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FIELDTRIP 6

THE GEOLOGY OF MAYOR ISLAND (TUHUA): A BRIEF INTRODUCTION

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INTRODUCTION

This one-day excursion aims to give the participants an introduction to Mayor Island (Tuhua) volcano through a cruise around the island to look at coastal cliff exposures, followed by a short period ashore to access some views in the caldera, or to visit deposits near the landing spot at Southeast Bay. The work presented here represents many years of work by a group of colleagues: Bruce Houghton (University of Hawaii), Marvin Lanphere (U.S. Geological Survey), Steve Weaver (University of Canterbury) and Jenni Barclay (University of East Anglia). The information in this guide is based on the outline given in Houghton et al. (1992), modified by information incorporated in an unpublished map of the geology of Mayor Island compiled by CJNW and being used as the basis for a paper currently in preparation.

GEOLOGY OF MAYOR ISLAND

Mayor Island (Tuhua) volcano lies offshore from the North Island of New Zealand, in the western Bay of Plenty about 80 km behind the line of active volcanism of the Taupo Volcanic Zone (TVZ; Fig. 1(a)). Its location is controlled by localised extension associated with the continuation of the Havre Trough back-arc rift on to the edge of the New Zealand continental crust, southwest of the Ngatoro Basin (Cole, 1978). The island represents the topmost 300-350 m of a largely submerged 15-km-high conical accumulation of composite shields which is surmounted by a ~3 km wide caldera. The eruption products are unusual in Quaternary New Zealand volcanism in being dominated by peralkaline comenditic to pantelleritic rhyolite, with trace amounts of olivine basalt to benmoreite, and no intermediate compositions (Ewart et al., 1968; Weaver et al., 1990; Houghton et al., 1992; Barclay et al., 1996). When compared with the contemporaneously active calc-alkaline silicic caldera volcanoes of the TVZ, Mayor Island is unusual in its magma composition, its low productivity, the small size of many of its eruptions (often $\leq 10^7$ m^3) and wide range of eruption styles. The eruption styles include Strombolian through Plinian fall activity, surge and flow activity, welded fall deposits, and both conventional and spatter-fed lava flows and domes (Houghton et al., 1985a, b; 1987; 1992; Houghton & Wilson, 1986).

The overall history of the island has been established through two contrasting techniques.

- Radiometric dating of local eruptive units by ^{14}C, K-Ar and $^{40}Ar/^{39}Ar$ techniques (Buck et al., 1981; Houghton et al., 1992, and unpublished determinations by M.A. Lanphere).
- Recognition and correlation of calc-alkaline air-fall tephras derived from Okataina and Taupo volcanoes for which independent age determinations are available (Wilson et al., 1995, 2007).

These data can be used to divide the subaerial history of the volcano into four major age groupings and sequences of eruptive units (Fig. 1(b)). (N.B. All ages are given in terms of calendar years before present.)

1. Before 61 ka, i.e., prior to deposition of the Rotoehu tephra from Okataina volcanic centre. Eruptive products from this time period are mostly confined to the northeastern sector of the island.
2. Post-61, pre-7.2 ka. During this time period most of the subaerial framework of the island was constructed. The oldest of the three caldera-forming events occurred at about 45 ka and left a strong influence on the topographic relief of the island. A second, minor collapse event occurred around 17 ka, but the evidence for this is

subtle, and will not be seen on this excursion. The mid-point of this sequence is marked by deposition of the paired Maketu and Hauparu tephras from Okataina volcanic centre dated at ~38 ka.

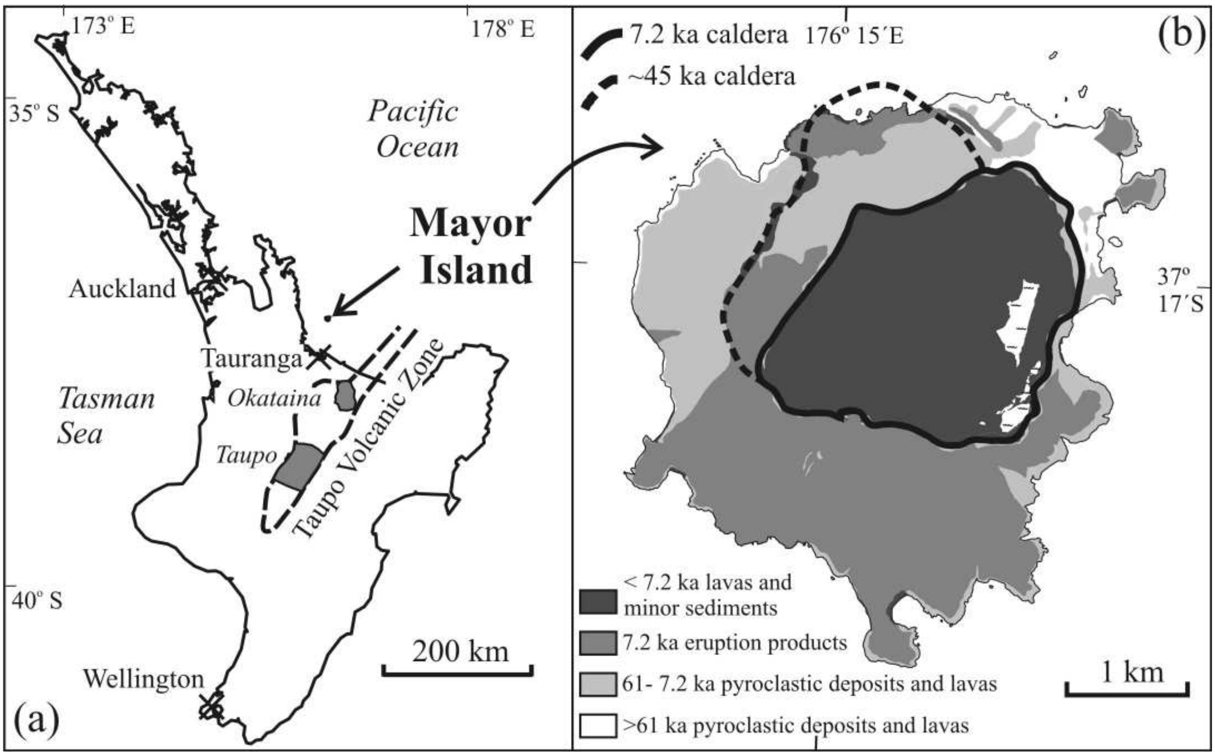


Figure 1. (a) Location of Mayor Island with respect to Tauranga and the Taupo Volcanic Zone (with the present-day frequently active centres of Taupo and Okataina). (b) Simplified geological map of Mayor Island (modified after Houghton et al., 1992), showing the main chronostratigraphic units.

3. 7.2 ka. At this time the largest eruption known from the volcano occurred, producing a widespread air-fall deposit (Tuhua tephra: Hogg & McCraw, 1983; Manighetti et al., 2003) plus numerous pyroclastic flows that entered the sea on all sides of the island. Caldera collapse associated with the eruption overlapped with that of the ~45 ka event to produce the modern structure of the centre of the island.
4. <7.2 ka. Numerous lava flows and domes have been erupted from vents within the 7.2 ka caldera to produce a dome complex. Ages for these flows (and hence the latest activity at the volcano) are poorly constrained, but ^{14}C ages from cores recovered from the intra-caldera lakes imply that at least one episode of dome growth occurred around 2.2 ka (Empson et al., 2003).

FIELD GUIDE

Part 1: Boat trip around the coast

This part of the trip involves circumnavigating the island in an anticlockwise direction, slowing or stopping to view selected parts of the cliff sections. The corresponding part of the field guide below is based around a series of annotated pictures linked to viewpoints. Fig. 2

shows place names referred to in this guide, and Fig. 3 shows the viewpoints where photographs were taken.

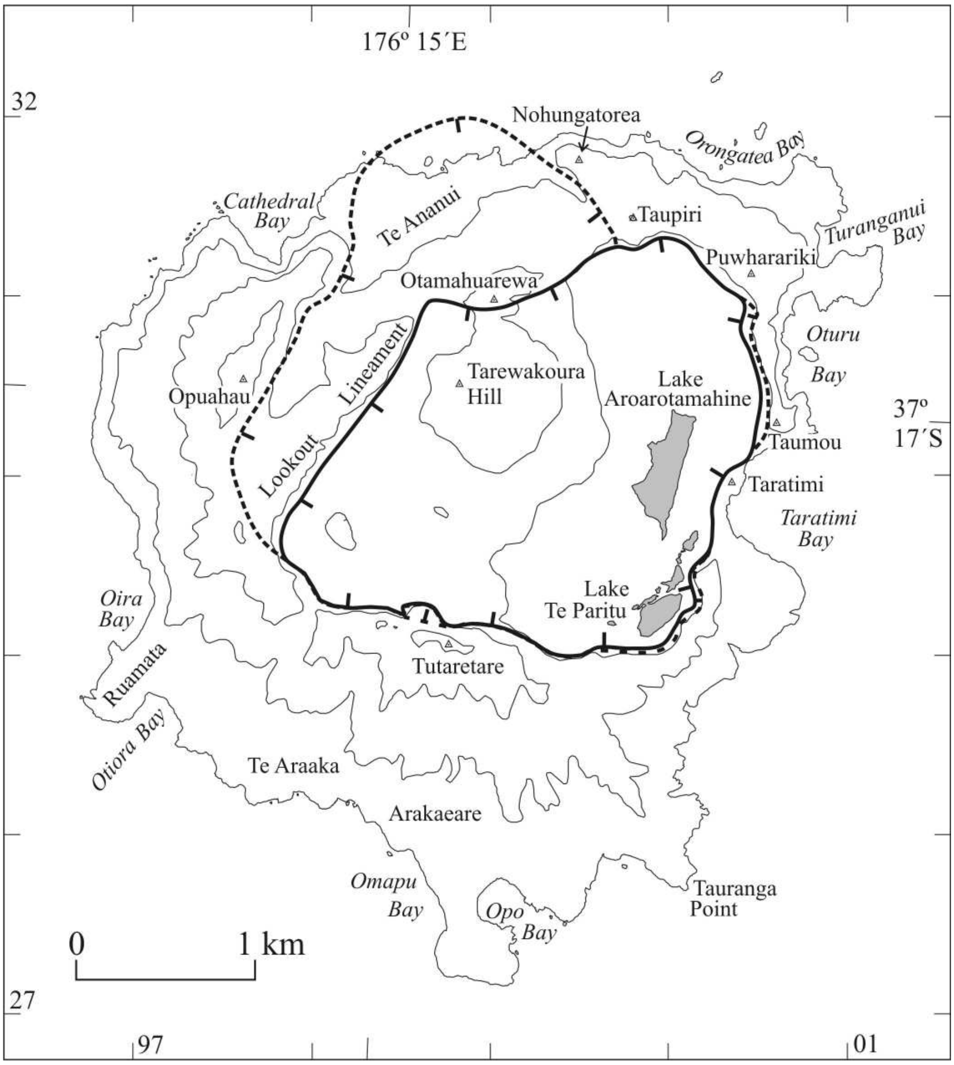


Figure 2. Simplified topographical map of Mayor Island, showing place names referred to in this guide. Marginal numbers are the New Zealand metric map grid.

