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Field Trip Guides

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Field Trip Guides – Contents

<u>Field Trip 1</u>	Taupo Volcano	1-10
	Mike Rosenberg & Geoff Kilgour	
<u>Field Trip 2</u>	Geothermal systems	13-40
	Stuart F. Simmons, Patrick R.L. Browne & Bradley J. Scott	
<u>Field Trip 5</u>	Stratigraphic Architecture and Sedimentology of King Country and Eastern Taranaki Basins	43-86
	Peter J.J. Kamp, Adam J. Vonk, & Campbell S. Nelson	
<u>Field Trip 6</u>	The Miocene-Pliocene interior seaway of the central North Island: sedimentary patterns and tectonic styles in the Kuripapango Strait	89-109
	Greg H. Browne	
<u>Field Trip 7</u>	Caldera Volcanism in the Taupo Volcanic Zone	111-135
	Karl D. Spinks, J.W. Cole, & G.S. Leonard	

Field Trip 1

Taupo Volcano

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INTRODUCTION

The purposes of this excursion are to illustrate:

- the complexity of the interactions between tectonic and volcanic processes in the Taupo area
- the emplacement style of a small dacite lava dome
- the diversity of eruption sizes and styles at a single volcano,
- the extent of post-eruptive sedimentary response and re-establishment of Lake Taupo,
- the dependence of our awareness of volcanic hazards on the information available in the geological record

These notes are intended to be a brief guide to some localities of geological interest around the local Taupo area. The notes are not all-encompassing, but we have referenced some topics as a starting point for further reading that you might like to pursue. The field trip will visit 8 localities within a 15 km radius of Taupo (see map at back of guide). A key point is that no one of these, or any other localities around the volcano, offers the full geological record or the full story of the hazards associated with Taupo volcanic centre – at best each is a small snapshot through a narrow window.

STOP 1: Huka Falls upper viewing area; volcanic and fluvial histories

Looking east across the Waikato River from the viewing platform, Mount Tauhara is prominent in the middle distance, while the high plateau across and slightly downstream is the accumulation surface of the 26,500 year old Oruanui ignimbrite which is there at least 150 m thick. The lower, rolling surface between us and Tauhara is a post-Oruanui pre-10,000 year old fluvial erosion surface which, alongside the river itself, is flanked by a 40 m thick terrace of ponded ignimbrite from the 1800 year old Taupo eruption.

There are two features that we want to draw your attention to here.

1. Huka Falls and the Waikato River

The Waikato River at this point flows over pre-26,500 year old sediments (Huka Falls Formation) that represent deposits of a large lake that has probably varied in size and position in response to tectonic and volcanic influences. The Huka Falls themselves are cut into these sediments which have been locally hardened by silica cementation associated with warm groundwater outflows around the margins of the Wairakei geothermal system. The Huka Falls Formation is continuous for tens of square kilometres and provides the cap for the reservoir. The present river flows in a narrow slot which is incised into the wider valley floor, and it appears that sudden drainage of the newly reformed Lake Taupo in the aftermath of the 1800 year old Taupo eruption caused the Waikato River to occupy the full width of the valley floor. The extent of this catastrophic flood has been mapped downstream (Manville, 2002). Manville's studies show that the maximum flow rate of the flood was about 20,000-40,000 cumecs (compared to about 140 cumecs for the mean modern Waikato discharge) sustained for about 1-2 weeks. Putting this in more easily visualised terms, the normal outflow of the Waikato River would fill up the *WestPac-Trust* Stadium in Wellington in about 75 minutes, or roughly the duration of a rugby game. The peak discharge of the Taupo break-out flood would fill that stadium in 30 seconds. We suspect that any eruption from Taupo would have some effect on the flow of the Waikato (and most certainly on the water quality!), but evidence for downstream flooding from all earlier events apart from the Oruanui is lacking. Major episodes of flooding and sedimentation in all large river systems of the central North Island are known to have accompanied the two caldera-forming eruptions of Taupo. Smaller events at the volcano would have mostly affected the Lake and the outlet Waikato River only, but these effects have not yet been quantified.

