7

VOLCANOLOGICAL ANALYSIS AND NEW ERUPTIONS

Studying the Area of Total Devastation

The administrator in February was hard at work coping with the many diverse aspects of the disaster recovery phase at Lamington. Volcanologist Tony Taylor, meanwhile, was concentrating on scientific investigations aimed at trying to understand the geophysical conditions that led not only to the catastrophic eruptions of 21 January and their effects, but also to the ongoing eruptions at Lamington volcano.

Plants and fungi were active in re-establishing and colouring their presence on the mountain and its surrounds, as if they were in recovery mode too, and the early regrowth of tropical vegetation was of interest to agriculturalists and plant pathologists. In particular, the fact that many cultivated plants, especially root crops in destroyed gardens, were beginning to sprout luxuriantly green among the dull, grey ash meant that supplies of taro, yams, sweet potatoes and bananas could be gathered as supplements to the emergency supplies being provided by air and from newly planted gardens (Figure 7.1). The fresh ash seems to have formed a compost from the buried vegetation, which may have been enriched by potassic and phosphoric salts from the volcanic ash itself (Taylor 1958). Presumably too there was less competition from the slower-growing plants in the area.

Figure 7.1. Taylor and assistant undertaking fieldwork near shooting taro

Taylor and an unknown assistant are here photographed in the devastated area and tree blow-down zone of Mount Lamington. Note the shooting of taro plants to the right of the jeep. The lava dome at the rear of the photograph is growing and is emitting strong amounts of vapour. The precise date of the photograph is unknown. Photograph supplied courtesy of Geoscience Australia (negative number M/1733-3).

The first type of vegetation to be seen in the disaster area by Taylor and by agricultural officer Fred Kleckham was a bright orange-yellow fungus of the genus *Neurospora* (Burges and Chalmers 1952; Taylor 1958). The fungus appeared only three days after the main eruption of 21 January and after light rain had moistened the ash substrate. It was seen in patches and it disappeared gradually over the following six weeks. Very little of it appeared after subsequent eruptions, although small patches were noted on logs that had been buried by the pyroclastic flows. The species of the *Neurospora* was never determined, but the most likely contenders were either *N. crassa* or *N. intermedia* (Perkins, Turner and Barry 1976; Shaw 1980–82; Shaw 1982). Such precise taxonomic discrimination was not of immediate interest to volcanology and disaster relief. *Neurospora* species, however, require heat-shock to germinate and bloom in places such as bakeries or after grass and forest fires. The fungus, therefore, was of interest in providing some indication of the temperatures of emplacement of the pyroclastic flows. A temperature of 60°C lasting for an hour was one early published estimate for germination (Burges and Chalmers 1952).

Hundreds of people had been severely burned and killed in the Higaturu–Sangara area, yet volcanic temperatures at Higaturu were not sufficiently high that wood was ignited or charred (Taylor 1958). A reel of cotton and a leather drive belt of a sewing machine in one remaining house were unaffected by the heat, and there had been a softening and collapse of a plastic lamp shade above the sewing machine. Further, an unopened bottle of ether in the ruins of the hospital had not blown its cork, and an analysis of penicillin found in the hospital corresponded to temperatures of 145°C or more applied for 1 or 1.5 minutes. The most probable temperature and duration, concluded Taylor, was 200°C for 1 or 1.5 minutes. The two violins used by Mrs Cowley and daughter Pam at the district commissioner’s house at Higaturu had not been burnt in these temperatures. Both instruments were retrieved and later sent by the administrator through the Australian Red Cross to Mrs Cowley in Sydney, but repairing them and recovering their tone seemed unlikely (Franceschi Cowley 1951; Wardrop 1951a). Judge Phillips bought Pam a new violin—a thoughtful gesture that, perhaps, was tinged with some guilt (Virtue 2018).

Figure 7.2. The Hendersons at a charred tree trunk

Toby and Hendy Henderson of Sangara Rubber Plantation are seen here at a charred tree trunk in the blow-down zone ‘about two miles from the crater’ (Taylor 1958, fig. 72). Higher-temperature charring of vegetation like this was absent further downslope in the Higaturu–Sangara area. The date of the photograph is unknown, but grasses have grown in what formerly had been the devastated area meaning the photograph may have been taken well after the last of the major explosive eruptions in March 1951. Photograph supplied courtesy of Geoscience Australia (negative number GB/2479).