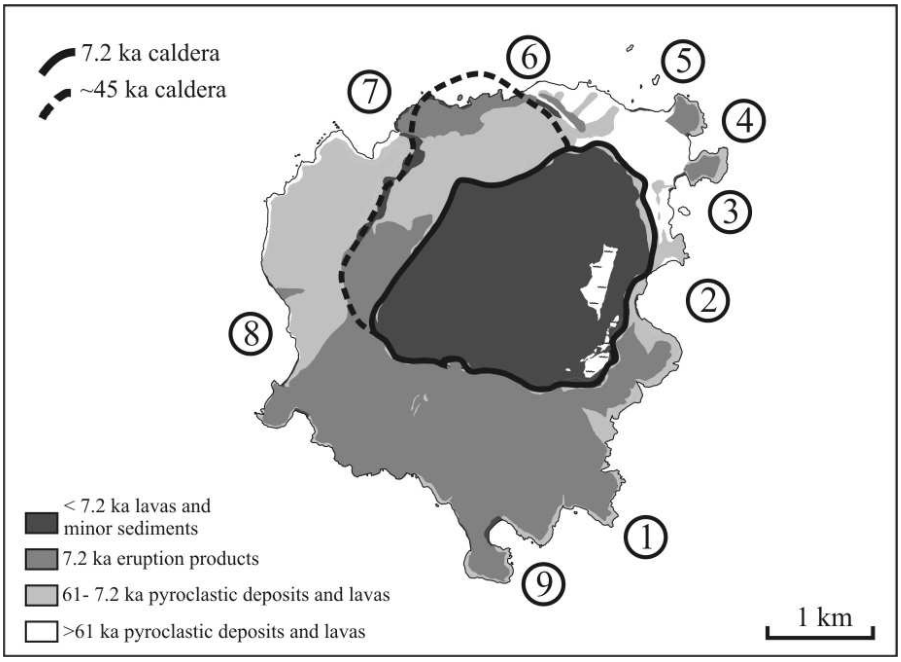


Figure 3. Sites where photos were taken. Photos follow in Figs. 4 (site 1) to 12 (site 9).

We first draw close to the island to see the lavas forming the south-easterly edges of a shield built after a caldera collapse around 45 ka. These lavas have a minimum age, at Tauranga Point, controlled by the presence of a pair of distinctively yellow-orange stained fall deposits from Okataina: the Hauparu and Maketu tephras, both identified from their grain size and mineralogy. A calendar age estimate for these tephras is around 38 ka. These paired tephras occur at several other locations around the island.

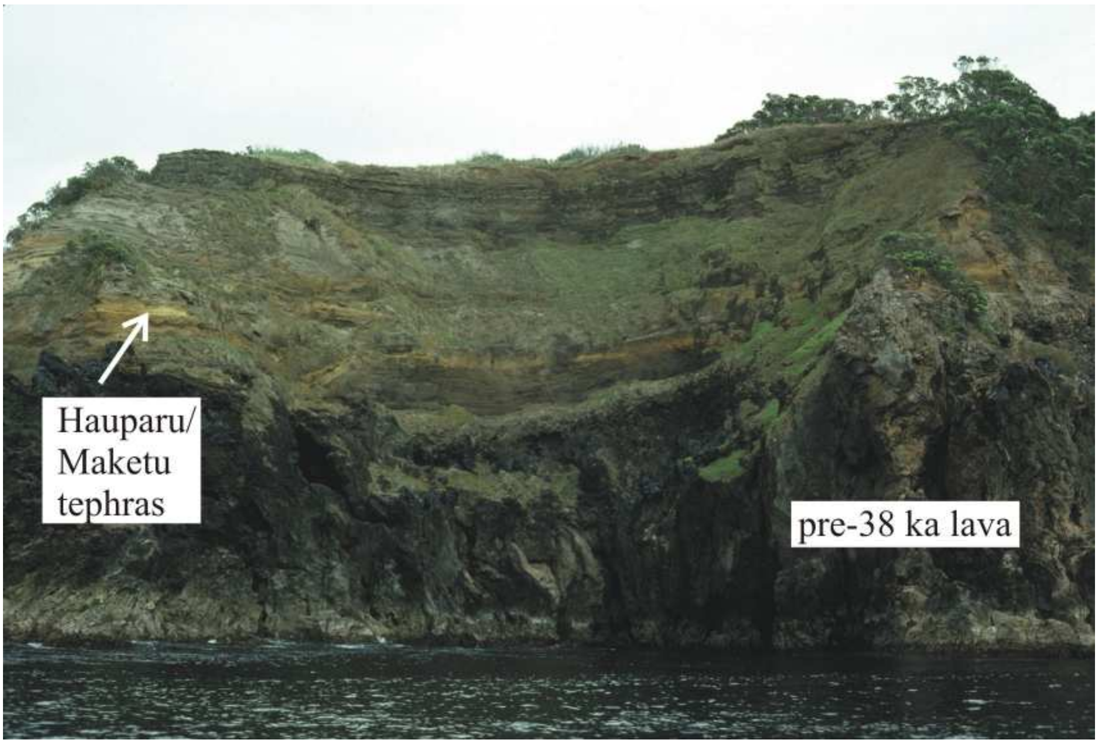


Figure 4. Viewpoint 1: Tauranga Point. The mainland-derived Hauparu and Maketu tephras serve as ~38 ka marker plane to provide a minimum age for many parts of the island.

From Tauranga Point, we pass cliffs of 7.2 ka pyroclastic deposits at Te Horo, then enter Taratimi Bay for Viewpoint 2 (Fig. 5).

The southwestern wall of the bay (Fig. 5(a)) consists of a thick sequence of pyroclastic deposits from the 7.2 ka caldera-forming eruption, including thick channel-filling ignimbrite and lithic breccias. These deposits rest on a spatter-fed lava erupted at 9.2 ka; this is the lava described by Stevenson et al. (1993) and Gottsman & Dingwell (2002) (the 8 ka age often ascribed to this lava is a conventional 'Libby' ^{14}C age).

The western wall of the bay (Fig. 5(b)) represents the lowest point on the caldera rim, and the hills of post-7.2 ka lava domes and flows can be seen behind the cliffs. Pyroclastic deposits enclosing the ~38 ka Hauparu/Maketu mainland tephras rest on a 44 ka lava flow just above sea level.

The northern rim is the prominent hill capped by Taumou Pa (Fig. 5(c)). The hill is capped by a lava flow that flowed both inboard and outboard over a sharply-defined topographic ridge. This geometry suggests (i) that there was a steep inboard surface at the time of the eruption, which possibly could be part of the ~45 ka caldera margin (Houghton et al., 1992), and (ii) that the lava has to have been spatter-fed to have been able to flow simultaneously down on each side of the older ridge.

