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EXCURSION GUIDE

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ANCIENT VOLCANISM
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NORTHLAND AND TAUPO ZONE VOLCANISM, NORTH ISLAND, NEW ZEALAND

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FIELD TRIP C6

NORTHLAND AND TAUPO ZONE VOLCANISM, NORTH ISLAND, NEW ZEALAND

Sunday 3rd October 1993

to

Monday 11th October 1993

Leaders:

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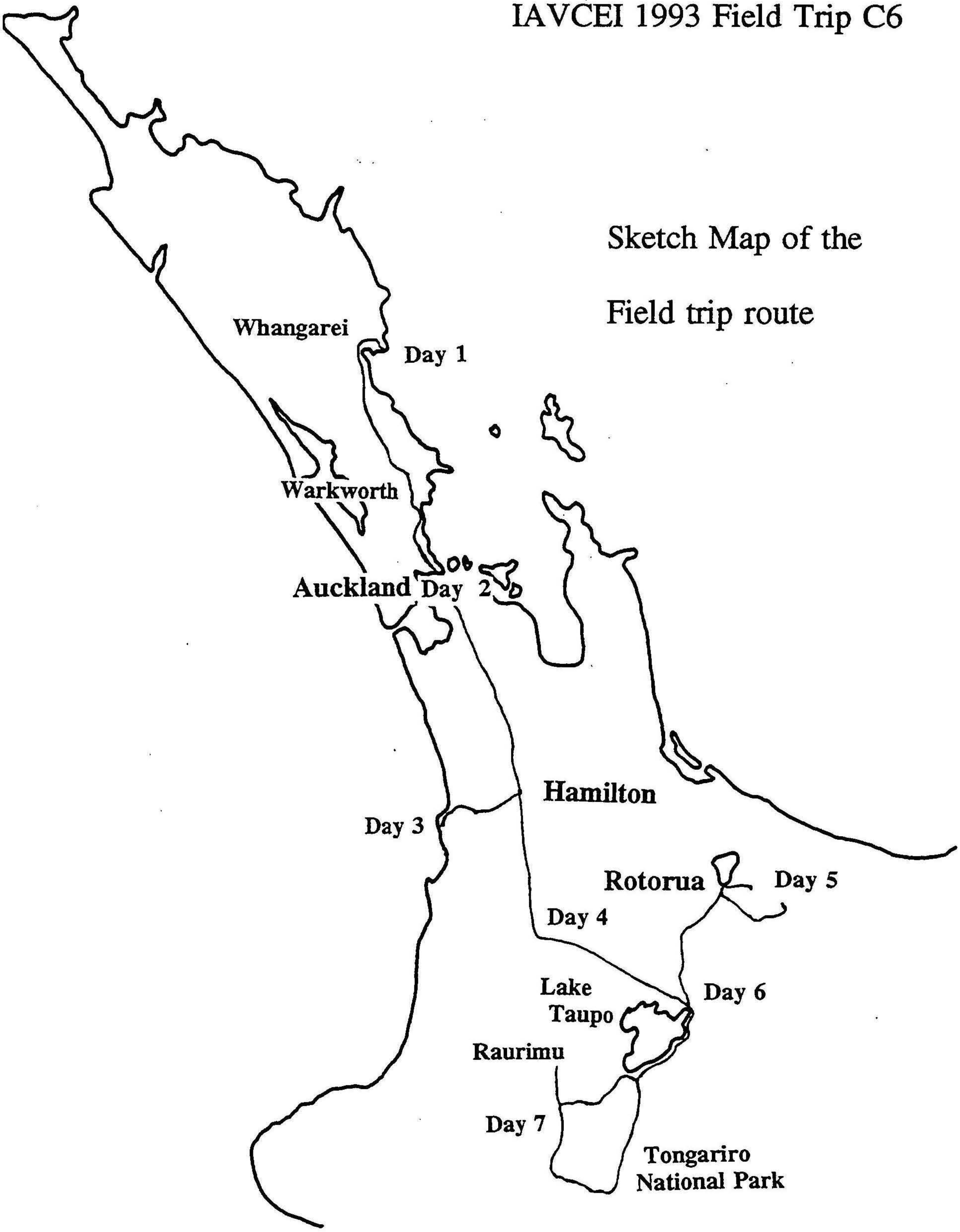
John A. Gamble (Department of Geology, Victoria University of Wellington)

IAVCEI 1993 Field Trip C6

Sketch Map of the

Field trip route



SYNOPSIS OF TOUR C6

Sunday 3rd October
Assemble in Auckland
Accommodation at Railton Hotel 411 Queen St., Auckland.
Evening free

<u>DAY 1.</u> **Monday 4th October** (pages 1-4)
Garnet-bearing andesites of Taurikura Volcano, Northland.
Depart 8am returning about 9pm. Dinner in Warkworth en route. The format of the day will be coach travel with stops to visit coastal exposures. The stops will involve short walks.
Accommodation at Railton Hotel 411 Queen St., Auckland.

<u>DAY 2.</u> **Tuesday 5th October** (pages 5-9)
The Auckland volcanic field
Depart 8.30 am by coach for excursion in Auckland City area and drive to Hamilton arriving about 6pm. The day will involve short walks and a boat trip.
Accommodation Southern Cross Motor Inn, 222 Ulster St., Hamilton.
evening free

<u>DAY 3.</u> **Wednesday 6th October** (pages 10-14)
Alexandra Volcanic Field
Depart 8.30am by mini buses for day in Raglan area returning about 6pm. The day will involve short walks.
Accommodation Southern Cross Motor Inn, 222 Ulster St., Hamilton.
evening free

<u>DAY 4.</u> **Thursday 7th October** (pages 23-24)
Taupo Volcanic Zone
Depart 8.30am by bus for excursion in the northwestern part of the Taupo Volcanic Zone including a visit to the Institute of Geological and Nuclear Sciences centre at Wairakei and ending at Rotorua about 6pm.
Accommodation Princes Gate Hotel, 1 Arawa St., Rotorua.
evening free

<u>DAY 5.</u> **Friday 8th October** (pages 25-26)
Rotorua area and Mt Tarawera.
Depart 8.30am by coach. This will be a long day with a long (about 7km) walk to the summit of Mt Tarawera. You will need good footwear as well as warm and protective clothing. Return about 6pm.
evening free

<u>DAY 6.</u> **Saturday 9th October** (pages 27-29)
Rotorua to Taupo
Depart 8.30am by coach, travel south to Taupo area and on to Raurimu arriving about 6pm.
Accommodation Slalom Ski Lodge, Raurimu
evening free

<u>DAY 7.</u> **Sunday 10th October** (30-31)
Andesite volcanoes of National Park.
Depart 8.30 for excursion in National park. The activity will depend on weather conditions but will include some walking if possible so be prepared. Return about 6pm.
Accommodation Slalom Ski Lodge, Raurimu
evening free

<u>DAY 8.</u> **Monday 11th October**

Raurimu to Auckland
Departure by coach at 8.30 for travel to Auckland and end of tour C6. Travel time should be about 4-5 hours.

Objectives of the Tour

The objective of the tour is to provide an overview of the different styles of volcanic association in the northern part of the North Island of New Zealand. Our emphasis is on the petrology of the rock types and is based mainly on recent work. We will also be seeing some of the variety of different kinds of deposit and discussing the types of eruption which produced them.

As far as possible we will be taking you to important localities where we have comprehensive petrological and geochemical data.

The days will be long and we will need to start early so we have left the evenings free. However we will be happy to discuss issues which have arisen during the excursion and will have on hand copies of recent publications for those who wish to follow up on particular topics.

All map references to the 1:50000 series 260 sheets.

Day 1 Garnet bearing andesites of Taurikura Volcano, Northland.

At Whangarei Heads on the eastern side of the Northland Peninsula there is the remnant of a large andesitic strato-volcano of lower Miocene age known as Taurikura. This volcano was approximately 30km across and remnants also occur on some of the islands offshore. Taurikura Volcano forms part of the lower Miocene arc-type volcanic association in Northland but is almost unique in containing garnet-bearing andesites.

Geology of the Northland Peninsula

The Northland peninsula extends for over 350km north of Auckland (fig.1). Although it represents a relatively small proportion of the total area of the North Island it contains the greatest variety of Cenozoic volcanic associations.

The geological record of the Northland Peninsula is dominated by volcanic episodes which reflect a complex tectonic history. Three main volcano/tectonic associations are recognised: a basaltic association of mainly MORB-type Cretaceous to Eocene rocks which is interpreted as an obducted ophiolite (Malpas et al., 1992); a lower Miocene arc-type assemblage of predominantly andesitic rocks (Smith et al., 1989); and a varied group of predominantly basaltic rocks of late Cenozoic age (Smith et al., 1993)

The oldest exposed rocks of the peninsula are a Permian to lower Mesozoic flysch-type sedimentary sucession which includes minor basaltic volcanics and associated cherts. These have been regionally metamorphosed to zeolite and prehnite-pumpellyite grade (Black, 1989). They are exposed mainly along the eastern margin of the Northland Peninsula where they typically form steep hilly country. These rocks which are broadly comparable to the basement formations of the main ranges further south are known as the Waipapa terrain.

Early Miocene (25-15Ma) arc-type volcanic rocks occur in two geographically and petrographically distinct belts of volcanic centres. The belts are 15-40km apart and in total extend the length of the Northland Peninsula. The known portions of the two belts have similar lengths although the eastern belt lies further north. A total of 12 spatially distinct groups of volcanic rocks can be recognised, each the remnant of a major volcano.

The western belt centres consist mainly of a variety of rocks dominated by basalts and basaltic andesites but ranging to rhyolites. The eastern belt contains basaltic andesite, andesite, dacite and rhyolite. Each volcanic centre can consist of various combinations of pillowed flows, pillow piles, hyaloclastics, massive lava flows, dykes, volcaniclastic mudflows, conglomerate, agglomerate, ignimbrite and sub-volcanic intrusive bodies. Dacite to rhyolite domes occur both within some of the centres and as exclusively felsic dome complexes aligned along major faults. The eastern belt centres are essentially subaerial, the western centres are a mixture of sub-marine and subaerial deposits. Erosion has reduced all of the centres to remnants which at times form spectacular landforms.

The arc-type volcanic rocks of Northland represent a lower Miocene volcanic arc linked to southwestward subduction subsequent to opening of the South Fiji Basin.

The youngest of the volcanic associations in Northland is represented by mainly basaltic rocks of the Northland intraplate basalt province (Smith, 1989). Intraplate volcanic activity began in Northland about 10Ma ago and by 8Ma had spread along much of the eastern side of the peninsula between Whangarei and Te Ngaire 100km to the north (Smith et al., 1993). In Quaternary times this style of volcanism has been confined to small monogenetic basalt fields at Whangarei, Kaikohe and Bay of Islands.

Rock types of the Northland intraplate basalt province are alkali, transitional and tholeiitic basalt together with hawaiite; intermediate and felsic rock types are rare and include peralkaline rhyolite. Although the volcanism followed closely the cessation of arc-type activity, there is apparently no trace of an arc-type signature in the geochemistry of these rocks (Smith et al., 1993) and they are interpreted as the result of small scale melting of small mantle plumes.

Garnet Bearing volcanic rocks in Northland.

Although arc-type volcanic rocks are widespread in Northland, garnet bearing examples are very restricted in their distribution. The most important garnet bearing localities are andesites and dacites at Whangarei Heads; two other important localities are a small sub-volcanic stock at Taipa 125km northwest of Whangarei and Whatupuke Island 25km southeast of Whangarei Heads.

Rock types associated with the garnet bearing andesites and dacites are strongly porphyritic, plagioclase-phyric basaltic andesite, andesite and dacite; mafic phenocryst assemblages most commonly consist of augite and hypersthene, augite and hornblende, or hornblende and biotite. The subordinate rhyolite in the Whangarei Heads area contains sparse phenocrysts of plagioclase, quartz and biotite.

Garnet occurs both as rare (<1%) irregularly distributed single crystals typically 1-5mm across and as rare clusters of crystals within rocks which typically have a very high (>50%) phenocryst content and SiO_2 >58wt.%. The garnets occur as euhedral discrete crystals with oscillatory zoning, resorbed crystals with no evident reaction rim or as resorbed crystals with pronounced reaction coronas of hornblende and/or plagioclase. Associated phenocrysts are mainly plagioclase, hornblende and minor ilmenite; biotite is found in the more Si-rich samples.

Xenoliths are a feature of many of the garnet-bearing outcrops in which they range from sparse to abundant (≤20 vol.%). They typically have maximum dimensions of 2-20cm, are rounded to subangular and equant to tabular in form. They have been classified as igneous (type 1) or metamorphic (type 2) (Day et al., 1992).

Garnet is extremely rare in volcanic rocks. It occurs as a rare accessory phenocryst phase in felsic calc-alkaline volcanic rocks (Birch and Gleadow, 1974; Wood, 1974) which are interpreted as S-type melts of lower crust. It is also associated with I-type volcanics in southeast Japan (Ujike and Onuki, 1976) and Hungary (Embey-Isztin et al., 1985). Host rocks are interpreted as shallow fractionates of hydrous peridotitic mantle at 10-15Kb (Japan; Tatsumi and Ishizaka, 1981; 1982) or as the product of fractionation of hydrous basaltic andesite magma within or at the base of the crust (Hungary,; Embey-Isztin et al., 1985).

Experimental work on garnet bearing andesite from Whangarei Heads (T.H. Green pers. comm.) has demonstrated that garnet is an equilibrium phase at pressures of 11-14Kb. The pressures estimated from phase assemblages of type-1 inclusions are similar (Day et al., 1992) and represent a depth of >35km which is deeper than the discontinuity of the crust-mantle boundary in Northland as determined from seismic reflection studies (Stern et al., 1987). Currently the type-1 inclusions are regarded as belonging to the same magmatic system as the volcanic rocks they are found in. The unusual occurrence of garnet in the andesites and dacites of Taurikura Volcano is attributed to low normative Di/Hy for the proposed basaltic andesite parent magma caused by assimilation of Al-rich crustal material in a crust-mantle interaction zone, together with an unusual tectonic situation causing extensive augite-hornblende fractionation from a hydrous magma at the critical pressure of 10-14Kb (Day et al., 1992).

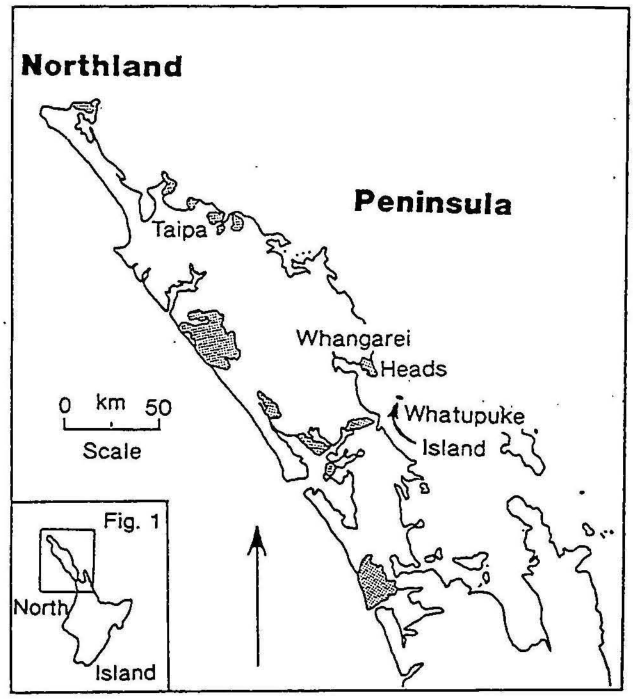


Figure 1. Distribution of the lower Miocene arc-type volcanic association (shown stippled) in Northland.

FIELD GUIDE

The drive north along State Highway 1 to Whangarei takes about 2 hours and passes through the towns of Warkworth and Wellsford. Much of the route passes through the Waitemata Basin, a sequence of lower Miocene volcanigenic sandstones and siltstones with some intercalated submarine debris flow deposits. These sediments are the time equivalent of arc-type volcanic systems of the Waitakere Hills to the west and the Coromandel Peninsula to the east. They were deposited in a deep marine basin between these two volcanic arcs. Sediments of the Waitemata basin are normally deeply clay weathered but some impression of their character can be gained from roadside exposures.

The topography here and further north in Northland consists of deeply dissected Pleistocene erosional terraces and there is a notable accordance in the heights of ridges and terrace remnants. The rivers are generally deeply intrenched and their lower reaches typically drowned. The grain of the country is mostly east-west and the road winds down into valleys and then up across interfluves.

North of Wellsford the nature of the geology and the topography changes. The sediments are now Cretaceous and lower Tertiary chaotic mudstones and sandstones of the Northland Allochthon (Ballance and Sporli, 1979). After the village of Kaiwaka the road passes through a series of dacite domes of lower Miocene age which are part of the Miocene arc-type association.

The road then climbs over the tilted basement fault block of the Brynderwyn Range (397m). At the top of the range there is a spectacular view toward Whangarei and the Whangarei Heads area. To the east are a group of small islands the largest of which is Taranga (Hen) Island consisting of andesitic rocks of Taurikura Volcano; the smaller islands are known as Marotiri (the chickens) and consist of basement intruded by lower Miocene granodiorite.

To the north and east are a series of ranges standing above a low lying surface developed on Cretaceous and lower Tertiary sedimentary rocks. The ranges extending along the eastern side of Northland are basement intruded by small dykes and stocks of diorite; to the west there are volcanic massifs consisting mainly of basalt and basaltic intrusives of the Northland Ophiolite.

North of the Brynderwyn Range the road runs close to the shoreline on Quaternary terraces and foredunes. Near Whangarei a prominent landmark on the eastern side of the road is the hill quarried for Cretaceous-Eocene limestone to supply the Portland cement works.

At Whangarei the route takes the road to Whangarei Heads. This follows the northern shore of Whangarei harbour. To the left the hills are initially lower Miocene dacite, then basement. There are also several small remnants of basalt lava flows along the left side of the road and at Onerahi the road crosses a large flat topped flow about 5Ma old. These basalt flows belong the late Miocene to Recent intraplate basalt association of Northland.

Stop 1.1 Munro Bay garnet andesite

The most interesting outcrop of garnet bearing volcanic rock in the Whangarei Heads area is on the shore platform between Reserve Point and Munro Bay (fig.2). Here, three dykes of hornblende-bearing andesite containing an unusually abundant and varied collection of xenoliths outcrop on the shore platform.

Garnet occurs in the host andesite as sparse discrete crystals up to 5mm across, and in rare crystal clusters. The other phenocrysts are plagioclase and hornblende. A whole rock chemical analysis of the host andesite is presented in table 1. The compositional range of garnet crystals is illustrated in figure 3.

