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GEOLOGY OF THE TAURANGA AREA

Occasional Report No 22
Department of Earth Sciences
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Hamilton
New Zealand

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SHEET U14 1:50 000

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Department of Earth Sciences, University of Waikato,
Private Bag 3105, Hamilton, New Zealand

*Institute of Geological and Nuclear Sciences,
Wairakei Research Centre, Private Bag 2000,
Taupo, New Zealand

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Published in collaboration with Environment B.O.P. (Bay of Plenty Regional Council) and Institute of Geological and Nuclear Sciences.

ISSN 0110-0947

Cover: Mt Maunganui and view of Tauranga Harbour. The urban and industrial area of Mt Mauganui (foreground) occupies a narrow neck of dune sand (tombolo) that connects Mt Maunganui to the Mainland.
Photo: D L Homer

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ABSTRACT

The Tauranga area consists of a late Pliocene to Pleistocene sequence of volcanics rocks and volcanogenic sediments. The oldest rocks are Late Pliocene andesitic lavas and volcanic breccias (Otawa Volcanics), but all later eruptions are dominantly rhyolitic or dacitic. These comprise (in younging sequence); Minden Rhyolite (lava domes and flows, carapace pumiceous breccias), Matakana Basalt (small lava outcrop, Matakana Island), Kopukairua Dacite (lava dome and flows), Waiteariki Ignimbrite, Papamoa Ignimbrite, Ongatiti Ignimbrite, Te Puna Ignimbrite, Te Ranga Ignimbrite, Waimakariri Ignimbrite and Mamaku Ignimbrite. These volcanic formations are intercalated with terrestrial and estuarine sedimentary deposits of the Matua Subgroup, formed after the deposition of the Waiteariki Ignimbrite, and in response to fluvial, lacustrine and estuarine processes of erosion, transportation and redeposition of consolidated and unconsolidated volcanic debris. The Matua Subgroup contains a wide variety of lithologies including fluvial pumiceous and rhyolitic sands, silts and gravels, lacustrine silts, estuarine sands, lignites, intercalated with airfall tephras and thin distal ignimbrites.

Waiteariki Ignimbrite forms the local basement in the Tauranga Basin and has been tilted during uplift of the Kaimai Ranges. It dips 3 - 5° NE into the Basin where it is unconformably overlain by a subhorizontal, mainly undeformed younger volcanic and sedimentary sequence. There may be a series of NNE-striking normal faults in the basement which could have controlled the localisation of volcanic vents, the NNE alignment of the terraced peninsulas of Tauranga Harbour, and the dominant NNE direction of major rivers.

Much of the Tauranga region is covered by a thick blanket of Late Pleistocene and Holocene tephras, including the Hamilton Ash, Rotoehu Ash, and a sequence of younger tephras derived from Taupo Volcanic Zone. Also during the Late Pleistocene and Holocene, coastal and alluvial sedimentation has occurred which has constructed low terraces, coastal sand dune complexes, barrier islands and tombolos.

PREFACE

Tauranga is a region of intensive agriculture, horticulture and forestry, and has a rapidly growing population. Land uses are diverse and there are increasing demands for urban, industrial and port development. However, little is known about the geology of the Tauranga district, and the only existing geology maps for the area were published by Henderson and Bartrum (1913) and Healy *et al.* (1964) on a scale of 1 : 250 000.

In an attempt to understand the regional and urban geology of Tauranga, the University of Waikato, with financial assistance from Environment B.O.P. (Bay of Plenty Regional Council), has undertaken a number of geological studies through mapping projects by MSc students. This report has compiled these projects to cover all of Sheet NZMS 260 U14 : Tauranga, at a scale of 1:50 000. This report has also involved collaborative work with the Institute of Geological and Nuclear Sciences on further detailed stratigraphical, volcanological and radiometric studies on the link between the older Coromandel Volcanic Zone (CVZ) and the presently active Taupo Volcanic Zone (TVZ).

This report provides a general description of the nature and characteristics of the lithologies of the Tauranga region. It incorporates MSc thesis data by Harmsworth (1983), Morgan (1986), Hughes (1993), Whitbread-Edwards (1994), Hall (1994), Hollis (1995), and some further mapping carried out by Glennis Hall and Annette Rodgers (née Whitbread-Edwards) in the summer of 1994-95.