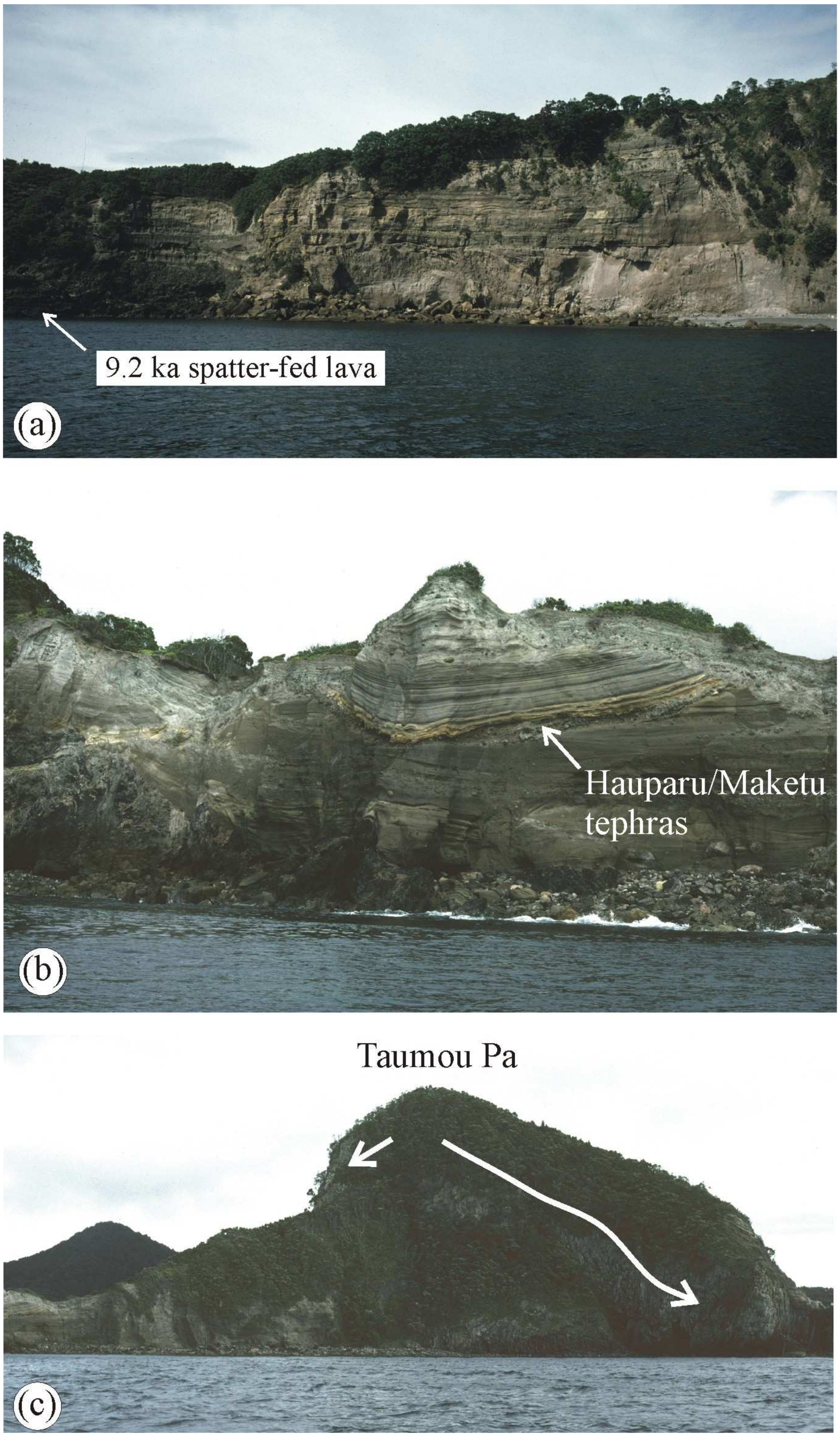


Figure 5. Viewpoint 2: Taratimi Bay. (a) Southern wall of the bay, showing thick pyroclastic deposits of the 7.2 ka eruption overlying the 9.2 ka spatter-fed lava. Note the palaeochannel for pyroclastic flows entering the sea. (b) Taratimi section. Note the Hauparu/ Maketu pair

dividing pyroclastic deposits that rest on a 44 ka lava at sea level. (c) Youngest lava below Taumou Pa, overlying a steep ridge and flowing both into and outboard from the caldera rim.

North of Taratimi Bay is a complex sequence of lavas and pyroclastic deposits. The youngest lava is the 46 ka Taupiri lava (Fig. 5(c)), and no signs of the 61 ka Rotoehu tephra have been found here or in the Orongatea Bay area, suggesting that these sequences are post-61 ka in age (though geochemical data suggest that some flows may pre-date 61 ka and hence that the Rotoehu tephra has been eroded from the steep slopes). A pumice cone (the Oturu cone of Houghton et al., 1985b) is cut by a dike which in turn feeds the second youngest lava, dated at 55 ka.

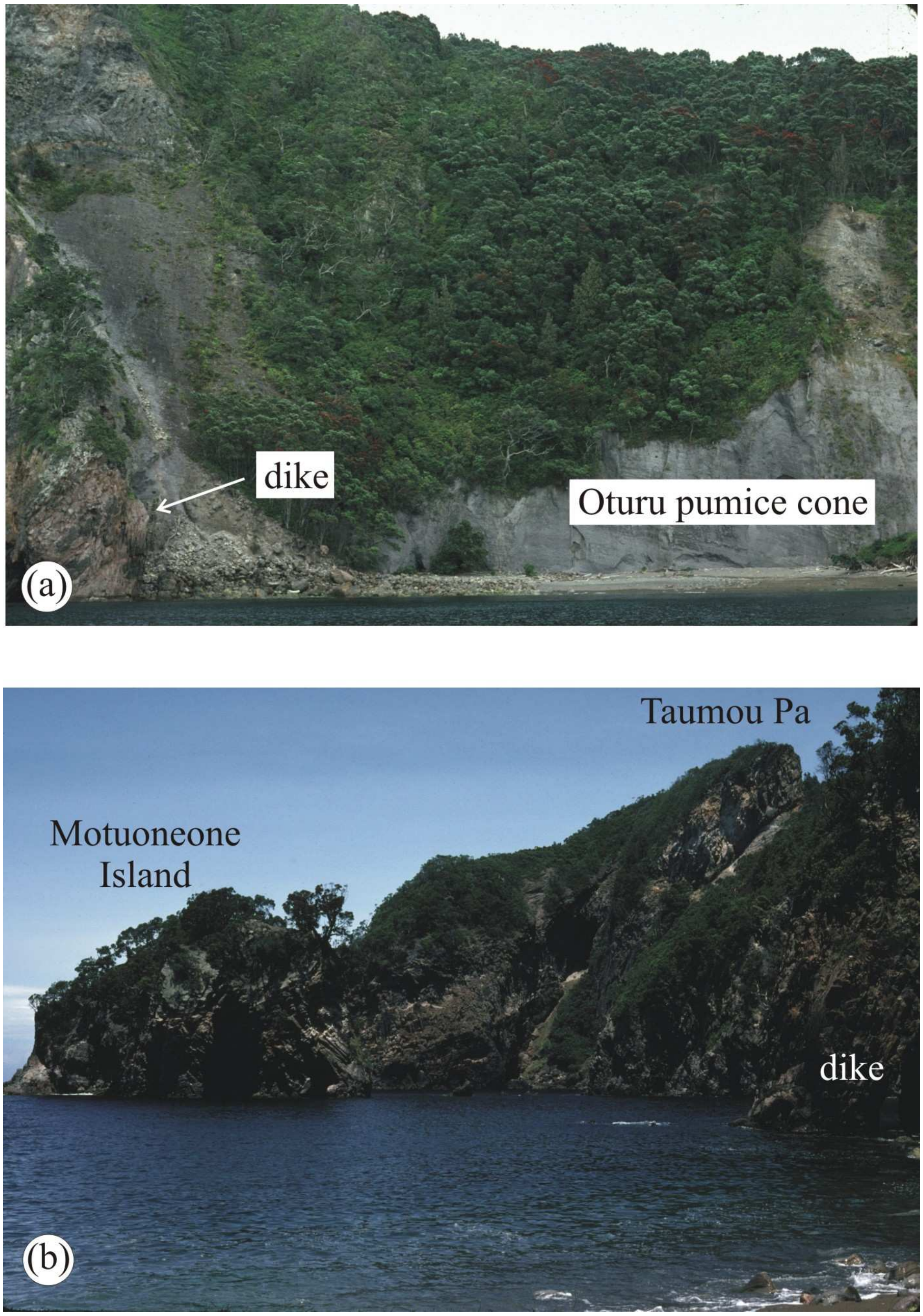


Figure 6. Viewpoint 3: Oturu Bay. (a) Oturu pumice cone, cut by a dike feeding a 55 ka lava flow. (b) View from the beach below the Oturu pumice cone, looking towards the south. Note the steep outboard dip of the Taumou lava. An older lava has been eroded back to form Motuoneone Island.

Passing north from Motuoneone Bay, the route skirts two lava domes erupted from extra-caldera sources, Paretao and Turanganui, the former of which has been dated at 33 ka. In Turanganui Bay the Paretao lava can be seen abutting an old sea cliff (Fig. 7). Consideration of the variations in sea level suggests that the old cliff must have been cut during the last interglacial high-stand at ~125 ka, and that the lava must be older than this.

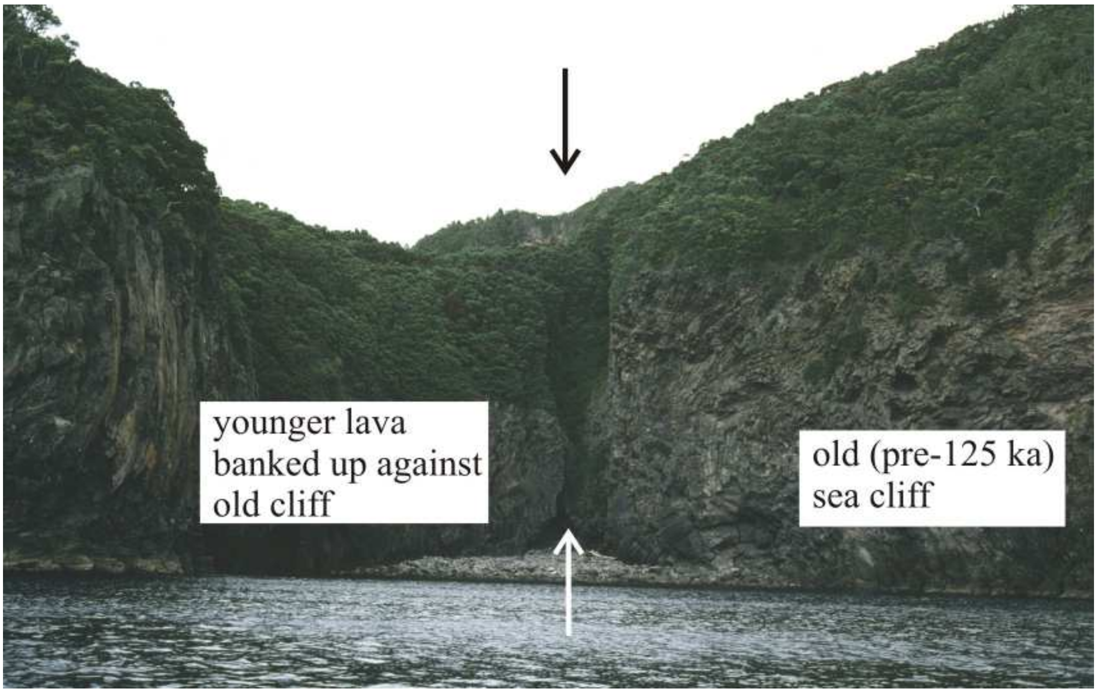


Figure 7. Viewpoint 4: Turanganui Bay. An extra-caldera lava (Paretao) dated at 33 ka abuts an old sea cliff cut into an undated lava. Arrows mark the contact.

We then pass around the NE corner of the island and into Orongatea Bay (Fig. 8(a)). The cliffs behind the bay are composed largely of pyroclastic deposits, with a large pumice cone to the east (Fig. 8(b)) and complexly bedded deposits to the west (Fig. 8(c)). Ages of these deposits are poorly constrained as none of the mainland tephras have been found in this area, but they are generally inferred to be post-Rotoehu (61 ka) in age. Two remnants of lava flows occur as offshore islets, Towakewake Island (‘The Queen’, from the resemblance in profile to Queen Victoria) and Tokopapa Island. In addition, a dike forms two stacks in the bay, while its continuation forms a small exposure cutting the western bedded pyroclastics (Fig. 8(c)). The presence of these offshore islets and stacks suggests that pyroclastic deposits and lavas once extended several hundred metres farther outboard from the modern cliffs, but have been eroded back by Holocene high sea levels.