Higher temperatures elsewhere in the zone of complete destruction were deduced from the distribution of charred trees, but they had 'characteristically erratic distributions that were not easy to explain', wrote Taylor (1958, 45). The charred tree trunk seen in Figure 7.2, for example, was only about 3 kilometres from the crater, so wood charring might be expected, but not all such trees were similarly affected. The conclusion reached for the charred trees was that the pyroclastic flow was so dense that it not only retained a high temperature but also caused the visible abrasion of the land surface, something not seen in areas of non-charred trees.

The speed and force of the laterally moving, ground-hugging, pyroclastic flows at Higaturu were other properties that received scientific attention. One early conclusion was that people at Higaturu may have seen the deadly pyroclastic flow coming towards them down from the mountain and that they may have had some time, perhaps just a few minutes, in which to attempt an escape. This was concluded, subjectively, from the disposition of bodies that seemed to correspond to people trying to evacuate from Higaturu (e.g. C. Champion 1951). This means, in turn, and if correct, that they died not from the near-instantaneous, lateral, atmospheric pressure wave or 'blast' that results from large explosions, such as an atomic bomb. Nevertheless, the force that created the physical damage to buildings at Higaturu and Sangara Mission was substantial. The new mission house was the only building that was practically undamaged by the pyroclastic flow at Sangara, and only one house at Higaturu remained reasonably intact. This was the:

U-shaped residence of the District Commissioner ... [which] was pushed fifteen feet northwards and damaged on the southern side by flying debris. Most of the other buildings at the government station were carried away and in most cases only floors remained. A group of three steel Sydney-Williams huts on the eastern side of the parade ground was badly damaged and had partly collapsed; on the opposite side of the parade ground the superstructure of the District Office was swept away completely. (Taylor 1958, 40)

Estimating what the speed and force of the cloud or flow may have been was not straightforward. A great deal of attention was spent later by specialists in attempting to determine the velocity and force from an inspection of a steel flagpole in the ruins of the Higaturu hospital where the otherwise straight pole had been bent conspicuously in two places. The pole was eroded on one side so the cloud consisted not just of air

but also contained volcanic ash, and so was denser and more forceful than air alone. Further, the double bend in the hospital flagpole could be taken as evidence that velocities in the horizontally moving cloud were vertically stratified, and the fact that a jeep could be flung up into a tree probably meant that there were vortices in the cloud as well (Figure 7.3). Larger materials such as corrugated iron and wooden planks had been picked up and flung against other objects creating additional force and damage in some places. An overall conclusion, however, was that ‘damage at Higaturu conformed well with hurricane-force winds, that is, with velocities of the order of 75 miles per hour’ (Taylor 1958, 43).

Figure 7.3. Destroyed and stranded jeeps at Higaturu

This is a close-up of the destroyed and stranded jeeps at Higaturu seen also in Figure 5.3. Photograph supplied courtesy of Geoscience Australia (negative number GA/9830).

Figure 7.4. Three parts of a pyroclastic flow

Three different parts of a pyroclastic flow, or *nuée ardente*, being emplaced during an explosive eruption are shown in this diagram, which is based in part on Taylor's landmark study of the 1951 eruption at Mount Lamington (amended after Francis 1993, fig. 12.9): 1) a basal, dense part of the flow that is restricted to valley floors (open-circle pattern); 2) the less dense 'ash cloud hurricane' above it that spreads laterally across topography; and 3) ash falling from a cloud that has risen thermally from the underlying hot parts of the pyroclastic flow and that, in this sketch, discharges lightning. The reader must imagine facing into the direct path of the fast-encroaching flow.

Taylor introduced to volcanology the name 'ash hurricane' for this part of a pyroclastic flow, thus avoiding such potentially misleading terms as 'lateral blast' caused by an atmospheric wave of highly compressed air spreading outwards from an explosion. This ash hurricane component was in contrast to the lower, denser and hotter part of the pyroclastic flow that tended to follow valley floors gravitationally (Figure 7.4). Taylor (1958, 51) simply referred to this lower part as 'ash flow' and described its movement as 'ponderous'.