2. A section through loess and tephra deposits

The road cutting at this point is the only section we will see that shows the earliest post-Oruanui fall deposits from Taupo volcano and illustrates why evidence for small eruptions is preserved only in certain favourable situations. Erosion after the 26,500 year old Oruanui eruption is inferred to have been extremely rapid; the lower part of the cut exposes a c. 21,500 year old rhyolitic fall deposit (Okareka tephra; e.g. Nairn, 2002) from Okataina caldera volcano to the north, and its presence here implies >100 m of ignimbrite was removed at this point in less than 5000 years. About 5 m of loess is preserved, with the Okareka fall deposit towards the base and the sequence of post-12,000 year old pyroclastic deposits and palaeosols above. The loess here and elsewhere in the Taupo area, is characteristically pinkish brown ash-grade material derived by wind deflation of the Oruanui ignimbrite during cold, drier and windier conditions during the last stages of the latest glacial period. Three small fall deposits (units A, psi Ψ , and omega Ω ; ca. 17, 000 to 20, 500 years old; Wilson, 1993) from Taupo are preserved in the loess, along with a number of thin dark beds inferred to be distal ash deposits from eruptions of Ruapehu or Tongariro (Figure 1).

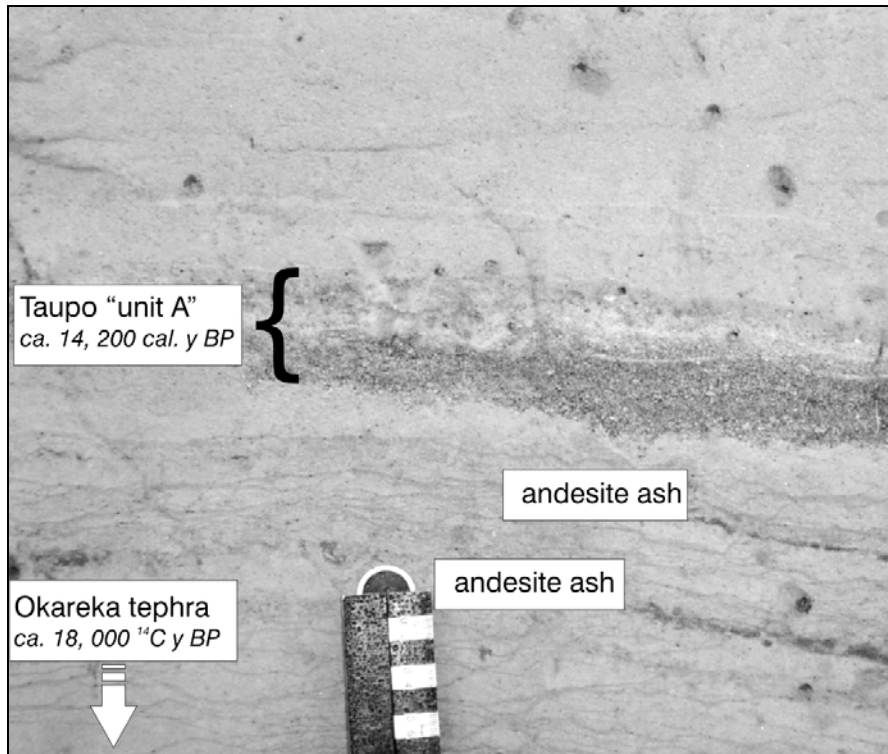


Figure 1. Exposure at Huka Falls loop road (Stop 1) of post-26.5ka volcanic loess with intercalated Okataina- and Taupo- sourced rhyolitic tephra layers, plus Ruapehu/Tongariro sourced andesitic tephra.

Evidence for such small eruptions is only preserved in environments where the deposits are buried rapidly; in contrast, in today's environment of abundant vegetation and no loess accumulation, such thin deposits (cf. 1995-1996 Ruapehu) would not survive. It is apparent from sites such as this one that our record of activity from New Zealand's volcanoes may be much less complete than is required for accurate assessment of how often eruptions of certain sizes occur.

STOP 2: Lake Taupo viewing point; general setting and geology, plus overview of Taupo volcano

Lake Taupo (lake level 358m asl, ~180m maximum depth) is the largest lake in New Zealand (600 km²), being 35 km from north to south and 30 km from east to west. The lake is the major water supply for eight hydroelectric power stations along the 425 km long Waikato River.