The pyroclastic deposits at Orongatea Bay overlie to the west a prominent lava flow that continues to the west until it is cut off by an older (45 ka) caldera margin below Nuhungatorea (Fig. 9(a)). This lava is overlain by a prominent strongly coloured pyroclastic sequence, then cut by an erosion surface, then in turn by more pyroclastic deposits that incorporate the Rotoehu tephra. The lower, continuous lava has returned an age of 147 ka (from K-Ar dating of obsidian) which was reported in Houghton et al. (1992), but not utilised on the basis that the sample was inferred to contain excess argon. Further work on the island now suggests that this age determination may, in fact, be accurate. The youngest lava is overlain without any signs of weathering or erosion by the distal pumice fall deposit coeval with the Oira cone seen later in the trip. The lava (and the Oira cone) are cut by the earliest of the three caldera collapse structures, the eastern margin of which runs out to sea at this viewpoint. (Fig. 9(a)). This caldera is partly infilled by a pile of lavas that culminate at Otamahuarewa Hill. The lavas were cliffed by the post-glacial sea level high-stand, then have been partly buried by thick deposits from the 7.2 ka eruption. The view west from Nohungatorea towards Cathedral Bay is shown in Fig. 9(b).

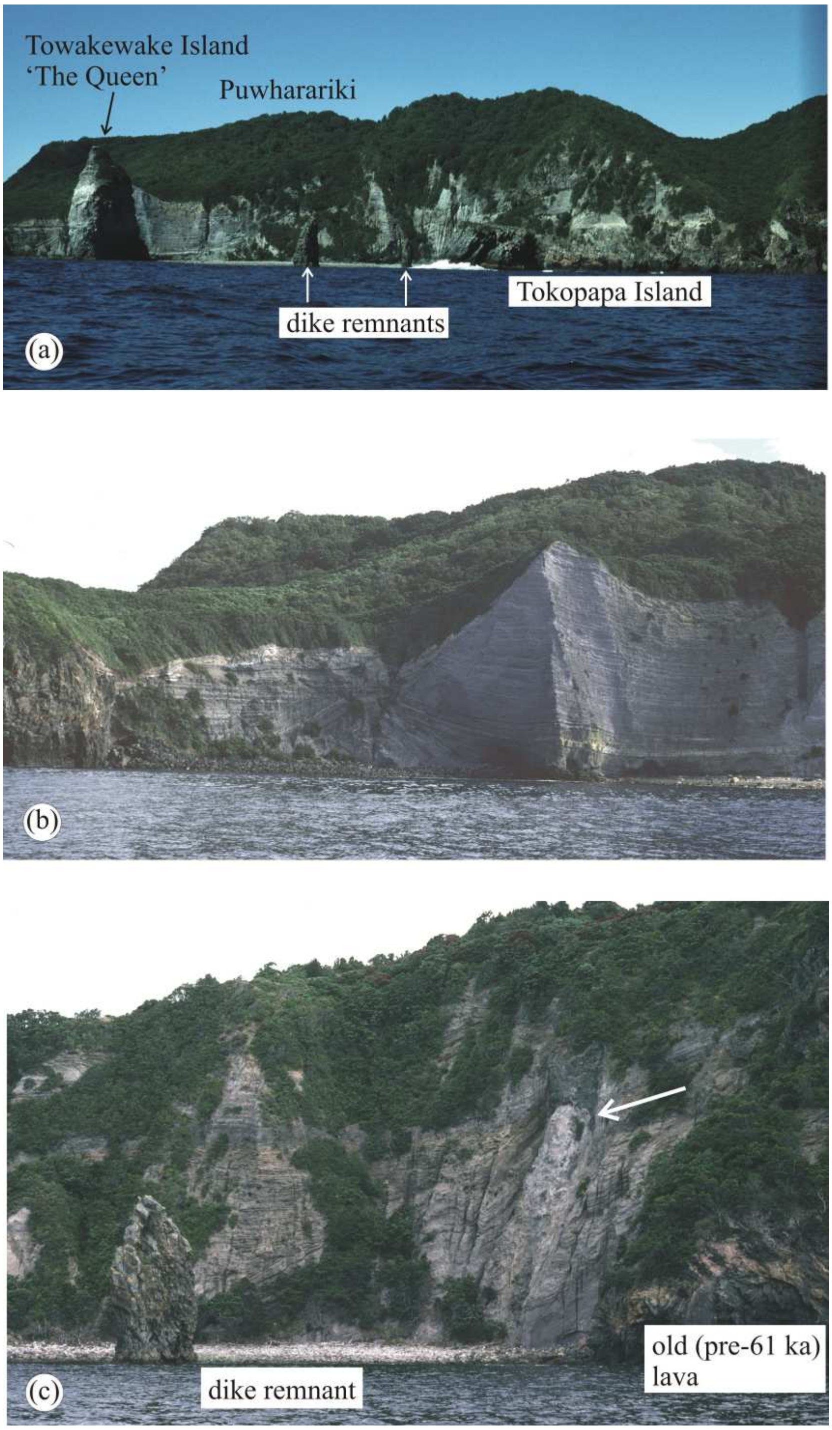


Figure 8. Viewpoint 5: Orongatea Bay. (a) General view, showing dike and lava flow remnants forming offshore islets. (b) Orongatea pumice cone at the eastern end of the bay. (c) Complex pyroclastic deposits at the western end of the bay, resting on an old lava and cut by a dike remnant (arrowed).

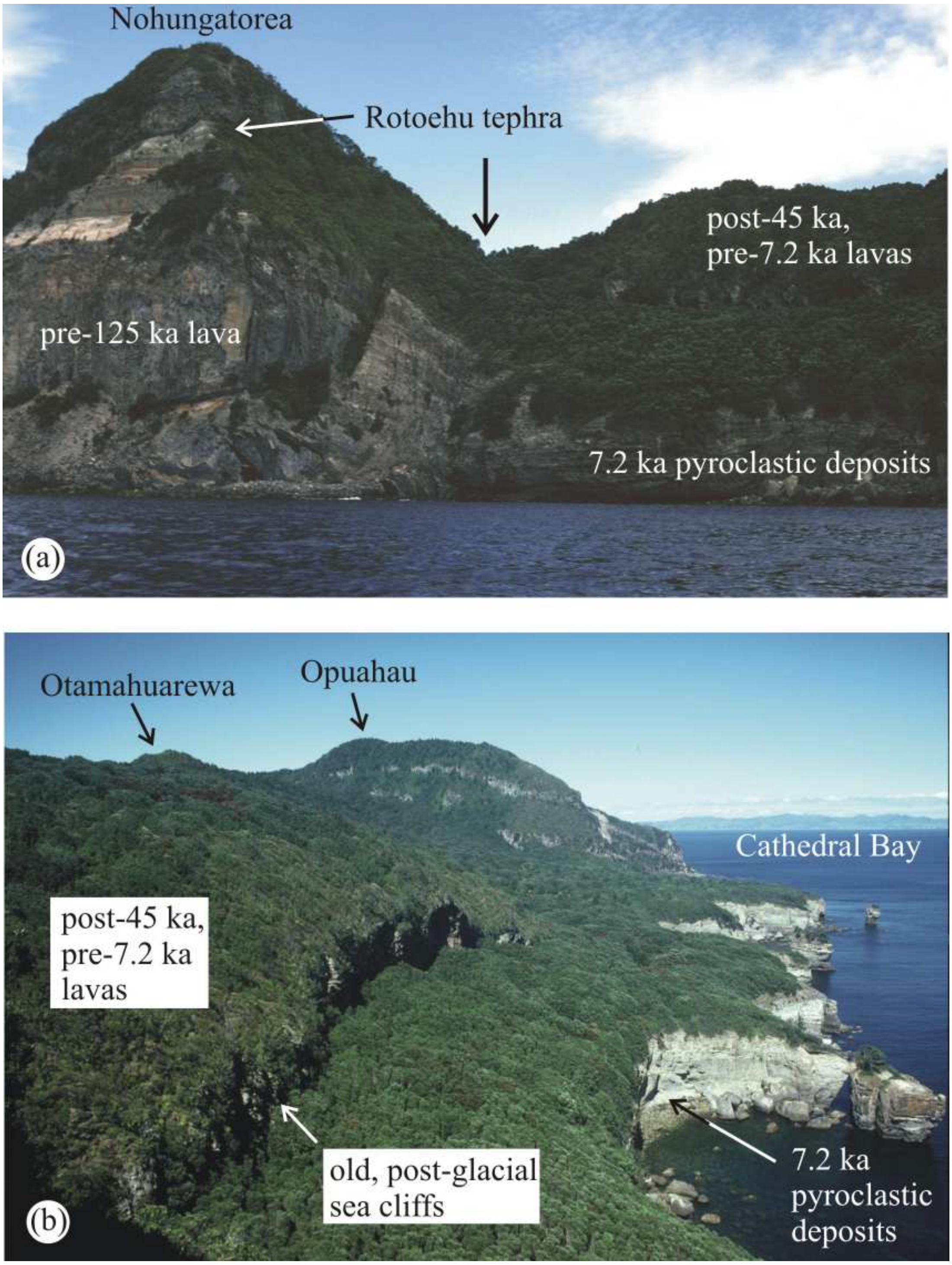


Figure 9. Viewpoint 6: Nohungatorea. (a) The V-notch (arrowed) marks where the wall of the ~45 ka caldera passes out to sea, truncating the lavas and pyroclastic deposits to the left. The caldera has been partly infilled by lavas, which were then cliffed by the post-glacial sea level high-stand before the coastline was built out by aggradation of pyroclastic deposits in the 7.2 ka Tuhua eruption. (b) View from the top of Nohungatorea towards the west. The distant ridge culminating in Opuahau is truncated on its eastern side by the margin of the ~45 ka caldera, which is partly infilled by lavas. Thick pyroclastic deposits from the 7.2 ka Tuhua

eruption were depoited on the coastal margin of the island and have not been entirely removed by subsequent marine erosion.