The map and report are only intended to provide reconnaissance and some interpretative data of the Tauranga district, and is not comparable in accuracy or interpretation with formally published maps, e.g. those published by the Institute of Geological and Nuclear Sciences.

Some preliminary data are also included on rock character, i.e. engineering properties such as wall strength and spacing of joints and discontinuities. However, it must be emphasised that the consolidated and unconsolidated materials of the Tauranga region are highly variable, both vertically and horizontally, and the map should not be used for site-specific investigations such as building site assessment, engineering projects and quarry operations. The scheme used for description and quantification of rock character follows that of Brown (1981) on Rock Characterization Testing and Monitoring : ISRM Suggested Methods.

Fig. 1 The terraced peninsula of Omokoroa Point, Tauranga Harbour. The uplifted Kaimai Ranges are on the right Skyline.

Photo: D.L. Homer

PHYSIOGRAPHY

Six principal physiographic units form the Tauranga region: Kaimai Range, Whakamarama Plateau, Tauranga Basin, Mamaku Plateau, Papamoa Range, and the group of prominent volcanic domes e.g. Mt. Maunganui, Mt Minden, Kopukairua (Fig. 2).

Kaimai Range

The Kaimai Range is an upfaulted block of Miocene-Pliocene basaltic to rhyolitic volcanic rocks, bounded on the western side by the eroded fault scarp of the Hauraki Fault (Houghton and Cuthbertson, 1989). It forms a range of rugged, bush-covered hills with summit heights between 570-850 m.

Whakamarama Plateau

The Whakamarama Plateau is a tilted, gently sloping surface that dips 3 - 5° in a northeasterly direction from the Kaimai Range down into the Tauranga Basin where it is buried beneath younger fluvial sediments and ignimbrites (Houghton and Cuthbertson, 1989). The plateau is underlain by Pliocene - early Pleistocene dacitic and rhyolitic welded ignimbrites, e.g. Waiteariki Ignimbrite, Aongatete Ignimbrite.

Tauranga Basin

Tauranga Basin is a Pleistocene, predominantly fluvial/estuarine basin (570 km^2) which was partially infilled during a period of rapid subsidence after the eruption of the Waiteariki Ignimbrite (Houghton and Cuthbertson, 1989). The infill in the basin is comprised of terrestrial and estuarine volcaniclastic sediments and non-welded or partially welded distal ignimbrites and airfall tephras. The ignimbrite formations of the Whakamarama Plateau form the local basement at depths of 50-150 m below the surface of the basin (Houghton and Cuthbertson, 1989).

Much of the Tauranga Basin is occupied by the Tauranga Harbour (c. 200 km^2) which is a shallow mesotidal estuarine lagoon (Healy and Kirk, 1982). The harbour covers an area of sheltered water extending 35 km northwest to southeast along the Bay of Plenty coastline with an average