To the east and southeast along the horizon are the Kaimanawa ranges of Mesozoic aged greywacke/argillite/low-grade schist rocks (Torlesse composite terrane) – part of the North Island's axial ranges. Gently sloping surfaces dipping towards the lake are the surfaces of the Oruanui and Taupo Ignimbrites; they are also exposed in the prominent white cliffs visible to the south. Immediately to the east of Taupo is Mt Tauhara (1088m), a complex of six dacite lava domes and flows. To the west, the low hills and ridges on the skyline are formed in Oruanui ignimbrite, uplifted Huka Falls Formation lacustrine sediments, rhyolite lava domes and small basalt scoria cones.

New Zealand is home to classic examples of two of the major kinds of large volcanic landforms; caldera volcanoes (such as Taupo) and cone volcanoes (such as Ruapehu). This stop provides us with a chance to compare and contrast the shapes of these two volcano types.

The foreground is dominated by Taupo caldera. This consists of a large collapse structure (caldera), now partly infilled by Lake Taupo, which is partly encircled by a halo of inward-sloping topography, producing what has been termed an 'inverse volcano'. The modern shape of the volcano is due in part to catastrophic caldera collapse events during the two largest eruptions 26,500 and 1800 years ago and in part to downwarping associated with

WNW-ESE rifting of the Taupo Volcanic Zone. That combination of processes in the Taupo area mean the vent area for the youngest eruptions is the lowest point on the Earth's surface for 40 km in any direction.

Taupo is one of two active caldera volcanoes in the Taupo Volcanic Zone (Okataina being the second). Taupo volcano is unusual on a world scale in having experienced two young caldera-forming eruptions 26,500 and 1800 years ago. In the last 25,000 years, 28 explosive and dome-building eruptions have occurred from vents mostly now concealed beneath the modern Lake Taupo, making Taupo the world's most productive and frequently active rhyolite volcano (Wilson, 1993; Houghton et al. 1995). Many of the post Oruanui vents are aligned in a narrow band along the eastern portion of the lake, passing through Horomatangi Reefs, along a line between Tauhara and Motuoapa Peninsula. By far the larger of these younger events was the eruption 1800 years ago (the 'Taupo eruption'), the products and aftermath of which we will be looking at today.

In the background can be seen (weather permitting) the cone volcanoes of Pihanga, Tongariro-Ngauruhoe and Ruapehu. In contrast to Taupo, their eruptions have tended to be smaller, to occur at more frequent intervals (years to tens of years), and have not been accompanied by caldera collapse. The products of the eruptions have accumulated around the vent to produce the overall cone. However, this highlights one of our major difficulties in educating the public - few people would have difficulty recognising the cones as active volcanoes, because of their shape and the fact that most of them have erupted in historical times. In contrast, caldera volcanoes are much less well-known, and few people would immediately recognise Lake Taupo as an active volcano. Despite this the largest single eruption from Taupo volcano (Oruanui; a few hours to several days duration) is equivalent in volume to the entire cone of Ruapehu (which formed in many hundreds of eruptions over at least 250,000 years).

STOP 3: Tauhara quarry; emplacement history of the Hipaua dome

Tauhara Volcano is a complex of six coalesced dacite lava domes/cryptodomes and their associated lava flows and pyroclastic deposits. Buried or partially buried rhyolite lava bodies adjacent to the main edifice may be genetically related (Graham & Worthington, 1988).

Hipaua is a small volume dacite lava dome located in the northeast of the Tauhara Complex. It probably formed prior to extrusion of the largest dome (Main Dome), but at ~190 ka it is not the oldest lava. Tauhara dacites are pale grey and coarsely porphyritic (containing plagioclase, orthopyroxene, clinopyroxene, hornblende and quartz, plus accessory olivine, biotite, ti-magnetite and ilmenite). The Hipaua stone is used almost everywhere in the Taupo area for chip seal on the roads and as decorative facing stone. The lava exposed in the quarry is columnar-jointed, blocky, or brecciated and is mantled by post-26.5 cal. ka. tephra and tephric loess. However, in one exposure near the top of the quarry, dacite tephra conformably covers lava flow breccia. In another exposure, brecciated lava is directly overlain by thinly bedded, siliciclastic, lacustrine Huka Falls Formation sediments.

Recent earthworks at the quarry exposed ~4m of well-bedded, dacite ash and lapilli (Figure 2). Angular and variably dense clasts, vesiculated ash tuff beds, mud-coated clasts, and liquified fine ash indicate that the tephra was generated by a phreatomagmatic eruption (Rosenberg & Kilgour, 2003). Huka Falls Formation sandstone and dacite lava lithics occur in the initial-phase deposits. The sandstone clasts are evidence that dacite magma erupted through saturated lake sediments. This style of activity has not previously been recognised at Tauhara.

