

## 14. Eruptions of the Early Twenty-first Century: 1998–2008

... it has been a very eventful week ... Tavurvur resumed eruption on Monday evening and Manam produced another paroxysmal eruption on Thursday night ... . Our observation post at Warisi village was wiped out completely by what is described as pyroclastic flow ... . All our equipment was destroyed by the event. There were about 14 people at Warisi at the time of the eruption and all got injured while trying to escape ...

Ima Itikarai, 29 January 2005

### International Developments and Modern Near Oceania

The year 2000 marked the 300th anniversary of William Dampier's 'volcanological voyage' through the Near Oceania region, when eruptions and volcanoes were described in greater detail than in any of the known records of the earlier Spanish and Dutch explorers. The three centuries had started during the European Enlightenment with visions of a happier, more rational and more informed world following the Scientific Revolution of the seventeenth century. Those three centuries concluded in the last few decades of the twentieth century with technological advances that would have been unimaginable to the early 'natural philosophers' and secular humanists of the Enlightenment. The world by the end of the twentieth century had also become economically and politically globalised, to an unprecedented degree. Old European empires had disappeared, but inequity remained in the distribution of wealth and political power amongst the 193 countries represented as the United Nations. Smaller 'developing' countries struggled to keep up with massive, global, political and social changes and with the influence of more powerful nations and of multinational companies, such as in the mineral and petroleum industries.

The world's high technology had produced extraordinary advances in electronic communication, and changes to the way in which people measured their place in the world geographically, socially and philosophically. The list of technological achievement is extraordinary: invention of the silicon chip and development of personal computers and laptops; development of the Internet and the World Wide Web and their enormous capacity for linking to vast databases and information sites, and for social networking; electronic mail, mobile and satellite

telephones, and the development of a 'smart-phone' industry; GPS positioning, geographic information systems, and spatially referenced digital datasets in general; digitisation and computer-base cataloguing of printed materials; and the ongoing sophistication of the collection of images of a range of earthbound parameters from space.

Earth-observing platforms and satellites were equipped with multispectral scanners, ground temperatures on volcanoes could be measured using infrared detectors, and deformation of volcano surfaces could be measured by space-borne radar interferometry. International aviation was being served by a global network of Volcanic Ash Advisory Centres (VAAC), including one at Darwin in northern Australia, which together formed an International Volcano Watch. Land-based networks were globalised too, including the worldwide monitoring of earthquakes, and the International Monitoring System of the Comprehensive Test Ban Treaty Organisation (CTBTO), for the detection of nuclear explosions whether recorded seismically through the earth, hydroacoustically through the oceans, or infrasonically through the atmosphere — including volcanic explosions. All of these advances showed no signs of slowing as the first decade of the new millennium unfolded, and inevitably they impacted on the way volcanoes were monitored, and volcanological information was obtained, stored, and used, in Near Oceania.

Tracing in narrative form a history of volcano discoveries and volcanic disasters in the near-backwater of 'Near Oceania' inevitably has become focused on only one part of the region — that of the single nation state of Papua New Guinea. No active volcanoes are known in the New Guinea Island part of eastern Indonesia — that is, in western Near Oceania — although Dampier had mistakenly reported an active volcano there in 1700. Furthermore, the Solomon Islands have played, to date, only a marginal part in the volcanological history. This is despite strong, ongoing concerns that volcanoes such as Savo, Simbo and Kavachi cannot be ignored and that they require the maintenance of strong linkages between at-risk communities and government volcanic-risk management programs.<sup>1</sup> The small volcanological agencies in both countries, however, were becoming more fully integrated into the national structures of natural hazard disaster management. Papua New Guinea and the Solomon Islands were also having to work in an enlarged and more complex environment of increased international development assistance, particularly bilaterally with Australia, the European Union, the United States, Japan, and increasingly with China, as well as multilateral agencies such as the United Nations Office for the Coordination of Humanitarian Affairs, the United Nations Development Program, and the World Bank, whose offices are in Port Moresby.

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1 Cronin et al. (2004).

## Ulawun: A Decade Volcano

International volcanology advanced steadily on several fronts into the first decade of the new millennium. Applied volcanology was no longer the ‘Cinderella science’ of the 1960s and was becoming increasingly multifaceted and multidisciplinary. This meant, for agencies such as the Rabaul Volcanological Observatory (RVO), an increased capacity to cover many aspects of the volcanic risk reduction spectrum. Perhaps most significant have been the international and national efforts made to link with the social sciences and to focus on how communities are structured in both a physical and social sense; the extents to which different societies are vulnerable, or susceptible, to the impact of volcanic disasters; the importance of volcanic-risk awareness-raising campaigns in volcanically vulnerable communities; and, how the volcanological sciences can link with and assist communities in developing strategies for economic development. One example of such efforts internationally was the ‘Decade Volcanoes’ initiative which ran during the 1990s as part of the United Nations-sponsored International Decade for Natural Disaster Reduction (IDNDR).<sup>2</sup> Sixteen volcanoes worldwide were selected for special attention, including Ulawun volcano in West New Britain Province — the only ‘Decade’ volcano in Near Oceania.

A major disaster in Papua New Guinea on 17 July 1998 diverted public attention away from questions about Rabaul and volcanic risk in general when a tectonic earthquake in the Bismarck Sea triggered a submarine landslide off the north coast of New Guinea near Aitape, producing a devastating tsunami that killed more than 2,100 people.<sup>3</sup> RVO staff were not involved in the post-disaster scientific assessments of the tsunami and its impacts, as these were undertaken largely by international visitors and staff from the University of Papua New Guinea and Port Moresby Geophysical Observatory. Nevertheless, the vulnerability of shoreline communities in the Bismarck Sea area and knowledge of the disastrous tsunamigenic collapse of Ritter Island in 1888, drew the attention of RVO staff once again to the tsunami-generating capabilities of coastal volcanoes — and to Ulawun.

Ulawun, from most directions, appears as a high, steep, and symmetrical cone. It is, at about 2,350 metres above sea level, the highest volcano in the Bismarck Volcanic Arc — higher than its immediate and equally imposing neighbour Bamus at about 2,250 metres.<sup>4</sup> The vegetation-free slopes of Ulawun near to the summit exceed 35° in places, and the symmetry of the volcano is broken on the southern flank and in views from the east and west, by a long, northward-facing, east-west escarpment against which the upper and younger parts of

<sup>2</sup> Barberi et al. (1990).

<sup>3</sup> See, for example, Davies (2002) and Synolakis et al. (2002).