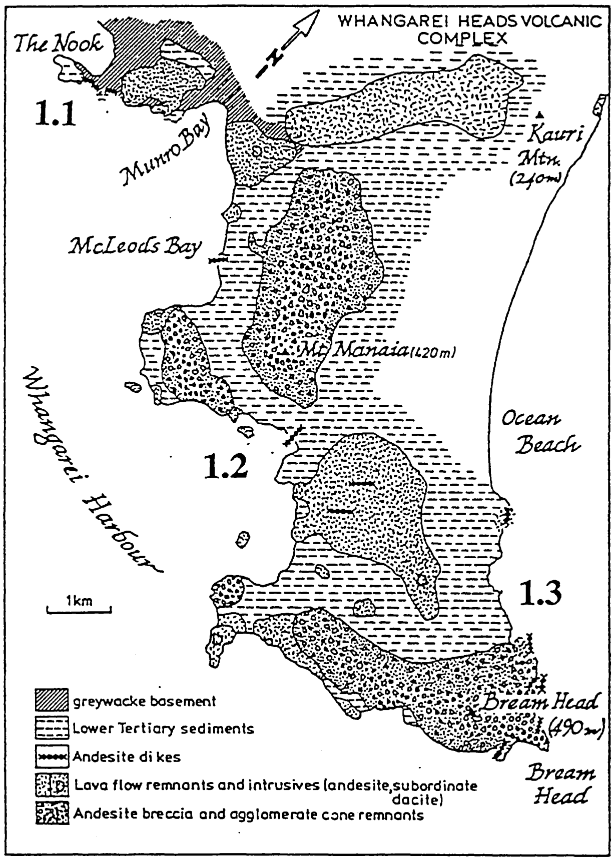


Figure 2. Shetch map of the Whangarei Heads area showing main localities.

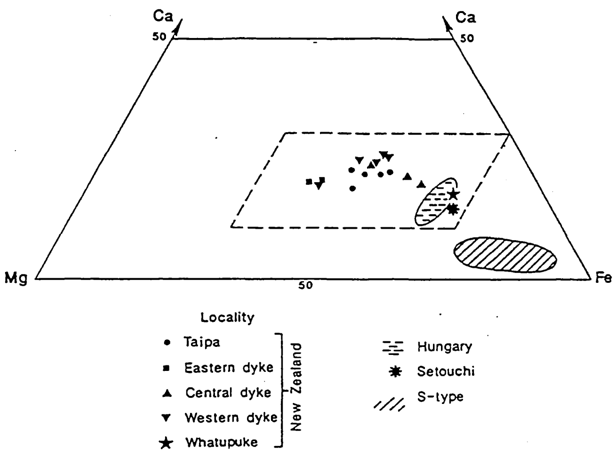


***Figure 3.** Composition of garnet crystals in the andesite at the Nook plotted in terms of Ca-Mg-Fe. Compositional fields or points for garnet from S-type volcanic and plutonic hosts and from I-type volcanic hosts are also shown for comparison. (After Day et al., 1992).*

Two main types of xenolith occur within the andesite at this locality:-

1. Foliated inclusions characterised by strongly foliated textures, basaltic compositions and a mineral assemblage of green hornblende, albite and quartz with minor epidote, Fe-Ti oxides and sphene. They have intermediate 87/86Sr ratios (.7034-.7048) and chemical compositions comparable to oceanic basalt.
2. Igneous inclusions composed of variable proportions of brown hornblende and plagioclase with or without orthopyroxene and clinopyroxene and rarely, garnet. These inclusions have a wide modal and bulk chemical range. Mineral compositions and 86/87Sr ratios (.7062-.7072) are similar to those of the host rock and other andesites of Taurikura Volcano.

Representative whole rock chemical compositions of the inclusions are presented in table 1. A discussion of their origin and significance is given in the introduction above.

Stop 1.2 McLeods Bay natural jetty and breccia.

At the western end of McLeods Bay are large blocks of a clast supported monolithic volcanic breccia. Clasts are porphyritic pyroxene bearing basaltic andesite and the matrix is tuffaceous. The blocks derive from the cliffs behind the beach. Examination of the cliffs reveals sheets of breccia with a weak stratification and a shallow dip. These are interpreted as thick debris flow deposits shed from a major volcanic edifice. The location of the eruption centre is not known. Breccia of this type is the predominant formation of Taurikura Volcano.

In the centre of McLeods Bay is a natural jetty formed by a dyke of augite andesite intruding limestone. This an exceptional example of a dyke and the local people take a considerable interest in its preservation. **No hammering please**

Stop 1.3 Ocean Beach garnet andesites

At the southern end of the beach there is a series of andesitic lavas and small intrusives which are typical of the range of rock types forming Taurikura Volcano; some of these rocks contain garnet.

At the northern end of the beach the outcrop is of intrusive hornblende bearing andesite; garnet is present as sparse individual crystals and in crystal clusters up to a centimetre across.

Table 1. Chemical compositions of volcanic rocks and inclusions from the Whangarei Heads area.

	1	2	3	4	5	6
wt.%						
SiO_2	54.94	59.34	64.01	45.69	44.79	48.36
TiO_2	0.67	0.59	0.52	1.06	1.04	2.15
Al_2O_3	16.54	16.11	16.78	17.12	16.79	13.86
Fe_2O_3	2.11	1.52	1.50	10.91	10.80	14.66
FeO	4.67	3.82	2.28	nd	nd	nd
MnO	0.13	0.09	0.06	0.18	0.17	0.23
MgO	6.36	5.11	2.48	10.43	10.02	7.09
CaO	8.05	5.73	5.17	10.76	10.58	9.98
Na_2O	2.81	3.87	3.74	1.77	1.83	2.58
K_2O	1.13	1.58	1.96	0.38	0.38	0.46
P_2O_5	0.12	0.14	0.12	0.12	0.12	0.24
LOI	1.11	1.37	0.97	1.19	2.88	2.39
Total	98.64	99.27	99.59	99.80	99.40	100.33
ppm						
Ba	250	323	490	70	146	17
Rb	47	92	74	<1	2	8
Sr	127	249	260	58	294	106
Zr	77	154	189	51	50	141
Nb	4	2	7	4	4	5
Y	34	7	16	29	30	44
La	10	7	14	<5	<5	9
V	145	96	54	354	134	354
Cr	319	325	109	1205	136	96
Ni	94	81	22	237	118	54
Cu	57	25	18	35	32	2
Zn	66	59	57	102	107	131

nd = not determined

1. AU33058 pyroxene andesite
2. AU331209 andesite (minor garnet and hornblende)
3. AU32967 garnet bearing andesite (stop 1.1)
4. NB19 type-1 inclusion, hornblendite
5. NB21 type-1 inclusion, hornblende garnet gabbro
6. NB2 type-2 inclusion, schistose metabasalt

Day 2 The Auckland Volcanic Field

The Auckland volcanic field is one of three late Pliocene and Quaternary fields of essentially basaltic volcanoes in the Auckland volcanic province (Smith, 1989). The field is small (20km radius, $7km^3$ erupted volume) and is made up of 49 discrete monogenetic eruptive centres occurring as tuff and cinder cones (fig.4). The earliest activity is thought to have been about 150,000 years ago and the most recent eruption was that of Rangitoto in about 1400AD.

Rock types in the Auckland volcanic field are most commonly alkali basalt and basanite with subordinate nephelinite but the most recent and largest eruption produced transitional and tholeiitic basalt. Petrographically they are variably porphyritic with phenocrysts of olivine and less commonly clinopyroxene (typically titaniferous) in a glassy to holocrystalline groundmass of plagioclase, clinopyroxene, subordinate olivine, accessory Fe-Ti oxides and in some specimens, nepheline. Larger olivine crystals (up to several millimetres across) found at a few centres are xenocrysts.

The eruption sequences at a number of the Auckland centres show a clearly developed trend in chemical composition from early nephelinite or basanite to later basanite or alkali basalt; at Rangitoto the trend is from tholeiitic to transitional basalt. This trend toward less fractionated magma within individual eruption sequences is interpreted as the result of successive tapping of a fractionated magma column and is remarkable in view of the very small volumes of magma represented at each centre.

The Auckland volcanoes were produced by a range of eruptive styles controlled by availability of water to the erupting vent. Wet eruptions have produced phreatomagmatic surge deposits (at water:magma ratios about 30%) and block and ash air fall deposits (at higher water:magma ratios) to build low tuff rings with characteristic wide craters. Dry eruptions have produced Hawaiian to Strombolian deposits of scoria to build small steep sided cones with well defined summit craters. Lava flows originate either by intense Hawaiian activity or from the quiet effusion of degassed magma toward the end of an eruption sequence.

Thirty four of the centres are principally phreatomagmatic in origin ranging from water dominated eruptions containing little or no juvenile magmatic material to magma dominated. Subsequent Hawaiian-Strombolian activity at 23 of these centres built cones within the tuff rings. Many of these small cones are complex 'castle and moat' structures. Twenty six of the Auckland volcanoes are small steep-sided cinder cones ranging in size from a few hundred square metres to more than $8x10^6m^2$. Fifteen lava fields and 10 minor lava flows extend beyond their original eruptive centres and lava was extruded at 7 other centres to form tholoids or lava ponds. The longest lava flow extends nearly 10km from source and the thickest accumulation of flows reached 60m. The total area of lava is about $75km^2$ and the largest individual area is the lava field of Rangitoto ($23km^2$).

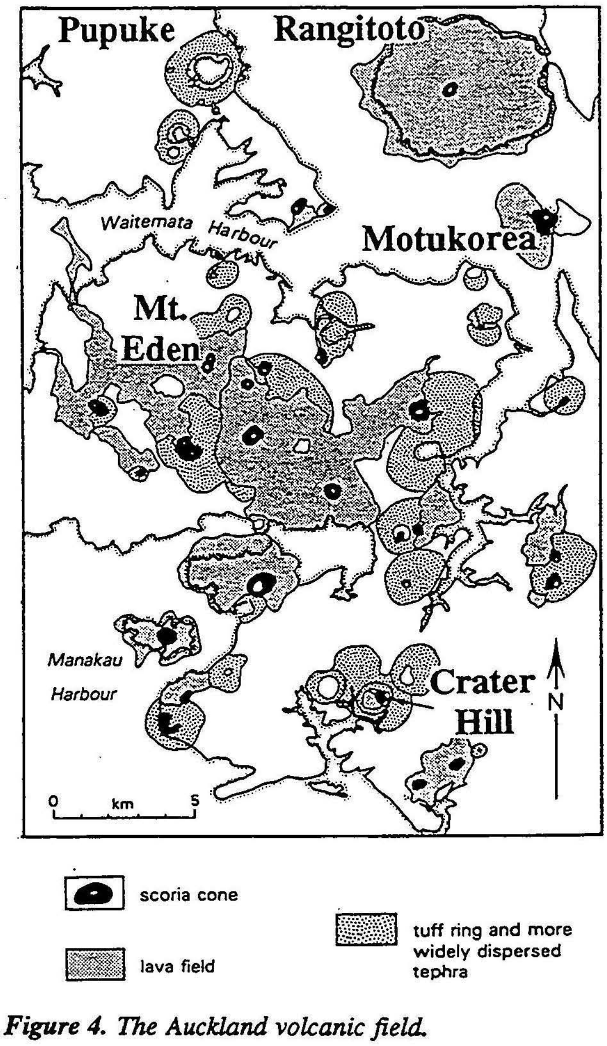


Figure 4. The Auckland volcanic field.

FIELD GUIDE

The route goes first to Mount Eden for a general view of the Auckland volcanic field. Thence over the harbour bridge and northern motorway to the Northcote Road exit and, skirting the Lake Pupuke tuff ring, to the northern end of Takapuna beach. From Takapuna Beach south to Devonport for a ferry ride around Motukorea to Rangitoto Island (lunch). Returning to Auckland City the excursion proceeds by bus to Crater Hill and from there south over the Bombay Hills (south Auckland volcanic field) and up the Waikato River Valley to Hamilton.

Stop 2.1 Mount Eden

Mount Eden is a fine example of an Auckland volcano. The most prominent feature is the cone itself with its well developed summit crater. There are some signs of the period after about 1400AD when Maori used the hill to construct a fortified village or Pa. Lava flows from vents low on the cone extend out from its base.

Stop 2.2 Takapuna Beach foreshore

Along the foreshore to the north of Takapuna Beach (fig.5) there are excellent exposures of lava flows which originated from Pupuke Volcano. Pupuke Volcano consists mainly of a wide explosion crater surrounded by a low angle tuff ring. The sequence of events from the centre is thought to have been an initial explosive phreatomagmatic phase which cleared the vent of water saturated material followed by the extrusion of lava accompanying Strombolian and Hawaiian eruptions. Finally, phreatomagmatic explosions from vents within the area of the present lake built the tuff ring. Lapilli tuff from this last eruptive phase overlies the lava flows between Takapuna beach and Thorne Bay. Thermoluminescence dating (Wood, 1991) suggests that Pupuke Volcano was active about 140,000 years ago.

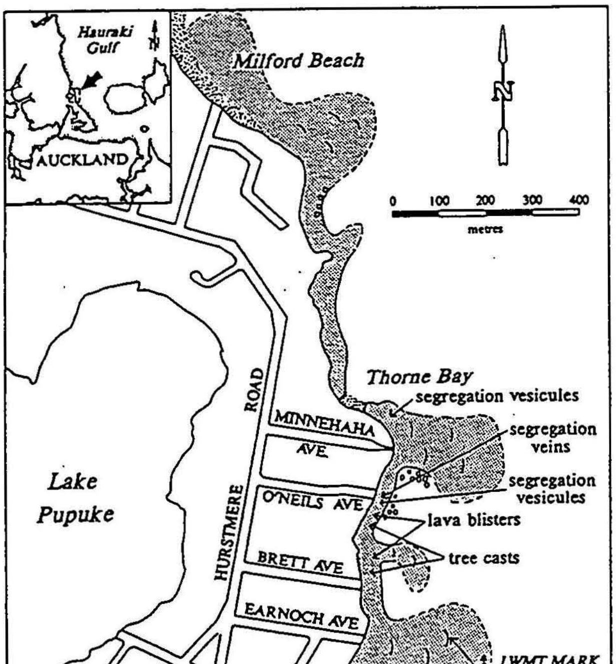


Figure 5. Location of features in the lava flows north of Takapuna beach.

The lava flows at Takapuna Beach overran a forest and several of the features including tree and branch casts are a direct result of this. However, there are also pahoehoe texture, gas blisters, pahoehoe toes and segregation veins and vesicles which are intrinsic to the flows themselves (Allen and Smith, 1992).

Tree moulds occur as circular structures either flat lying within the lava or as raised stumps above the surface of the shore platform. They typically have slightly raised rims and depressed or hollow centres. Cooling structures and flow bands are aligned concentrically to the rim and vesicles are concentrated in the bands. The preservation of these tree moulds is due to different response to erosion of the different parts of the two lava flows.

Tree casts of various sizes are preserved along the coast to the north and south of Brett Avenue. The largest is a vertical cast with a diameter of 1.3 metres and a depth of 3 metres representing approximately the thickness of the lava flow at this point. From examination of bark imprints on the interior walls of the cast it is thought to be of a Kauri tree engulfed in its growth position. Other well displayed tree casts are smaller and are most commonly disposed horizontally; they presumably represent branches or felled tree trunks.

The section of lava flow about 50m north of Brett Avenue reveals a number of roughly oval cross sectional forms fitted into each other with a more of less concentric arrangement of rows of vesicles and in some cases with open centres. These are pahoehoe toes developed as small protrusions in front of an advancing lava flow, a sucession of toes producing the interlocking texture observed. Most pahoehoe toes are solid or nearly so but some are hollow and since lava could not have drained from the inside to leave an open space these hollow toes are interpreted as balloon like blisters inflated by the expansion of gas within them. The lava blisters are cavities which occur near the top surface of the flow. They are distinguished by their characteristic oval or convex upward shape from tree moulds which are typically round in section. Some blisters have small spiky lava stalactites on their roof and lava driblets on their floor. Clearly the magma surrounding the blister was still hot and dripped from the upper to lower surfaces of the blister.

The local abundance of lava blisters in the Takapuna lava flows suggests an unusual quantity of gas and this is further indicated by abundant vesicles. Although many basalt lava flows do contain quite high concentrations of magmatic gas it is possible that in this case magmatic gas concentrations were augmented by methane produced by the hot anaerobic distillation of vegetation overrun by the flow.

Segregation vesicles appear as a vesicular film up to a few millimetres thick in the bottom of larger vesicles. They are interesting because they have a composition different from that of the lava flow as a whole and in some cases contain very small crystals of vapour phase minerals. They are thought to develop at an advanced stage in the cooling of the flow where vapour-rich magma accumulates and cools at the bottom of larger gas bubbles near the top of the flow.

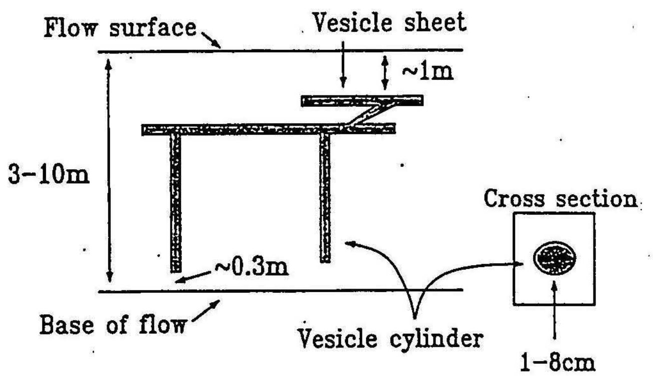


***Figure 6.** Schematic illustration of a cross section of a lava flow showing the typical spatial relationships between vesicle cylinders and sheets and their host flow.*

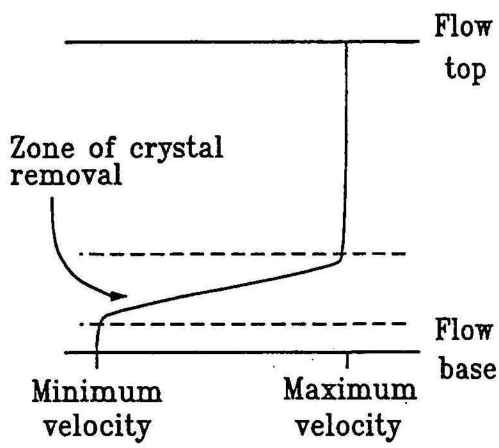


***Figure 7.** Plug flow velocity in a lava flow. The zone of highest shear is immediately above its base. From this zone crystals are mechanically elutriated to produce a chemically evolved liquid which is high in volatiles. With vesiculation of this layer a density instability develops and the evolved layer rises buoyantly to form cylinder and sheet forms in the upper part of the flow.*

Vesicle cylinders and sheets are analogous to segregation vesicles in that they are also features which develop late in the crystallisation of lava flows. They are lensoid to parallel sided elongate vertical (cylinders) or horizontally (sheets) oriented structures (fig.6) which are markedly more vesicular than the surrounding rock.

The vesicle sheets and cylinders have whole rock and mineral chemical compositions which are systematically different from that of the host flow (table 2). These differences can be modelled as the result of 51% removal of the observed mineral phases in the proportions olivine 17%, feldspar 24% clinopyroxene 9% and Ti-magnetite 1%. Fractionation clearly took place within the flow once it had come to rest and these features are interpreted as the result of flow differentiation in a layer of high shear above the base of the flow (fig.7).