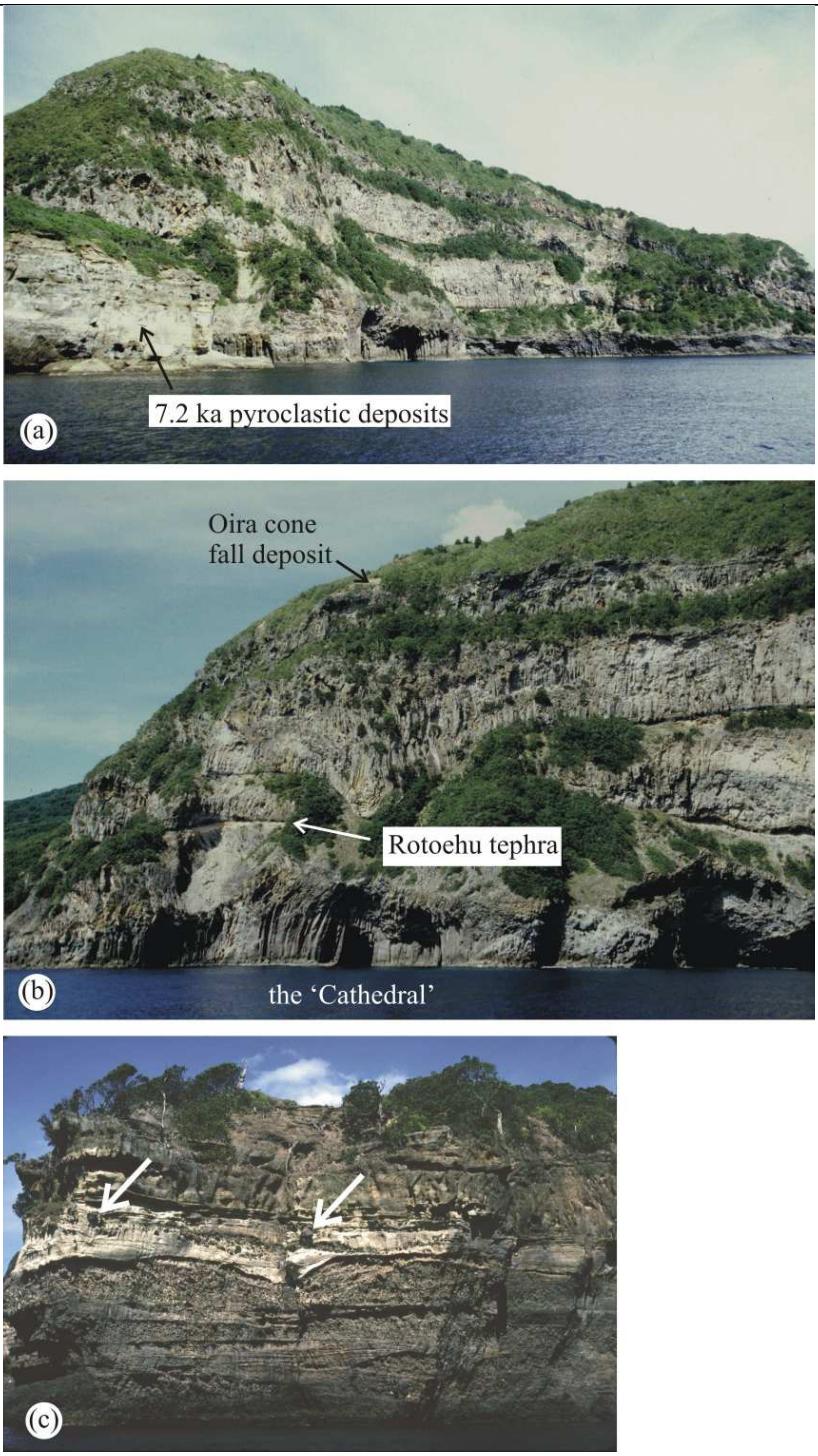


Figure 10. Viewpoint 7: Cathedral Bay. (a) General view of the lava pile. Note how the fourth lava overlies a surface truncating the earlier lavas. (b) View of the main cliff face. The Rotoehu tephra occurs in a prominent orange-brown zone between the first and second lavas,

and the sequence is capped by the Oira cone fall deposit. (c) View of the 7.2 ka pyroclastic deposits at Cathedral Bay. Coarse lithic breccias are overlain by cemented ignimbrite flow units. Ballistic blocks (arrowed) indicate the primary, co-eruptive nature of these deposits.

At Cathedral Bay (Fig. 10(a)), there is a spectacular view of an accumulation of four lava flows, the oldest of which is dated at 63 ka and is overlain by the Rotoehu tephra (Fig. 10(b)). The youngest lava rests on a surface that appears to truncate the earlier three lavas, then in turn is overlain by the 'distal' fall deposit from the Oira cone. This entire sequence is then truncated on its eastern side by the ~45 ka caldera wall. Pyroclastic deposits from the 7.2 ka Tuhua eruption form the coastal flats just east of the cliffs and, like at several other places around the coast (e.g., Taratimi Bay, Fig. 5(a)) has a consistent stratigraphy of multiply bedded lithic breccias overlain by multiple ignimbrite flow units. At some sites, two plinian pumice fall beds are interbedded in with the ignimbrite (Houghton & Wilson, 1986: Houghton et al., 1992, their Fig. 10), but are not present here. A syn-eruptive origin for these deposits (cf. Buck et al., 1981) is indicated by sparse ballistic lithic blocks in the sequence. Most parts of 7.2 ka deposits here are cemented. Evidence from sequences at Omapu (Western) Bay suggests that this cementation is due to alteration of fresh glass, caused by seawater percolating into the deposits below high tide level and sending steam up through the deposits.

From Cathedral Bay, the route skirts the edge of the northwestern domes, which represent some of the largest lava flows on the island. The fall deposit that rests on the lavas (with a poorly developed soil horizon intervening) thickens gradually to the south until it culminates in the large Oira pumice cone at the bay of the same name (Fig. 11(a)). This cone is inferred to have contributed to collapse of the caldera at ~45 ka. An erosion surface cutting the cone deposits and weathering horizon is then overlain by a few metres of soils and tephras, including the Hauparu/Maketu tephras (Fig. 11(b)) and traces of the 26.5 ka Oruanui fall deposit (Wilson et al., 1995). The distal fall material from the Oira cone eruption is possibly the tephra unit labelled M4 by Shane et al. (2006), but I infer that the age attributed to this tephra by them (37.4 ka) is too young.

The southwestern limit of Oira Bay is defined by the Ruamata lava flow (Fig. 2), dated at 24 ka (Houghton et al., 1992), that rests on a tuff-ring deposits exposed at the back of the Oira Bay beach (Fig. 11(b)). The Ruamata lava, and other lavas exposed to the southeast were originally thought to be part of the old (pre-45 ka) accumulations of lavas, but new (unpublished) ^{40}Ar/^{39}Ar age determinations by M. Lanphere shows that these lavas, forming the lower 2/3 of Tutaretare hill (Fig. 2, and see Fig. 13, below) are post-45 ka in age.

Much of the coastal cliff exposure from Ruamata southeast to Omapu Bay is of pyroclastic deposits from the 7.2 ka Tuhua eruption. The cliffs themselves consist mostly of indurated tuff (like that in Fig. 10(c)), then at Omapu (Western) Bay, the deposits are only indurated where exposed below the high tide mark, but are otherwise loose and non-cemented. Our route then goes around the extra-caldera lava flow forming the southernmost tip of the island and into Opo (Southeast) Bay (Fig. 12(a)) for the on-land portions of the excursion.

At Opo Bay, exposures on the southwestern side are of a small tuff cone which underlies a lava flow (Fig. 12(b)). Although the lava has not been dated directly, the Oruanui fall deposit occurs over a weathering horizon developed on the lava, suggesting an age of ~ 28-30 ka. Note that the Opo Bay lava, Paretao (Fig. 7) and Ruamata are all erupted from sources external to the calderas and all date from ~24 to 33 ka, representing a time period when the vent structure for the volcano differed greatly from the Holocene.

The Opo Bay tuff cone represents a very small eruption, involving magma that had largely degassed interacting with minor amounts of external water to produce rather poorly sorted deposits rich in poorly vesicular juvenile ejecta (Fig. 12 (c)); Houghton et al., 1987).