<sup>4</sup> Johnson et al. (1983).

the active volcano have been built. Volcanoes do not grow indefinitely. Some, like Rabaul, form calderas that reduce the original height of any ‘ancestral’ mountain that may have existed previously. Others simply become too high and too steep and they collapse gravitationally, like Ritter Island did in 1888. Indeed, the east-west escarpment on Ulawun is similar to the double-cusp shape of the escarpment at present-day Ritter, leading to the idea that Ulawun may have collapsed catastrophically in the distant past towards the north, possibly entering the sea and generating a tsunami.



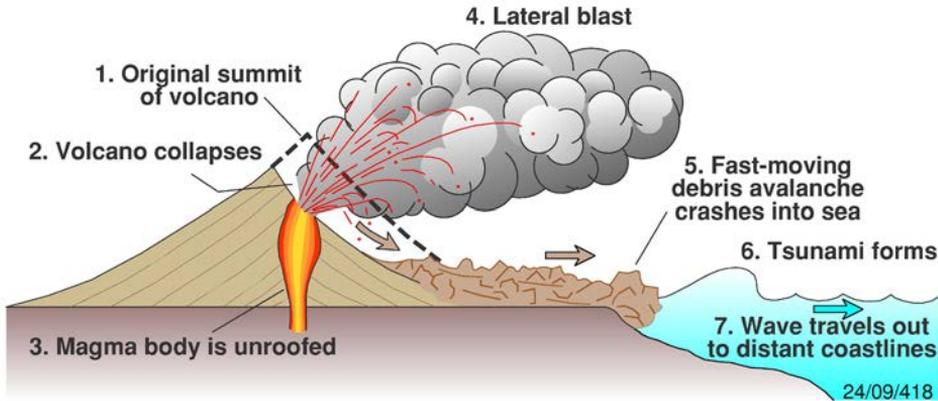
**Figure 116. Distribution of main volcanoes in central-north New Britain, including offshore islands. Several eruptive centres, such as at Cape Hoskins, Cape Reilnitz and Cape Deschamps are not labelled here.**

Source: Adapted from Johnson (1977, Figure 6).

The evidence in support of a prehistoric cone-collapse at Ulawun is not as strong as one would like. In particular, much of the large debris-avalanche deposit that would form as a result of such a catastrophic collapse may not be well exposed on land because it could have been covered by materials from later eruptions at Ulawun. A debris-avalanche deposit was identified about 15–30 kilometres north of the Ulawun shoreline during a marine-geoscience research cruise in 2004.<sup>5</sup> The deposit, however, is partially buried by sediment and it has not been traced into shallower water nearer the coast, where it may well be concealed by even thicker sediments washed into the sea from the coastal volcanoes. Thus, a direct link between the deposit and Ulawun cannot yet be made. Other origins

<sup>5</sup> Silver et al. (2009).

for the escarpment are possible, but again, supporting evidence for these may well be concealed beneath the young cone. For example, the escarpment is perhaps a simple geological fault cutting across the volcano and the older part of the volcano to the north conceivably could have dropped down vertically by slower and non-catastrophic movements. Nevertheless, Ulawun does seem too high and too steep and the possibility of future Ritter-like catastrophic collapses cannot be disregarded.



**Figure 117.** One way in which a high, steep-sided and coastal volcano, such as Ulawun, might collapse and produce a devastating tsunami is illustrated in stages 1–7 of this cartoon. Stages 1–4 are based on what is thought to have happened at Mount St Helens, United States, in 1980.

Source: Ulawun Workshop Report (1998, p. 14).

The tragic Aitape disaster in 1998 was coincidental — to the extent that an IDNDR workshop entitled ‘Volcano Cone Collapses and Tsunamis’ was already being planned to be held later in 1998 at Walindi in West New Britain Province, using Ulawun volcano as a case study. There remained at this time a still-elevated international interest in volcanic cone collapses as a result of the Mount St Helens eruption of 1980 in the western United States, when flank collapse released pressurised magma and produced a deadly lateral blast. The 40 participants at the Walindi workshop — half of them from overseas, including the United States — produced 25 recommendations. The overall conclusion was that volcanoes as steep and as high as Ulawun could indeed be inherently and gravitationally unstable, and that such volcanoes require special vigilance, particularly those at sea level which might have tsunamigenic potential — assuming that the cone collapses were rapid and therefore catastrophic.<sup>6</sup>

<sup>6</sup> Ulawun Workshop Report (1989).

## Ulawun 2000: A Short-lived, Powerful Eruption

Ulawun was one of five high-risk volcanoes in Papua New Guinea selected in 1995 for an upgrade of instrumental monitoring during the Australian Agency for International Development (AusAID)-funded Papua New Guinea – Australia Volcanological Service Support Project (VSS Project), and subsequent Twinning Program. The other four volcanoes were Rabaul, Manam, Karkar and Lamington. A seismometer and electronic tiltmeter were installed on the slopes of Ulawun, electronic signals were relayed by radio-telemetry to Ulamona Mission at the coast and then by HF-radio to a central ‘hub’ computer in the recording room at RVO headquarters in Rabaul. Lindsay Miller and Trevor Dalziell, both Geoscience Australia (GA) technicians, designed and developed the hub system, and United States Geological Survey (USGS) Volcanic Disaster Assistance Program (VDAP) software was used to process the received signals, including from the other remote volcanoes of Manam, Karkar and Lamington. Thus, for the first time, a national, instrumental, ‘volcano watch’ could be made from the RVO recording room of four high-risk volcanoes in the distant parts of Papua New Guinea, which represented a significant technical landmark.

Ulawun had been in eruption in 1985 and in most of the previous years since its spectacular activity in 1978. Some mild explosive activity had also taken place from the summit crater of Ulawun in 1989 and 1993, but for some years the volcano had produced only emissions of vapour — for example, as seen during the Walindi workshop in October 1998. This situation lasted until October 1999 when explosive activity resumed and then, a year later, in September 2000, a new, rapid-onset, but short-lived eruption began. The response to this powerful eruption by affected people in West New Britain and the involvement of RVO represent a significant, but perhaps singular, example of how the results of instrumental monitoring of a Papua New Guinea volcano can be crucial in making decisions to evacuate at-risk communities to safer refuges.