The exact cause of the human deaths in the ash hurricane at Mount Lamington could not be clarified by autopsy because cadaveric 'putrefaction was too advanced when the medical services were free from their urgent obligations to the living', wrote Taylor (1958, 49). The deaths, however, appeared to have essentially the same cause as those deduced at Mont Pelée and St Vincent in 1902, and through post-mortem examination of bodies after house fires. Respiratory systems probably suffered rapid damage through ingestion of hot, ash-laden air causing internal swelling,

exfoliation and haemorrhaging. A form of asphyxia was also suggested by the difficulty rescuers had in distinguishing European from Papuan bodies because of the intense post-mortem lividity caused by blood migrating to the extremes of the body. Rigidity or cadaveric spasm was also noted, some corpses ‘frozen’ in sitting or kneeling positions a result of heat stiffening of muscles. Few people seem to have been killed by flying objects or crushed by falling buildings or trees, and no dismemberments were observed at Lamington, such as were common at Mont Pelée.

Taylor, as a result of his fieldwork in the devastated area at Higaturu–Sangara concluded, importantly, that the kind of lateral, atmospheric pressure wave or ‘blast’ that can result from bomb explosions had not taken place at Lamington, in contrast to some of the views expressed in newspapers and magazines at the time. The damage had been done by the ‘ash hurricane’. This term, however, did not become used widely in the later volcanological literature. The preferred term today is ‘pyroclastic surge’.

The origin of the new U-shaped crater was not addressed fully by Taylor, although he concluded that it had not been produced by an outward ‘blast’ as was commonly supposed by more casual observers of the effects of the Lamington eruption. Further, and notably, he retained the name ‘avalanche valley’ that he had used in interpreting the 1947 aerial photographs of the pre-1951 crater on Lamington. This implies that Taylor may have thought the new crater had formed through disintegration and avalanching of the crater wall. Debris-avalanche deposits formed in 1951 were identified many years later at Lamington, providing evidence for a lateral collapse origin for the U-shaped crater, much like the one at Galunggung volcano (Figure 3.10) rather than by outwards blast (Belousov et al. 2011a, 2011b; Hoblitt 1982).

Monitoring the Ongoing Explosive Eruptions

Tony Taylor was busy throughout February observing the volcano from the air (Figure 7.5) and during visits to the crater area (Figure 7.6). Not surprisingly, he was particularly concerned with the ongoing activity taking place at the summit crater, as this had been the source of the catastrophic eruptions of 21 January and was the most likely place where large eruptions might take place again. Taylor classified all of the observed

crater activity of January–March 1951 into eight different types, plotting these systematically and individually in detailed time series charts, starting with the first emissions of vapour on 15 January and ending on 7 March (Taylor 1958, line figs 11–18). These valuable charts also include detailed plots of the number of earthquakes recorded on the Sangara seismograph from 8 February onwards, together with the ‘height’ of the earthquake vibrations on seismograms—that is, ‘earthquake amplitude’—and shown in relation particularly to explosive eruptions.

Taylor gave particular attention to what he termed ‘shallow-pocket’ explosions, a term derived from the work of American volcanologist F.A. Perret during eruptions at Mont Pelée volcano in 1929–32 (Perret 1937). The shallow-pocket explosions are of interest in that they provide an indication of what happened on the morning of 21 January on a much larger scale, and how the pyroclastic flows, or *nuées ardentes*, were formed at Lamington. Explosions of notable shallow-pocket type took place on 5, 11 and 24 February 1951 (Figures 7.5–7.6). Taylor described their development as follows:

Successive explosions fountained rapidly and extensively from many parts of the crater floor and filled the crater bowl with a massive convoluted cloud of fragmental lava and gas. The cloud usually showed little tendency to rise. The heavy, yet buoyant, mass seemed to behave as a layered hydrostatic column raised in the bowl of the crater. The heavier fractions poured out through the low gaps in the crater wall; the lighter fractions poured over the crater rim. (Taylor 1958, 32)

The whole bowl of the crater on 5 February ‘filled with a huge seething cloud of ash’ (Taylor 1958, 33). A pyroclastic flow moved down the avalanche valley and part of the cloud spilled over the western rim as seen in Figure 7.5. The whole cloud, however, soon lost ‘its close-knit compactness and became diffuse’ (33). Thus, pyroclastic flows can emerge gravitationally from the base of quite low eruption clouds, which nevertheless must be dense with ash and not yet forceful enough to be thrust high into the atmosphere.