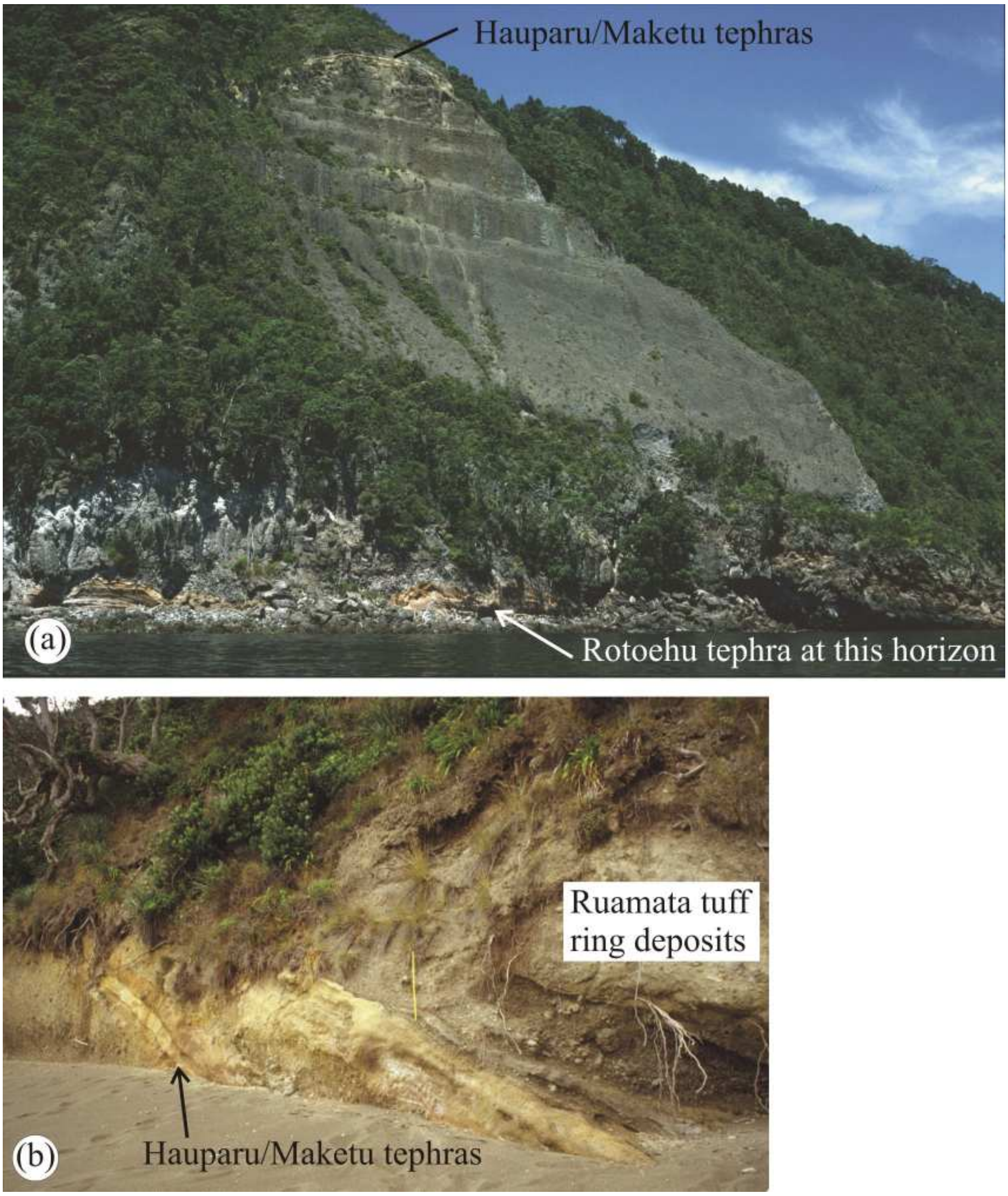


Figure 11. Viewpoint 8: Oira Bay. (a) General view of the thickest exposure of the Oira cone. (b) Section exposed at the south end of Oira Bay beach, showing the eroded top of the Oira cone overlain by a sequence of soils and local and mainland tephras, then the 24 ka Ruamata tuff ring deposits.

Part 2: On land excursions

After landing at Opo Bay, there are two alternative excursions presented below. For the reasonably fit participants, we will take the track up to the caldera rim and around to a viewpoint above Taratimi Bay where other parts of the island can be viewed. For those preferring a look at deposits, there is a short walk over the ridge behind Opo Bay to Omapu Bay, where pyroclastic deposits of the 7.2 ka Tuhua eruption are well exposed. Both trips may be possible, depending on timings. Swimming and sunbathing are additional alternatives.

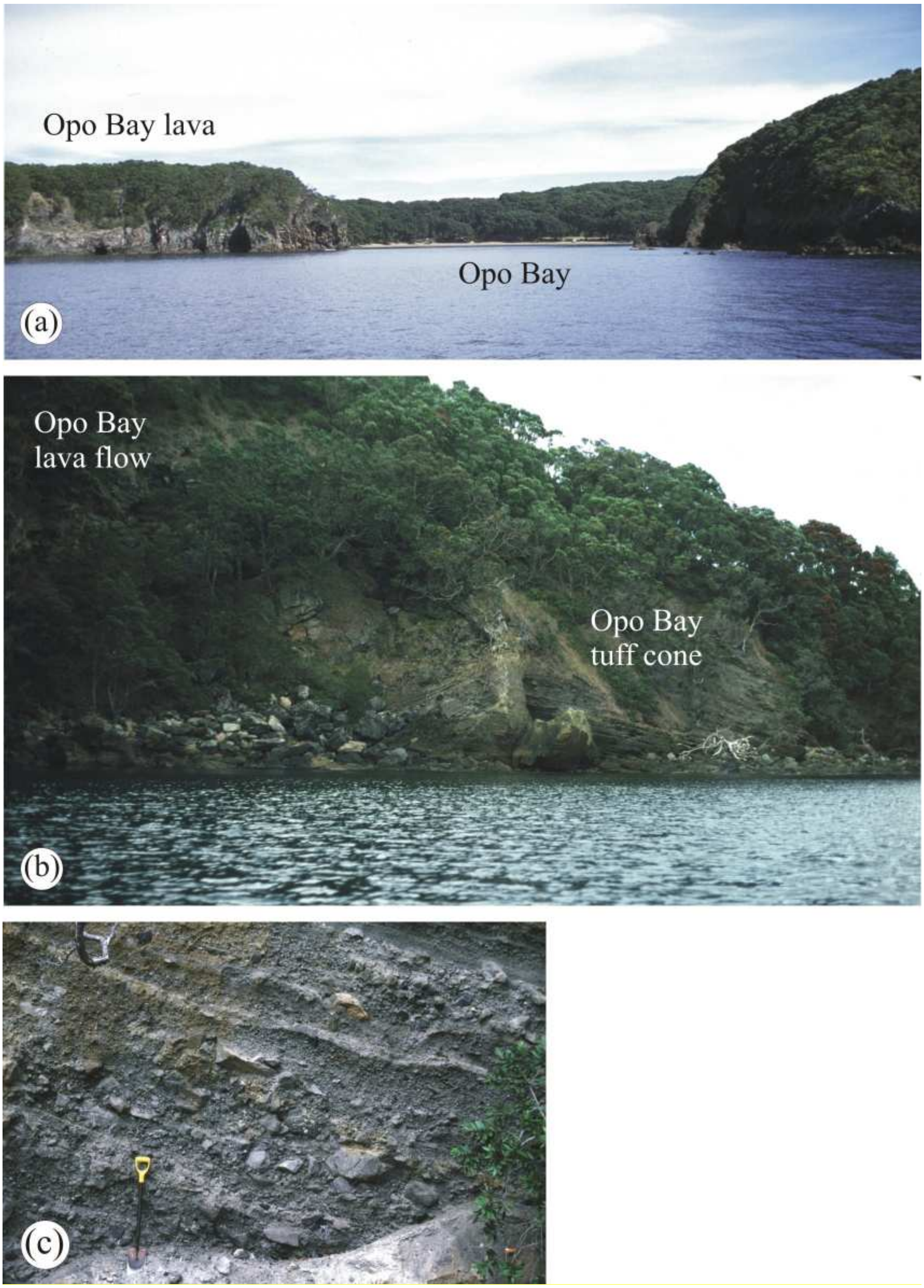


Figure 12. Viewpoint 9: Opo Bay. (a) View into Opo Bay, showing the Opo Bay lava flow to the left. Note that prior to the 7.2 ka eruption, there was a channel between the Opo Bay lava and the rest of the island. (b) View of the Opo Bay lava overlying the northern rim of the earlier syn-eruptive tuff cone. (c) Poorly sorted deposits on the Opo Bay tuff cone on its outer slopes, occurring at the southern end of Opo Bay beach.

(a) Rim track for viewpoints

From the northern end of Opo Bay, a well-defined track leads upslope for a ~220 m climb to the track junction where the Tutaretare track takes off to the left. We follow the rim track anticlockwise until it emerges from forest and hugs the sharply defined topographic rim of the caldera. We will go as far as the top of a lava flow above Taratimi bay, where views can be had of the caldera interior and the cliff sections seen from the boat (Figs 13-16).

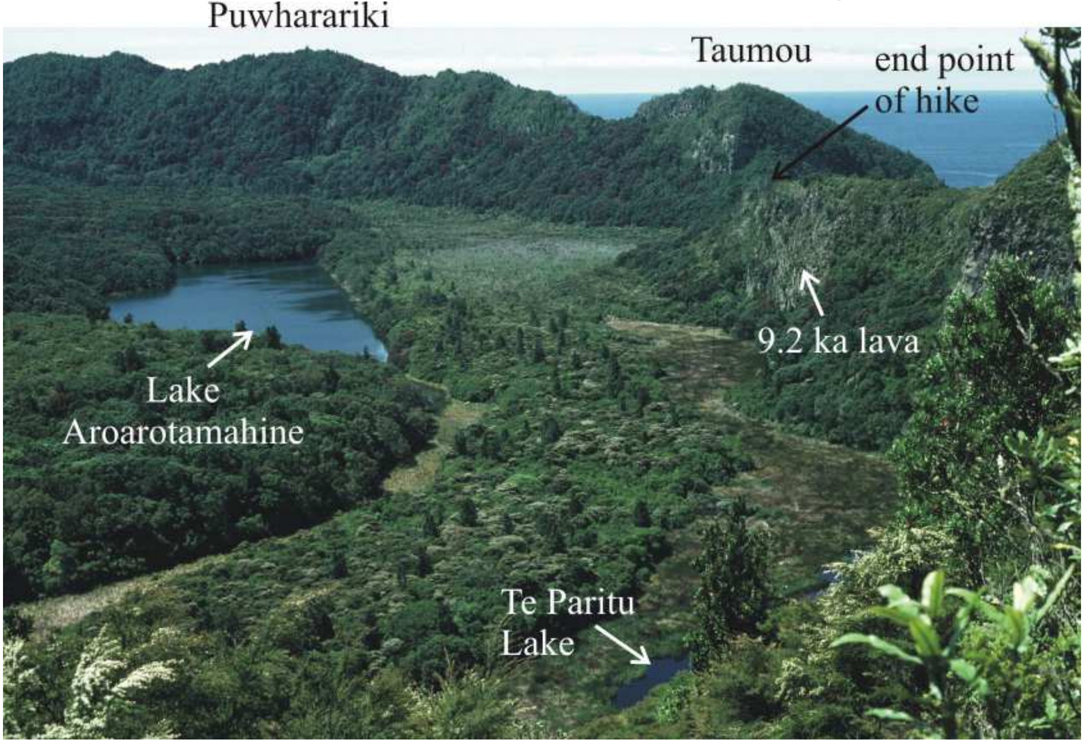


Figure 13. View from the rim track towards the northeast, showing the eastern floor and rim of the 7.2 ka caldera.

There are four main features to be seen (Figs 13-17) that could not be readily seen from the boat.