Table 2. Representative chemical analyses showing the rang of volcanic rock compositions in the Auckland volcanic field.

No.	1	2	3	4	5	6
wt.%						
SiO_2	48.23	49.26	49.10	49.35	46.24	45.41
TiO_2	1.77	3.48	2.04	1.83	2.60	2.25
Al_2O_3	13.71	12.93	14.86	13.83	13.39	13.04
Fe_2O_3	13.58	15.95	12.59	12.38	14.55	13.58
MnO	0.18	0.23	0.17	0.18	0.17	0.18
MgO	10.04	4.38	8.36	9.61	8.40	10.98
CaO	9.38	9.17	9.65	9.59	8.98	9.94
Na_2O	2.45	3.33	2.83	2.62	3.67	3.30
K_2O	0.54	1.05	0.74	0.62	1.45	1.01
P_2O_5	0.22	0.44	0.27	0.25	0.66	0.43
LOI	0.12	0.12	0.05	0.05	0.00	0.11
total	100.22	100.34	100.66	100.31	100.11	100.23
Mg#	63.34	39.09	60.81	64.46	57.43	65.39
Ba	100	199	129	109	251	193
Rb	5	10	13	11	26	17
Sr	300	298	372	315	632	485
Zr	107	217	145	122	250	165
Nb	16	31	17	14	49	35
Y	19	37	22	23	22	20
La	10	20	13	14	43	31
V	190	302	229	214	201	204
Cr	317	22	280	355	0	381
Ni	256	40	147	193	193	203
Cu	86	144	65	71	157	nd
Zn	116	150	113	113	nd	nd

Total iron as Fe_2O_3. nd = not determined

1. AU44521 Basalt, Takapuna foreshore
2. AU44522 Vesicle cylinder, Takapuna foreshore
3. RT9 Rangitoto Island, olivine tholeiite
4. RT10 Rangitoto Island, olivine tholeiite
5. AU39359 basanite, Crater Hill
6. AU39371 alkali basalt, Crater Hill

Stop 2.3 Motukorea

Motukorea (Browns Island) is thought to have erupted about 8000years ago and is therefore one of the youngest of the volcanoes in the Auckland field. Initial eruptions were phreatomagmatic and involved relatively homogeneous, weakly vesiculating magma and copious amounts of water from an aquifer at the base of the Waitemata Group sediments. The early eruptions constructed a thin-bedded tuff ring which is now well exposed in the cliffs at the eastern end of the island. Detailed analysis of these tuffs shows them to be mainly small volume surge deposits.

The consumption or exclusion of water from the vent by construction of the tuff ring resulted in successively drier eruptions. Deposits in the upper part of the tuff ring are indicative of an alternation of open-vent conditions, magma ponding and weakly phreatomagmatic eruptions; the latter is the result of weak recharge of the aquifer and explosive disruption of magma pond crusts.

Subsequently, truly Strombolian eruptions led to an alternation of scoria cone formation with accompanying tuff-ring and scoria-cone breach. During the final stages of the eruption sequence a scoria cone was constructed.

The eruptive history of Motukorea Volcano is clearly seen in the geomorphology of the island. The differing eruptive styles which have build the island are a consequence of differing vent parameters acting on a single batch of basanitic to nephelinitic magma. It is an example of a complete sequence of the types of eruption which have occurred in the Auckland volcanic field.

Although we will not land on Motukorea, the main features of its eruptive history can be clearly seen as we cruise around the island. Approaching from Auckland the flat areas on the western side of the island are lava ponds and flows. Scoria mounds above these are remnants of early cones. The main cone building episode produced the symmetrical central cone with a well developed crater. The early tuff cone is breached toward the west and is clearly seen forming the eastern end of the island.

Stop 2.4 Rangitoto Island

Rangitoto is the largest and youngest of Auckland's volcanoes. Radiocarbon dates and palaeomagnetic measurements indicate that it was active about 1400AD although no Maori legends record the event despite clear evidence of their presence at the time. The total volume of the cone is estimated at 2.3km3 (2.0 DRE) or 57% of the total volume of magma erupted in the field. The magma erupted differs from that produced from the other centres in the field in that is mainly olivine tholeiite with subordinate transitional tholeiite. This intriguing change in the nature of erupted magma in the most recent (and biggest) volcano signals a change in the conditions of magma generation perhaps to larger scale partial melting of a shallower source. Some idea of the range of compositions in Rangitoto volcano is given by the two analyses in table 2.

The initial eruption from Rangitoto occurred at a time when sea level was essentially as a present. Early activity must have involved phreatomagmatic explosions although no evidence for this is now exposed. Hawaiian to Strombolian activity built the island to its present elevation and lava effusion from vents high on the flanks of the cone together with fire fountains fed the flows which produced the near-circular gently sloping lava field which forms the lower slopes of the island (fig.8).

The Rangitoto Volcano represents the eruption of a single batch of magma over a period of months to years. Although big on an Auckland scale the eruption was small in an international scale and its effects very localised. There is no evidence for Rangitoto ash on the city side of the island but air fall deposits from the eruption do occur along a north easterly dispersal axis on adjacent Motutapu Island.

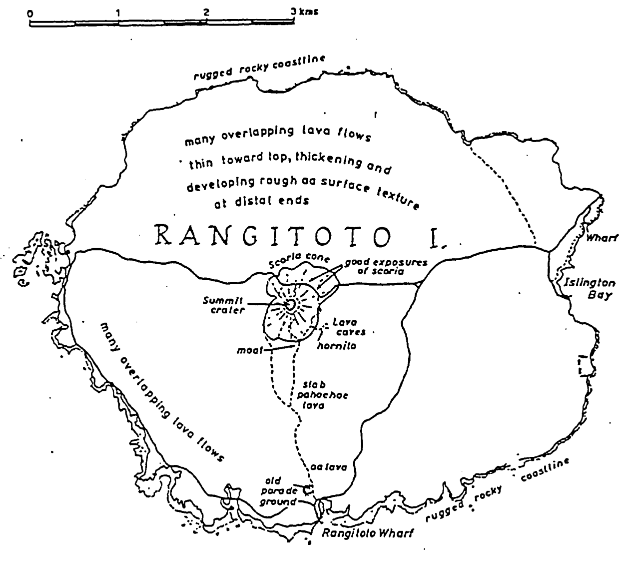


Figure 8. Rangitoto Island.

The walk from Rangitoto wharf to the summit takes about 1 hour. In the initial stages it climbs up a moderately thick lava flow where there are good examples of slab-pahoehoe texture, medium scale flow structures and marginal levees. Higher in the lava field, abrupt changes in slope signify flow fronts and, as the top of the field is approached the flows become steeper and thinner. The 'moat' at the top of the lava field is a collapse feature probably related to withdrawal of magma from high level storage chambers. A tube and trench system is exposed at this level along a side track to the east of the main summit route. Above the moat the track climbs the flanks of the summit scoria cones - there are in fact three distinct cones each with a summit crater. The reward for climbing Rangitoto comes at the summit where there is a panoramic view of the Auckland area.

Stop 2.5 Crater Hill Quarry

Crater Hill is one of a group of volcanos in the southern part of the Auckland field known as the Papatoetoe centres. It consists of 4 near-concentric landforms, now severely modified by quarrying. In order of eruption these are, the outer tuff ring, the inner scoria rampart, the lava shield and the innermost scoria cone (fig.9). Six pyroclastic units were deposited during the Crater Hill eruption, 2 phreatomagmatic (P1, P2) and 4 magmatic (S1-4).

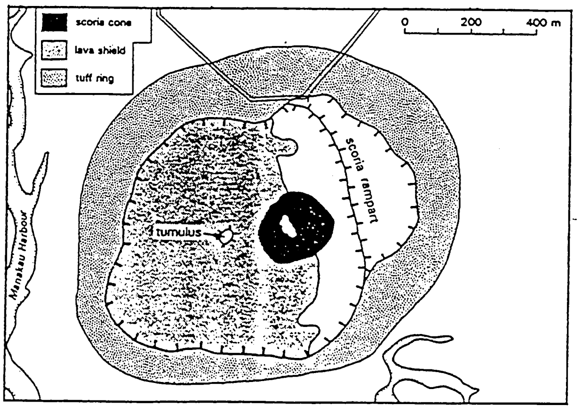


Figure 9. Interpretive diagram showing the main features of Crater Hill (from Houghton et al., 1991).

The Crater Hill eruption is thought to have taken place about 28,000 years ago. Evidence for this is the existence of rhyolitic tephra correlated with the 22,500 year eruption from Taupo overlying Crater Hill tephra in the southeast corner of the quarry. Confirmation of this general age comes from evidence for a magnetic excursion recorded in Crater Hill rocks which has been tentatively correlated with an excursion recorded elsewhere at 25-30Ka (Shibuya et al., 1992).

The deposits of the Crater Hill eruption have been well exposed by quarrying. The outer tuff ring is near circular, 450-550m wide and 9-15m high. It was constructed principally in 2 stages, an early phreatomagmatic phase (P1) and a later magmatic phase (S1); these are the prominent light and dark bands in the face at the back of the quarry. The overlying beds (P2) are essentially synchronous with the collapse of the inner walls of the tuff ring to form a maar.

The inner scoria rampart is constructed from the S2, S3 and S4 magmatic phases. Remnants of the rampart are preserved only in the northern and eastern part of the quarry between the outer tuff ring and the inner scoria cone. The magmatic activity which produced these deposits ranged from Strombolian to Hawaiian; in at least one instance intense Hawaiian fountaining produced a lava flow.

The remnants of lava flows forming a shield within the outer tuff ring can be seen along the southern and western crater walls. The shield was originally 300m wide and has been strongly modified by collapse of its core at or after the close of this phase of the eruption. The margins of 2 or possibly 3 individual lava flows can be traced from aerial photographs. A mound near the centre of the shield is a tumulus on the youngest flow.

The final phase of Crater Hill volcanism built a 20m high 180m wide scoria cone on the northern margin of the lava shield. Quarrying has removed all but the core of the cone now marked by a steeply-dipping dyke which intrudes pervasively oxidised and densely welded air fall scoria.

The clear progression of deposits at Crater Hill has provided an ideal situation to sample through an erupted batch of magma. Chemical analyses of clasts in the pyroclastic deposits and of lava flow samples, has revealed a systematic variation in the composition of erupting magma. The early magma was a basanite with Mg number of 57, the last magma to erupt was alkali basalt with Mg number of 65. The range in composition represented by the erupted material is illustrated by the 2 analyses in table 2.

Interpretation of the chemical variation in the Crater Hill deposits is providing an intriguing puzzle. Although trends appear to result from crystal fractionation they cannot be modelled as the result of removal of the observed phenocryst phase - olivine. Fractionation, if that is the explanation, must have involved a Ca-bearing phase. The current suggestion is that fractionation of a parental Crater Hill magma took place at sub-crustal depths where pyroxene was a liquidus phase, and that the magma batch rose as a fractionated column.

Day 3 Alexandra Volcanic Field

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Introduction

As participants presumably have already noted, this excursion has as one of its emphases volcanic provinces northwest and north of the Taupo Volcanic Zone that are dominated by basalts. An exceptionally interesting such province is the Alexandra Volcanic Group ("AVG") of the Waikato Region. Edifices of the AVG are well aligned along a northwesterly lineament (Briggs 1983; Briggs and McDonough 1990; fig. 10), were active during late Pliocene and early Pleistocene times (Briggs et al., 1989), and erupted both alkalic (Okete Volcanics) and calc-alkalic (Pirongia and Karioi Volcanics) magmas (Briggs and McDonough 1990). Recent studies of the Karioi volcanic edifice, at the far northwestern limit of the AVG (fig.11) suggests that there is some kind of genetic link among the alkalic magmas of the Okete Volcanics, which both pre- and post-date construction of Karioi, and the calc-alkalic magmas of Karioi itself. Both the nature of this putative link, if indeed it exists, and the character of controls on the location and volume of individual volcanoes within the AVG are matters of considerable interest not only to those working on North Island volcanism but in the context of convergent margin volcanism and tectonism worldwide.

This excursion will focus on the Karioi edifice, both to outline recent results of our stratigraphic studies and to call attention to interesting questions that have arisen from those studies. We shall examine in detail outcrops in and near Te Toto amphitheatre, a critical locality for understanding the stratigraphic succession and petrologic evolution of Karioi. We shall also examine more briefly three areas of special interest in exemplifying the stratigraphic successions of the Okete and Karioi Volcanic Formations. Figure 12 schematically indicates results of reconnaissance mapping of the Karioi edifice, based on work by Matheson (1981) and, more recently, ourselves, and show locations of stops 3-6.

FIELD GUIDE

stop 3.1. Raglan saddle.

At this stop participants will be able to view much of the AVG, especially its central part dominated by Pirongia, the largest volcano of the AVG. The general field setting of the AVG will be outlined (see fig.10).

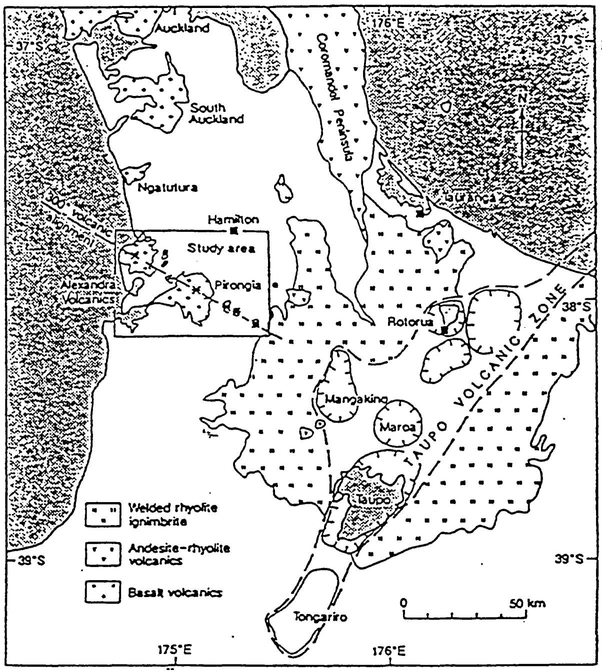


Figure 10. Map of the central North Island, New Zealand, showing the tectonic setting and volcanic alignment of the Alexandra Volcanic Group in relation to the Taupo Volcanic Zone.

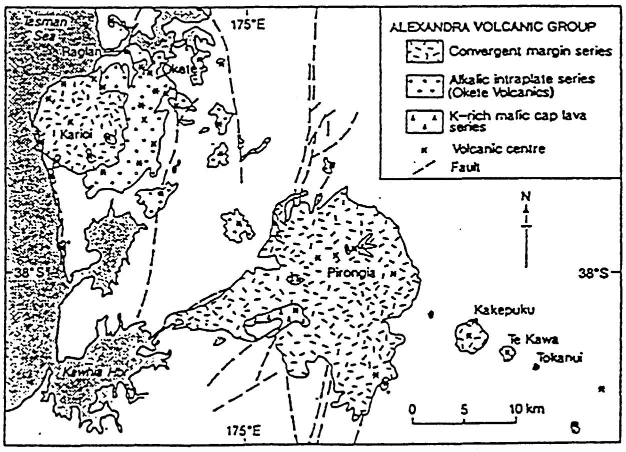
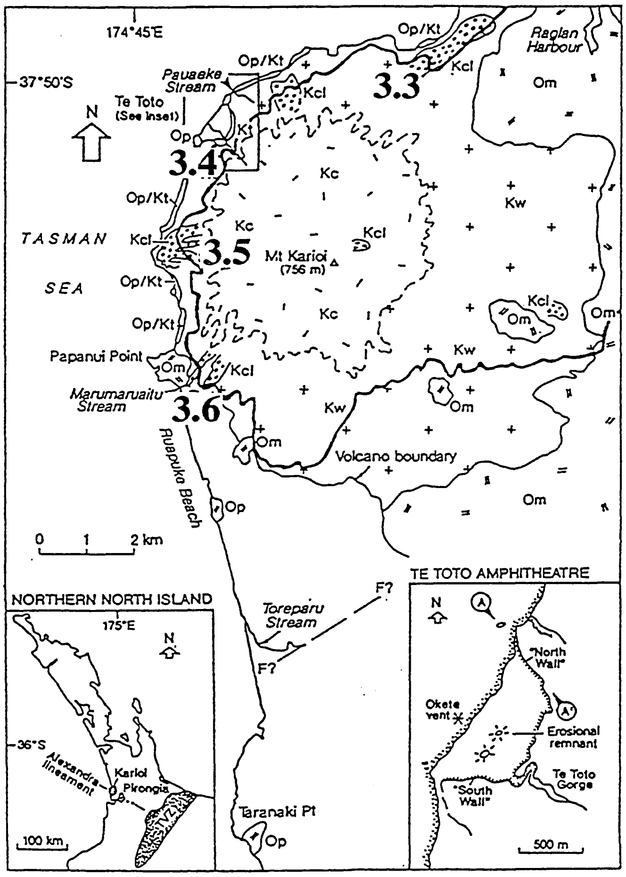


Figure 11. Distribution of the calc-alkalic lavas (Karioi, Pirongia, Kakepuku, Te Kawa, Tokanui) and alkalic basalts (Okete Volcanics) of the Alexandra Volcanic Group.

Stop 3.2. Overview from the northeast of Karioi.

The profile of what remains of the Karioi edifice can be examined here. Its central part was a moderate-sized composite cone, but that has been heavily eroded. The present highest point is a hornblende-andesite dike, markedly eccentric to the centre of the former cone and perhaps representing a late-stage large subsidiary vent. A subtle break in slope on the skirts of the edifice can still be distinguished, and marks the contact between the outermost parts of the composite cone and the subjacent shield volcano on whose slopes the cone had been built. We have defined three members of the Karioi Volcanic Formation, primarily on the basis of work in and near Te Toto amphitheatre, shown schematically in Figure 12 and as a generalized section in Figure 13. The break in slope that can be seen at Stop 3.2 occurs between the second and third of these members, the Whaanga (shield building) Member and the Wairake (cone building) Member, but is too vague to be of use in defining these stratigraphic units.



LEGEND

Karioi Volcanic Formation

Kc Wairake Member: Cone-building lavas, tuffs, dikes, volcanic breccias, laharic deposits (Kcl), and valley-filling lavas

Kw Whaanga Member:- Sheet lavas, volcanic breccias, minor interbedded tuffs, and rare dikes

Kt Te Toto Member: Lavas, volcanic breccias, interbedded tuffs

Okete Volcanic Formation

Om Marumaruaitu Member: Lavas and interbedded tuffs postdating Karioi volcanics

Op Pauaeke Member: Lavas, lapilli tuffs predating Karioi volcanics

Figure 12. Map of Karioi volcano showing the distribution of volcanic formations and members. Some data from Matheson (1981) and Keane (1985).