Figure 7.5. Shallow-pocket eruption from Popondetta airstrip

A shallow-pocket eruption is seen in the right-hand background in this view southwards from Popondetta airstrip on 5 February 1951 (this detail was used by Taylor 1958, in his fig. 30). The low cloud on the right shown by the arrow is from a small pyroclastic flow running west of the crater. The aircraft is a De Havilland Dragon (Sinclair 1986), one of the aircraft that Tony Taylor, in the foreground, used for aerial inspections. Photograph supplied courtesy of Geoscience Australia (negative number GB/2770).

Administration officers were attuned to the results of the observational work being undertaken by volcanologist Taylor on these new explosive eruptions. They were aware that Taylor had remained vigilant and was concerned about the destructive impact of the ongoing eruptions, and indeed about the possibility of still larger eruptions taking place. Ivan Champion responded to this uncertainty by releasing a circular, dated 23 February, for the attention of all personnel in the area under control of the Administration Field Group. The threat of escalating volcanic activity clearly was still on the minds of the administration because Champion's circular was entitled 'Evacuation Instructions in Event of Second Major Eruption' (I.F. Champion 1951a).

Figure 7.6. Shallow-pocket eruption on 11 February 1951

A rising ash column from a shallow-pocket explosion was photographed on 11 February 1951 (Taylor 1958, similar to his fig. 51). Small pyroclastic flows (*nuées ardentes*) are issuing northwards from the base of the cloud, out through the avalanche valley where Taylor and others had been working in the morning (see in Figure 5.8). Photograph supplied courtesy of Geoscience Australia (negative number M/1770-16).

A large explosive eruption of a quite different kind to the February ones took place on 3–5 March 1951. It was the largest since the two major eruptions of 21 January and would not be exceeded by any of the explosions that took place afterwards. The March eruption is also illustrative of the ‘ash densification’ phenomena that characterised the massive eruption cloud of 21 January 1951. In practice, the early March eruption marked the end of the more dangerous phase of the 1951 eruption as a whole and thus the beginning of serious discussions on how the displaced Orokaiva could best be resettled in areas away from settlements that were devastated in January.

Tony Taylor informed the administration in Port Moresby, and hence the Department of Territories in Canberra, on Saturday 3 March that the new eruption had started at about midnight (Administration 1951e) and that pyroclastic flows had been emitted at about 6.00 am on Monday 5 March (Administration 1951f). Taylor was at the Sangara Observation Post and so was able to witness the 5 March eruption and its effects in some detail, as illustrated in the following extracts:

At 0558 hours a small earthquake was felt at Sangara Observation Post and a moment later a brilliant display of stellar and chain lightning drew attention to the fact that an eruption had begun. A *nuée* [pyroclastic flow] covered all the upper slopes and a vertical column ascended, to expand prodigiously above the volcano. A few minutes later the column was short and thick with massive lateral extensions at its base and summit. The whole column appeared to thicken as the gas clouds billowed up from the laterally moving material ... and it soon became evident that the main *nuée* was flowing down the avalanche valley on to the north-eastern slopes ... Two streams then broke away from the main *nuée* and began flowing north in the direction of the Observation Post ... the larger one ... followed the valley of the Ambogo River. The realization that the main body of the *nuée* ardente was being strictly controlled by topography was the only reassuring point in an alarming situation. The main north-easterly body of the *nuée* appeared to have already exceeded the limits of the earlier devastation [of 21 January] and the eruption showed still no signs of abating. The northerly component, in the Ambogo valley, appeared to be advancing at a rate of 30 miles per hour ... and the lubricant gases from this river of fragmental lava boiled up in turbulent convolutions to form a great wall which marked the course of the river valley. (Taylor 1958, 36, as shown in Figure 7.7)

Figure 7.7. Pyroclastic flow of 5 March 1951 in Ambogo River valley

A pyroclastic flow moves down the Ambogo River valley on 5 March 1951 and passes close to the observation post at Sangara Plantation (Taylor 1958, fig. 42). Photograph supplied courtesy of Geoscience Australia (negative number GA/8197).