In addition to the lithic blocks in the tephra at ~600m asl, we recorded Huka sediments at two lower elevations in the quarry: 1) baked and enclosed by blocky lava at ~580m asl and 2) in direct contact with matrix-poor, blocky hyaloclastite lava breccia in the lower face at ~540m asl (Figure 3). At the lowest elevation, the Huka sediments are at least 150m above the highest elevation of equivalent strata encountered in wells at Wairakei and Tauhara geothermal fields. Taking into account fault displacements and ground subsidence, we suggest that the difference can be explained if Hipaua Dome growth started as a cryptodome that thrust up the Huka sediments. Explosive interaction of fresh dacite magma and saturated Huka sediments was probably contemporaneous with subaerial emergence of the dome.



Figure 2. Non-graded and thinly plane-parallel bedded, dacitic phreatomagmatic coarse ash and lapilli in conformable contact with Tauhara dacite autoclastic block breccia (at base of 1m ruler).

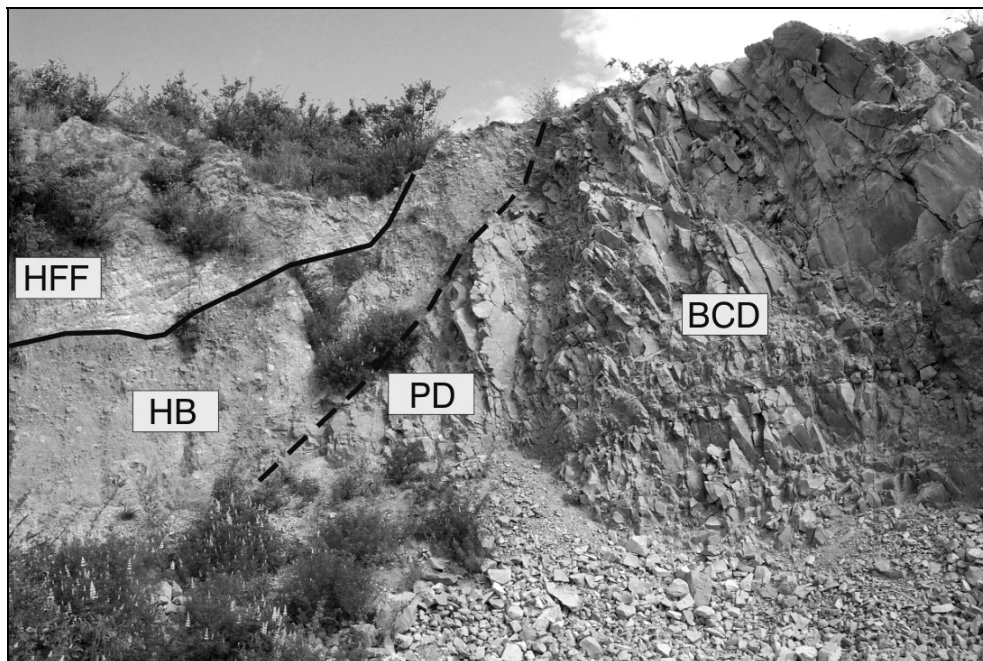


Figure 3. Huka Falls Formation (HFF) volcaniclastic fine sandstone and diatomaceous siltstone in direct (± 20 cm) contact with hyaloclastite dacite breccia (HB). The sediments and brecciated lava display very little thermal oxidation near the contact. The ~ 5 m thick breccia is separated from the block/columnar jointed (BCD) dacite lava by a 2-3 m wide "platy" jointed zone (PD).

Based on tephrostratigraphy, Worthington (1992) estimated Hipaua Dome to be between 19-22.6 ka. The age of Huka Falls Formation is between ~330ka (340-320ka Whakamaru Group ignimbrite) and 22.6ka (Oruanui ignimbrite), so the presence of Huka sediments in conformable contact with Hipaua dacite indicates that the dacite is older than 22.6 ¹⁴C years BP. We favour the ⁴⁰Ar/³⁹Ar age of 190ka obtained on Hipaua lava by Wilson et al. (1995), above an earlier K/Ar age of 31ka (Stipp, 1968). The latter has been suggested as unreliable due to excess radiogenic Argon.