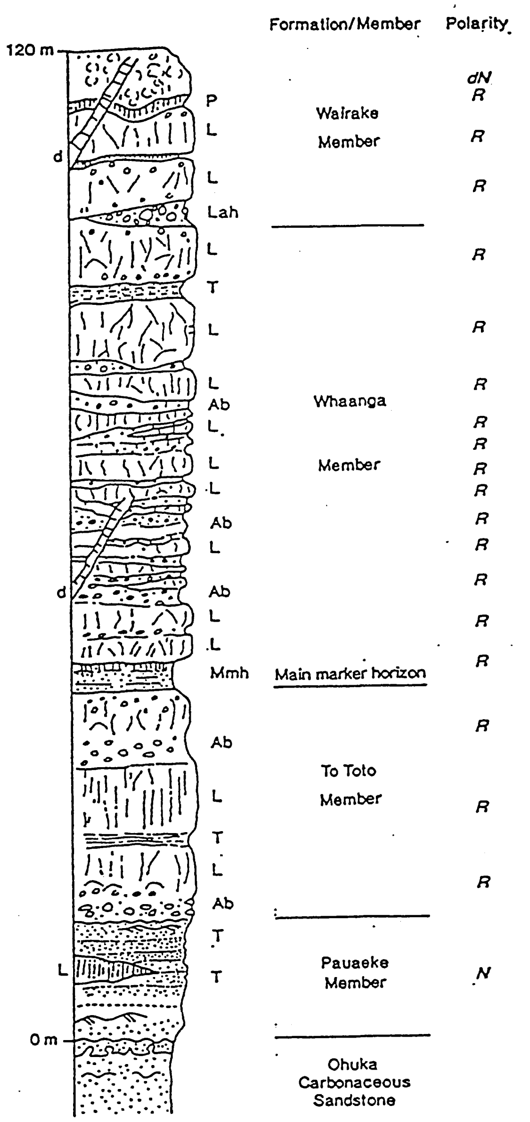


Figure 13. Composite stratigraphic section through the Karioi Volcanics exposed in the south wall of Te Toto amphitheatre and in Te Toto Gorge. L = lava; Ab = autoclastic breccia; T = tuff and lapilli tuff; d = dike; Lah = laharic deposit; Mmh - main marker horizon; P = paleosol.

Stop 3.3. Wainui Road section near Manu Bay.

In this small roadcut a Karioi lahar overlies distal TVZ rhyolitic air-fall ash. Laharic deposits are a characteristic feature of the Wairake Member of the Karioi Volcanic Formation, and the early lahars generated by the Wairake composite cone probably were relatively limited in their distribution. Thus this distal lahar probably was deposited late during Wairake times. That tentative inference still makes the underlying air-fall ash a product of an eruption during early Matuyama Chron, about 2.2 to 2.3 Ma ago.

Stop 3.4. Te Toto amphitheatre and environs.

This "Stop" is in reality a complex of stops. We shall begin with a general overview of Te Toto amphitheatre from the parking area off Whaanga Road. Then, we shall examine the roadcut just east of the parking area, where are exposed uppermost units of the Whaanga Member (including a strikingly plagioclase-phyric lava that serves as a good marker in this general area), the erosional unconformity that caps the Whaanga units, the basal Wairake lahar in this area, and three Wairake lavas above that lahar (fig.14). Participants shall then follow the trail down into Te Toto Gorge and amphitheatre, to encounter: a) the vent-proximal facies of the Te Toto Member of thick calc-alkalic lavas and breccias near the base of the trail; b) the Pauaeke type section at the seaward end of the North Wall of the amphitheatre (fig.15) (examining archaeological features en route); c) lunch; and d) Okete (Pauaeke Member) lavas and enclosed xenoliths, and contacts with underlying Ohuka Carbonaceous Sandstone beds, near the end of the South Wall.

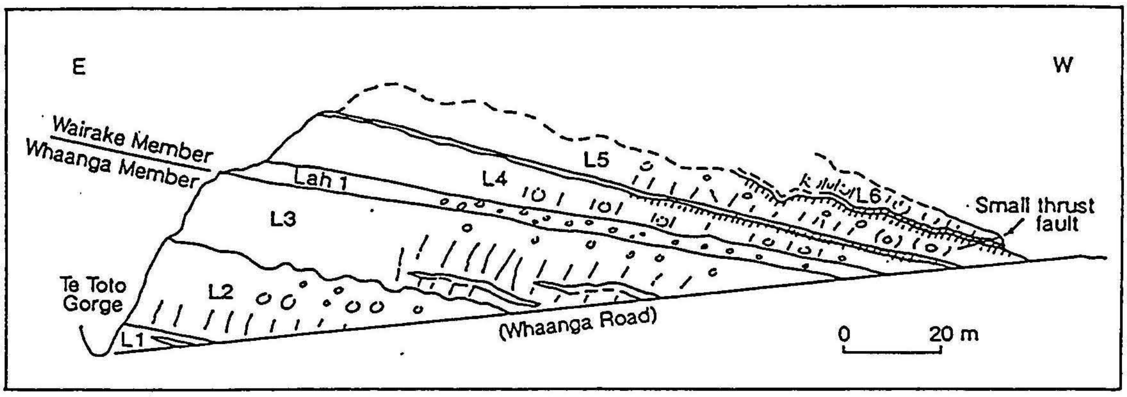


Figure 14. *Sketch of lava flow sequence (L1 - L6), with intercalated laharic deposit marking the local base of the Wairake Member, at the Whaanga Road section in Te Toto Gorge.*

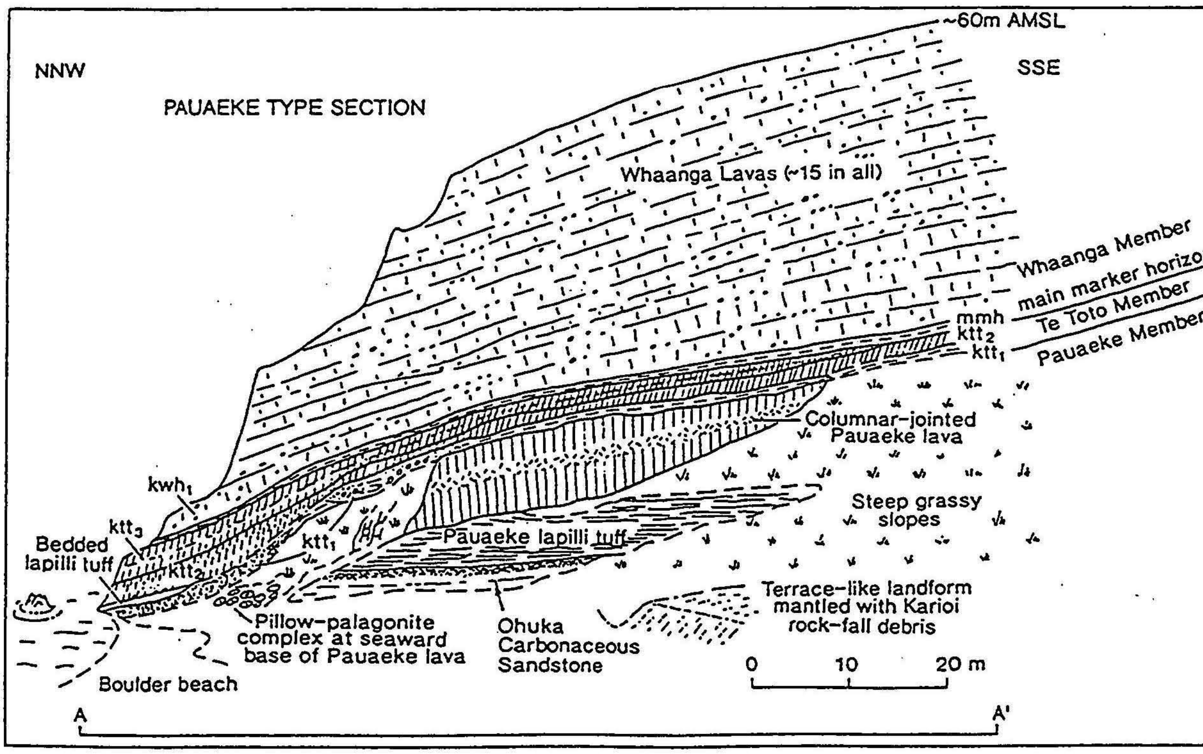


Figure 15 *Sketch of Panaeke type section at the north wall of Te Toto amphitheatre (from A to A^1 in inset map of fig.12). Ktt_1 - Ktt_3 are Te Toto Member lava flows overlying Pauaeke lava; mmh - main marker horizon; kwh_1 = basal Whaanga lava.*

While in Te Toto amphitheatre, participants will see some of the indications of a close relationship between the Pauaeke Member of the (alkalic) Okete Volcanic Formation and the Te Toto Member of the calc-alkalic Karioi Volcanic Formation. These indications include suggestions of a relatively short interval between cessation of eruption of Pauaeke magmas and beginning of Te Toto activity, and evidence that both sets of magmas were erupted from small central vent volcanoes under much the same kinds of structural control. In figure 16 below, we show schematic normalized 'spidergrams' for data on rocks from these two units. There is a tendency for some of the Pauaeke lavas to have greater Ba contents than Te Toto lavas, and there is a strong contrast in Nb abundance as commonly observed between these magma types; Pauaeke lavas also have greater contents of LREE, Sr, P, Zr and Ti. Microprobe studies of selected specimens are underway, to see if there is any evidence that Pauaeke alkalic magmas were transformed into calc-alkalic strikingly augite-phyric Te Toto ones by zone-refining reactions somewhat like those described (in a different context) by Kelemen (1990).

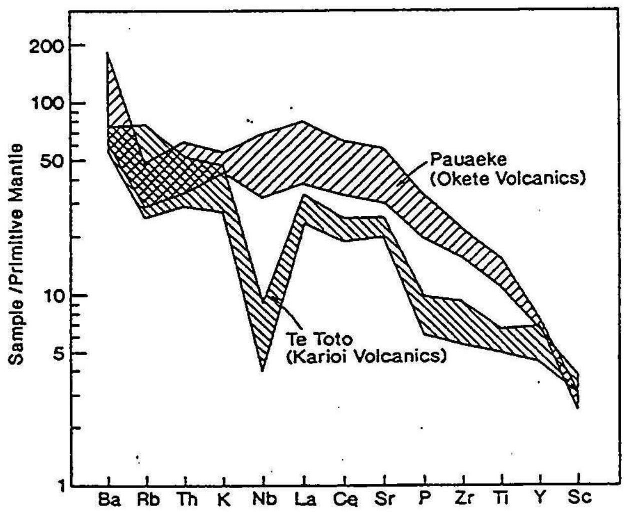


Figure 16 Primitive mantle normalized diagram for Pauaeke Member (Okete Volcanics Formation) and Te Toto Member (Karioi Volcanics Formation) lavas from Te Toto amphitheatre.

Stop 3-5.Laharic deposits near "Jackson's Cut" section of Matheson (1981).

Here we shall examine briefly a road cut through a coarse lahar of the Wairake Member. The variety of lithologic types present in this laharic deposit indicates something of the diversity of products of the Karioi volcano during this, its last notable, stage of construction. It seems likely that many small magma chambers, located beneath the edifice at depths such that they could lose heat and therefore fractionate rapidly, were present during construction of the Wairake composite cone. These then gave rise to diverse eruptive or shallow intrusive products, unlike the Te Toto and most of the Whaanga units which display only limited diversity.

Stop 3.6. Type section of the Marumaruaitu Member of the Okete Volcanic Formation, at and near the north end of Ruapuke Beach.

Figures 17A and 17B show schematically a map of this area, and three informative cross-sections. The Marumaruaitu Member is defined as that part of the Okete Volcanic Formation which can be shown to overlie Wairake Member units of the Karioi Volcanic Formation. Here, Marumaruaitu lavas overlie two well developed Wairake lahars, themselves overlying a distal Karioi basalt cut by a small fault. At least at the type locality, two Marumaruaitu lavas at the base of the section show transitional palaeomagnetic character, suggesting that further magneto-stratigraphic work may allow identification of Marumaruaitu units not directly associated with units of the Karioi Volcanic Formation. Marumaruaitu lavas along this part of the Tasman Sea coast in general are overlain by Pleistocene sands of the Awhitu Formation.

From this stop, we shall return to Hamilton.

Summary

The Karioi volcanic edifice is only roughly 70 km^2 in area, yet shows a remarkable diversity of magma types and physical volcanological processes. Early alkalic magmas brought an extraordinary array of mantle-derived xenoliths to the surface. The Pauaeke lavas and tuffs were succeeded after (apparently) only a short pause by calc-alkalic augite-phyric Te Toto breccias and lavas. Vents for both Pauaeke and Te Toto eruptions built small volcanic centres, with locations apparently controlled by (?)regional-scale fault systems. After a hiatus (marked by the transgressive erosion surface beneath the 'main marker horizon', and by the 'main marker horizon' itself), the Whaanga shield was built by a series of fissure eruptions some of which are represented by dikes visible in the walls of Te Toto amphitheatre. Field evidence suggests that recurrence intervals between Whaanga eruptions initially were short, but became longer (allowing incision of the shield by streams) late in Whaanga times. A proto-Wairake composite cone may have been under construction before Whaanga eruptive activity had completely died away, but the exact temporal relationship between fissure eruptions that built the Whaanga shield and central vent eruptions that built the Wairake cone can only be determined by mapping in detail. The first clear indication of the existence of the Wairake cone in most locations is laharic debris. These same laharic deposits may afford the most complete presently-recoverable record of Wairake volcanism, although owing to the alteration of most such deposits deciphering that record would be difficult. At least one of those lahars, that seen at Stop 3.3, provides a valuable indication of the age of initiation of TVZ volcanism.

Late in the history of the Wairake composite cone, it was intruded by at least one large hornblende andesite dike. That dike may have fed a flow of similar lithologic character, found on the western slopes of the edifice.

A curious feature of the volcanic history outlined here, as we presently know it, is that there seems to be an antithesis between alkalic Okete volcanism and calc-alkalic Karioi volcanism. We have found no instance of an alkalic eruption contemporaneous with or interdigitating with products of calc-alkalic eruptions. Our stratigraphic control is far from tight, however, and details of the temporal relations among units of the five member-scale stratigraphic entities we have defined require much further study.

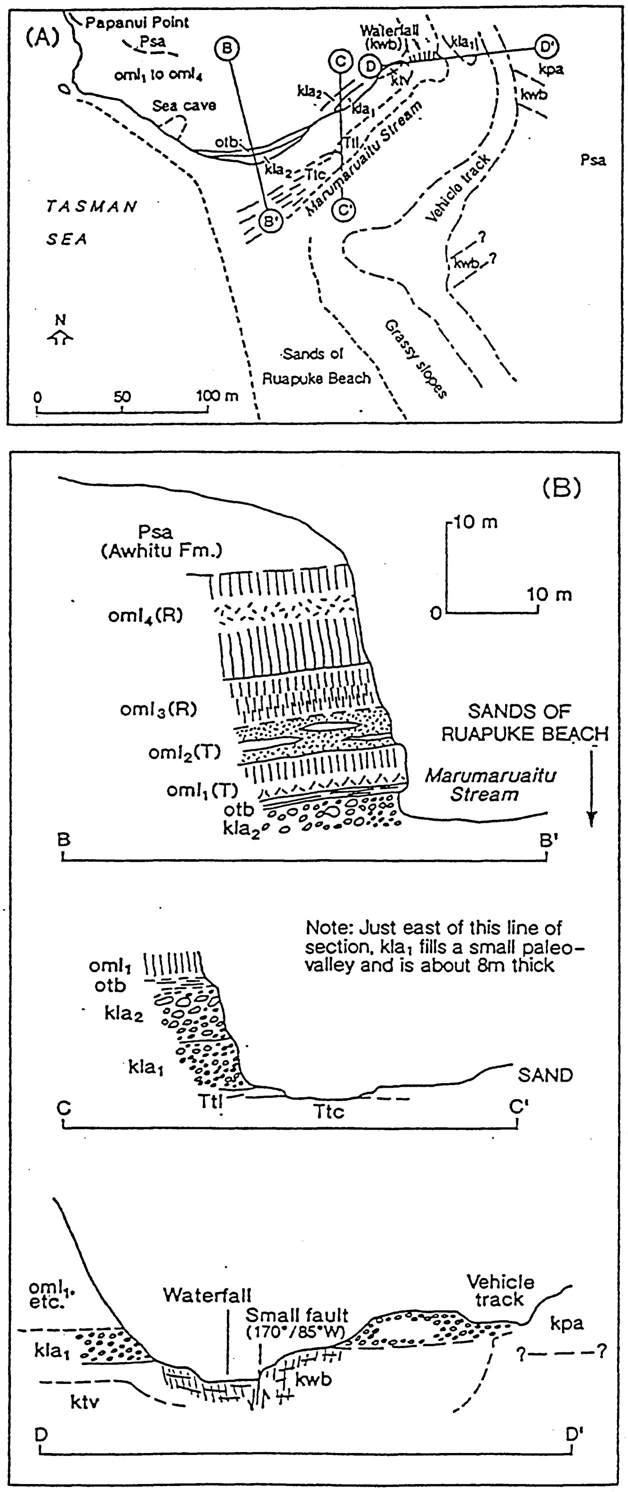


Figure 17.

(A) Geologic map of northern end of Ruapuke Beach. Ttc - Tertiary chalazoidite tuff; Ttl = Tertiary lapilli tuff; Ktv = Karioi tuff; Kpa = Karioi basaltic andesite; Kwb = Karioi basalt exposed in waterfall; Kla_1 and Kla_2 = laharic deposits; otb basal Marumaruaitu Member tuff; oml_1 - oml_4 = Marumaruaitu Member lavas; Psa = Pleistocene eolian sands of Awhitu Formation.

(B) Sketches showing stratigraphic relations of Marumaruaitu Member units overlying Karioi units at north end of Ruapuke Beach. (Locations of sections shown in Fig. 8A.) oml_2 consists of discontinuous sheet lavas with autoclastic breccias. ***T*** *= paleomagnetically transitional;* ***R*** *= reversed.*

Days 4-7 Taupo Volcanic Zone

Introduction

The Taupo Volcanic Zone (TVZ) is a Quaternary volcanic arc associated with subduction at the southern end of the Tonga-Kermadec arc-trench system. At least 10,000km^3 (dense equivalent) of volcanic rocks have been extruded during the last 2Ma along the 200km long segment of continental arc extending between White Island in the Bay of Plenty to Ruapehu in the central North Island. These consist dominantly of rhyolite lavas and pyroclastics (80% by volume) with subordinate andesite, dacite and basalt. The observed crustal heat transfer of about 5650Mw is anomalously high and correlates with the fact that the TVZ is one of only a few currently active large scale rhyolitic systems on earth.

