk based on the integration and analysis of observable, but multifaceted, facts about hazard, exposure and vulnerability. An important historical development in this regard, which was evident in Australia and elsewhere for some years up to 2000, was the use of spatially referenced, or 'georeferenced', digital information in computer-based geographic information systems (GIS). The origin of GIS can be traced back to the 1960s and 1970s, when computers began to be used for cartographic purposes, replacing pen and ink, but the full power of GIS began to be recognised when spatial data from field land-resource surveys, geophysics and remote sensing from aircraft and satellites, were married with traditional computer-assisted cartography.[15]

GIS, in the context of disaster management, represents an attempt to use the spatial 'overlays' as digital maps to quantify and then analyse multiple natural hazard risks. K.J. Granger undertook GIS research work for crisis-management purposes at Rabaul immediately after the 1983–1985 seismo-deformational crisis[16] and subsequently, with others, he was at the forefront of this type of research in Australia. This included promotion of the concept of national information infrastructures for disaster-management purposes in Pacific islands countries.[17] Granger, in 1997, introduced the expression 'Risk-GIS' as a way of focusing attention on the benefits of GIS as an essential tool for disaster risk-reduction analysis.[18] Modern field collection of spatially referenced information for GIS usage is facilitated by handheld computers that are pre-programmed

14 L. Mano (personal communication, 2011).
15 See, for example, Burrough (1986).
16 Granger (1988).
17 Granger (2000).
18 See, for example, Granger (1997).

for exposure and damage assessments, and equipped with GPS, camera, and preloaded imagery and building addresses. Similar equipment can be mounted on vehicles for data collection throughout urban areas at large-city scale.

Georeferenced spatial data sets for land-use, population, and natural resource purposes, including from East New Britain, had already been captured in a digital inventory called the Papua New Guinea Resource Information System (PNGRIS) as a result of mapping methodologies pioneered by CSIRO in the 1970s for land-use and agricultural purposes.[19] New spatial-data sets for East New Britain have also been obtained more recently as a result of, for example, a provincial GIS-based transport study.[20] Furthermore, and importantly, spatial data for the province has been compiled by the University of Papua New Guinea in a digital 'Geobook' for the province, supported by the National Economic and Fiscal Commission.[21] Similarly, the World Bank and Asia Development Bank recently funded a Pacific Disaster Risk Assessment of 15 countries, including Papua New Guinea, which included the collection of some georeferenced data for the urban areas of Rabaul and Kokopo.[22]

East New Britain is now in the fortunate position of having a comprehensive collection of such spatial sets for use in disaster management and economic development. These are being exploited currently by a new, but low budget, risk-assessment project that is supported by the provincial administration and AusAID.[23] The results are potentially important because they may well demonstrate the applicability of such a GIS-based methodology as a means of reducing volcanic and other sudden-impact, natural hazard risks in other parts of Papua New Guinea and the Solomon Islands. Data management and analysis is at least as important for volcanic risk reduction as is the development of effective, instrumentally based, warning systems.

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19 See, for example, Bryan & Shearman (2008).
20 Scales (2010).
21 University of Papua New Guinea Remote Sensing Unit (2010).
22 See, for example, SOPAC (2010).
23 This new activity is is entitled 'Strengthening Natural Hazard Risk Assessment Capacity in Papua New Guinea'. It is scheduled to be completed in 2013–2014.

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