The pyroclastic flow curved past the observation post about 700 metres to its west and continued down the Ambogo River beyond the former area of devastation. ‘The main north-easterly body of the nuée’ mentioned by Taylor ran down the Bangula River, also beyond the devastated area, and almost reached Jegarata (Figure 4.6). Taylor, on the morning of 5 March, advised the administration in Port Moresby that the pyroclastic flows as a whole had covered little more than half the area of the original devastated area and that no damage outside of the restricted area was expected in the event of a further eruption (Administration 1951f). No mention was made of any ‘ash hurricane’ effects. A change in wind

direction, however, meant that ‘heavy pumice dust’ was falling on both Popondetta and Embi where both airstrips were closed. There would be a threat of mudflows once heavy rains took place.

Administrator Colonel Murray and Director of Public Health Dr Gunther were able to fly into Embi on a Royal Australian Air Force (RAAF) Dakota later that morning when visibility had cleared to assess the situation for themselves. They reported that fine volcanic ash covered the area all the way to the coast, including the evacuation camp at Oro Bay (Phillips Deputy 1951). The administrator recorded in an evening message from Popondetta to the Department of External Territories in Canberra that the local people at Oro Bay, Eroro Anglican mission, Embi and Dobudura were all upset by the eruption (Murray Administrator 1951). Refugees at the coast, however, had been calmed and settled by the European staff of the mission and administration, including Mr and Mrs Foldi, Dr Biggs and Father Anderson. The eruption had also upset the 600 refugees at Popondetta. However, Ilimo camp and the Kumusi area had been little affected by the eruption. The administrator gave praise to all involved, including wireless-communication staff, the RAAF and airline services.

Cadet Patrol Officer R.M. Claridge was at Awala Plantation on 5 March, writing a comprehensive and informative report on the status of resettlement camps along the Wairope–Sangara road (Claridge 1951a). The people living in nine camps along that sector of the road already had identified escape routes and they had evacuated quickly and in an orderly fashion, northwards towards distant Togahau when the larger eruption took place that morning. Claridge reported that the water supply in the nine camps was satisfactory, but there were ongoing hygiene problems, as some latrines had not been dug deep enough and some people were ‘still using the roadway and near-by bush for defecating’ (Claridge 1951a, 2). Three people had died in the camps over the last two weeks—one old man and two children, one from pneumonia. Food requirements were being met satisfactorily by existing supplies from old village gardens, but taro had been rotting, caused either by poor air circulation in which the taro had been covered by ash—called ‘dry rot’—or by ‘damp rot’ in which volcanic acid was absorbed by the plants. New village housing was being planned, including schools and teaching coordinated by the Anglican mission. There had been a breakdown in a double telephone line between Awala and Sangara but this was being fixed.

The following day, 6 March, Acting Government Secretary Steve Lonergan signed-off on a list of European 'dead and missing' (Lonergan 1951b). The bodies of only 16 of the 35 dead had been identified by this time, more than six weeks after the catastrophic eruption, but the full names of all the adults, and those of some of the children, were given together with the names and addresses of next of kin, mainly in Australia.

A heavy electrical storm took place in the Lamington area on 23 March leading, wrote Taylor in a telegram to Port Moresby on 24 March, to a 'spectacular [secondary] eruption in hot ash beds and river valleys'. He noted, too, that 'the effect at Sangara was similar to a major eruption[,] the area being blacked out for three hours by dust clouds' (quoted in Murray Administrator 1951m). A large, hot mudflow had moved down the Ambogo River valley temporarily destroying communication with Popondetta and flooding a village. District Services officers were again able to calm the Orokaiva people in the Sangara area.

All of Taylor's considerations about the nature of the explosive eruptions at Lamington, from 21 January to 23 March, led him to reflect that:

In some respects the Peléan type volcano resembles a normal explosive volcano that has degenerated into a low-pressure activity while still retaining the power of voluminous discharge ... In the course of an eruptive cycle, however, the volcano occasionally 'reverts to type', producing normal vertical explosions, included among which may be vulcanian outbursts of great violence. The largest, purely vulcanian outburst from Lamington occurred at 2045 hours on 21st January 1951, ten hours after the catastrophic eruption. (Taylor 1958, 35)