STOP 4: Five mile bay; old lake cliff, giant pumice blocks and post-eruption lake sediments

After the major explosive activity of the 1.8ka eruption, Lake Taupo re-filled; a process which probably took some years to decades and reached a height at least 34 metres above the modern lake level. The lake then rapidly fell back to the modern level as the confining barrier at the lake outlet catastrophically failed and was eroded away (e.g. Manville, 2002). At some time when the lake level was above its modern value and rising to its maximum, further eruptive activity occurred under the lake, generating lava domes (thought to be Horomatangi Reefs and Waitahanui Bank). Parts of the gas rich, pumiceous outer skin of the lava broke off, floated to the lake surface and were driven ashore by the prevailing westerly winds, along the contemporary beach (Wilson & Walker, 1985; von Lichten et al. 2002). From this stop we can see an old cliff line and the pumice blocks exposed within (Figure 4). This lava production represents the youngest known eruptive activity at Taupo.

The cliffs here were formed during the retreat of Lake Taupo from its maximum high stand; they cut through a sequence of pumiceous sands and gravels laid down as the lake was rising. Note the “tortoiseshell” polygonal joints generated by contraction during rapid cooling of the pumiceous lava. Many of the blocks along the north-eastern shoreline have the same paleomagnetic alignment, which indicates internal temperature was at or above the Curie point when they stranded. Note also the grey pumice cobbles that were rounded in the contemporary wave zone then incorporated into the transgression sediments (Figure 5).



Figure 4. Pumiceous lava block ~4m x 2m exposed in the post 1.8ka, “+34m” shoreline cliff. The giant floated pumice blocks are the carapace of lava extruded in the final phase of the 1.8 ka Taupo eruption, from a vent ~10 km to the southeast of this site (probably near the present day Horomatangi reef area). The pumice were exposed and eroded when lake level had fallen to ~2-5m above modern level.



Figure 5. Sequence of post 1.8ka, lacustrine gravels and sands that represent rise and fall of the post-Taupo eruption caldera lake. Sediments include cobbles of the final-phase pumiceous lava (indicated by person).

STOP 5: Highway 5; medial products of the 1800 year old Taupo eruption

**BEWARE OF ROAD TRAFFIC AT THIS STOP!
PLEASE KEEP OFF THE TARSEAL AT ALL TIMES**

The long, gentle gradient followed by Highway 5 out of Taupo represents the inward c. 20 km sloping surface of the Taupo 'inverse volcano' that we could see from Stop 1. The whole 'width' of the Taupo volcanic structure is actually some 60-70 km, much larger than the dimensions of the lake at the heart of the volcano.

The Taupo eruption is the youngest explosive eruption at Taupo volcano, occurring about 1800 years ago. A summary of the products of this eruption is given in the table below. The eruption is notable in two respects:

- Its extreme violence; it is probably the most violent and energetic eruption known to have occurred in the world in the last 5000 years, and
- The uniform chemical composition of the magma. However, although the chemistry of the magma was uniform, other controls (notably the presence or absence of interaction with water in an earlier Lake Taupo) acted to generate a wide variety of eruption products.

Table 1. Summary of the deposits and activity during the 1.8 ka Taupo eruption

phase	name of unit formed	type of deposit	interaction with the lake?	notes
1	Initial ash	fall	yes	minor activity at start of eruption
2	Hatepe plinian pumice	fall	no	dry powerful fall activity
3	Hatepe ash	fall	yes	wet-deposited, pumice rich, hence pale grey colour. Followed by erosion break
4	Rotongaio ash	fall	yes	wet-deposited, obsidian-rich, hence dark grey colour
5	Taupo plinian pumice and early ignimbrite flow units	fall plus flow	no (displaced lake)	dry very powerful fall activity accompanied by localised flow activity
6	Taupo ignimbrite	flow	limited	devastating, widespread flow deposit

For several reasons, this event has served worldwide as a type example for large explosive rhyolite eruptions. In particular, at this and subsequent localities, we want to show you the following features:

1. The contrast between fall deposits and flow deposits, and the controls that may have caused one or the other or both kinds of eruption.
2. The contrast between 'dry' fall activity (phases 2 and 5), powered solely by expansion of gases originally dissolved in the magma (molten rock) itself, and 'wet' fall activity (phases 3 and 4) where interaction between the magma and a former Lake Taupo lead to huge steam explosions and ejection of water from the lake.
3. The contrast between an average 'dry' fall event (phase 2) and an exceptionally powerful one (phase 5).
4. The nature of an unusually widespread pyroclastic flow deposit (ignimbrite) which was generated by an extraordinarily powerful flow (phase 6).