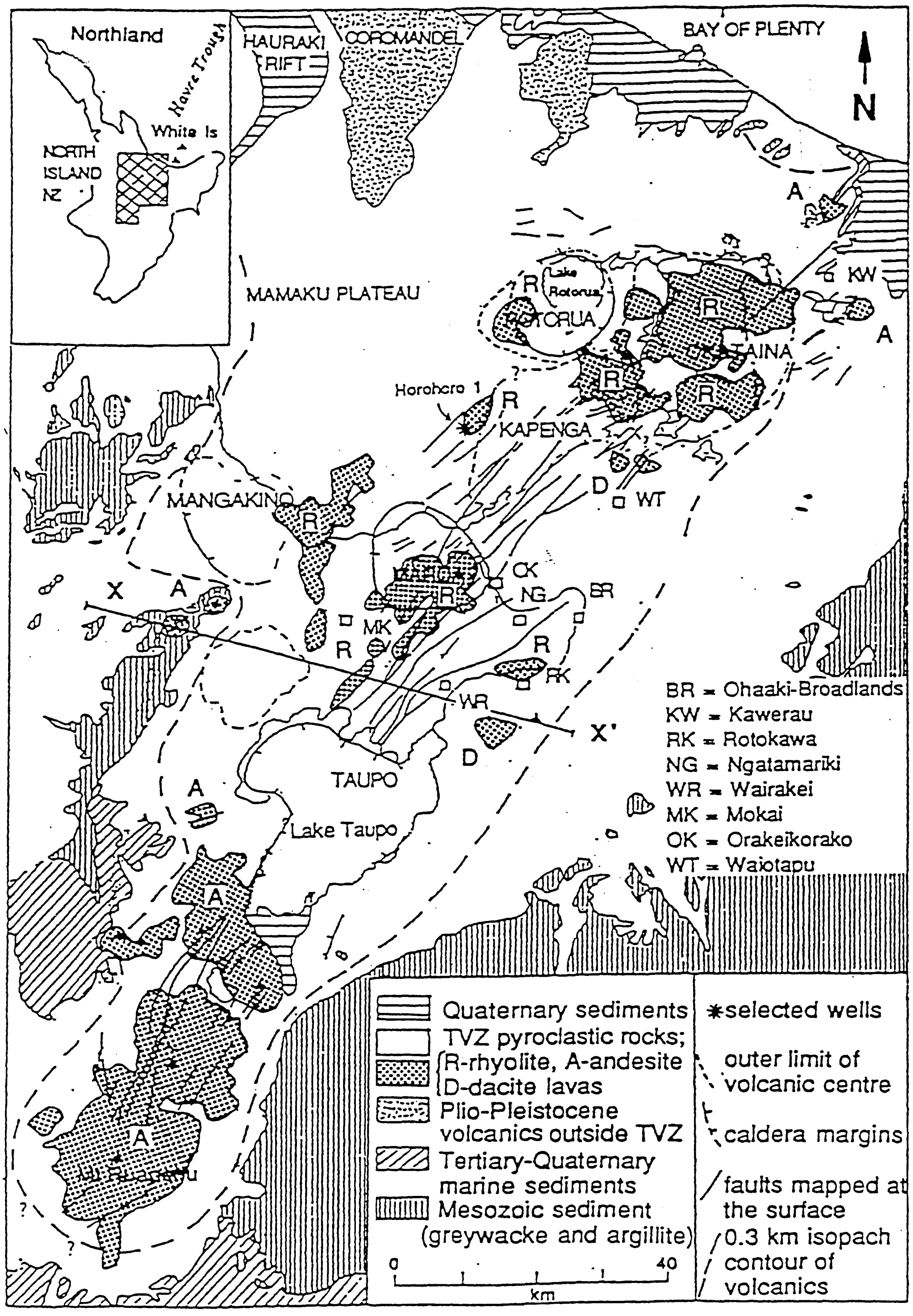


***Figure 18.** Simplified map of the Taupo Volcanic Zone (from Hochstein et al., 1993)*

Although generally considered as a single system the TVZ can be subdivided into 2 distinct domains. The central part contains at least 6 rhyolitic caldera-type volcanoes (Wilson et al., 1984; fig.18). Two of these, Okataina (last active about 800 years ago) and Taupo (last active about 1800 years ago) are considered to be active; the remainder are extinct. The caldera-type volcanoes have erupted mainly pyroclastic materials seen today as welded and unwelded ash flow tuffs and air fall tuffs; lavas, as domes and thick flows are subordinate. Basalts occur within this part of the TVZ as phreatomagmatic tuffs, scoria deposits and lava flows. Dacite forms small volcanoes within this rhyolite dominated domain. Andesite is rare and is known mainly from drill core and geophysical anomalies which indicate the presence of major strato volanoes at depth (Browne et al., 1992).

Andesite volcanoes occur to the north (White Island, Whale Island, Mt Edgecumbe) and south (Tongariro Volcanic Complex) of the caldera-type volcanoes. They are best developed in the strato volcano complexes of the Tongariro National Park. They are complex edifices composed of lava dominant cones surmounting ring plains of debris flow and pyroclastic deposits. White Island, Tongariro, Ngaruhoe and Ruapehu have all been active during the past 150 years.

TVZ Rhyolite Petrogenesis.

The large volumes of rhyolite (in excess of 12,000 km3) in TVZ, which have erupted over a period of around 2Ma concerning their petrogenesis. The polemic stems from lines of evidence which permit equivocal interpretation of results. In this regard, the extreme heat flow (an average of around 700 mW/m2, reported in Allis, 1980), coupled with extension rates in the order of 10 - 20 mm/yr (Grapes et al, 1987; Cole, 1990; Wright, 1990) and apparently thin crust (~ 15 km, Stern, 1986; 1987) are similar to measurements on oceanic islands such as Iceland, are strong evidence for mantle involvement, yet are occurring in a continental setting. Upwelling mantle can provide a) a heat source to promote partial melting of crust and, b) a decompressive regime in which to generate basaltic magma. However, there is no unequivocal evidence for an asthenospheric plume beneath the TVZ and arguably such a feature would be difficult to accommodate within the identified subduction zone setting. Hochstein et al. (1993) have suggested an alternative in which plastic deformation within a narrow tectonic hinge line provides a mechanism for crustal heating.

Thus two opposing models for rhyolite magma genesis materialise, one, a model of crustal fusion either by massive transfer of heat from the mantle to the crust or by injection of mantle-derived magmas into a crust already heated by plastic deformation. The alternative model invokes advanced fractional crystallisation of basaltic magma, usually accompanied by assimilation of crust. Both crustal fusion (Ewart, 1965; Ewart et al, 1975; Reid, 1983) and basalt fractionation (Blattner and Reid, 1982) have been advocated. Moreover, various lines of circumstantial evidence can be cited to advance the priority of either model. For example, the vast volumes of rhyolite (> 12,000 km^3) would require > 100,000 km^3 of basalt to evolve by crystal fractionation, assuming that rhyolite is a 10% residual of basalt fractionation, yet there is scant evidence of basalt or fractionated derivatives in the central part of TVZ. The TVZ rhyolites have remarkably uniform compositions and this has been used as an argument for an origin by large scale melting of a lower crustal source (Hochstein et al., 1993).

Alternatively, it may be argued that mafic magmas are too dense to erupt through extending, low density crust and therefore become density bound in the vicinity of the moho where they subsequently fractionate to produce evolved magmas such as rhyolite. Such models can also readily embrace complications such as assimilation with fractional crystallisation.

Available trace element and radiogenic isotopes (McCulloch et al, in press) provide important clues to the processes involved but interpretation of the data remains somewhat equivocal. In figure 19 Sr and Nd isotopes for plagioclase separates from TVZ rhyolites are compared to TVZ and Taranaki basalts and metasedimentary basement rocks belonging to the Torlesse (eastern basement) and Waipapa (western basement) terranes in the central North Island. Basalts from TVZ and Taranaki are very similar, the former defining an elongate array with increasing 87Sr/86Sr and decreasing 143Nd/144Nd which is best interpreted in terms of contamination by radiogenic crust (Gamble et al, 1993). The field occupied by TVZ rhyolites overlaps with the radiogenic end of the basalt array and with the field of Waipapa Terrane metasediments. Torlesse Terrane metasediments are markedly more radiogenic with high 87Sr/86Sr and low 143Nd/144Nd in keeping with derivation from older crustal granitoids.

Plots of 206Pb/204Pb versus 207Pb/204Pb and 208Pb/204Pb are also shown in figure 19. These plots are valuable in that they permit distinction between the western and eastern basement as likely contaminants of the Taranaki and TVZ basalts respectively. Basalts from Taranaki, which lies well to the west of the TVZ (sensu stricto) are erupted through Waipapa crust and overlap with the Waipapa sediment field on figure 19. In contrast, the TVZ basalts show a strong trend towards the Torlesse sediment field. As the metasediments have appreciably higher Pb, Th and U contents than the basalts, assimilation of relatively small amounts of crust can effectively swamp the systematics of the basalt. Gamble et al, 1993 calculated that < 10% assimilation of Torlesse type crust could account for the Sr - Nd isotope array of TVZ basalts and this was also consistent with the available O isotope data. The Pb-isotope data lend support to this hypothesis.

Basalts in the TVZ

Basalts make up a small fraction of the total material erupted in the TVZ. They are associated, as a minor component, with andesite in the major strato volcanoes of the Tongariro National Park, as rare hybrids (streaky pumice) associated with ignimbrite, and as fault controlled monogenetic scoria cones in the central part of the zone. These faults are approximately NE-SW trending normal faults associated with regional extension in TVZ and they have acted to facilitate egress of mantle derived melts through the crust. At the same time these faults probably play a significant role in the circulation of meteoric waters and the often explosive character of the basaltic eruptions probably reflects interaction with groundwater.

The basaltic magmas are asthenospheric melts associated with active subduction of the Pacific beneath the Australian plate (Gamble et al., 1990; 1993). Their relatively small volumes at the surface can be interpreted as due to the density filtering effect of rhyolite magma chambers and low density volcanic rocks at shallow crustal levels. However, the presence of basaltic eruptives within rhyolite eruption sequences of the TVZ shows that some basaltic magmas have breached this density filter and it is logical also that basalt magmas have interacted with felsic magma chambers at shallow crustal levels.

The depth of crustal magma chambers beneath the TVZ is not well constrained but on the basis of experimental work on rhyolite phase relationships may be as little as a few kilometres. Geochemical work on rhyolitic eruption sequences indicates that magma chambers beneath the TVZ have active lives of the order of 10^4 years during which time they produce multiple eruptions at intervals of the order of 10^3-10^2 years. The periodicity of basaltic eruptions within the TVZ is not well known but is of the order of 10^3 years. Basaltic magmas have erupted as small cones of cone building sequences of Strombolian to phreatomagmatic character and also occur as thin air fall tephras within rhyolite pyroclastic sequences. These occurrences mark the eruption of basaltic magma as an essentially basaltic eruption. The most recent example was the 1886 Tarawera eruption.

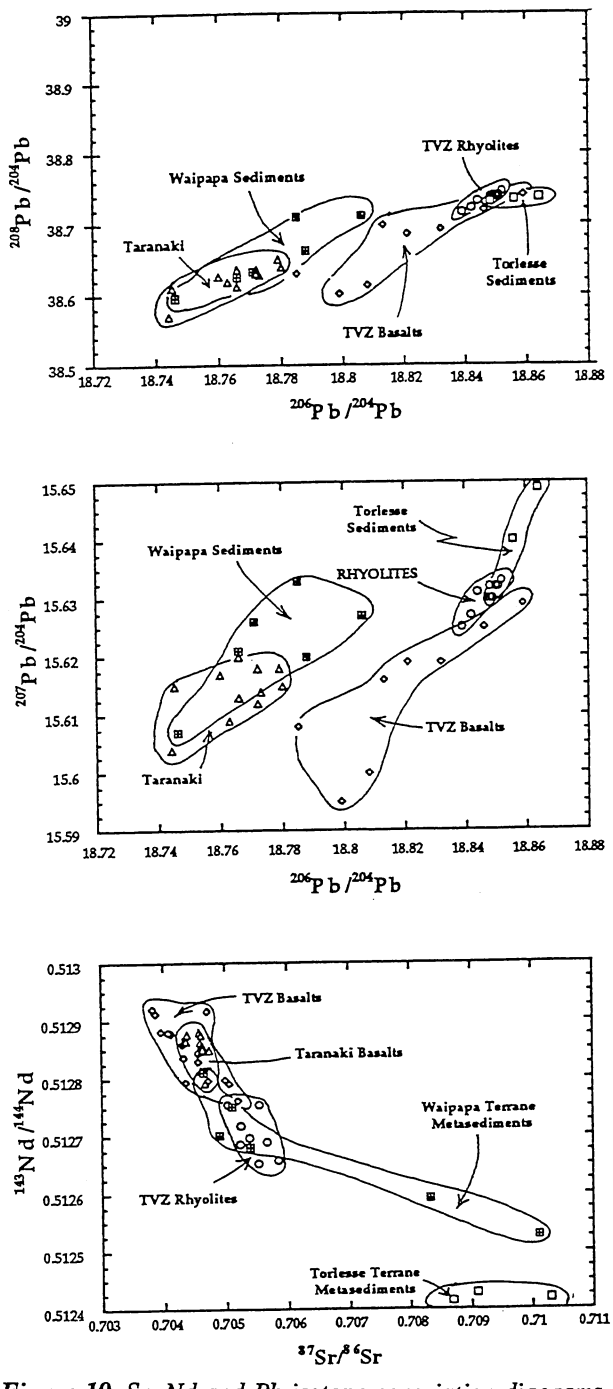


Figure 19. *Sr, Nd and Pb isotope covariation diagrams for basalts and rhyolites from TVZ, metasedimentary basement rocks of the Torlesse and Waipapa terranes and young basalts from Taranaki. Data from Price et al, 1992; Gamble et al, 1993; McCulloch et al, in press; Gamble and Woodhead (in prep).*

More subtly, basaltic material occurs as clasts within rhyolitic eruption sequences and as a component in mixed clasts. It is also a cryptic component in some intermediate rocks interpreted as the products of magma mixing (eg Tauhara, Graham and Worthington, 1987). These occurrences provide evidence for the interaction of mafic and felsic magmas at relatively shallow depths; logically these locations are the magma chambers which feed rhyolite eruptions.

Two scenarios, representative of the range of degrees of involvement of mafic magma have been recognised in the explosive rhyolitic eruptions in the TVZ.

1. Individual clasts in pyroclastic deposits in which two physically distinct phases are intimately mingled on millimetre to centimetre scale. Such clasts represent mafic/felsic magmas which are physically but not chemically mixed. They are typically a rare to minor proportion of any particular tephra layer and may occur at particular time/stratigraphic intervals in a particular eruption sequence.
2. Uniform light to dark coloured pumiceous clasts in pyroclastic deposits representing magma mixes which have been homogenised on at least a centimetre to decimetre scale.

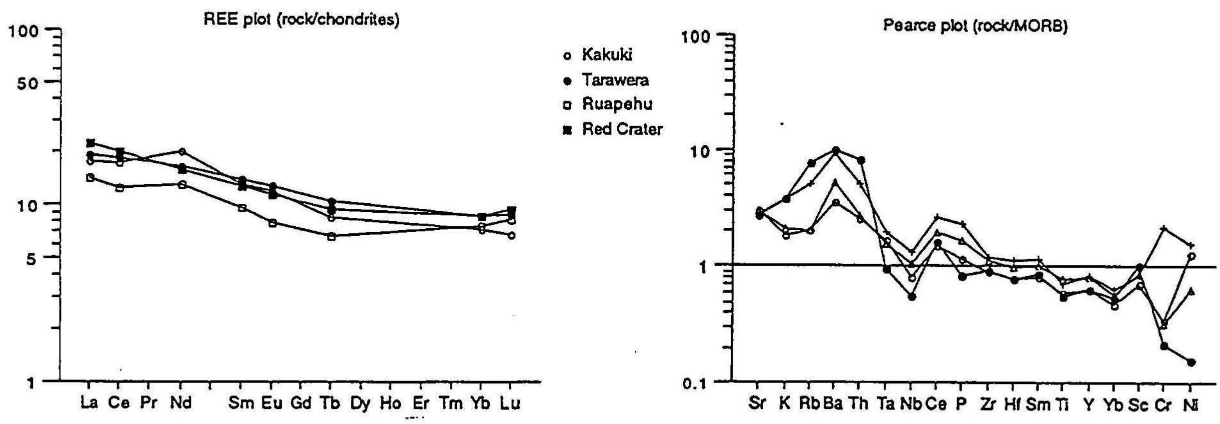


Figure 20. Chondrite normalised rare earth element and MORB normalised multi-element plot for basalts from TVZ. Data include the primitive Kakuki, evolved Tarawera and volcanic front basalts from Ruapehu and Tongariro (Red Crater) volcanoes. (Data from Gamble et al, 1993).

Andesite Lavas of Ruapehu Volcano.

Ruapehu volcano is the largest of the andesite volcanic edifices in the Tongariro National Park with volume of around 110 km3, Hackett and Houghton, 1986. The summit (Tahurangi, 2797m) is permanently snowcapped and supports a number of permanent snow and ice fields. A crater lake fills the present day active crater in the plateau-like summit area and phreatic and phreatomagmatic explosions from this have been responsible for a number of minor eruptions and lahars over the last 50 years. A lahar from the crater lake was directly responsible for the Tangiwhai disaster on Christmas Eve 1953, when the Wellington - Auckland express train plunged into the swollen waters of the Whangaehu River after bridge supports had been swept away by a lahar. More than 150 lives were lost in the disaster.

Topping (1973) reported the detailed tephra-stratigraphy of andesitic tephras from the Tongariro Volcanoes and Hackett (1985) described the proximal stratigraphy of Ruapehu volcano in detail, recognising four main stratigraphic formations:

Formation	Age (ka)*
Whakapapa	<15
Mangawhero	<50
Wahianoa	<150
Te Herenga	<300

* NB dates are approximate, very few reliable K-Ar dates are available for the Tongariro volcanoes.

Andesites are the dominant lava type throughout Ruapehu but overall the lavas range between basalt and dacite. Graham and Hackett (1987) identified six lava types, based upon a combination of petrographic and geochemical parameters. The six types reflect the complexity of magmatic processes beneath an established calc-alkaline volcano. These processes include source heterogeneity, mixing, hybridisation, fractional crystallisation and assimilation and some or several can be demonstrated to have operated simultaneously. Representative chemical analyses are contained in table 3 and variation diagrams shown in figure 21.

Type 1: Plagioclase-pyroxene phyric lavas which are the dominant lava type in all Tongariro Volcanic Centre volcanoes, occurring in all the Ruapehu formations. Phenocrysts range from 15 - 40% comprising plagioclase > pyroxene > olivine. The latter only occurs in the most basic lavas and orthopyroxene exceeds clinopyroxene in the more acidic lavas.

Type 2: Plagioclase phyric lavas which are probably accumulative with respect to plagioclase.

Type 3: Pyroxene -(olivine)- phyric lavas which represent accumulative lavas transitional from Type 1 but richer in pyroxene and olivine.

Type 4: Pyroxene phyric lavas which are similar, petrographically, to Type 3 yet chemically distinctive.

Type 5: Olivine - pyroxene phyric lavas with plagioclase restricted to a groundmass phase.

Type 6: Hybrid lavas with phenocrysts showing marked disequilibrium textures and abrupt chemical zonation.