RVO volcanologists in Rabaul began to detect significant changes at Ulawun on the evening of Wednesday 27 September 2000, from their analysis of the earthquake recordings being sent to Rabaul by HF-radio every 20 minutes from Ulamona Mission — a distance of about 130 kilometres.<sup>7</sup> Authorities in West New Britain Province were informed of the changes and alert stages 1 and 2 were declared overnight. RVO staff in Rabaul were in contact with Martina Taumosi, the volcano observer at Ulamona, by radio and together they tracked these and further changes in the earthquake activity at the volcano. A rapid build-up of seismic intensity started during the evening of Thursday 28 September, when constant ground shaking or ‘tremor’ began to be recorded, rather than single,

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7 H. Patia (personal communication, 2012) and Smithsonian Institution (1999–2000).

separate earthquakes. Taumosi rang the church bell that evening to inform the local community at nearby Ubili village and at Ulamona Mission on the status of activity of the volcano. The local people, who had gathered at the mission station, began to hear noises from the volcano and to see glow at the summit of Ulawun at about 8.45–9.00 pm. People living near Ulawun had had the opportunity only three weeks earlier, during a public-awareness campaign, to hear RVO staff talk about volcanic hazards at Ulawun, so they were well aware of the potential dangers from the volcano. The villagers were concerned about the current condition of the volcano. The Ulamona observer discussed the situation with RVO staff in Rabaul by radio, and a recommendation was provided by RVO to evacuate. An eruption began at 10.40 pm that night, and a full-scale, incandescent strombolian eruption peaked about four hours later in the otherwise darkened night sky.



**Figure 118. Pyroclastic flows were produced at Ulawun during vulcanian activity in 1985. A pyroclastic flow is seen here discharged down the north-western valley of the volcano on 20 November, eventually dumping its load when it came to rest east of Ulamona Sawmill, in the foreground. The hot pyroclastic material at the flow front then rose thermally, giving the false impression of a new eruption taking place low on the flanks of Ulawun.**

Source: P.L. Lowenstein, Rabaul Volcanological Observatory.

Many hundreds of people evacuated overnight, mainly by road from settlements west and north-west of the volcano, assisted by road transport provided by Ulamona Sawmill and using other private vehicles. Villagers from vulnerable places to the north and north-east such as Nuau, Voluvalu and Painave moved north-eastwards to Bakada, on the coast well to the north of Ulawun. Other people, from places such as Navo Plantation and from Ubili near Ulamona Mission and Sawmill, moved south-westwards to Kabaia and Soi, two places previously designated as refuge centres. A spectacular, forcefully ejecting ash column, which reached heights of 12–15 kilometres, could be seen after daybreak on the morning of Friday 29 September and throughout that day. Staff at the Volcanic Ash Advisory Centre in Darwin on the same day were able to observe an arc-shaped ash cloud on satellite images, and to issue a notification to aviation authorities. Ash fallout destroyed some gardens downwind of Ulawun, and three pyroclastic flows were produced, but they did not reach settlements. Strong discharges from the summit crater had ceased by early on 30 September. The results of this powerful but short-lived eruption had not been disastrous, but there remained the persistent question of whether similarly or even more intense eruptions might trigger gravitational collapse of the Ulawun cone, as discussed at the Walindi workshop. Evacuations under these circumstances are clearly prudent.

The time-sequence of instrumental early-warning signs, followed by a prompt recommendation to at-risk communities at Ulawun to evacuate, is not always as efficient as in the eruption of late-September 2000. Another explosive eruption took place on 25–30 April 2001 when, again, there were early-warning signs.<sup>8</sup> A Stage 1 alert was declared, but this eruption was relatively minor and only limited evacuations took place. More significantly, there was evidence seen after the 2001 eruption that a fissure eruption had taken place high on the flanks of Ulawun, again raising questions about the structural integrity and gravitational instability of the volcano.

Particularly strong earthquake activity was recorded at Ulawun in 2006 and again in 2008 and 2010, but there were no immediate eruptions. Nevertheless, there were concerns about public safety and the currency of existing evacuation planning, recognising particularly that oil-palm plantations and therefore the number of people, were increasing around the volcano. This led to a meeting in 2010 of representatives from both the East and West New Britain provincial administrations, and from RVO, and the production of a new response plan.<sup>9</sup>

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<sup>8</sup> Smithsonian Institution (2001).

<sup>9</sup> East/West New Britain Provincial Governments (2010).

## Pago 2002–2003: An Unexpected Eruption

Explosive eruptions at Pago volcano on 3 and 5 August 2002 surprised the staff at RVO in Rabaul. They also surprised the thousands of people in the Cape Hoskins area of West New Britain, including those in the provincial capital at Kimbe, only 40 kilometres west of Pago. Pago had not been active since the eruptive phase of 1911–1933,<sup>10</sup> there was no instrumental monitoring on the volcano, and no reports had been received of any early warning signs of an eruption. Aircraft pilots reported the presence of ash clouds on both 3 and 5 August and, on 6 August, Air Niugini reported a 1.8–2.4-kilometre-thick ash plume extending about 150 kilometres to the west-north-west of the volcano at a height of 7.6 kilometres.<sup>11</sup> Fine ash had spread over a sector of the Cape Hoskins area, affecting a population of about 20,000, triggering evacuations of villages and hamlets, and closing the Hoskins Airport to air traffic. Lava began to flow from vents on a fracture on the north-western side of the Pago.

RVO staff, led by Ima Itikarai, responded promptly by installing a seismograph at Malilimi Plantation, south-west of Pago, and establishing a surveying line from Malilimi towards the volcano in order to measure any ground-surface movements. Aerial inspections were made of the volcano and volcano information bulletins were released. A scientific Japanese Disaster Relief Team had arrived independently to investigate the eruption and its members stayed in the area from 25 August to 3 September, working in partnership with RVO. Foreign assistance had already been sought by RVO through official channels and a request had been directed to the Office of Foreign Disaster Assistance of the US Agency for International Development (USAID), as had happened after the 1994 eruption in Rabaul. A team of three from the USGS-VDAP left the United States on 5 September, and stayed in West New Britain until 13 October. RVO was heavily involved in coordinating this international volcanological effort.

External assistance also arrived in the province to deal with the welfare of 12,000 displaced persons, more than 8,000 of whom were in seven temporary care centres scattered along the coast westwards towards Kimbe, where some evacuees were accommodated in the high school.<sup>12</sup> The Provincial Disaster Committee (PDC) in West New Britain worked closely with a 'Mt Pago Disaster Task Force' established by the National Disaster Management Office and which included representation from national government departments, donor countries, and church groups. Officers from both United Nations Office for the

<sup>10</sup> Cooke (1981).

<sup>11</sup> Smithsonian Institution (2002–2006). Newspaper coverage of the Pago eruption includes feature articles and accompanying photographs in a special issue of the *Post-Courier* (2002). See also, Davies (2003). Much unpublished information is held by RVO, AusAID, and other agencies.