Volcanologists also use the nature of the deposits to infer a great deal about conditions of eruption. All the eruption products consist of two main components:

- **Pumice fragments**, which represents the frozen magma as it has been quenched and broken up by the eruption. The pumice fragments give us information on the composition of the magma (molten rock) beneath the volcano, and also provide a lot of information about the processes going on during the course of the eruption. Nearly all the magma erupted at Taupo is rhyolite. This is one of the most viscous (sticky) kinds of magma, containing about 73-76% silica. The high viscosity of the magma does not allow dissolved gases to escape easily, and this is why most of the eruptions at Taupo are very explosive.
- **Lithic fragments**. These are pieces of the rocks which once surrounded the vent area and were torn off during the eruption. These give information about the rocks making up the volcano (remember that at Taupo, most of the volcano is now hidden underneath the lake).

By studying the chemical and physical composition of the components making up each layer, we can build up a picture of the processes that operated during each eruption, and reconstruct the composition of the chamber of magma that underlay the volcano before each eruption. By studying a detailed sequence such as we see here, a picture can be built up of the timing, and nature of eruptions at the volcano. This information is important to us, because any forecasts that can be made of the (inevitable) next eruption at Taupo are dependent on knowing what the volcano has done in the past. This is a volcanic version of forensic science.

STOP 6: Mapara Road; Kaiapo Fault scarp

At this point Mapara Road crosses the main trace of the Kaiapo Fault, which is perhaps the only fault in New Zealand to have shown two surface ruptures in historical time (in 1922 and 1983; Grindley & Hull, 1986). The historic ruptures and frequent road repairs testify to the continuing activity along this fault. Swarms of shallow (<5 km) small magnitude ($\sim M_L 2 - M_L 3$) quakes along the northern end of the fault have occurred several times during the last few years.

The road cutting to the east exposes a sequence of lacustrine sediments, of broadly comparable age to those exposed at Huka Falls (i.e. pre-26,500y), that are truncated by the fault. In road cuttings to the west, through the downthrown block of the fault, only the 26,500 year old Oruanui ignimbrite and younger deposits are exposed. These outcrops are evidence that a 'Kaiapo Fault' has existed since at least 26,500 years ago, but nearby basal exposures of the Oruanui deposits show local scour features which implies that there was a scarp present prior to 26,500 years ago.

In front of us (towards NE), roughly 100 m above the valley floor, is a fault-splinter block containing post-Oruanui lake shoreline deposits. Elsewhere around the Taupo basin, shoreline and lacustrine deposits post-dating the 26.5ka Oruanui eruption lie at elevations up to 500 m a.s.l. (140 m above modern lake level). However, it is unclear if these deposits in the Kaiapo Fault splinter relate to a downthrown high-stand lake sequence, or an upthrown low-stand unit.

Farm land in the wider Mapara Road area is increasingly being developed into 1- 4 Ha (2- 10 acre) lifestyle blocks. From this stop, you can see that one of the houses (built after 1983) is built on a terrace perched on the edge of the Kaiapo Fault. Several other houses and their associated roads, power and water services are built close to the top of the scarp. This site emphasises the dilemma facing planners- how much should the type of land use be dictated by recognised geological hazards (e.g., rupture of a frequently active fault; eruption of a frequently active volcano)? This year, development/building planning guidelines that specifically address geo-hazards have been established for land use near active faults (Kerr et al., 2004). The guidelines are not legally

binding rules, but they can be applied in a nation-wide, consistent manner by local councils when they develop district plans.

STOP 7: Whakaipo Bay; old lake levels and tectonic implications

Whakaipo Bay is set between the high ground of the Whakaroa ridge to the west and the land uplifted by the Kaiapo Fault to the east. Whakaroa ridge is composed of pre-65,000 years rhyolite lava domes, and its steep eastern side reflects a combination of faulting and pre-existing topographic relief generated by piling up of the rhyolite domes.