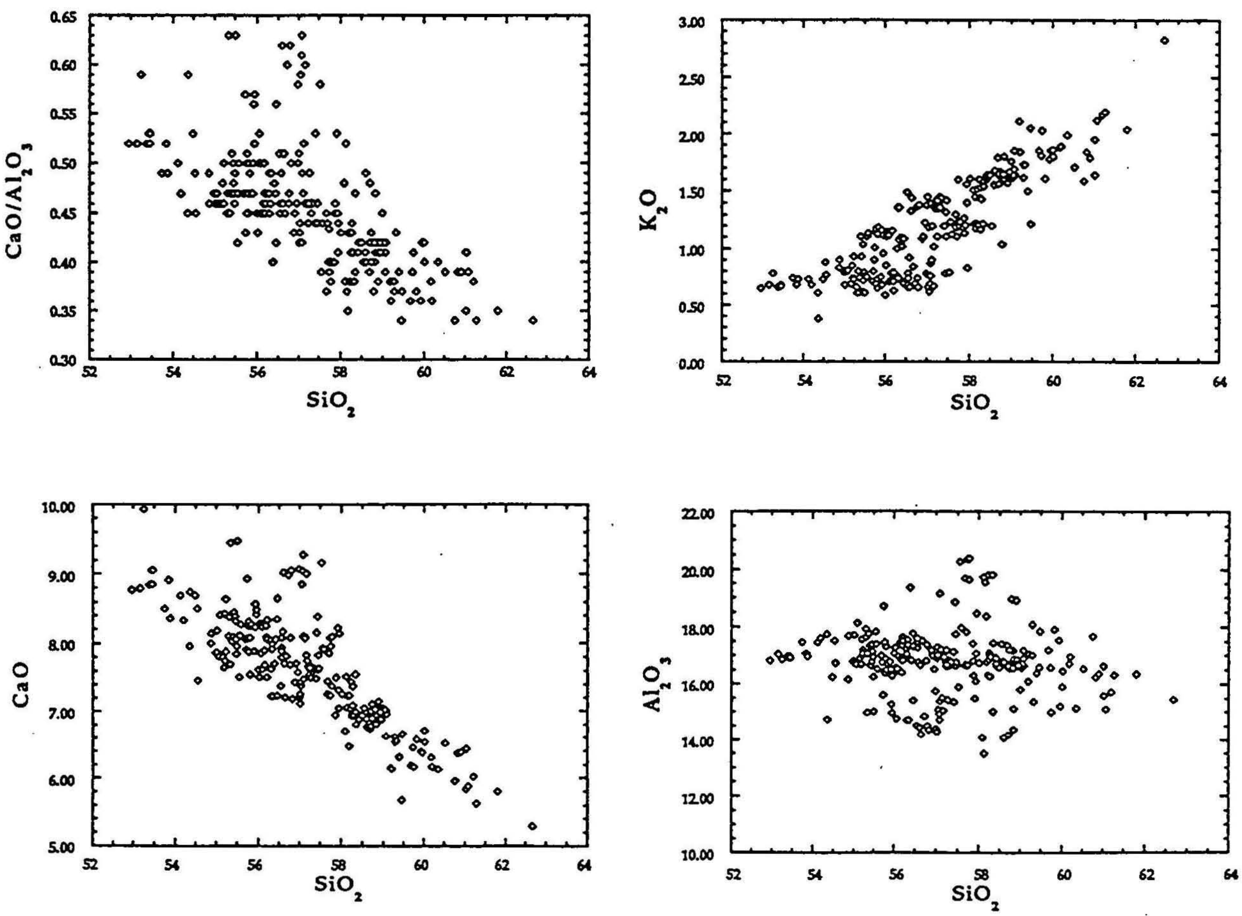


Figure 21. SiO_2 versus selected oxides and CaO/Al_2O_3 plots of 300 lavas from Ruapehu volcano. Departures from linearity on trends reflect accumulation of clinopyroxene (CaO) and plagioclase (Al_2O_3). Data sources: Hackett (1985); Graham (1985); Wysoczanski (1989); Graham and Hackett (1987); Gamble (unpublished data).

Table 3. Representative chemical analyses of basalts, dacites and andesites from the Taupo Volcanic Zone.

No.	1	2	3	4	5	6	7	8
wt.%								
SiO_2	48.52	50.63	52.27	67.55	59.04	56.29	57.01	56.79
TiO_2	0.89	0.83	0.64	0.38	0.67	0.75	0.69	0.53
Al_2O_3	18.09	17.17	15.34	14.81	16.65	16.6	14.29	14.50
Fe_2O_3	1.05	1.24	1.12	*4.26	*6.90	*9.19	*7.84	*8.86
FeO	6.99	8.26	7.45	-	-	-	-	-
MnO	0.13	0.17	0.16	0.09	0.11	0.15	0.15	0.19
MgO	9.12	6.17	9.15	2.49	4.67	5.18	8.64	7.07
CaO	11.16	11.34	9.61	4.54	7.03	8.32	7.26	9.05
Na_2O	2.49	2.12	2.76	3.61	3.30	3.11	2.75	2.32
K_2O	0.27	0.55	0.58	2.20	1.62	1.15	1.45	0.66
P_2O_5	0.14	0.10	0.08	0.07	0.12	0.16	0.11	0.07
LOI	0.20	0.25	0.00	0.30	0.08		0.83	0.73
Total	99.82	100.86	99.93	100.00	100.19	100.90	101.02	100.77
ppm								
Ba	70	201	182	495	360	214	355	144
Rb	4	15	12	70	61	38	49	16
Sr	350	318	199	324	264	247	277	390
Pb	2	-	5	-	10	-	6	3
Th	0.51	1.64	1.09	9	-	-	-	-
U		0.10	-	0.40	-	-	-	-
Zr	79	82	48	117	117	95	115	65
Nb	3	2	1	5	3	-	5	3
Hf	1.89	1.87	1.48	-	-	-	-	-
Ta	0.30	0.17	0.36	-	-	-	-	-
La	5.73	6.33	4.64	21.5	-	-	15	-
Ce	14.9	15.94	10.7	48	-	-	29	-
Nd	12.7	10.45	8.2	23	-	-	-	-
Sm	2.65	2.83	1.95	5.4	-	-	-	-
Eu	0.91	0.97	0.60	1.25	-	-	-	-
Tb	0.40	0.50	0.32	5.8	-	-	-	-
Yb	1.6	1.87	1.67	0.80	-	-	-	-
Lu	0.23	0.30	0.28	-	-	-	-	-
Sc	28	40	35	10	-	28	21	31
V	-	191	256	245	74	173	220	181
Cr	85	55	375	42	73	100	507	192
Ni	113	14	139	25	37	29	237	39
Cu	56	25	78	18	34	41	96	102
Zn	70	94	88	48	68	89	71	74
Ga	14	18	15	17	18	19	16	18

* Total iron as Fe_2O_3

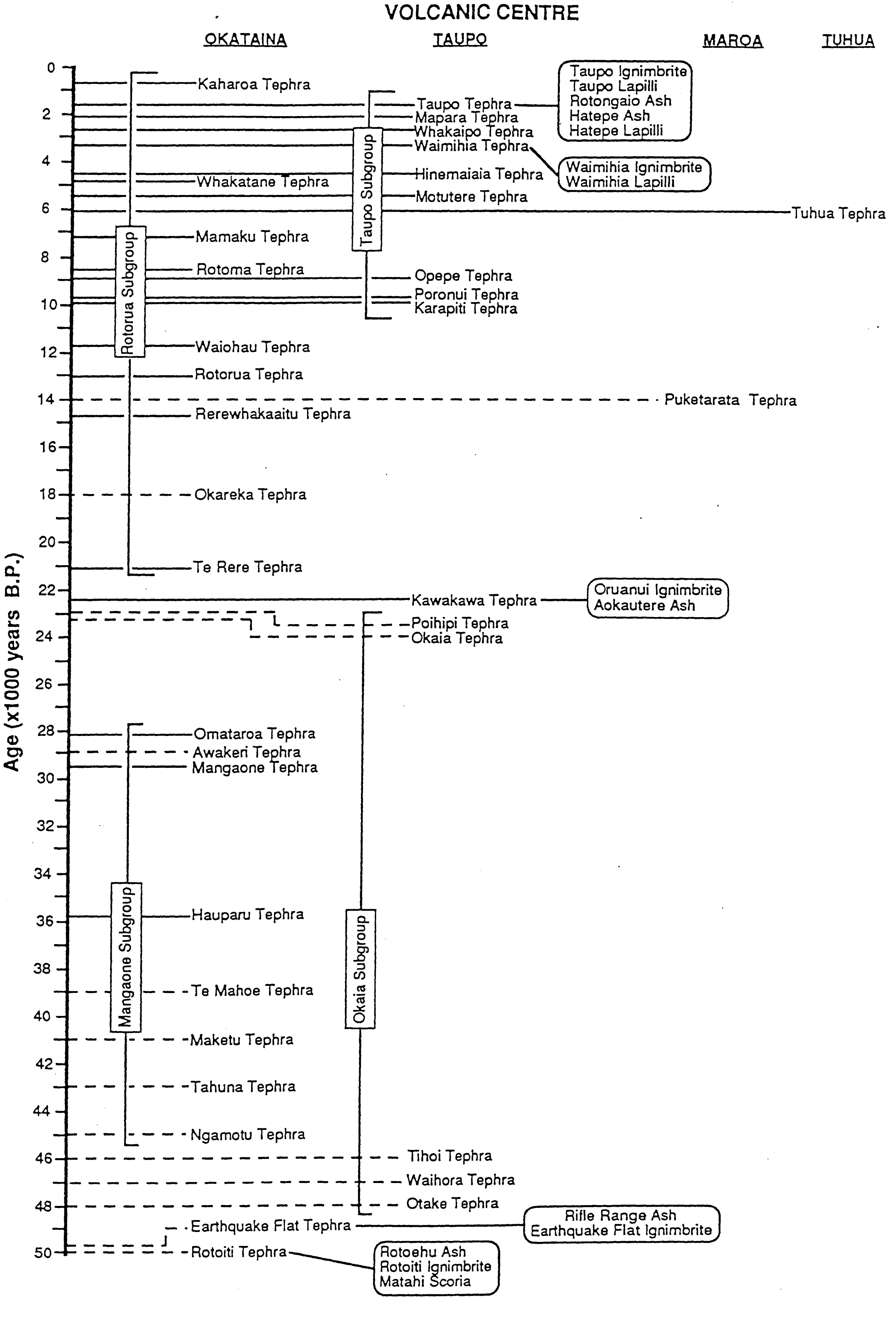
1. Kakuki Basalt, Gamble et al. (1993).
2. Tarawera Basalt, Gamble et al. (1993).
3. Ruapehu Basalt, Gamble et al. (1993).
4. Hornblende Dacite, Hipaua Dome, Tauhara (mean of 27 analyses), Graham and Worthington (1987), REE from Reid (1982).
5. Andesite, Whakapapa Formation, Mt Ruapehu, Wysoczanski (1989), analysis A-10.
6. Andesite, Ngaruhoe 1954 flow, Mt Ngaruhoe, Graham and Hackett (1987).
7. Andesite, Type 6 hybrid lava, Pukeonake Scoria Cone, Tongariro National Park, Graham and Hackett (1987).
8. Andesite, Ohakune Craters,Graham and Hackett (1987).

Table 4. Representative chemical analyses of rhyolitic rocks from the Taupo Volcanic Zone.

	1	2	3	4	5	6	7	8	9
wt.%									
SiO_2	72.49	77.45	75.08	72.99	74.99	75.91	74.31	75.84	78.97
TiO_2	0.28	0.14	0.20	0.19	0.24	0.05	0.29	0.24	0.13
Al_2O_3	13.64	12.15	13.16	12.89	13.36	13.3	13.55	13.38	12.18
Fe_2O_3	2.26	1.08	1.55	1.81	2.37	1.66	2.53	1.86	1.33
MnO	0.07	-	0.06	0.06	0.08	-	0.09	0.10	-
MgO	0.46	0.10	0.23	0.22	0.29	0.24	0.43	0.25	0.12
CaO	2.02	0.75	1.10	1.04	1.51	1.25	1.74	1.47	0.16
Na_2O	3.90	3.35	4.63	4.25	4.23	4.69	4.18	4.03	3.16
K_2O	3.30	4.76	3.29	3.33	2.87	2.73	2.84	2.82	3.18
P_2O_5	0.07	-	0.03	0.03	0.06	0.08	0.05	-	-
LOI	-	4.92	0.40	2.99	2.19	-	2.98	2.23	-
Total	98.49	99.78	99.72	99.80	100.00	100.00	100.12	99.99	100.00
ppm									
Cs	3.4	-	-	-	-	-	2.3	-	-
Ba	977	-	740	693	579	-	570	585	598
Rb	128	-	111	107	103	-	90	84	100
Sr	128	-	82	78	137	-	152	157	127
Pb	-	-	18	22	19	-	14	13	11
Th	16.7	-	11	18	10.4	-	10.5	9.2	11
U	3.7	-	3	3	2.0	-	2.2	0.9	2.0
Zr	155	-	221	216	242	-	217	217	151
Nb	-	-	11	10	8.5	-	-	-	-
Hf	3.9	-	-	-	5.8	-	5.7	-	2.8
Ta	0.8	-	-	-	0.7	-	0.7	-	-
La	25.2	-	27	29	24.3	-	22.7	-	24
Ce	54.3	-	54	53	56.6	-	53.7	-	47
Nd	-	-	-	-	19.7	-	20.2	-	29
Sm	3.44	-	-	5.54	-	-	5.12	-	3.5
Eu	.04	-	-	1.00	-	-	1.06	-	0.6
Tb	0.5	-	-	-	0.93	-	0.84	-	0.5
Yb	2.4	-	-	3.2	-	-	3.0	-	2.2
Lu	0.43	-	-	0.6	-	-	0.53	-	-
Sc	5	-	5	5	10.7	-	10.1	-	-
V	17	-	7	6	<1	-	3	394	-
Cr	2	-	-	-	<1	-	36	23	-
Ni	-	-	2	2	-	-	4	8	11
Cu	8	-	3	6	2	-	7	6	5
Zn	-	-	50	68	72	-	73	62	41
Ga	18	-	15	16	-	-	-	-	-

1. Whakamaru Ignimbrite - average of 19 major and trace element analyses (Reid, 1982). REE from P.C. Froggatt (pers comm).
2. Glass from Whakamaru Ignimbrite, alectron microprobe analysis (Kohn et al., 1992)
3. Ngongotaha Rhyolite (Shepherd, 1991).
4. Ngongotaha Rhyolite (Shepherd, 1991).
5. Waimahia Ignimbrite, average Blake et al. (1992(. REE from P.C. Froggatt (pers comm).
6. Waimahia Ignimbrite, electron microprobe analysis of glass (Blake et al., 1992).
7. Taupo Ignimbrite (Froggatt, 1982 and pers comm).
8. Taupo Ignimbrite, glass, major elements by electron microprobe, trace elements on separated glass (Froggatt, 1982).
9. Oruanui Ignimbrite, electron microprobe analysis of glass, traces on whole rock. REE from P.C. Froggatt (pers comm).

Table 5 Post 50,000 ka tephrochronology for Okataina, Taupo, Maroa, Tuhua (Mayor Island) volcanic centres from the Taupo Volcanic Zone (from Froggatt and Lowe (1990). Solid horizontal lines are based on mean conventional radiocarbon ages. Dashed lines indicate that no radiometric data are available.



Day 4 Taupo Volcanic Zone

Route Guide: Hamilton to Rotorua. From Hamilton travel SE to Cambridge and Tirau on State Highway (SH) 1 following this route to Tokoroa. From Tokoroa, take Route 28 (Whakamaru Road) to Mangakino and Maraeiti Dam. Here the road descends through a thick sequence of Whakamaru Ignimbrite. Stop 4.1 Whakamaru Ignimbrite. Retrace route to bridge and take Route 30 to Atiamuri turning right onto SH 1. Drive south c. 17 km turning left into Tutukau Road and, after c.8 km into Orakeikorako Road. Stop 4.2 Kakuki Stream and Kakuki olivine basalt. Return to SH 1 turn left and proceed south to Wairakei. Stop 4.3 Wairakei Geothermal Field. From the Geothermal Field drive south along SH 1 for about 1 km, turning left to the Taupo Observatory, our lunch stop. Stop 4.4 Taupo Volcano Observatory. From Wairakei take SH 5 north to Waiotapu. Stop 4.5: Waiotapu Geothermal Field. Follow SH 5 to Rotorua and on towards Ngongotaha turning left after 6 km into cemetery road. Stop 4.6 Henderson's Quarry in Ngongotaha Rhyolite Dome. Return to Rotoroa and accommodation.

FIELD GUIDE

Stop 4.1 Whakamaru Ignimbrite (T16/492139)

The Whakamaru Group Ignimbrites, dated at 332±2ka (Pringle et al. 1992), are among the most voluminous rhyolitic deposits of the Taupo Volcanic Zone, with erupted volumes exceeding 1000 km^3 of magma (Wilson et al. 1986). Exposures of this ignimbrite are to be found both east and west of Lake Taupo and because of the restricted nature of exposure, considerable debate has surrounded the lateral correlation of units. For example, to the west of Lake Taupo, members of the Whakamaru Group have been mapped as Maranui and Whakamaru Ignimbrite whereas to the east of the lake, possible correlatives, have been mapped as Te Whaiti and Rangitaiki Ignimbrite (Grindley, 1960; Martin, 1961; 1965; Healey et al. 1964; Briggs, 1973; 1976a, b). The location of vents for the eruptions is also in debate with some authors (e.g. Grindley, 1960; Briggs, 1976a,b) favouring Lake Taupo, others (e.g. Wilson et al. 1986) favouring an area north of Lake Taupo and more recently, still others (e.g. Lamarche & Froggatt, 1993) inferring a multiple series of vents.

At Maraeiti Dam a good section through the upper part of the Whakamaru Ignimbrite is exposed in a road cutting. Here the unit measures > 220 m in thickness and continuous sections in excess of 300 m have been recorded in drill holes associated with geothermal exploration in the Wairakei area. Healy (in Ewart, 1965) recognised 3 poorly defined units or sheets on the basis of physiography and drill cores associated with engineering exploration for the Waikato River hydro dams.

In hand specimen Whakamaru Ignimbrite is a greyish to pinkish-purple, variably welded porphyritic rock with a relatively high crystal content. In thin section the ignimbrite varies from poorly welded to intensely welded and contains phenocrysts of plagioclase, quartz, sanidine, hypersthene, magnetite, hornblende and biotite (Ewart, 1965). Glassy fiamme are quite common. The phenocryst content shows a vertical zonation with total phenocrysts increasing from ~ 10% at the base of Sheet 1 to around 30% at the top (Ewart, 1965). Plagioclase and quartz are the major phenocryst minerals but sanidine, an uncommon mineral in TVZ rhyolites, occurs in small amounts in Sheet 2 and in the uppermost part of Sheet 1. The major ferromagnesian mineral is hypersthene with both hornblende and biotite present in lesser amounts. Chemical analyses of Whakamaru Ignimbrite (whole rock and glass, the latter by electron microprobe) are contained in Table 4. Glass compositions are higher in SiO_2, Na_2O and K_2O than the whole rock which shows higher Al_2O_3, TiO_2 and iron, traits which are attributable to the observed phenocryst minerals. In figure 22, rare earth elements from Whakamaru Ignimbrite are shown plotted on a chondrite normalised diagram. Data from two of the post 20 ka eruptive episodes from Lake Taupo (Wiamihia Ignimbrite and Taupo Ignimbrite) are shown for comparison. All the samples display Eu-anomalies and relatively flat intermediate to heavy REE pattens with strong fractionation of the light REE.