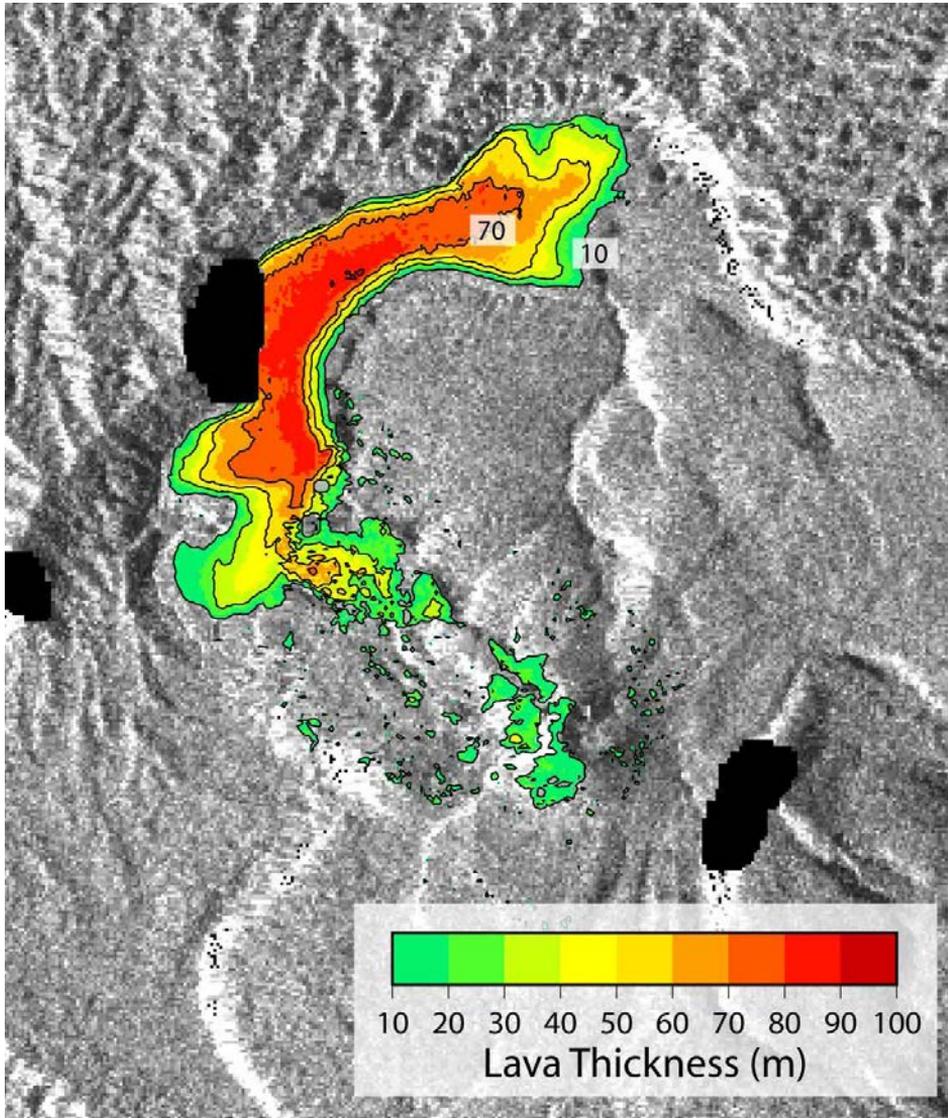
<sup>12</sup> Macatol et al. (2002).

Coordination of Humanitarian Affairs (OCHA) and AusAID were also involved with provincial authorities in assessing the situation, making a risk assessment, and addressing key concerns and questions about food and water supplies, health and sanitation. The closure of Hoskins Airport did not help the disaster response, although smaller airstrips were used at both Biialla and at an old airstrip at Talasea, which was reopened. There were also delays in deciding whether evacuees should return to their villages, despite the minimal impacts and ash thicknesses of only few millimetres. Crucial questions to be answered regarded the potential length of the eruption and the possibility of it escalating into a worse incident. There was also consideration to be given to the longer-term impacts on the province's transport links and agricultural industries, especially on the newly established oil-palm plantations. An eruption of the scale and duration of the previous eruptive period in 1911–1933 could have worse effects in 2002 because of the greater number of people who would be affected and the risk to investment.



**Figure 119. Dark lava is issuing slowly from vents on the north-western flank of Pago volcano, which is seen in the lower right. This undated view is taken from the south-south-west later during the 2002–2003 eruptive period. The escarpment of Witori Caldera is visible across the upper part of the photograph and the large-volume lava from the most north-westerly vent is seen buttressed and curved against it. The lava has also spilled a short distance towards the south-west.**

Source: E. Endo. United States Geological Survey. Originally published in the IAVCEI Calendar for 2005 (December).



**Figure 120.** The Pago eruption was observed from space. This satellite image is of the contoured thicknesses of the large-volume lava flow erupted in 2002–2003. The thicknesses were obtained by calculations from data obtained from successive overpasses of a satellite carrying a distance-measuring radar instrument.

Source: Image supplied courtesy of C. Wicks (see Wicks et al. 2008).

The explosive eruptions at Pago in August 2002 did not escalate. Pago itself is in an unpopulated area isolated within Witori Caldera and the explosions and ash falls inflicted little damage on settlements outside the caldera. No lives

were lost. Explosive activity declined at Pago and, by January 2003 — after the turn of seasons and the arrival of the north-west monsoon — Hoskins Airport was reopened and normal life was resumed in the province. The most striking geological product of the Pago eruption was not the ash deposits but, rather, the multiple extrusions of lava from the vents in a line on the north-western flank of Pago. The lowest of these vents produced a huge, slow-moving lava flow, which gradually moved eastwards around the foot of the caldera escarpment of Witori. This lava probably stopped flowing in about March 2003, thus marking the likely end of the eruption, although emissions of vapour and gas continued for many months. Large, caldera-constrained lava flows were also produced during the early part of the 1911–1933 eruption, particularly in 1914–1918.

An important outcome of the Pago eruption was establishment of permanent instrumental monitoring at Pago and the addition of Pago to the list of high-risk volcanoes for ongoing support by the AusAID-funded Twinning Program. Digital signals from a seismometer and GPS station within the caldera near Pago, which had been donated by USAID and installed by the USGS-VDAP team, were received at a recording station near the governor's residence at Kimbe. There is, however, no direct line of sight between the instruments in Witori Caldera and the Kimbe Volcanological Observatory, so the signals must be relayed through another station on the high summit of the intervening Mount Oto. This monitoring system now has to be maintained and sustained by RVO, but accessing the isolated instruments within the caldera and climbing to the top of Mount Oto for repairs or clearance of vegetation is not easy. Questions of sustainability and identification of a suitable source of ongoing funding, therefore, could be raised, especially for a volcano such as Pago which — like many others in Papua New Guinea and the Solomon Islands — may not erupt again for many years, even decades. However, the Kimbe Volcanological Observatory can also be used to receive signals from other monitored volcanoes in the province and so its ongoing use, despite the difficulties, may be justified.