This is volcanologically important in the taxonomy of volcanic eruptions and is one of several reasons why '*peléan*' is no longer used widely for volcanoes that simply produce pyroclastic flows as a biproduct. The basic explosive eruption type at Mount Lamington was 'vulcanian', a term used commonly for many eruptions worldwide including elsewhere in Papua New Guinea. *Nuées ardentes* are often a secondary product of vulcanian explosions, but commonly their lethal nature attracts more attention than do the primary eruptions that generate them (e.g. Francis 1993). Similarly, the name *nuées ardentes* is no longer fashionable taxonomically because pyroclastic flows can be of different types and not restricted to the kind of pyroclastic flows witnessed at Mont Pelée in 1902. Nevertheless, most of the *nuées* at Mont Pelée in 1902 appear to have been what Lacroix himself referred to as '*nuées ardentes d'explosions vulcaniennes*' rather than

the less common ‘directed’—perhaps meaning lateral blast—type that he referred to as ‘*nuées peléens d’explosions dirigées*’ (Lacroix 1904; Francis 1993). Volcanological taxonomy was not, however, foremost in the minds of the administration officers who were managing the practical aspects of the recovery phase of the Lamington disaster.

Four Other Aspects of the Eruption

Dome growth

The dominant type of eruptive activity in the summit crater after 5 March was not explosive activity, but rather the long-term growth of the lava dome that had been partly destroyed by the large eruption of 5 March. This new phase of dome growth lasted throughout 1951 up to January 1952, the dome eventually filling much of the crater and reaching a height greater than that of the crater rim. Taylor monitored and reported on this dome growth in some detail and with reference not only to ongoing earthquake activity but also to measurements of ground tilting using a single-component, spirit level tiltmeter at the Sangara Observation Post. These were, however, far from ideal geodetic conditions for a single, basic, one-component instrument located more than 12 kilometres from the crater. While the results conformed to changes in eruptive activity, they had to be interpreted in the context of crustal movements also being caused by the gravitational influences of the sun and moon, and by changes in temperature, air-pressure and rainfall.

A period of particularly rapid growth of the lava dome took place between 3 and 9 February when the top surface of the dome rose at a rate of 100 feet, or 30 metres, each day. Taylor noted that this rate was probably the highest on record for dome uplift anywhere up to that time. Rapid growth also continued after the 5 March explosive eruption, but was spasmodic from mid-May to mid-August, after which the dome crumbled, producing flank avalanches (Figure 7.8). Then a new phase of growth took place at the end of October, culminating when a summit spine of lava reached a terminal height of more than 1,900 feet (580 metres). The volume or mass of the lava dome continued to grow throughout 1952, even though its height diminished a little, and the final shape looked like a truncated elliptical cone having a height of about 1,850 feet (565 metres) above the crater floor (Figures 7.9–7.10).

Figure 7.8. Avalanche on northern side of lava dome

An avalanche is seen descending from the new northern part of the lava dome in August 1951 (Taylor 1958, fig. 136). The camera was tilted when this photograph was taken. Photograph supplied courtesy of Geoscience Australia (negative number GA/9889).

Figure 7.9. Fully grown lava dome in Lamington avalanche amphitheatre

The lava dome appears to be fully grown in this photograph, exceeding the heights of the surrounding residual peaks. Its height is given as 1,679 metres above sea level on a Royal Australian Survey Corps topographic map published in 1974. The date of the photograph, which was provided by Albert Speer, is unknown but likely was late 1951 or early 1952, judging by the direction of the winds of the 'north-west' monsoonal season. The lava dome is still hot and water vapour emissions are prominent. There is a slight greening of valley walls and slopes, and there are no obvious new deposits such as pyroclastic flows or mudflows.

Figure 7.10. Sketch map of summit dome and avalanche amphitheatre

The shape of the avalanche amphitheatre and lava dome at the summit area of Mount Lamington is shown diagrammatically in this detail from the map by Taylor (1958, fig. 52). The dome is elliptical in plan, measuring 3,300 x 2,100 feet (Taylor 1958, 58). Note also that the western side of the avalanche amphitheatre is much straighter than the eastern side, possibly because it is controlled by a geological fault. The cross in the top left-hand corner refers to collection point for the radiocarbon sample in the Embogo Valley that yielded a radiocarbon age of $13,000 \pm 500$ years (Taylor 1958, 17).

Earth tides

Taylor had a particular interest in studying the possible gravitational influence of the sun and moon on the eruptive activity at Lamington—what he referred to as ‘luni-solar influences’. He thought that the gravitational pull of the sun and moon at critical times of the year had an eruption-triggering effect, particularly during the early, highly explosive phase of the 1951 eruption. Most of the large explosions, including those of 21 January and 5 March, he pointed out, took place around the spring tide periods of full and new moon, and the three explosive eruptions on 18, 22 and 24 February were grouped about the time of the full moon on 21 February.