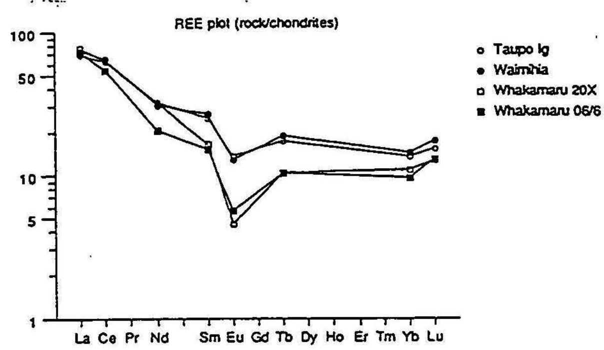


Figure 22. Chondrite normalised rare earth element diagram for Whakamaru Group (~330 ka) ignimbrites and young (<10,000 y) ignimbrites from the Taupo (1800 bp) and Waimihia (~3400 bp) eruptions, data from P.C. Froggatt (unpublished data).

Stop 4.2 Kakuki Basalt, Kakuki Stream (U17/834958)

The olivine basalt from Kakuki Stream (Lloyd, 1972; Houghton et al, 1986; Gamble et al, 1990; 1993) is the most primitive basalt so far recorded from the Taupo Volcanic Zone. The basalt is from a partly eroded scoria cone sited on the East Wainui Fault (Lloyd, 1972). K-Ar age dating has furnished two dates of 104 ka and 300 ka (pers. comm., J.J. Stipp, recorded in Lloyd, 1972). In thin section, the basalt is fine grained to glassy and vesicular containing euhedral, often skeletal, phenocrysts of olivine (Mg# = 86 - 66) and swallow-tail plagioclase (An = 79 - 69). A chemical analysis is shown in table 3 . Rare Earth Elements and a multi-element plot are contained in Figure 29. The REE show light REE enriched patterns with (Ce/Yb)n = ~2 with flat heavy REE. The multi-element plots (normalised to MORB, after Pearce, 1983) show enrichments of LIL elements and depletions of HFS elements relative to MORB and are typical of basalts from subduction zone tectonic settings elsewhere.

Gamble et al. (1993) plotted selected incompatible element abundances and transition element ratios against Zr and observed that the primitive Kakuki basalt plotted in the middle of the TVZ basalt data array. This led them to suggest that while a portion of the variation could be attributed to a secondary modification process such as crystal fractionation, variable degrees of source partial melting are also significant.

Stop 4.3 Wairakei Geothermal Field. (U17/790818)

At Wairakei, electricity has been generated from geothermal heat since 1958. The present geothermal power stations at Wairakei and Broadlands (Ohaaki) contribute around 8% of New Zealand's requirements. Both feed power directly into the national grid and operate continually at full capacity. The geology of the Wairakei geothermal system has been described by Grindley (1965) and the petrology by Steiner (1953). In summary, the geology of the region consists of a thick rhyolitic pumice breccia (Wairoa Formation) which varies in thickness from 450 m to > 900 m. This horizon provides the aquifer for the geothermal system and it is capped by impermeable fine grained lacustrine sediments (60 - 150 m thick) of the Huka Formation. In turn, the beds of the Huka Formation are overlain by younger hydrothermally altered rhyolitic deposits (Wairoa Breccia) which outcrops at the surface in the geothermal area. The rhyolitic breccias of the Wairoa Formation are underlain by the Wairakei Ignimbrites (possible correlatives of the Whakamaru Ignimbrites).

Stop 4.4 Taupo Observatory. (U17/794809)

This stop is our lunch stop. The Observatory is open for you to visit, view exhibits and purchase any literature you may find interesting.

Stop 4.4 Waiotapu Geothermal Field.

An optional stop, which, time permitting, we will make en route to Rotorua. This stop is at one of the better examples of an upwelling hot geothermal field in the TVZ. There are examples of spectacular crystal clear, near boiling, alkali chloride hot springs and, by way of contrast, turbid acid sulphate mud-pools.

This is a commercial privately owned enterprise and there is a gift shop and souvenir shop on site.

Stop 4.5 Ngongotaha Rhyolite Dome (U15/916402)

This locality offers the opportunity to examine rhyolite in the core and carapace of a rhyolite dome. The dome forms part of a complex of 8 lava domes comprising the Ngongotaha dome complex, which, together with other domes, were emplaced following collapse of the Rotorua Caldera around 140ka. In total these post 140ka rhyolite domes comprise an erupted volume of ~ 4.2km^3 compared to the >300km^3 volume of the caldera forming Mamaku Ignimbrite, which forms the skyline to the north and north east of Lake Rotorua. The locality is noteworthy for the range in textural varieties of rhyolite showing various stages in devitrification from porphyritic obsidian, to spherulitic and lithophysal varieties. These occur in definite zones in the rhyolite and make superb teaching specimens.

The Ngongotaha rhyolite is sparsely porphyritic (~ 3% phenocrysts) with phenocrysts of plagioclase (zoned from An42 - An26), pyroxene (hypersthene), and minor quartz, hornblende, biotite, ilmenite and Ti-magnetite. Rare iron rich olivine (Fo_{12-13}) has been recorded from this quarry, one of the few records of this mineral from TVZ lavas. In addition, there is a wonderful array of vapor phase minerals in the lithophysal cavities which include mullite, osumilite, titanite, hematite and tridymite. Younger (post 50ka) rhyolites of the Rotorua Caldera are distinctly more porphyritic than the Ngongotaha rhyolites. These lavas, exemplified by rhyolite from Mokoia Island in Lake Rotorua have phenocryst contents approaching 30%, with higher phenocryst quartz contents. Chemical analyses of the Rotorua domes are given in table 4, analyses 3-4.

Day 5 Tephrochronology of the Rotorua Caldera, Mt Tarawera rhyolite domes and 1886 basalt fissure eruption.

N.B. This will be a long day with a long (~7km) walk to the summit of Mt Tarawera. The walk is strenuous, but not over demanding and well worth the effort as the view is fantastic. Wear stout and comfortable footwear, bring protective rain wear and a warm sweater.

FIELD GUIDE

From Rotorua drive NE on SH 33 along the east shore of Lake Rotorua to Te Ngae (about 12.1 km) and stop 5.1, which exposes a virtually complete, but condensed tephra sequence of the post 22 ka eruptions from the Okataina - Rotorua and Taupo volcanic centres. Then retrace path back along SH 33 to Lake Okareka road and turn left following this road to Stancorp pumice quarry, stop 5.2, 13 ka Rotorua Ash. Follow the Okareka Loop Road to Lake Okareka, then Lake Tikitapu and on to the west shore of Lake Tarawera and stop 5.3, Lake Tarawera and Mt. Tarawera viewpoint. Retrace route back to Rotorua, turning left onto SH 5 and driving south towards Taupo until intersection with SH 38. Turn left onto SH 38 and follow signs to Rerewhakaaitu and from here via Ash Pit road to the foot of Mt. Tarawera. By foot we scale the rhyolite domes (~15ka - 770±20 years) of the Tarawera Volcanic Complex to the rim of the rift formed during the 1886 basaltic fissure eruption, stop 5.4. Tarawera Rift. Those who wish may make the walk to the summit and then descend into the rift. Following descent from the crater rim we will examine pyroclastic deposits associated with the growth of the 700 yr Kaharoa dome building event. Stop 5.5 Disused quarry on Crater Road, Kaharoa pyroclastic deposits.

Stop 5.1 Te Ngae Road section (U15/019422)

This section exposes post 20 ka airfall tephras from both the Taupo and Okataina Volcanic centres. Rhyolitic tephras predominate but a number of basaltic markers are present. The majority of the rhyolite tephras are associated with dome emplacement in the Okataina Volcanic centre but some are airfall deposits associated with major ignimbrite eruptions. The top of the section is marked by basaltic and phreatic (Rotomahana Mud) products from the 1886 Mt. Tarawera eruption. The base of the section is a paleosol dated at around 22 ka which contains glass and occasional accretionary lapilli associated with the Oruanui event in the Taupo centre further to the south. Between these two marker beds a number of distinctive tephra layers can be identified, they include: Kaharoa (770±20); Taupo (1850±10); Rotokawau (3440±70); Whakatane (4830±20); Mamaku (7250±20); Rotoma (8530±10); Waiohau (11,850±60); Rotorua (13,080±50) and Rerewhakaaitu (14,700±110). The distinctive tephra layers are separated by a number of paleosol horizons which delineate time breaks, erosion and/or weathering. Full details as to where these units occur within the local stratigraphic framework can be assessed from Table - which is taken from Froggatt and Lowe (1990).

Stop 5.2 Stancorp Quarry, Okareka (U16/015316 - 022315)

At this locality we will see landscape draping air fall deposits of the 13.5 ka Rotorua Ash. Note the well sorted nature of the deposits and the manner in which they drape over the existing topography. Also note the thickness of the deposit at this locality compared to that from the Te Ngae Road section (stop 5.1), only a few kilometers away. The Rotorua ash is one of very few TVZ rhyolitic tephras to show marked vertical chemical zonation, reflected in the higher abundance of biotite phenocrysts in the upper parts of the deposit. The deposits rest on an older paleosol which is underlain by poorly sorted glassy obsidian deposits which are probably rhyolite dome carapace breccias or block and ash flow deposits associated with nearby rhyolite domes. The direction of their emplacement cannot be inferred at this outcrop.

In the main quarry dome, rhyolite is extracted for road metal. This rhyolite is one of a large number of rhyolite domes within the Okataina Caldera. It's age is not accurately known but it is presumed to be between 17 and 20 ka. The rhyolite is a vitric vesicular rock containing phenocrysts of quartz and plagioclase. Note the cooling joints in the rhyolite.

Stop 5.3 Mount Tarawera view point, west shore of Lake Tarawera. Photographic stop. (U16/073296)

This is a brief photographic stop but it is particularly instructive in demonstrating the steep-sided rhyolite domes which make up the Tarawera Volcanic Complex. These domes date from ~ 15 ka but the youngest are around 700 yr and these form the present day flat topped summit domes.

Stop 5.4a Ash Pit Road, Mt Tarawera. (V16/173197)

The 10 June 1886 eruption of basalt at Mt Tarawera is the last major eruptive event to have occurred in New Zealand. The following account is compiled from the work of Cole (1970), Cole and Nairn (1975), Nairn (1979), Nairn and Cole (1981), Walker et al (1984) and the unpublished work of Nairn, Houghton and Wilson.

The June 1886 eruption of Tarawera is noteworthy for the apparent lack of precursor activity and the short duration and violence of the eruption. For example, peculiar waves, approaching 0.3m high, were reported on the west shore of Lake Tarawera on 1 June 1886. Earthquake activity was reported at Te Wairoa and Rotorua, beginning about 00.30 hours on 10 June. These increased in intensity until the eruption commenced around 01.30. According to the accepted eruption narrative (reconstructed from eye witness accounts; Grange, 1937) the eruption began near Wahanga Dome on the northeastern side of the mountain and extended to the south west. At 02.10 a violent earthquake was accompanied by the rise of an eruption column from Tarawera Dome. This column was estimated to rise to a height of 9.5 km. At this time phreatomagmatic and hydrothermal eruptions began in Lake Rotomahana (the site of the world famous Pink and White Terraces which were destroyed in the eruption) and by 03.30 the entire 17 km fissure system from Wahanga Dome to Waimangu (= black water) was in eruption. The eruptive episode was all but complete by 06.00 on 10 June. Estimates of the total volume of ejecta differ, a recent estimation of ~ $2km_3$ for the basalt (equivalent to ~0.7 km_3 magma) being from Walker et al. (1984).

The character of the eruption products varied with the availability of groundwater. In the Tarawera rift, at Waimangu and also probably at Lake Rotomahana en-echelon dikes, (Nairn & Cole, 1981) acted as feeders for the magma rather than a single fissure system. From detailed stratigraphic mapping of the layers in the Tarawera Rift (Houghton & Wilson, pers comm) it is apparent that a number of fire fountains interplayed from different fissures at any given time, leading to a complex overlapping of tephra layers. Within the Tarawera Rift, Nairn et al, (1986) recognise 3 parts to the eruption sequence:

a) A discontinuous basal zone rich in rhyolitic wall rock clasts and containing conspicuous cauliflower bombs.
b) A thick middle zone of red and black coloured, often intensely welded, scoria. Fragments of rhyolitic wallrock in these deposits frequently show signs of rheomorphism.
c) An upper zone rich in ballistic blocks and lithic ash.

Away from the rift, exposures on the flanks of Tarawera show a basal zone of basaltic lapilli sized scoria which passes up into a zone characterised by mudlumps and accretionary lapilli.

The eruption products from the Lake Rotomahana and Waimangu segments of the fissure system reflect the explosive interaction of hot basaltic magma with groundwater and the geothermal system. The resulting phreatomagmatic and hydrothermal explosions generated the Rotomahana Mud phase of the eruption (Nairn, 1979). Deposits include ground-hugging surge deposits which topped adjacent hills up to 360m above the lake level and travelled more than 6 km west of the main source in Lake Rotomahana. It was these deposits and the associated mudfall which brought about the major loss of life (estimated at more than 150) during the eruption.

A chemical analysis of the Tarawera Basalt is given in table 3, analysis 2 and additional details are to be found in Cole, (1973) and Gamble et al, (1990; 1993). The basalt is fine grained and vesicular with phenocrysts of plagioclase and rare clinopyroxene and olivine. Examination of hand specimens show that fragments of dome rhyolite are thoroughly disseminated throughout the basalt, no doubt a function of the explosive nature of the eruption.

Stop 5.4b Crater Rim, Mount Tarawera. (V16/182254)

At this position we are standing between Ruawahia and Wahanga Domes. In the rift one can observe dome mantling rhyolitic tephras of the 700 ka Kaharoa eruption, overlain by the basaltic deposits of the 1886 eruption. Note the lower deposits containing much wall rock and which pass up into the thick, often densely welded, variably oxidised zone of maximum accumulation and the upper units rich in ballistic blocks. Interpretation would suggest an early vent clearing explosive phase giving way to establishment of a series of fire fountaining eruption columns along the fissure system and waning with magma withdrawal and ending with vent clearing explosions. Follow the track south west around the crater rim and ascend Ruawahia Dome to the trig point. From here the outline of the 700 y dome is quite clear. Descend the large scree to the floor of the crater and observe the 1886 basaltic dike in the fissure. Follow the track to the north east along the floor of the rift and ascend to the rim through the 1886 eruption sequence. As we return to the coach we shall examine a section through the Rotomahana Mud, the contemporaneous phreatomagmatic part of the eruption.

Stop 5.5 Disused quarry, foot of Mount Tarawera. (V16/173197)

This locality exposes an excellent sequence of silicic pyroclastic deposits associated with the ~ 700 yr dome forming events of the Tarawera Volcanic Complex. Amongst the deposits exposed in the quarry are airfall, thin pyroclastic flows (containing carbonised logs), surge and block and ash flow deposits. The sequence is topped by a thin layer of the 1886 Tarawera lapilli and Rotomahana Mud.

Day 6 Rotorua to Taupo and Tokaanu via Paeroa Fault Scarp, Ohakuri Ignimbrite, Puketarata Tuff Ring, Huka Falls Tauhara Dacite Domes, Taupo 1800 eruption deposits.

From Rotorua follow SH 5 south to Waiotapu (~ 30 km) and turn right onto Waikite Valley road. This road cuts across the Paeroa Fault Scarp. Stop 6.1 Paeroa Fault Scarp. Follow this road on to Te Kopia road, turning left into Te Kopia and drive along the foot of the scarp. Continue to Puaiti road and turn right into Puaiti road. Follow this road and stop at bridge over an arm of Lake Ohakuri, Stop 6.2 Taupo Ignimbrite (distal). Drive across bridge, turn left and cross another bridge, soon after turning left onto Poutakataka road. Take this road and turn left into Galatos road, follow this road and turn left into Maleme road. Follow this road to Ohakuri road, turn left and drive to Lake Ohakuri Powerhouse. Stop 6.3, Ohakuri Ignimbrite. Follow Ohakuri road to intersection with SH 1 and turn left (south) towards Wairakei. Drive south for around 20 km and stop at road cutting through Puketarata tuff ring. Stop 6.4, Puketarata Rhyolite Domes and Tuff Ring. Drive south to Wairakei and Huka Falls on Waikato River, Stop 6.6 Huka Falls. Retrace route back to SH 5 and turn left taking route to Taupo. From Taupo take Centenial Drive east to the junction with Broadlands Road. Turn left into Broadlands Road and then take right into Mc Kenzie Road and on to Hipaua Road. Stop 6.7 Tephra section at road intersection shows Oruanui Ignimbrite (~ 22 ka) and Taupo post 20 ka eruptives. Stop 6.8 Tauhara Dacite Dome Complex. Retrace route along Broadlands road and take left turn into Crown Road. Follow Crown Road to intersection with SH 5 and take left turn. Follow SH 5 to type section at Hotel de Bretts. Stop 6.9 Hotel De Bretts type section through post 20 ka Taupo tephras. Take SH 5 west to intersection with SH 1 on outskirts of Taupo. Turn left onto SH 1 and follow route to road cut at Waitahanui. Stop 6.10 Waitahanui cut through Taupo Ignimbrite. Follow SH 1 to Hatepe Hill. Stop 6.11 Photographic stop, Valley Fill of Taupo Ignimbrite and southern Lake Taupo. Take SH 1 south to Hatepe and follow shoreline to Turangi. At Turangi, take SH 41 to Tokaanu.

FIELD GUIDE

Stop 6.1 Paeroa Fault Scarp (U16/997147)

The Paeroa Fault Scarp is one of the more spectacular examples of NE (~0.400) normal faulting in TVZ. A downthrow to the north west in excess of 500m has exposed a number of ignimbrites in the steep scarp and recent dating on sanidine (rare in TVZ rhyolites) phenocrysts (Pringle et al, 1992) has strengthened the claim that these ignimbrites correlate with the Whakamaru Group (~332 ka). The fault scarp is also the locus of a number of small geothermal fields.

Stop 6.2 Taupo Ignimbrite. (U17/868099)

This locality is more than 65 km from the source vent of the 1850 year eruption from Lake Taupo. At this stop we can observe an exposure of the "valley pond" facies of the Taupo Ignimbrite. The deposit exposes several metres of unwelded pumice rich ignimbrite. A number of gas escape channels, producing "fines depleted" ignimbrites can be noted in the section.