## **Threat of a Caldera-Forming Eruption at Pago-Witori**

Disaster managers and volcanologists at Pago in 2002–2003 were aware of the possibility of a much larger, caldera-forming, explosive eruption developing in the area. Pago is a small volcano within a prominent caldera atop Witori volcano, the low-angle slopes of which give it a profile rather like that of an inverted saucer. Geologists had demonstrated from earlier field studies that Witori had produced several major eruptions during the last 10,000 years,

leading to the deposition of widespread ignimbrites and related air-fall deposits. Such eruptions, were they to recur in 2002, could devastate the economy, lives and livelihoods in this part of New Britain.<sup>13</sup>

The north-central coast of West New Britain, including its hinterland and Willaumez Peninsula, are vulnerable to the effects of a range of eruption types, including large catastrophic ones from several caldera systems, and not from Witori alone. Other active and potentially active caldera systems in the New Britain area as a whole are at Garove, Unea, Dakataua, Hargy and Lolobau, as well as at Rabaul and Tavui. Furthermore, considerable archaeological evidence is available that past eruptions of this large scale affected pre-industrial communities in West New Britain, an area well known and valued for its sources of obsidian for trade and exchange purposes.

Willaumez Peninsula in West New Britain Province is an area that has received considerable research attention over many years from a large, multidisciplinary group of archaeologists, volcanic geologists and historical environmentalists.<sup>14</sup> Indeed, no other area in New Oceania has received the same level of interdisciplinary research attention, and it is clearly the best example for consideration of the ways in which people in prehistory may have coped with and adapted to the threat and impact of volcanic hazards in the region. Volcanological studies in the Willaumez Peninsula area benefitted greatly from this work, especially the improved descriptions of the tephra stratigraphy and the increased number of radiocarbon dates on the tephras and their palaeosols. The area has been called a ‘remarkable 40,000 year record of human-volcano interactions’.<sup>15</sup>

Two main areas on Willaumez Peninsula have received intensive archaeological treatment: Garua Island east of Talasea, and the so-called ‘isthmus’ area at the southern end of Willaumez Peninsula. Correlations have also been made with sequences elsewhere in New Britain, including at Yombon in the central ranges to the south of the peninsula. Evidence of human occupation on Willaumez Peninsula extends back 35,000–45,000 years, to when human colonisation is thought to have first taken place, but the best exposed sequences are from the mid- to late Holocene, a time when the area was subject to the known impact of nine explosive eruptions and four minor episodes of more limited extent.<sup>16</sup> Four of five especially large eruptions of VEI 5–6 scale took place from nearby Witori volcano to the

13 Blake & Bleeker (1970), Blake & McDougall (1973), Blake (1976), Machida et al. (1996) and McKee & Kuduon (2005).

14 See, for example, Torrence et al. (2000, 2004, 2009), Boyd et al. (2005), Torrence & Doleman (2007) and Neall et al. (2008). These references are examples of the now extensive literature on the prehistory of Willaumez Peninsula ranging back to the early 1980s (see, for example, Specht, 1981). The more recent papers quoted here include extensive bibliographies of earlier work.

15 Cashman & Giordano (2008, p. 326).

16 Machida et al. (1996), Torrence et al. (2004, 2009), Neall et al. (2008) and Petrie & Torrence (2008).

south-east and produced tephra which have been named W–K 1–4, and the fifth from Dakataua volcano — its tephra is labelled ‘Dk’ — at the northern end of the Peninsula. W–K4 overlies Dk, but there is no intervening palaeosol and the radiocarbon dates are indistinguishable from each other. All five of these eruptions clearly must have had a major impact on the people living nearby, blanketing livable landscapes including reef and forest resources, and creating new land surfaces that would have remained barren and unsettled for years.

**Table 7. Dates of Major Eruptions from Witori (W–K) and Dakataua (Dk) Volcanoes**

Tephra	Radiocarbon date (years Before Present, BP)	Date range (years BP) from Bayesian analysis <sup>a</sup>
W–K4	1344±38 <sup>b</sup>	1310–1170
Dk	1383±28 <sup>b</sup>	1350–1270
W–K3	ca 1800 <sup>c</sup>	1740–1540
W–K2	ca 3300 <sup>c</sup>	3480–3160
W–K1	ca 5600 <sup>c</sup>	6160–5740

a. Petrie & Torrence (2008).

b. McKee et al. (2011).

c. Machida et al. (1996).

All listed eruptions are VEI–5 or 5–6.

The artefacts found on Willaumez Peninsula are predominantly of worked and retouched obsidian pieces, together with some ‘manuports’ — stones believed to have been transported by humans — and a few objects made from crystalline rocks. Lapita-style pottery appears later in the Holocene sequence. Four obsidian sources have been identified in West New Britain: three in the Talasea area — Kutau/Bao, Gulu, and Baki and Hamilton together on Garua Island — and one at Mopir in the south-western part of Witori volcano.<sup>17</sup> These Talasea-Mopir obsidians have been ‘finger-printed’ geochemically and are, therefore, known to have been traded and exchanged widely, although to different extents, throughout much of Melanesia and into Remote Oceania. The obsidian could, therefore, have been valued and quarried as a commodity in West New Britain, thus encouraging local settlement. Mopir appears to have been a well-exploited source during the Pleistocene, but less so during the Holocene when access may have been made more difficult because of burial by young tephra from nearby Witori. One of the more striking features of the artefact sequence is the presence of finely and skillfully constructed ‘stemmed’ blades of obsidian. These are pieces of technological craftsmanship that may have had cultural values beyond

simply the utilitarian, such as the delicate cutting of skin, including perhaps for tattooing.<sup>18</sup> The stemmed blades are not found above the 3,300-year-old W–K 2 tephra, whereas Lapita pottery is not found below it.



**Figure 121. Obsidian artefacts from the Talasea–Mopir area of New Britain have a wide range of size and shape. Some blades include skillfully produced stems or hafts. The graded scale is 20 centimetres long.**

Source: R. Torrence and G. Britain, Australian Museum.

These archeological results have been used as a basis for extensive and detailed discussions on cultural evolution and possible human behavior, and especially for hypotheses and speculations about what may have happened in terms of volcanic disaster recovery, resettlement, and cultural adaptation. For example, much of the discussion has focused on the return periods for resettlement after each eruption; on the degrees to which people formed mobile or settled communities; on sites of possible refuge and their links and distance along long-distance trading networks; on the possible urgency of resettlement caused by the need to reclaim obsidian sources; and, on inferred population-density changes. Key questions, however, related to human decision-making concerning volcanic risk reduction, strategies for family safety, and such matters as early warning identification and evacuation are virtually impossible to answer solely on the basis of stone and pottery artefacts and their distributions in space and time, as the answers to the questions are fundamentally social rather than archaeological ones.