The influence of earth tides on volcanic activity is a contentious subject among volcanologists but was a theme that Taylor and colleagues also pursued strongly in later years in the Territory. Volcanoes, at the very least, have to be ready or, as it were, ‘primed’ for eruption if the slight changes in the forces of earth tides are to have any effect. The earth tide effect may be more noticeable at volcanoes in equatorial zones, such as at Lamington.

Tectonic stress release and eruption time clusters

Another topic pursued resolutely by Taylor was the influence of periods of regional, tectonic earthquakes on phases of eruption at active volcanoes in the Papua and New Guinea region. This idea was examined at a time well before the theory of plate tectonics had emerged and when mapping the positions of many tectonic earthquakes was made difficult by a deficiency of data caused by the small number of seismological stations in the region. Nevertheless, Taylor suggested that the release of stress from tectonic earthquakes could be sufficient to trigger eruptions across a volcanic region at more than one volcano.

Taylor pointed out that the Lamington eruptive activity of 1951–52 was part of a time cluster of eruptions that ranged up to 1954 at volcanoes that included Long, Tulumán and Langila, as well as at Bagana—starting in 1950—during what he called a ‘seismic fever’ (Taylor 1958, 86–87). Activity at an unnamed submarine volcano near Karkar Island in 1951 can also be included in this range, as well as eruptions at Manam and Bam volcanoes where the range is extended up to 1957.

Eruption periodicity

Finally, Taylor was also interested in how often major eruptions take place at Mount Lamington. The 1951 eruption was clearly the only one known historically and there was no unambiguous evidence of eruptions having been witnessed by the Orokaiva before colonisation. Eruption periodicity was not easy for Taylor to establish through comprehensive geological studies over a wide area given the priority of monitoring the ongoing eruption. However, he pointed out that a radiocarbon sample from an old deposit in the Embogo Valley within the devastated area yielded a radiocarbon age of $13,000 \pm 500$ years (Taylor 1958, 17; see also Figure 7.10). This is not necessarily the age of the previous major eruption at Lamington but may be indicative of long periods between successive eruptions.

Reconstructing the Catastrophic Eruption of 21 January

An attempt, then, can be made to summarise what happened volcanologically on 21 January 1951 using Taylor's conclusions and by incorporating the results of more modern field studies at Lamington and at volcanoes such as Bezymianny, Russia, in 1957; Mount Helens, United States, in 1980; and Soufrière Hill, Montserrat, in 1997 (Belousov et al. 2011a, 2011b; Hoblitt 1982). Such an attempt is based on the premise that the whole eruptive period at Lamington conforms to that of a series of vulcanian eruptions, including the formation of pyroclastic flows and the long-term growth of a lava dome. Vulcanian eruptions commonly take place at so-called 'andesitic', circum-Pacific volcanoes where 'andesite'—named after the Andes—is a rock name for lavas generally rich in large crystals such as those found at Mount Lamington. The name 'vulcanian', however, derives from Vulcan Island in the Mediterranean, named after the Roman god of fire.

Vulcanian magmas are, in general terms, hot, gas rich and 'viscous', and they fragment intensely where gas is emitted explosively from a volcanic vent. The explosions produce dust, ash, loose crystals, pumice and lava fragments that range from pea-size pieces to blocks a few metres in width. Vulcanian eruptions also form so-called 'breadcrust bombs' in which the glassy rind or crust of a chilled but still molten lava fragment is split open by the swelling interior of the lava as gas bubbles increase in size. The dense, hot, volcanic clouds of enduring vulcanian eruptions rise in thermally driven columns up to heights up to 20 kilometres, although generally they are much lower and shorter lived. The columns once formed can rise quite noiselessly, even eerily.

First, then, in this interpretation: hot, gas-rich magma is emplaced beneath Mount Lamington at an unknown time in a reservoir of still unknown depth, size and shape. The magma is buoyant and begins rising through a conduit directly beneath the floor of the old crater, or debris-avalanche amphitheatre, that faces northwards towards Higaturu and Sangara. Ascent of the subterranean magma causes cracking of rocks and local felt earthquakes take place that became most noticeable on Monday 15 January, but may well have taken place also in previous days if not weeks.