Stop 6.3 Ohakuri Ignimbrite. (U17/798058)

The Ohakuri Ignimbrite at Ohakuri Dam exposes the uppermost part of a fossil geothermal system. The ignimbrite is pumice rich but highly silicified, fractured and traversed by quartz veins. It has been the subject of a drilling programme associated with epithermal gold exploration. Dating, reported by R.C. Henneberger (pers comm) suggests an age of ~ 250 ka, making this ignimbrite somewhat younger than the Whakamaru Group ignimbrites. Primary glass, plagioclase, hornblende and pyroxene have all but been destroyed by alteration and in a central zone quartz + adularia, with minor illite, hematite, leucoxene, chlorite and pyrite can be identified. Mass balance shows that Mg, Ca and Na have been almost completely removed while K, Si and Al have been added.

Stop 6.4 Puketarata Rhyolite Dome and Tuff Ring. (U17/752903)

N.B. Take great care with road traffic at this locality which is located on a major trunk route.

The rhyolite dome and tuff ring complex at Puketarata is one of a number of small dome-building eruptions in the Maroa Complex and approximately 0.062 km^3 of lava was erupted in the Puketarata event (Brooker, 1988). Dated on tephrochronology at between 14 - 15 ka the rhyolite is biotite bearing with phenocrysts dominated by plagioclase (11-34%) but including quartz (3 - 6%), biotite (up to 1.6%), hornblende (up to 1.3%) and traces of hypersthene and magnetite (Ewart, 1968). The sections we will observe comprise a part of the outer slopes of the tuff-ring and expose pyroclastic surge and air-fall deposits associated with phreatomagmatic activity. These deposits reflect the variable interaction of rhyolitic magma and groundwater. Wet surges are fine grained and variably sorted with subordinate well sorted lapilli fall beds. Pinch and swell structures are commonly observed within coarse to medium ash layers and are suggestive of emplacement by wet surges. Ballistic blocks with associated sag structures can be observed in some layers. Dry surges are generally coarser grained and better sorted than the wet surge layers.

Stop 6.5 Huka Falls. (U18/789791)

These spectacular falls developed where the Waikato River flows over the silicified upper members of the Huka Falls Formation, a sequence of water reworked rhyolitic deposits.

Stop 6.6 Oruanui Ignimbrite. (U18/868761)

This section exposes the upper part of the ~22 ka Oruanui Ignimbrite (Self, 1983) and overlying wind-reworked material and post 22 ka Taupo deposits. The Oruanui Ignimbrite and its associated airfall deposits have been known by a bewildering array of names such that it's stratigraphy is unnecessarily complicated. Froggatt and Lowe (1990) have reviewed the literature and advocate retention of the term Kawakawa Tephra Formation with Oruanui Ignimbrite for the ignimbrite and Aokautere Ash for all associated airfall ash deposits. The Oruanui Ignimbrite is typically unwelded, pumice poor with sparse phenocrysts of plagioclase, quartz, hypersthene, hornblende ± clinopyroxene.

The section is topped by the 1850 year Taupo ignimbrite. Between the Taupo ignimbrite and the 22.5 ka deposits a sequence of airfall tephras can be noted. A number of charred logs can be observed in the deposits from which 14C ages have been obtained. A chemical analysis is contained in table 4, analysis 9.

Stop 6.7 Tauhara Cumulo- dome Complex. (U18/866756)

The dacite cumulo-dome complex of Tauhara comprises 6 mappable dacite domes (Lewis, 1968; Graham and Worthington, 1987). The domes are porphyritic dacites with phenocrysts of distinctive opacite rimmed hornblende, seived and complexly zoned plagioclase, orthopyroxene, clinopyroxene, Fe-Ti oxides and rare quartz. The latter are mantled by coronas of orthopyroxene. Based upon the petrographic evidence for disequilibrium in the phenocryst assemblages and the major element, trace element and Sr-isotopic data Graham and Worthington, (1987) favour an origin by magma mixing between andesitic and rhyolitic end members. Chemical analyses are contained in Table 3, analysis 4.

Stop 6.8 Taupo post 20 ka eruption sequence at Hotel De Brett's. (U18/797728)

This section, which is partly annotated, is the type section of airfall and pyroclastic flow units of the Taupo Subgroup (Vucetich and Pullar, 1973). The section, with revised ages (Froggatt & Lowe, 1990, Table 1) is as follows:

Tephra Formation	**Age (ka BP)**
TAUPO PUMICE FM	
Taupo Ignimbrite	
Taupo Lapilli	1.8
Rotongaio Ash	
Hatepe Tephra	
MAPARA TEPHRA FM	2.1
WHAKAIPO TEPHRA FM	2.7
WAIMIHIA TEPHRA FM	3.3
HINEMAIAIA TEPHRA FM	5
MOTUTERE TEPHRA FM	5.4
OPEPE TEPHRA FM	8.9
PORONUI TEPHRA FM	9.7
KARAPITI TEPHRA FM	9.9
KAWAKAWA TEPHRA FM	22.5

Stop 6.9 Road cut through Taupo Tephra Formation at Waitahanui. (U18/773623)

The 1850 year eruption from Lake Taupo was the last major ignimbrite eruption in New Zealand and involved around 50km^3 of rhyolitic magma. The rhyolite is relatively sparsely porphyritic with phenocrysts of plagioclase, hypersthene and Fe-Ti oxides. Chemical analyses of individual pumice clasts from the plinian and ignimbrite deposits show very limited compositional range and no systematic variation through the eruption sequence; analyses are given in table 4.

Based upon isopach maps and lake bathymetry the source vent of the eruption is thought to lie in Lake Taupo in the vicinity of Horomatangi Reefs, which lie ~ 5km offshore between Waitahanui and Hatepe. The eruption has been studied in detail by Walker (1980), Froggatt (1982), and Wilson (1985), and a short eruption allegory is available in the text book by Cass and Wright (1986).

A complete stratigraphic sequence of the Taupo Tephra Formation is not exposed owing to the erosive effects of the ignimbrite phases and the lateral facies variations resulting from ash dispersal. Based on the work of the above authors a typical sequence consists of 6 distinctive units, distinguishable by characteristics such as grain size and degree of sorting.
These units are as follows:

Taupo Ignimbrite - Poorly sorted pumice rich ignimbrite. Three flow units at Waitahatanui.
Taupo Plinian Pumice - Well sorted airfall deposit
Rotongaio Ash - Fine grained phreatomagmatic deposit.
---Erosion---
Hatepe Ash - Phreatoplinian ash deposit.
Hatepe Plinian Pumice - Well sorted airfall deposit.
Initial Ash - Fine grained initial phreatomagmatic ash.

The eruptive sequence, grain size characteristics and magma discharge rate are summarised diagramatically in figure 23. This figure also summarises the section at Waitahanui; this is the closest we shall approach to the source vent of the ignimbrite, which is considered to be in the lake.

Stop 6.10 Hatepe Hill view point. Photographic stop. (U18/742564)

We stop here for a few minutes overlooking the Hinemaiaia River valley where "valley pond facies" of the Taupo Ignimbrite forms the flat, now incised floor of the valley. In this valley we have the interesting stratigraphic situation, brought about by successive periods of river downcutting, where the high ground is in part occupied by welded Rangitaiki Ignimbrite (~ 330 ka) and successively lower terraces by unwelded Oruanui Ignimbrite (~ 22 ka) and Taupo Ignimbrite (1850 years).

Stop 6.11 Lake Taupo Overview. (T19/495423)

From this vantage point an excellent panorama of the Taupo Volcanic Centre is available. To the north, at the far end of Lake Taupo, is the dacite dome complex of Tauhara, adjacent to Taupo township. To the right of Tauhara, the white cliffs forming the lake shore are composed of Taupo Ignimbrite. To the left of Tauhara, rhyolite domes form the prominent features at the north end of the lake. In the far distance, on a clear day it is possible to see the rhyolite domes of Tarawera. The promontory extending into the lake north of the delta of the Tongariro River is the rhyolite flow and dome of Motuapa. A small rhyolite dome (Maunganamu) is in the foreground. Behind us (i.e. to the south) are the predominantly andesitic massifs of the Tongariro National Park.

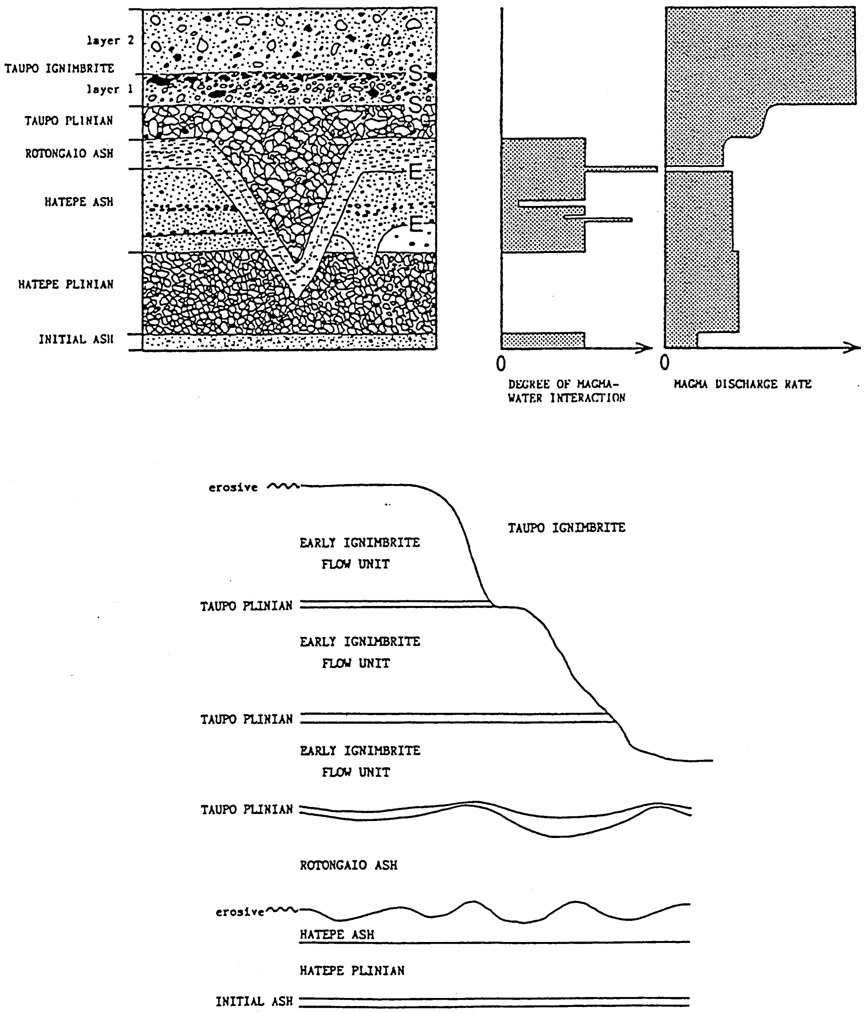


Figure 23. Summary of the characteristics of the Taupo eruption (from Houghton and Wilson, 1986). The lower part of the diagram shows a schematic section of the eruption sequence at Waitahanui.

Day 7 Andesite volcanoes of Tongariro National Park.

N.B. Much of todays part of the excursion will be in National Park. We ask you to respect the laws of New Zealand and not collect samples or use geological hammers in the National Park. Route Guide 10th October 1993

Because of the unpredictable and often savage weather cycles that can be encountered on Ruapehu Volcano at this time of the year, we have scheduled a number of potential trips for today. It will not be possible to visit all the localities described in this section of the field guide.

Stop 7.1 Early Tongariro Andesite Lavas. (S19/297300)

This stop is outside the National Park, so samples may be collected. This cutting exposes the central part of a thick andesite lava flow similar to a sequence of flows which flowed north west and west from Tongariro. This flow is petrographically similar to a flow at Mahuia Rapids some distance to the south and dated at ~230,000 years. The lavas are distinctive in that they carry large olivine phenocrysts (Fo_{90-92}) which are enclosed within reaction coronas of orthopyroxene (hypersthene). Other phenocrysts include hypersthene (with coronas of bronzite), clinopyroxene and plagioclase both of which are strongly zoned compositionally. These lavas have been interpreted as hybrids (Graham and Hackett, 1987). These lavas are distinguished by high MgO, Cr and Ni and low Al_2O_3.

Stop 7.2 Tongariro National Park Headquarters. (S20/293196)

This is a brief comfort stop to allow a visit to the National Park Headquarters. The building contains a display room and sells souvenirs, posters, etc.

Stop 7.3 Whakapapa Formation Andesite

This locality allows one to observe the massive, and in parts autobrecciated, interior of one of the andesite flows of the Whakapapa Formation, the youngest of the 4 mapped formations on Ruapehu volcano. Note the porphyritic nature of the lava where plagioclase + clinopyroxene + orthopyroxene + Fe-Ti oxides ± rare olivine are the principal phenocrysts. Note the abundant xenoliths of basement derived quartzite, metasediments and metaigneous rocks.

Stop 7.4 Meads Wall Dyke.

From this vantage point an excellent view of the angular unconformity between the younger (post-glacial) valley-filling Whakapapa Formation lava flows and the older Te Heranga Formation (pre-glacial) lavas can be appreciated. The Te Heranga lavas are in places hydrothermally altered and cut by shallow tonalitic intrusions. They form the jagged peaks of Pinnacle Ridge. Looking east from this vantage point in the direction of Ngauruhoe composite cone, the northern flanks of Pinnacle Ridge are draped with a distinctive welded air-fall andesite deposit whose source (~10 ka) Hackett (1985) is inferred to be in the summit area, near Pinnacle Ridge.

Stop 7.5 Debris Avalanche Deposit, SH 48. (S19/264232)

The deposits exposed in this cut are representative of the numerous knolls and mounds between 3 and 8 m high on this segment of the Ruapehu Ring Plain. Over the years, these units have been variously interpreted as drumlins, lahars and, more recently, debris avalanche deposits (Palmer & Neall, 1989) of the Murimoto Formation which is dated at around 9500 years.

The deposits are thought to have formed from a sector collapse episode on the N.W. flank of Ruapehu. The occurrence of hornblende bearing dacite blocks in the core of this exposure, is unusal as amphibole is very rare in Ruapehu rocks. Several possibilities have been offered in explanation ranging from a source in the vicinity of Tama Lakes (c.f. Hackett, 1985) to growth and collapse of a dacite dome on the N.W. flanks of Ruapehu, (Hackett & Houghton, 1988), whose remains have been buried beneath subsequent eruptions.

Stop 7.6 Ohakune Craters. Andesite Scoria Cone and Tuff Ring. (S20/176976)

Charcoal from distal tephras in the tuff ring of this deposit have been dated at 31.5 ka (Froggatt and Lowe, 1990). The deposits have been studied in detail by Houghton and Hackett (1984) who describe a tuff ring consisting of alternations of phreatomagmatic surge and airfall deposits and strombolian bomb beds. The tuff ring encloses a scoria cone of variably welded strombolian deposits.

The Ohakune rocks are basaltic andesite in composition and distinguished by the presence of glomeroporphyritic aggregates of olivine - clinopyroxene ± orthopyroxene and the absence of plagioclase as a phenocryst phase. Chemical analyses, table 3, analysis 8, reveal low SiO_2 and Al_2O_3 and high MgO and Cr compared to other andesites from Ruapehu. The Sr-isotopic analyses are also amongst the lowest recorded from Ruapehu lavas and related vents (range 0.70420 to 0.70442, Cole et al, 1986; Graham and Hackett, 1987).

Stop 7.7 Tangiwai Rail Bridge, Whangaehu River. (T21/317300)

The Whangaehu River drains the crater lake at the summit of Mount Ruapehu. The natural waters have a very low pH (~ 2-3) and are continually murky and turbid. This site marks the location of New Zealand's last volcanic disaster when more than 150 passengers on the Auckland - Wellington overnight train were killed after a lahar from the crater lake of Ruapehu swept away the rail bridge minutes before the train was due to pass.

Stop 7.8 Wahianoa Aqueduct view point. Photographic stop. (T20/434985)

This view point affords an excellent panorama of the southeast flanks of Mount Ruapehu, the ring plain and the Rangipo Desert, a cool temperate low precipitation area in the rain shadow of Mt Ruapehu. The channel-way in the foreground is part of the workings of the Upper Tongariro Power Scheme which was completed in the 1970's by the Ministry of Works for the NZ Electricity Commission. Here, waters from the Wanganui catchment were diverted across the divide and into the headwaters of the Tongariro River, leading eventually to the Waikato River Hydro Dams. In April 1975 when tunnelling was almost complete, a lahar from Ruapehu's crater lake descended the Whangaehu River and partially filled the tunnel workings. Fortunately the a work-crew had just (minutes previously) come out of the tunnel for a tea-break and no lives were lost. This led to design changes such that the channel-way and tunnel are now sealed.

Stop 7.9 Waihohonu Stream. Taupo Ignimbrite overlying Tongariro Sub Group Tephras. (T20/462172)

At this locality we are some 50 km from source and ~ 600m above Lake Taupo. The road cut exposes a distal section (~2-3 m) of the ignimbrite. Note the sharp (erosive?) contact with the underlying airfall deposits from the Tongariro andesite volcanoes. The lower part of the ignimbrite is fine grained, crudely layered and pumice poor and a relatively sharp transition separates it from pumice rich ignimbrite which comprises the upper part of the section. Numerous carbonised logs occur in this deposit. Dark brown andesitic ash layers from post Taupo eruptions from Ruapehu, Tongariro and Ngauruhoe overlie the ignimbrite. The tephra layers beneath the ignimbrite are named the Mangatawai Tephra (Topping, 1973) and are thought to originate largely from eruptions which built Ngauruhoe cone.

Stop 7.10 Pukeonake Scoria Cone (T19/321258)

Pukeonake Scoria Cone is the largest of three small cones of olivine bearing basaltic andesite alligned roughly N - S on the Ring Plain of the Ruapehu - Tongariro volcanoes. At one time the cone-building deposits were quarried to supply road metal for the National Park, but this activity has long ceased affording excellent exposures of the strombolian and phreatomagmatic deposits which drape the western flanks of the cone. Further into the interior of the cone, stream erosion has cut through massive, tack-welded bomb layer deposits. Overlying these deposits, a sequence of rhyolitic airfall tephras, associated with the 22ka Oruanui Ignimbrite event, are exposed as a sequence of water lain deposits which probably accumulated in a small crater lake in the summit of Pukeonake Cone. Included within these deposits are some spectacular accretionary lapilli deposits, a characteristic of distal Oruanui products.

The lava at Pukeonake is a low silica (basaltic) andesite with between 56 and 57% SiO_2, 9% MgO and high contents of Ni and Cr (respectively 230 and 550 ppm), Table 3. Incompatible trace element contents such as Rb and Zr (54 ppm and 115 ppm respectively) are high compared to primitive basalts from TVZ, Table 3. Mineralogically, the rock is complex, olivine phenocrysts (Fo_{94}) are jacketed by orthopyroxene and orthopyroxene phenocrysts are also complexly zoned (e.g. hypersthene cores are jacketed by bronzite - enstatite rims), as are clinopyroxenes and plagioclase. These lavas are considered to have originated by mixing between phenocryst bearing magnesian and dacitic liquids (Hackett, 1985; Graham and Hackett, 1987).

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