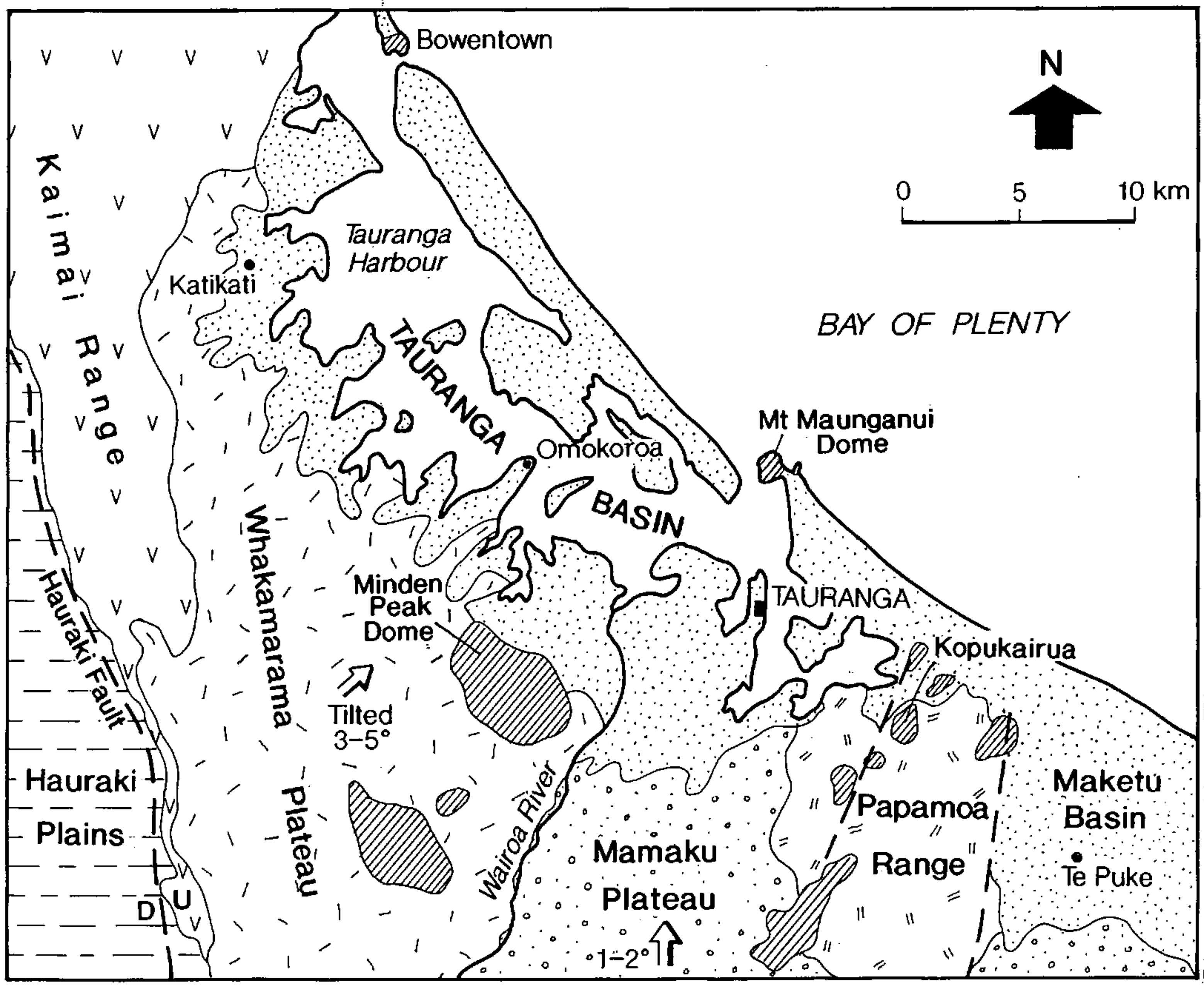


Fig. 2 Map showing the main physiographic features of the Tauranga area.

width of about 5 km. The harbour is blocked from the sea by tombolos at Bowentown and Mt Maunganui, and the 25 km long barrier island of Matakana Island. The entrances to the harbour are being continually deepened by tidal scour and artificial dredging carried out by the Port of Tauranga, but the rest of the harbour is shallow with extensive estuaries and mudflats that are exposed at low tide.

The Wairoa River is the main river draining into the Tauranga Basin, and flows along the boundary between the Whakamarama Plateau and the Mamaku Plateau.

Mamaku Plateau

The Mamaku Plateau dips gently towards the Tauranga Basin at approximately 1 - 2°. The plateau is mainly underlain by the Mamaku Ignimbrite which in turn is underlain by the Waimakariri Ignimbrite. In contrast to the tilted Whakamarama Plateau, the gentle dip on the Mamaku Plateau is a depositional feature resulting from the voluminous thick fans and lobes of pyroclastic flows that gradually thin towards the Tauranga Basin and slope away from the Rotorua caldera source to the south. The plateau's surface is deeply entrenched by numerous streams and rivers that flow northwards into the Tauranga and Maketu (Te Puke) basins (Fig. 3).