<sup>18</sup> Araho et al. (2002) and Specht (2005).

## Manam 2004–2005: Abandoning a Volcanic Island?

Many eruptions continued at Manam after the 1956–1960 volcanic crisis and related evacuation, thus confirming Manam — together with Bagana — as one of the two most frequently active volcanoes in Papua New Guinea. Especially large or ‘paroxysmal’ eruptions at Manam during the 1990s and up to recent times include several examples where dangerous pyroclastic flows descended and, in some cases, spilled over the sides of the radial valleys on the island. Particularly large eruptions, for example, had taken place in October and November 1992, producing pyroclastic flows as well as lava flows, which in the North East Valley, destroyed bush-material houses, small cocoa fermentaries, and food gardens.<sup>19</sup>

Another, but more deadly, paroxysmal eruption took place from the summit craters on 3 December 1996, following a build-up of smaller eruptions over several weeks.<sup>20</sup> Large pyroclastic flows descended the South East and South West valleys on the afternoon of 3 December, including one that reached the coast, killing 13 people at the site of Budua Old Village in the South West Valley, and flowing into the sea. Neither the start of the 1996 eruption nor its strong phases were anticipated by RVO from the monitoring data from the Tabele Volcanological Observatory, which was established in 1963–1964.

Eruptions at Manam in 2004–2005, starting on 24 October 2004, were even larger and more damaging than were those in 1992 and 1996.<sup>21</sup> Indeed, they could represent the most devastating of any reported eruptions on Manam, as they affected virtually the whole of the island, led to a major evacuation of the Manams to care centres on the mainland, and created social problems that continue to the present day. The full disaster-management story of this major eruption is, therefore, still unfolding and, indeed, a full scientific account of the eruption and disaster has yet to be completed. Manam had been included on the list of high-risk volcanoes for attention during the AusAID-supported RVO Twinning Program, and signals from the monitoring equipment at Tabele Volcanological Observatory could, up to 2001, be sent by HF-radio to Bogia on the nearby mainland and then on to RVO headquarters in Rabaul. This potential benefit of eruption early warning ceased in January 2001, however, because of compensation and access issues raised by the owner of the land at the observatory site, and because of subsequent vandalism. A smaller, makeshift observatory station equipped with a single seismograph, together with capability for radio-

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19 Smithsonian Institution (1992).

20 Smithsonian Institution (1996).

21 Smithsonian Institution (2004–2005). Other information on the 2004–2005 eruption used here has been taken from a range of unpublished sources including RVO and AusAID correspondence and related reports as well as newspaper articles.

voice reporting from the local observer to the volcanologists in Rabaul, was therefore established at Warisi village, eastern Manam, in May 2001. The Warisi station was limited in its scope and capacity to cope with the emergence and impact of the devastating eruptions of 2004–2005, although RVO staff continued to advise provincial disaster authorities with reports on the state of the volcano and provide advice on alert levels.



**Figure 122. A pyroclastic flow descends the South East Valley on Manam volcano during the paroxysmal eruption of 3 December 1996. A second flow can be seen on the left and in the distance moving down the South West Valley.**

Source: P. de Saint Ours, Rabaul Volcanological Observatory.

RVO had noted increased earthquake activity on Manam in mid-October 2004 and had declared a low Level 1 alert, but the eruption that began on 24 October and those that followed in November and December were much greater, and early warning of their severity was not possible. A pyroclastic flow ran down the South East Valley to the sea, and much of the eastern side of the island was affected by ash and scoria fallout from the October eruption clouds. The western and north-western sides of the island became affected by fallout too, from Tabele clockwise around the coast to Baliau in the north. Fist-sized rock fragments were reported to have punched through the thatch roofs of houses.

People moved to safer areas on the island, but evacuation of thousands had begun by late November to care centres on the mainland, attracting the start of external financial support for their welfare.

Eruptions on 27–28 January 2005 were even more severe than those in October–December of 2004, adding to the already difficult living conditions on the island.<sup>22</sup> Many people by this time were on the mainland in care centres, although some had returned to Manam. The whole of the island was covered by a layer of pyroclastic materials, up to several tens of centimetres thick in coastal areas and much thicker upslope towards the summit craters. Immediate resumption of living on Manam was untenable and the island was almost deserted. The volcanological facility and equipment at Warisi were destroyed by what seems to have been the cold edge of a pyroclastic flow. This included loss of a satellite telephone, which had been provided by Qantas Airways to provide a direct telecommunications link between Manam and Qantas headquarters in Australia. Those people who were still at Warisi managed to escape by a small boat, which, however, was struck by a falling rock and sank. They were injured and reached the shore. One person who had remained near Warisi was killed. RVO headquarters in Rabaul had been struck by lightning before Christmas 2004, thereby limiting the effectiveness of outside telecommunications and adding to the problem of responding effectively to the major disaster on Manam.

Monitoring the Manam eruption in 2004–2005 from space was as important as it had been during the earlier Pago eruption, and especially from an aviation-safety standpoint. In particular, meteorological staff of the Volcanic Ash Advisory Centre at Darwin in northern Australia, which is part of the International Airways Volcano Watch, paid special attention to the heights of the eruption plumes from Manam. There were several occasions when heights exceeded 10 kilometres — that is, a common flight level for international aircraft overflying the area. The highest detected ash column from Manam was for the eruption of 27–28 January, which reached well into the stratosphere to an estimated height of 21–24 kilometres.<sup>23</sup> Detecting such ash plumes is not straightforward in this region of tropical cloudiness and the reports from in-flight pilots and from volcanological observatories on the ground are important, if not critical. There were in this instance no aircraft/ash-cloud encounters of any significance, at least in part because of these cooperative measures.

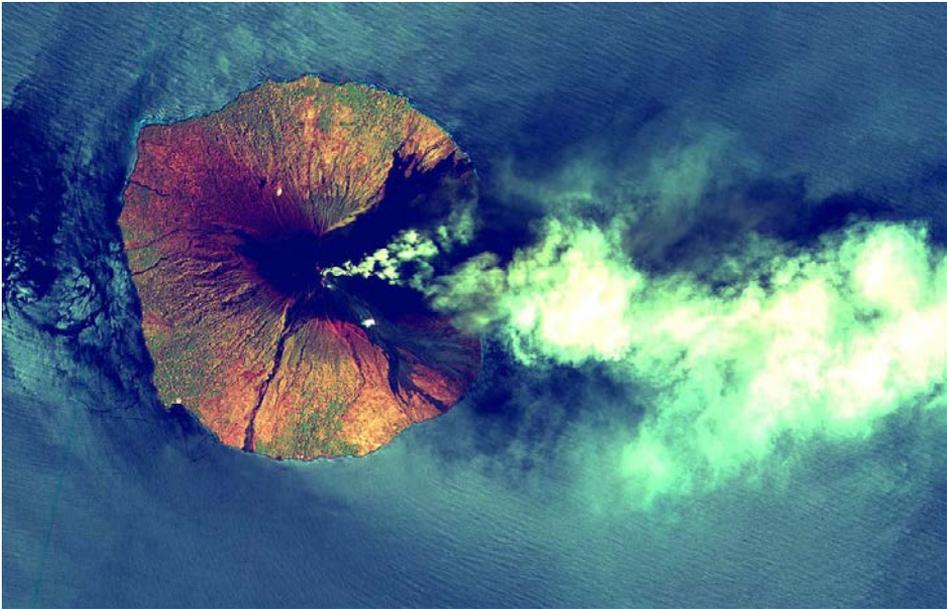
News of the January 2005 eruption on Manam was not dealt with as fully by national newspapers as it had been in October–November 2004. A contributing

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22 Tupper et al. (2007) and Smithsonian Institution (2005a).