The pumice road initially traverses an area of intense gullying, and then crosses a 3-4-m high scarp, between which and the lake the gullying is less intense. The scarp is the fossil cliff formed during the high stand of Lake Taupo following the 1800 year old Taupo eruption, and is particularly well developed here where southwesterly storms could erode into the thick 1800 year old ignimbrite. A key point to note is that the old shoreline here is approximately 35-36 m above modern level, whereas to the east at Kaiapo Bay and around to Acacia Bay, it is >40 m above modern level (Figure 6). In comparison, the old shoreline is about 34 m above modern level in the outlet area to the lake around Taupo township. In 1922, Whakaipo Bay saw some of the greatest deformation across the northern shore of Lake Taupo, with cumulative subsidence exceeding 3 m, in association with the earthquake swarms. What the evidence from the ancient shoreline suggests is that this subsidence represented a down-dropping of a previously-elevated region, rather than simply subsidence of the area relative to stable land on each side. This relationship was repeated on a smaller scale in 1983, when rupture of the Kaiapo Fault was preceded by several-cm scale up-doming of the area west to the fault, at least as far as Kinloch.

Continuing down to where the road parallels the beach, several other shore-parallel lines and minor scarps can be seen, reflecting the effects of storms occurring while the lake was dropping back to its modern level, together with probably two episodes of tectonic movement. In this area there is ample evidence for frequent and large-scale land movements relative to lake level, and to the north, numerous mapped fault scarps also bear witness to the frequency of tectonic/earthquake events. However, in this area also, we are on the edge of a large caldera, within which downfaulting of kilometres has occurred in the recent past. One of the challenges here is to try and discern the tectonic effects of eruptions, that is, how much of the movement along the faults north of Lake Taupo may have occurred in the immediate aftermath of, and in response to, major eruptions at Taupo. If significant movement has occurred, how would that affect interpretations of the seismic hazard along these faults?

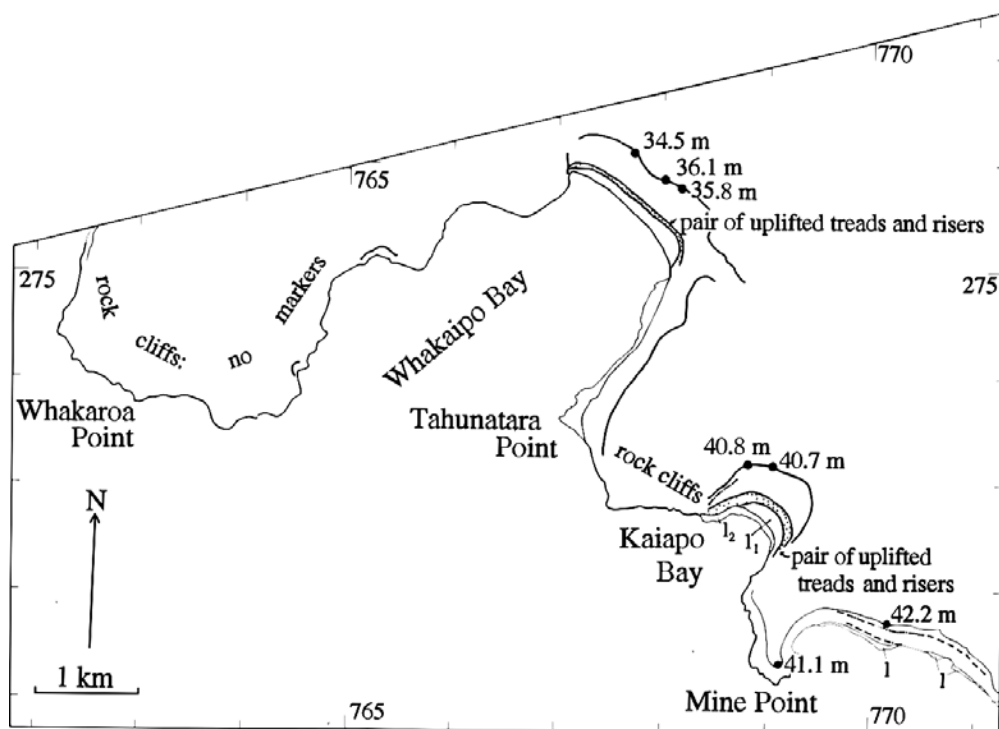


Figure 6. Post-1.8 ka shoreline features between Whakaroa point and Mine point, Lake Taupo (after Wilson et al. 1997).

Acknowledgement

This guide has been adapted from the itinerary and notes for a field trip designed and run by GNS for their “Hazards and Society” professional short course. Much of the content was originally written and compiled by V.R. Manville, C.J.N. Wilson and M.D. Rosenberg.

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