Papamoa Range

The Papamoa Range lies between the Tauranga and Maketu basins, and is flanked to the south by the Mamaku Plateau. The Papamoa Range comprises Pliocene andesitic volcanics, a series of younger NNE- aligned Pleistocene dacitic and rhyolitic domes, and dacitic ignimbrites. Healy *et al.* (1964) recognised two large NNE-striking faults that border the Papamoa Range and may control the alignment of the volcanic domes.

Volcanic Domes

Several volcanic domes occur within the Tauranga region, and are prominent features in the landscape seen from views that provide panoramas of the Tauranga Basin. Mt Maunganui (252 m; see cover) is a conspicuous steep-sided, flat-topped rhyolite dome, and is a tombolo that is connected to the Papamoa region by dune sands with thin peaty layers, intercalated with thin airfall tephras. Mt Drury and the islands of Moturiki and Motuotau are erosional remnants of rhyolite lavas associated with Mt Maunganui. Other prominent volcanic domes are Minden Peak, Manawata and Kaikaikaroro to the west (that have been flowed around by the younger Waiteariki Ignimbrite), and also the smaller domes to the east in the Papamoa region of Mt Misery (478 m), Pukunui (364 m), Mangatawa (117 m), Upuhue (78 m), Papamoa (224 m) (all mainly rhyolitic), and Kopukairua (265 m) (dacitic).

Terraces of the Tauranga Basin

A number of terraces occur within the Tauranga Basin that are generally preserved as NE or NNE trending peninsulas that extend into Tauranga Harbour (Fig. 1). For example, terraces occur at Omokoroa, Tauranga City and Greerton, Matua, Matapihi and Maungatapu. However, these flat surfaces are underlain by a variety of deposits and have probably formed in several ways (Harmsworth 1983; Hall 1994). Many of the terraces are intersected by broad shallow valleys and terminate seawards in low cliffs or steep slopes. Several terrace levels are evident, and vary from 0.5 m up to 80 m above present sea level, but most are between 20 - 40 m. Some terraces have a 1 - 2° dip to the northeast or north.

The terraces are attributed to four major origins (Harmsworth 1983):

(1) Volcanic constructional surfaces, e.g. the lobes of pyroclastic flow deposits, in particular the

Te Puna and Te Ranga ignimbrites, often variably degraded.

(2) Volcanic and/or fluvial degradation surfaces modified and covered by airfall tephra.
(3) Fluvial terraces formed by aggradation or lateral erosion, and variably degraded.
(4) Some of the lower terraces may be formed by marine aggradation as a consequence of a higher than present sea level.

Many of the peninsulas throughout the Tauranga Basin are constructed of sequences of fluvial, lacustrine, lignite, and estuarine deposits, intercalated with non-welded ignimbrites (e.g. Te Ranga and Te Puna ignimbrites) and airfall tephra (Pahoia Tephra), and covered by a thick (2 - 5 m) sequence of younger airfall tephra (Hamilton Ash, Rotoehu Ash, and a number of post-Rotoehu tephras derived from Taupo Volcanic Zone).

Fig. 3 Gently dipping plateau surface underlain by Waimakariri Ignimbrite, forming flat interfluves between deeply entrenched streams. Pyes Pa Road, Tauranga.

STRATIGRAPHY

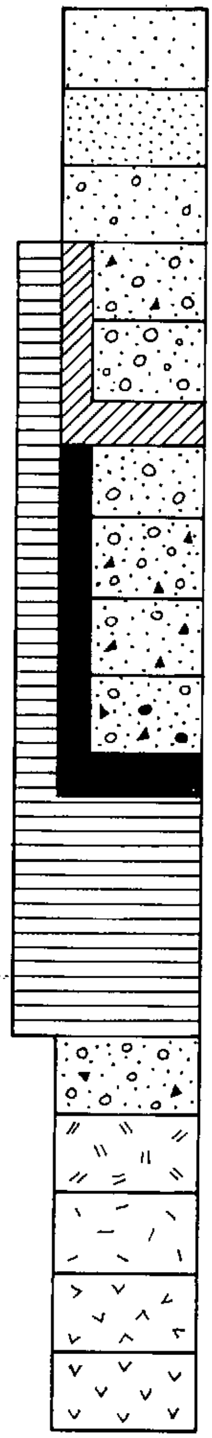
The strata of the Tauranga region are of both primary and secondary volcanic origin. The primary volcanics consist of basaltic to rhyolitic lavas, dacitic to rhyolitic ignimbrites and tephras, sourced from both the Tauranga region or southern Coromandel Volcanic Zone (CVZ) and the Taupo Volcanic Zone (TVZ). These units were in turn source to large volumes of volcanogenic debris which was reworked via fluvial, lacustrine and estuarine processes, and re-deposited in sequences interbedded with the primary volcanic units. Some of the units can be ascribed to established groups but many are not sufficiently understood to warrant association with other groups.