1. The young, caldera-infilling lavas that postdate the 7.2 ka caldera-forming Tuhua eruption. These lavas contrast markedly with the products of the Tuhua eruption in being very crystal rich and having virtually no pyroclastic material associated with them. The age of the youngest eruption is not known, but charcoal in cores recovered from bogs around Lake Te Paritu (Empson et al., 2003) is interpreted by me to suggest that the last effusive event (as opposed fires set by Polynesian settlers) close to that area may have been at around 2.2 ka.
2. The locally knife-edged rim to the 7.2 ka caldera. The draping relationships of lavas and pyroclastic deposits dated at ~45 ka, 17 ka and 9.2 ka show that the eastern part of the caldera rim has seen at least 3 closely aligned collapses, suggesting the presence of a deep seated ring-fracture through the young history of the volcano.
3. The lava accumulation that forms the lower parts of Tutaretare. As previously mentioned, this was originally interpreted to be part of the pre-45 ka shield-forming edifice of the island, but new radiometric age data show that these flows are younger than this, but pre-dating the intermediate caldera collapse event around 17 ka.

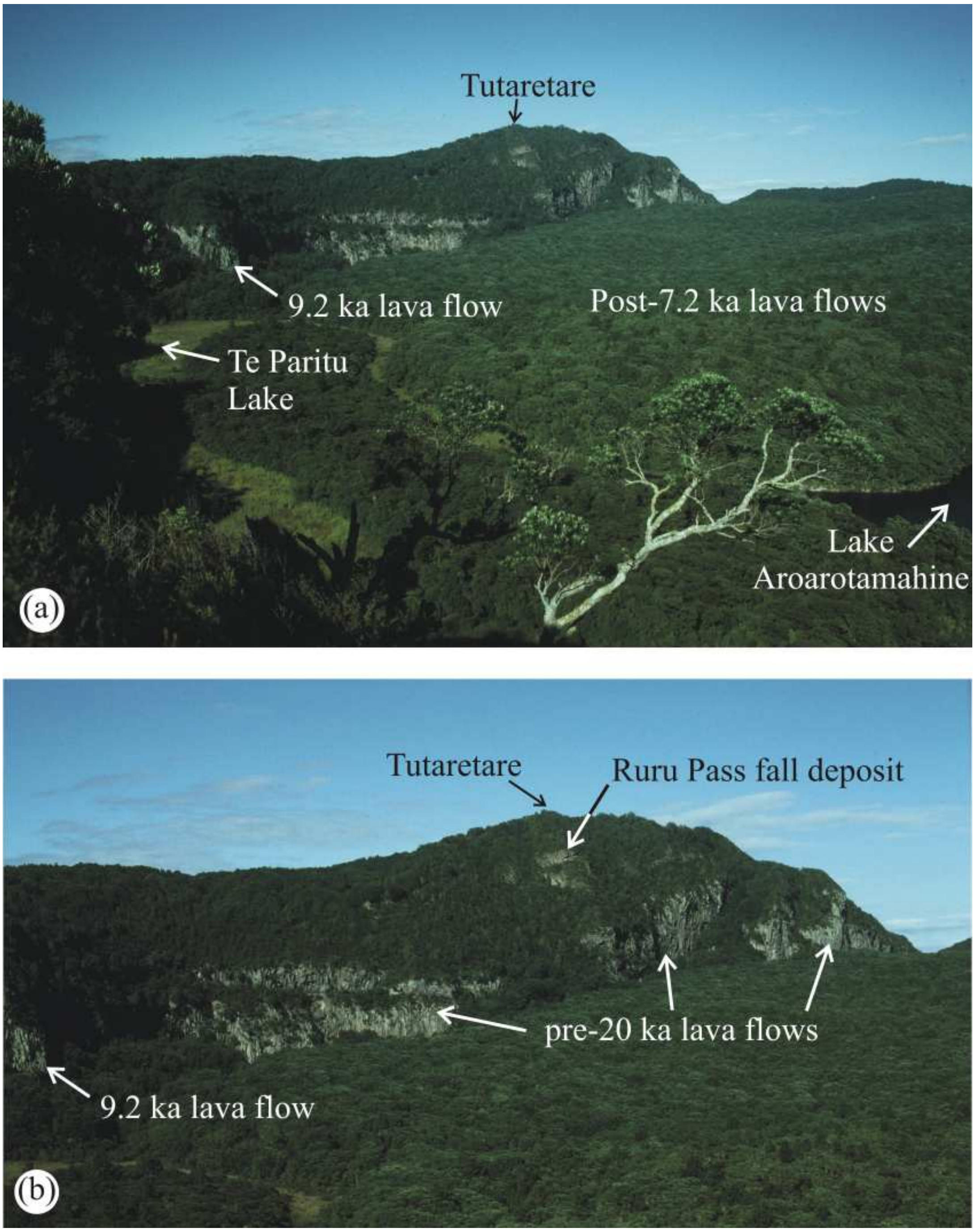
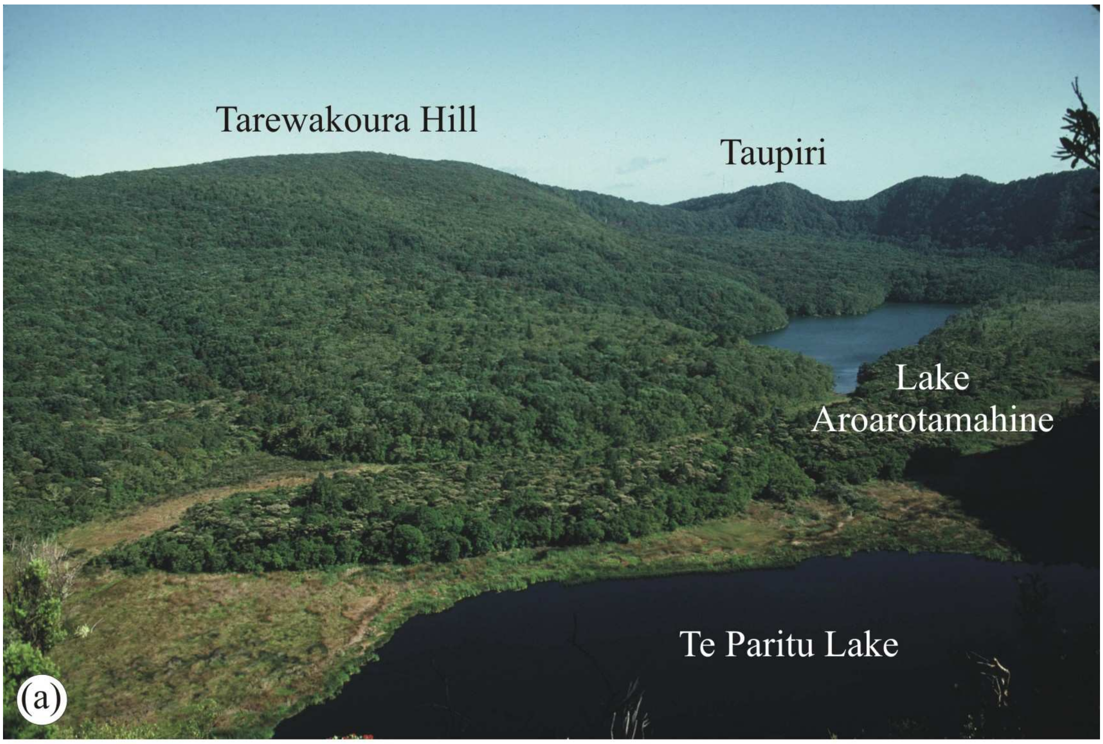


Figure 14. View from the end-point of the hike, looking southwest. (a) Wide view; note the lobes of the young lavas outlined by vegetation growth on the floor of the caldera. (b) Detail of Tutaretare showing the older lavas, draped by a lobe of the 9.2 ka lava flow. Note that the upper one-third to one-half of Tutaretare represents a cone of the Ruru Pass fall deposit erupted during the opening stages of the 7.2 ka eruption. To the left, this fall deposit passes into an intensely welded, mildly rheomorphic tuff (Houghton et al., 1985a).

4. The draping nature of some of the lava flows, in particular, the 9.2 ka example. The outboard flow forms prominent coastal exposures at and just south of Taratimi Bay (Fig. 5(a)), and three lobes that run down the inboard side of the caldera across a

surface that cuts 17 ka pyroclastic deposits (Figs. 13, 14(b) and 15(b)). These inward flowing lobes were then sliced through by the caldera collapse accompanying the 7.2 ka eruption. Textural evidence and these geometric relationships show that the flow was spatter fed, not simply effused (Houghton & Wilson, 1986; Houghton et al., 1992; Stevenson et al., 1993; Gottsman & Dingwell, 2003).



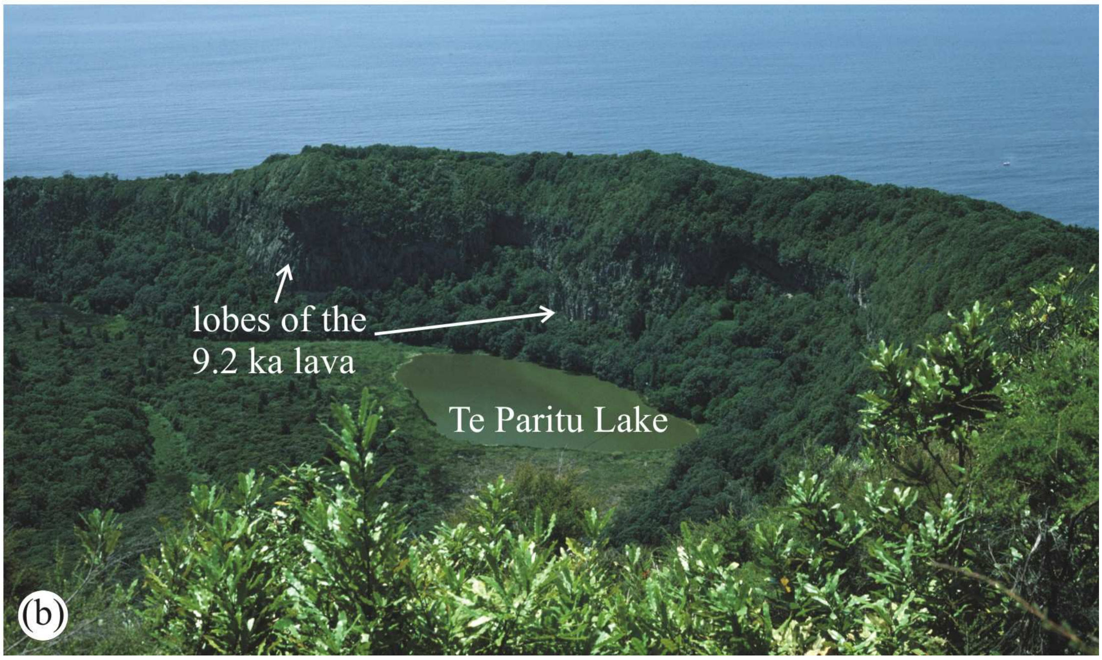


Figure 15. Two views of features inside the modern caldera. (a) The accumulated pile of young crystal-rich lava domes and flows, culminating Tarewakoura Hill. Note the flow lobe outlines, in part enhanced by differential growth of the vegetation, and the straight eastern

shoreline of Lake Aroarotamahine, inferred to be in part fault controlled. (b) View from the slopes of Tutaretare, showing two lobes of the 9.2 ka lava flow that have flowed down over an older (~17 ka) caldera rim, then been truncated by the 7.2 ka collapse.