The magma in the conduit comes close to the surface, heats the crater floor and causes emission of the first vapour clouds from vents in the crater, as well as causing small landslides that represent the first evidence during the volcanic unrest of instability in the walls of the old crater. Rocks in the steep walls of the old crater may have been weathered and weakened by tropical downpours since the previous eruption, possibly centuries or millennia earlier.

The first explosive eruptions take place, possibly including the breaking and expulsion of conduit-wall rocks as the magma clears a passage for the fresh magma that follows. Gases dissolved in the magma come out of solution, creating bubbles as well as the powerful disruption of the magma itself. These produce the first ash in rising eruption columns of 'vulcanian' type that are blown by low-level north-west winds away from Higaturu–Sangara (Figure 7.11a; see also Figure 4.4, left). Earth tremors continue. These initial eruptions are well established by Thursday 18 January and continue in the days ahead. They may have caused further widening of the conduit, as well as additional weakening of the crater walls and further landslides.

The eruption starts becoming climactic at 10.40 am on Sunday 21 January when major vulcanian explosive eruptions form a rapidly ascending cloud that conceals the summit area of the volcano and lofts ash high into the upper atmosphere initially forming a 'cauliflower'-shaped eruption cloud (Figures 5.9a(i) and 7.11b). This spectacular event is soon accompanied, however, by the catastrophic disintegration and collapse of crater-wall rocks, and the formation of rock avalanches that are discharged gravitationally northwards out of the crater area and onto the upper, northern flanks of Mount Lamington. The height of the entire volcano is reduced by several hundred metres. Further, the 'breached crater' is greatly enlarged forming a 1.2-kilometre-wide, amphitheatre-shaped crater that, like the earlier one, opens to the north and that, together with the avalanche valley, is about 3.5 kilometres long. These events were unlikely to have been observed, however, because of the ash cloud concealing them, but the proposed results of this catastrophic collapse are not unlike those mapped at Galunggung volcano in Indonesia (Figure 3.10).

Figure 7.11. Three-part evolution of catastrophic eruption of 21 January 1951

This is a highly diagrammatic sequence, a to c, of the events at Mount Lamington leading up to the catastrophic eruption of 21 January 1951. The diagrams are not to scale but the sections are shown roughly on the same south–north (left–right) orientation. Features are exaggerated, including the sloping basement on which the asymmetric volcano may have been built. ‘Phoenix’ clouds are seen (c) rising only from the extremities of the pyroclastic flows, as shown by the arrows pointing upwards.

The removal of so much rock from the summit of the volcano, and the ongoing widening of the conduit by the violent explosive eruptions, leads to a massive disgorgement of vesiculating magma forming ash clouds that rise into the ever-growing eruption column (Figure 7.11c). So much pyroclastic material is ejected, however, that the lower parts of the ash column become heavy through ash densification and the column begins to collapse gravitationally, crashing down to the land surface around the entire volcano. Voluminous hot pyroclastic flows move rapidly and radially down the flanks in all directions but especially on the northern flank where the new north-facing amphitheatre helps to guide the deadly flows, or *nuées ardentes*, in that direction towards settlements. The ‘ash hurricane’ component of these northerly flows destroys Higaturu–Sangara, and deposition from the flows covers much of the debris-avalanche material just deposited by the preceding crater-wall collapses.

Eruptions from the volcano decline after these overlapping and catastrophic events on the morning of 21 January, but there was still gas-rich magma ‘brewing’ beneath the volcano. This would reach the surface by the evening of 21 January, nine or 10 hours later, and produce the second major eruption of the day. The darkness of night prevented good observations being made, but the evening eruption appears to have been ‘pure’ vulcanian—that is, a highly explosive and high rising eruption that did not yield the heavy, laterally extensive, and disastrous discharges of pyroclastic flows experienced in the morning. The evening eruption was

certainly powerful, however, and the apparent absence of pyroclastic flows may mean that the newly created configuration of crater and conduit allowed the free, upward discharge of ash such that much less densification and column collapse took place.

Smaller vulcanian eruptions continued through February into March, some producing pyroclastic flows closer to the new amphitheatre and overlapping with the period of initial lava dome growth, but the last significant one was that of 5 March. Thereafter, the eruption at Lamington was characterised mainly by the slow and ongoing development of the summit lava dome, long-term cooling and a gradual decline in the emission of vapour and residual volcanic gases.

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