Most of the volcanic and sedimentary units are characterised by extreme lateral and vertical variations, and correlation of units is problematic. This is further compounded by the generally limited exposures of the strata, even in a hilly terrain with numerous volcanic domes and the lack of widespread marker horizons.

A generalised summary of the stratigraphy of the Tauranga region is given in Table 1. Each of the stratigraphic units are described in the following section, in stratigraphic order from oldest to youngest, except for the Matua Subgroup sediments and Pahoia Tephras which have a wide range of ages and are described later after the Mamaku Ignimbrite. For each stratigraphic unit, there are generalised notes on definition, lithology, distribution, stratigraphic relations and age, and rock character (simplified engineering properties).

Table 1

GENERALISED STRATIGRAPHY OF THE TAURANGA REGION



	Age
Holocene alluvium and dunes	
Holocene and Late Pleistocene tephras	<50 ka
Rotoehu Ash	> *c*.50 ka
Mamaku Ignimbrite	0.22 Ma
Waimakariri Ignimbrite	?
Hamilton Ash	0.35 Ma - *c*.0.1 Ma
Te Ranga Ignimbrite	?
Te Puna Ignimbrite	>0.78 Ma
Ongatiti Ignimbrite	1.21 Ma
Papamoa Ignimbrite	?
Pahoia Tephras	2.18 Ma - 0.35 Ma
Matua Subgroup (fluviatile sands and gravels, lignites, estuarine sands, lacustrine silts)	*c*. 2 Ma - *c*. 50 ka
Waiteariki Ignimbrite	2.18 - 2.13 Ma
Kopukairua Dacite	?
Matakana Basalt	?
Minden Rhyolite	2.36 - 2.28 Ma
Otawa Volcanics	2.95 - 2.54 Ma

Otawa Volcanics

Definition and Description:

Hornblende and pyroxene andesite lavas and volcanic breccias outcrop in the Papamoa Range west and southwest of Te Puke where they form the topographic highs of Otawa (564 m), Wharetetarakeho (331 m) and Otaua (325 m). Otawa is considered to be a remnant composite andesitic volcano and ranges in composition from basaltic andesite to dacite (55 - 67 wt% SiO_2, Hughes 1993). These andesites were originally mapped as Beeson's Island Volcanics by Healy *et al.* (1964) but this name is now redefined as a formation of Miocene age within the Coromandel Group (Skinner 1967; 1986), and hence is now inappropriate to use in the Tauranga region.

It is proposed here to name these rocks the **Otawa Volcanics** after the trig station at U14 961 728. The rocks are fine to medium grained blue-grey porphyritic basaltic andesites, andesites and minor dacites. Plagioclase is the dominant phenocryst with hornblende, hypersthene, ± augite, ± quartz, and Fe-Ti oxides. The groundmass varies from crystalline and intergranular to hyalopilitic and trachytic, and consists of plagioclase laths, granular pyroxene and Fe-Ti oxides and devitrified glass. Accessory minerals are chlorite, apatite, maghemite, pyrite, chalcopyrite, marcasite, and zircon. Some rocks are glassy and vitrophyric, and flow banding is often observed. Hydrothermal alteration occurs in places, e.g. around Moirs Reef, 8 km southwest of Te Puke, where gold mining has occurred in the past (1360 kg of gold from 65,000 tons of ore between 1912-1922, Slater 1986). Two major quartz veins (Moirs and Massey) occur in this area of hydrothermal alteration which parallel the NNE-striking fault mapped by Healy *et al.* (1964) and others.