23 The major eruption of 27–28 January 2005 appears to represent the climax of the eruptive period at Manam. The eruption climax at Manam in 1958 took place on 25 January — a similar time in the same month as in 2005. This raises again the possibility of a ‘seasonal’ relationship to earth tides for some eruptions at Manam, as suggested by Taylor (1960).

factor for this may have been the diversion of media attention towards the Indian Ocean or ‘Boxing Day’ tsunami of 2004 in Indonesia, its destructive impact throughout the northern Indian Ocean, and its huge death toll of more than 220,000. The exact number of fatalities at Manam in 2004–2005 is unclear, but in contrast to the tsunami death toll, it was very few — almost certainly less than ten, judging by the content of newspaper articles. Appeals for funding support for the evacuated Manams had already started, but those appeals by early 2005 included calls for additional support for in-need people and communities in neighbouring Indonesia. Nevertheless, the national newspapers played a crucial role in the following years in drawing attention to the plight of the thousands of Manam evacuees still in mainland care centres at Potsdam, Asuramba and Mangem.



**Figure 123. Manam volcano was imaged on 8 November 2004 from a SPOT (Système Pour l’Observation de la Terre) satellite. Key features are the fan-like area of devastation on the eastern flank of the volcano, another area of pyroclastic fallout on the north-western flank reaching to the coast, and vapour emission from the summit. The east-west width of the island through the summit is about 10 kilometres.**

Source: Image supplied by P. L. Shearman, University of Papua New Guinea. Remote Sensing Centre.

Tensions between mainland landowners and the Manams reached crisis point in the face of growing pressure on land for gardening for essential foods, and as serious issues of law and order developed. Eruptions continued on Manam, including another powerful one in February 2006, and four people died on 13

March 2008 when mudflows engulfed their homes at Dangala village on the north-north-eastern coast of the island. Permanent resettlement of the Manams seemed to be the most sensible option, if land could be identified on the mainland and the necessary funding found. A Manam Restoration Authority, which was rather similar in concept to the Gazelle Restoration Authority in Rabaul, was established. Furthermore, a draft plan by a Manam Resettlement Taskforce, set up specifically to explore the relocation options, was being developed by the PNG National Disaster Centre in late 2010.<sup>24</sup> Hundreds of Manams have returned to their respective villages on the island where, despite ongoing volcanic activity, including pyroclastic flows, they feel more secure and independent compared with the stressful condition of their lives as displaced people on the mainland.<sup>25</sup> The population on Manam Island today changes daily because villagers travel frequently across the strait between the island and the mainland care centres.

How permanent instrumental monitoring can be continued on Manam volcano remains problematic and is unresolved. The site of the Warisi Observatory, which was destroyed by the January 2005 eruption, had to be abandoned. Furthermore, there has been no resolution to the land-access and compensation issues at the inland Tabele Observatory, which was built at considerable cost in 1964, together with a cellar for instruments. The buildings at the old observatory have, in any case, disappeared as a result of scavenging for building materials. Some instrumental monitoring is achieved today through a single seismograph installed in a room at the mission and school at Tabele on the coast and by using the radiotelemetry link to Bogia on the mainland and then to Rabaul. This situation is not satisfactory for such a high-risk volcano as Manam, which remains a threat to people on the island and to international aviation.

## **Rabaul 2006 and other Volcanic Crises in 1999–2007**

An explosive eruption at Tavurvur on 7 October 2006 was the largest at Rabaul since the 1994 eruption.<sup>26</sup> It produced ash and dust that obscured visibility around the entire Rabaul Harbour area, destroyed vegetation that had been attempting to recover since 1994, thus causing increased run-off and siltation, which affected areas — such as at Ranguna where there had been clearing for new settlements — and covering roads with silt. This 2006 eruption also gave rise to a dramatic umbrella-shaped plume that rose about 18 kilometres into the

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24 Manam Resettlement Taskforce (2010).

25 Mulina et al. (2011).

26 Smithsonian Institution (2006b).

atmosphere. The wide extent of the plume, as seen from space, was reminiscent of the Vulcan plume in 1994, and there were other similarities, too — including the production of Vulcan-like pumice which fell hot near to Tavurvur, forming a lightly cemented deposit or ‘agglutinate’. Another significant period of both strombolian activity and explosive eruptions was in May to December 2008, when the cumulative ash thicknesses in Rabaul grew to be substantial enough to significantly impede day-to-day life in town.<sup>27</sup>

The eruptions and social impacts at Ulawun, Pago, Manam and Rabaul volcanoes were serious enough during 2000–2008, demanding the attention of RVO, provincial and national disaster managers, and international development assistance agencies. There were, however, other threatening situations at about the same time that added to the disaster management work load. The early to middle part of the first decade of the twenty-first century was, in fact, crowded with volcanic disaster management challenges for RVO, and these were having to be dealt with in a governmental context far more complex than had existed during, say, the eruption time-cluster periods of 1951–1957 and 1972–1975. A list can be compiled of seven of these other crises and false alarms.