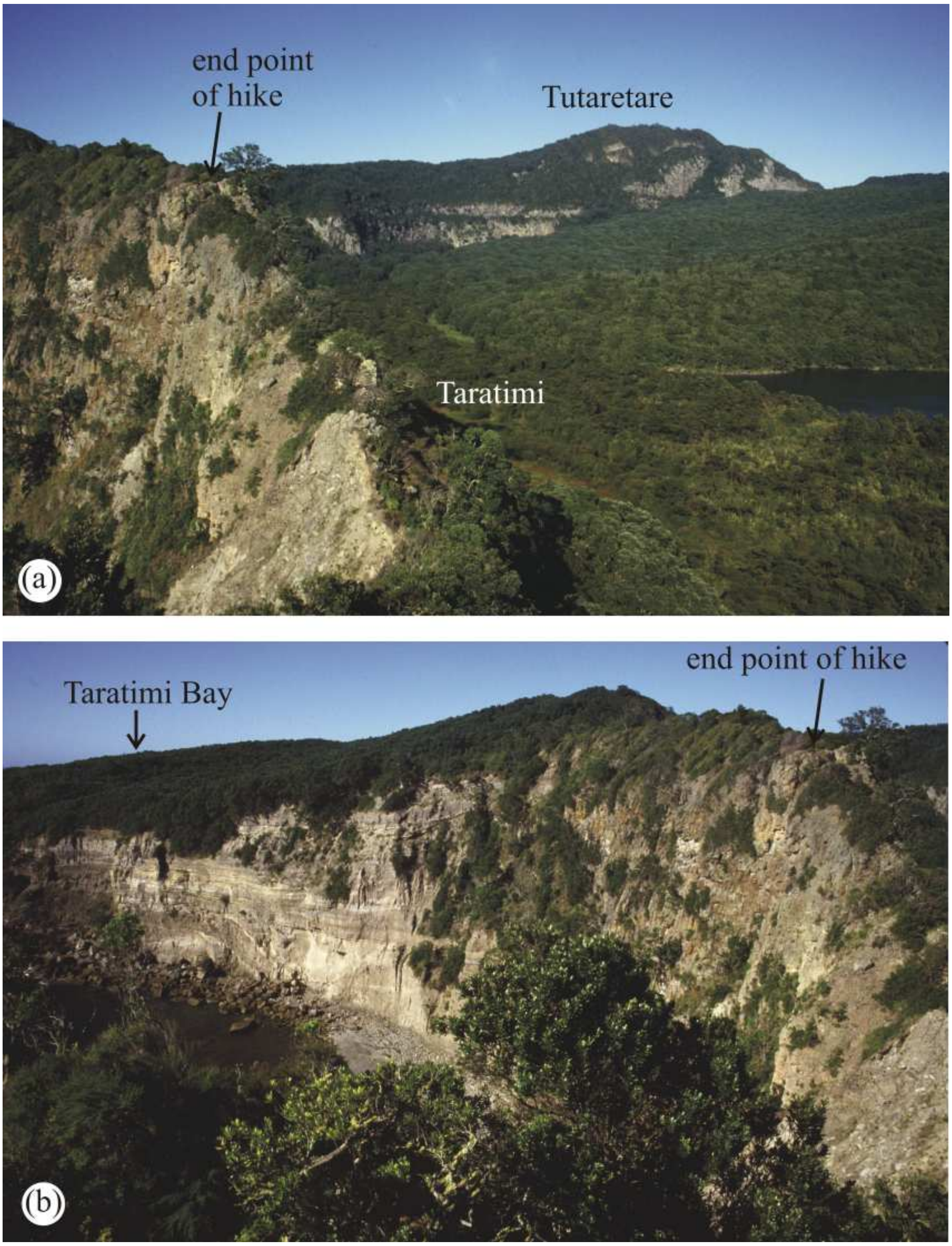


Figure 16. Two views from the slopes of Taumou hill, to show the setting of the end point to the hike. Note the narrowness of the caldera rim in this section. Part (b) shows the pyroclastic section in Taratimi Bay seen from the boat and shown in Fig. 5(a).

From the end point of this hike (Fig. 16), return to Opo Bay by the rim track.

(b) Omapu (Western) Bay for 7.2 ka pyroclastic products

From Opo (Southeast) Bay, participants can either climb the steep wall behind the generator shed at the back of the bay, or the vehicle track behind the caretaker’s house, to cross the isthmus and come down to beach level at Omapu Bay. The cliffs behind the bay area (Fig. 17) offer excellent sections through medial pyroclastic deposits of the 7.2 ka Tuhua eruption (the only deposit that is poorly developed to missing is the distal equivalent to the Ruru Pass fall deposit). Here can be found textbook examples of ignimbrite flow units showing coarse-tail grading, and other examples of laterally-emplaced, cross-bedded deposits. Two plinian pumice fall layers are also found and are accessible in the access track; these represent deposits of phases C and E of the eruption as summarised by Houghton et al. (1992).

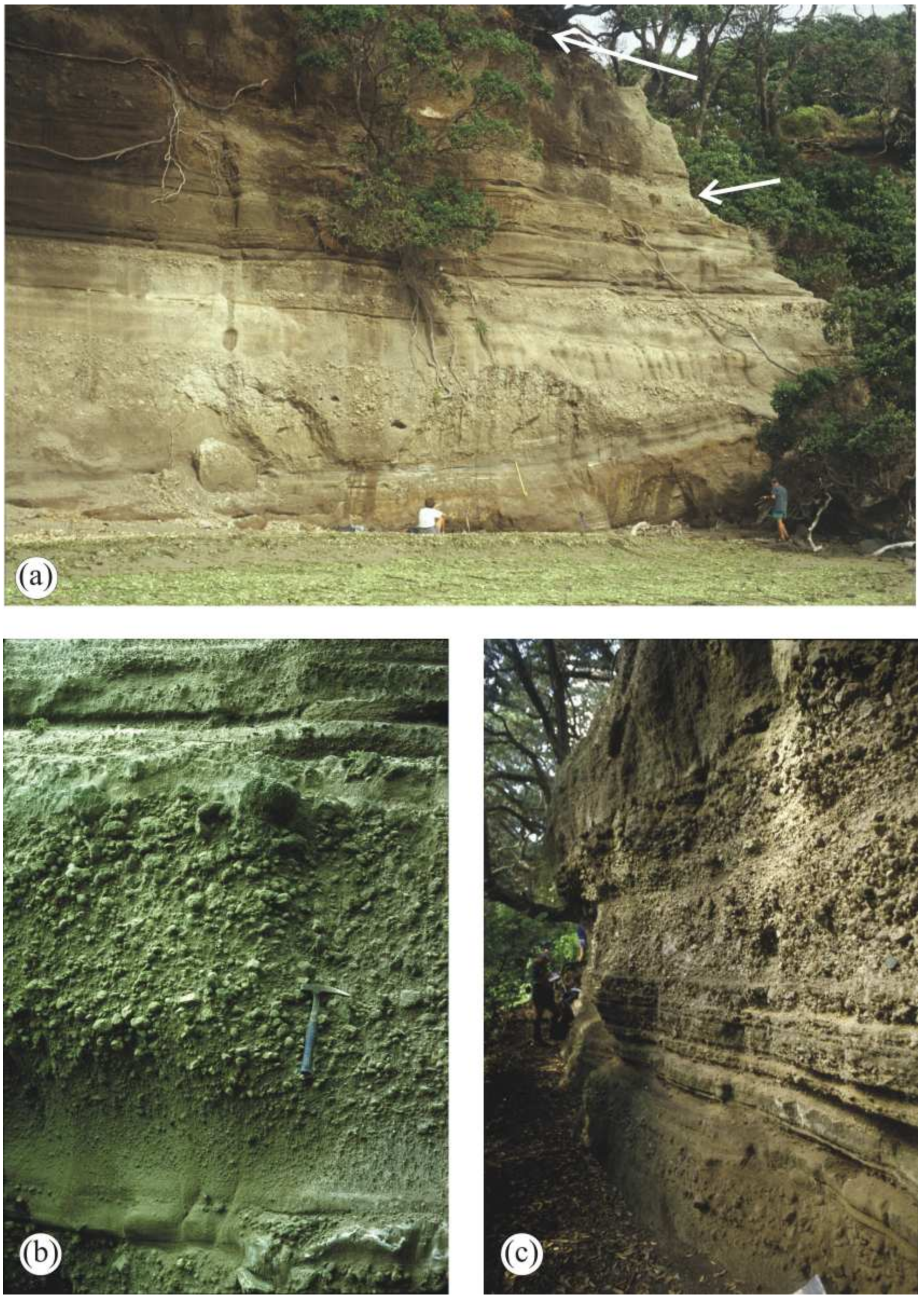


Figure 17. Examples of the 7.2 ka deposits at Omapu Bay. (a) Cliff section south of where the access route from Opo Bay comes down to the beach. Early ponded ignimbrite flow units lap up to the right on to older pyroclastic deposits that rest in turn on the Opo Bay lava flow. Two

coarse plinian pumice fall deposit layers occur here (arrowed) plus other cross bedded, laterally emplaced deposits, many of which are very lithic-rich. (b) Detail of one of the ignimbrite flow units, showing the inverse grading of large pumice clasts. (c) Detail of the lower plinian fall unit where exposed on the cuts above Opo Bay.

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