Distribution:

The Otawa Volcanics outcrop over an area of about 35 km^2 in the Papamoa Ranges (Hughes 1993). The rocks are poorly exposed and much of their deeply weathered surfaces are covered by a thick blanket of tephras. Lava outcrops vary from exhibiting blocky joints to platy fractures, and spheroidal weathering is common. Lavas have flowed into topographic lows and are valley-fillers, while in other places inverted topography has created ridges of lava flows radiating downslope and along the Range.

Stratigraphic Relations and Age:

The andesitic rocks are considered to be the stratigraphically oldest unit in the Tauranga region. No contacts have been observed with underlying rocks. Otawa Volcanics are overlain by the Papamoa Ignimbrite, but contacts with the Minden Rhyolite have also not been observed, although Houghton and Cuthbertson (1989) observed andesites overlain by Minden Rhyolite in the Kaimai Range.

Two K-Ar ages have been determined by Stipp (1968) for the Otawa Volcanics: 2.95 Ma at U14 944 703 at the No. 3 Road Quarry about 3 km southwest of Otawa; and 2.54 Ma at U14 933 759 in Waitao Stream about 2 km north of Otaua. However, Takagi (1995) determined an (anomalously young ?) age of 0.78 ± 0.03 Ma for the andesite in the same No. 3 Road Quarry (U14 945 707) as that sampled by Stipp (1968).

Rock Character:

Unweathered rock is very strong to extremely strong rock (R5-R6). Joints are common and occur throughout the rock mass; they have a moderate to wide joint spacing, averaging 0.5 - 2 m in width. The fresh unweathered andesites are well exposed at Kaiate Falls (Fig. 4), but most road-cut sections are weathered (R1 or S3), exhibit spheroidal weathering, and on gentle slopes are covered by several metres of brown tephra.

Fig. 4 Andesite lavas of the Otawa Volcanics, Kaiate Falls (U14 957 774).

Minden Rhyolite

Definition and Description:

The Whitianga Group consists of rhyolitic lava domes and flows and extensive ignimbrites (Skinner 1986) and contains two subgroups (Minden Rhyolite Subgroup, Coroglen Subgroup). Minden Rhyolite includes all hypersthene-, hornblende- and biotite-bearing rhyolites of the Coromandel/Bay of Plenty region north of the Taupo Volcanic Zone (Houghton and Cuthbertson (1989) that are mainly late Miocene to Pliocene in age (Adams *et al.*, 1994). Minden Rhyolite was first described as a formation by Healy *et al.* (1964) with the type section occurring at Te Puna (Minden) Quarry (U14 788 841) on the northern flank of Minden Peak dome. Since then, Thompson (1966) raised it to subgroup status within the Whitianga Group extending its distribution further north to the Coromandel Peninsula. In the Tauranga region, four formations are proposed (see table below) that each contain a number of individual rhyolitic lava domes and flows, based on spatial association, mineral assemblages and chemistry:

Subgroup	Formation	Dome
Minden Rhyolite	Kaikaikaroro	Kaikaikaroro Manawata Minden Peak
	Mt Maunganui	Mt Maunganui Moturiki Is Motuotau Is Mt Drury
	Mangatawa	Mangatawa Papamoa Waitao Upuhue (Otanewainuku)
	Pukunui	Pukunui Mt Misery Greenpark Waikite (Ohui)

Note: Domes in brackets () are situated further south in U15. Otanewainuku is spatially distinct from the other domes in the Mangatawa Formation but shows consistent geochemical relations (Hall 1994).

Fig.5 Mt Maunganui rhyolite dome and the related eroded rhyolite lava flows of Mt Drury and Moturiki Island.
Photo: D L Homer

Fig. 6a Flow banded rhyolite lavas, Mt Maunganui

Fig. 6b Flow folds in rhyolite lavas, Mt Maunganui

Minden Rhyolite occurs as steep-sided, eroded dome and flow complexes, and range from medium-K rhyodacites to high-silica rhyolites (68-77 wt% SiO_2). Some of the high-silica rhyolites show a high-K affinity (up to 4.2 wt% K_2O).