*Kasu, Enga Province, 1999.* The crater wall of Kasu, a small tephra cone and crater lake, collapsed into the lake on 20 April 1999, producing a 15-metre-high wave which broke over the crater rim killing a boy, injuring 11 others, destroying two houses, and flattening vegetation.<sup>28</sup>

*Lamington, Oro Province, 2002.* Rumours circulated in Popondetta town during the first three weeks of April 2002 of renewed volcanic activity at Lamington volcano, including reports of fire, smoke, dead vegetation, noises from the volcano, and people becoming dizzy and dogs fainting in the summit area. Some schools had closed for fear of an eruption. Subsequent investigations by RVO could not confirm any renewed activity at the volcano.<sup>29</sup>

*Garbuna, West New Britain Province, 2005.* An unexpected eruption and related earthquake activity took place at Garbuna on 17–18 October 2005 within the extensive geothermal area at the summit of the volcano. Mud-like ash was distributed around two vents and a 3–4-kilometre-high ash cloud spread to the north-west. The eruption was the first recorded historical eruption from the volcano. There was concern that the eruption, which seems to have been a geothermal blowout or phreatic eruption, could be a precursor to a larger eruption of new magma, and a major deployment of monitoring equipment was undertaken by RVO in partnership with a USGS-VDAP team. There were, however, no confirmed magmatic eruptions, although vapour emissions and

27 Smithsonian Institution (2008b).

28 Wagner et al. (2003).

29 Itikarai & Bosco (2002) and Smithsonian Institution (2003).

earthquake activity continued for some months and suspicion remained that new magma may indeed have been emplaced beneath Garbuna, but not actually erupted in any significant quantities.<sup>30</sup>

*Sulu Range, West New Britain Province, 2006.* An intense swarm of felt volcanic-type earthquakes began near the volcanoes of the Sulu Range on 6 July 2006. People in nearby villages began self-evacuating, supported soon after by provincial authorities who established temporary care centres for more than 1,000 evacuees. Geyser activity at a large and nearby geothermal field also became pronounced. No eruption took place, however. Magma is thought to have intruded into an active tectonic fault, but did not reach the surface — another example of a volcanic false alarm or so-called ‘failed eruption’.<sup>31</sup>

*Near Likuruanga, West New Britain Province, 2006.* A boy died by asphyxiation on 21 September 2006 at the coastal logging camp of Bakada north of Likuruanga, an extinct volcano. The boy had entered a deep hole — left empty by the logging company, which had been constructing latrines — in order to retrieve his dog and was overcome by inhalation of carbon-dioxide gas of uncertain origin. There were no other signs of potential volcanic unrest and the gas could have been of biogenic origin.<sup>32</sup>

*Ritter, Morobe Province, 2006–2007.* Small earthquakes followed by vapour emissions and diffuse ash clouds were reported for 17 October 2006. Occasional rocks slides were seen from the avalanche amphitheatre wall at Ritter Island, and an ash plume was observed from space. Further activity was reported for 19 May 2007 when sea surges destroyed a boat and four houses on nearby Umboi Island following an eruption, and 1,500–2,000 people from two coastal villages moved to higher ground.<sup>33</sup>

*Karkar, Madang Province, 2007–2008.* Signs of unrest were reported at Bagiai cone within the caldera at Karkar Island between early November 2007 and early March 2008, when increased vapour emissions and vegetation dieback were observed on the cone. Earthquakes were recorded using portable seismometers on several visits by RVO staff to the island during this time.<sup>34</sup> No eruption has since taken place.

Are any of these eruptions at Rabaul and at other volcanoes in the Bismarck Volcanic Arc during the 2000–2009 decade — including the so-called ‘failed

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30 Smithsonian Institution (2005b).

31 Smithsonian Institution (2006a), Taranu et al. (2007) and Wicks et al. (2007).

32 Smithsonian Institution (2006c).

33 Smithsonian Institution (2007). An eruption probably also took place at Ritter in 1997 (Saunders & Kuduon, 2009).

34 Smithsonian Institution (2008a). Karkar had been selected as one of the high-risk volcanoes for permanent monitoring during the AusAID VSS Project but the equipment had been vandalised repeatedly, evidently because of local land disputes, and so was not available for use during this period of increased unrest.

eruption’ at Sulu Range and the mysterious gas emission near Likuruanga — part of an eruption ‘time cluster’? Significant eruptions and periods of volcano restlessness in fact took place at as many as eight, possibly nine of these volcanoes — Likuruanga is the possible exception — within only four years between August 2002 and October 2006 and, accordingly, there is a hint at some sort of time-clustering. The period expands to seven years, and the number of volcanoes to 11, if the Ulawun eruptions of 2000–2001 and the unrest at Karkar in 2007–2008 are added to the list.



**Figure 124.** Tavurvur volcano, Rabaul, is seen here in explosive eruption at 9.57 am on 7 October 2006. The photograph was taken from the south-east at Takubar, near Kokopo. The nearly vertical western side of the eruption column can be seen clearly on the left, together with heavy ash falls over the sea to the right.

Source: J. McLean, Port Moresby.

The proposed 2002–2006 time cluster is reminiscent of the period, 30 years previously, when six volcanoes in the Bismarck Volcanic Arc were in eruption between 1972 and 1975.<sup>35</sup> An intriguing difference, however, is that all of the six volcanoes, except Ulawun, in 1972–1975 are in the *western* sector of the Bismarck Volcanic Arc, whereas six of the nine restless volcanoes in 2002–2006 are in the *eastern* sector of the arc. Each sector of the Bismarck Volcanic Arc corresponds to a different plate boundary, which raises the possibility that

<sup>35</sup> Cooke et al. (1976).

different tectonic characteristics control not only differences in the types of magma being formed and in the patterns of volcanic centres,<sup>36</sup> but also the timing of multiple eruptions in each sector.

**Table 8. Nine Bismarck Volcanic Arc Volcanoes in Eruption or Restless between August 2002 and October 2006**

Pago, 2002-3	First eruptive period since 1914-33
Manam, 2004-5 (and 2006)	Possibly the largest recorded eruption in historical time.
Garbuna, October 2005	First recorded eruption (phreatic) in historical time.
Sulu Range, July 2006	Inferred magma-intrusion event but no eruption.
Likuruanga, September 2006	Emission of carbon dioxide of uncertain volcanic origin.
Rabaul, October 2006	Largest explosive eruption at Tavurvur since 1994 activity.
Ritter, October 2006	First reported eruptions since 1997
Langila, ongoing	Eruptions of its long-lived period of activity continued.
Ulawun, ongoing	Some mild ash eruptions following the large eruption in 2000.

The eruption time clusters of 1951–1957 and 1972–1975 may be related to series of major tectonic earthquakes that preceded them. So too, apparently, was the 2002–2006 eruption cluster. A remarkable sequence of tectonic earthquakes took place in the New Britain and New Ireland area in late 2000.<sup>37</sup> A magnitude 6.8 earthquake along the New Britain submarine trench on 29 October 2000 started the sequence. This was followed on 16 November by a magnitude 8.2 earthquake along the Weitin Fault in southern New Ireland, producing large ground-surface displacements and tsunamis, and followed in turn on 16 and 17 November by two more large earthquakes along the New Britain trench. The earthquake pattern was like a seismic chain reaction of related releases of tectonic stress.

<sup>36</sup> Johnson (1977).

<sup>37</sup> Anton & McKee (2005) and Park & Mori (2007).

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