The rhyolite lavas vary widely and may be light to dark grey, or cream or pink, flow banded (Fig. 6) and commonly spherulitic. Volcanic breccias (carapace breccias, flow-base breccias, flow-front breccias) and pumiceous lava are common and some domes, e.g. Mangatawa (Fig. 7), Upuhue (Fig. 8), Mt Misery, retain portions of the outer dome carapace with finely vesicular pumiceous lava and perlite. Lavas are generally glassy and porphyritic, and contain phenocrysts of plagioclase, quartz, Fe-Ti oxides ± biotite ± hornblende ± hypersthene. Phenocryst abundance varies from 5% in Mt Maunganui rhyolites to 40% in rhyodacites and rhyolites at Upuhue, Kaikaikaroro and Papamoa. Groundmass textures are typically spherulitic and glassy with perlitic cracks, and exhibit pervasive devitrification. Microlites, crystallites and phenocrysts are usually aligned parallel to the direction of flow.

Distribution:
Minden Rhyolite domes are the most prominent landforms in the Tauranga Basin, especially typified by Mt Maunganui, a steep-sided flat-topped dome reaching 252 m in height (Fig. 5). Healy *et al.* (1964) mapped two inferred NNE-striking faults in the Papamoa Ranges in eastern Tauranga and implied the location of some of the rhyolite domes were fault controlled. However, in this work any control on the distribution of rhyolite domes by faults has not been observed or proven, and remain conjectural. However, some of the rhyolite domes in the west also have a NNE alignment which suggests that their locations may be fault related, possibly within the basement rocks (Whitbread-Edwards 1994).

Stratigraphic Relations and Age:
Minden Rhyolite in the Tauranga region is considered to be older than the Waiteariki Ignimbrite (2.13 - 2.18 Ma, Takagi 1995) which appears to flow around the domes of Kaikaikaroro and Minden Peak (Healy *et al.*, 1964, Whitbread-Edwards 1994). However, this is contradictory with a K-Ar age determination of 1.52 ± 0.23 Ma by Takagi (1995) for Minden Peak rhyolite lava at Te Puna Quarry (U14 788 841). Takagi 91995) also determined ages of 2.36 ± 0.07 Ma (whole rock) and 2.28 ± 0.15 Ma (plagioclase separate) for Mangatawa dome at Mangatawa Quarry (U14 962 842). Rutherford (1978) determined a glass fission track age of 4.34 Ma for Mt Maunganui. However, this is likely to be a maximum age because old methods of fission track dating did not recognise effects of annealing and stability of glass, and a somewhat younger age is considered more likely.

Fig. 7 Upuhue rhyolite dome, eastern Tauranga (U14 976 827).

Fig. 8 Mangatawa rhyolite dome and disused quarry (U14 962 842), south of SH2 between Mt Maunganui and Te Puke

Rock Character:
Unweathered rock is dense, very strong to extremely strong (R5 - R6) but weathers readily to a very weak rock (R1) or firm clay (S3). Fresh, unweathered rock is well exposed in Te Puna Quarry (Fig. 9), and the rhyolite here shows a random and irregular pattern of joints, spaced 0.2 - 0.6 m apart. Some rhyolite domes, e.g. Mt Maunganui, exhibit a well-developed flow banding which imparts a strongly foliated structure, often with flow folds (Fig. 5). Minden Rhyolites sometimes form steep-sided domes with occasional bluffs, and tend to erode by shallow rotational landslides and slumps, and also rockfall.

Fig. 9 Irregular jointing in Minden Rhyolite, Te Puna Quarry (14 787 841), Minden Peak dome.

Matakana Basalt

Definition and Description:

Henderson and Bartrum (1913) first noted very small outcrops of "pyroxene andesite" near the western coast of Matakana Island. These rocks were informally defined and named the Matakana Basalt by Hollis (1995). The Matakana Basalt is a dark grey, porphyritic basalt (52.3 wt.% SiO_2) containing phenocrysts of plagioclase, olivine altered to iddingsite, hypersthene, and Fe-Ti oxides. Plagioclase occurs as large phenocrysts up to 5 mm and is abundant, constituting 32 modal percent. The groundmass is intergranular and contains plagioclase laths, granular pyroxene and Fe-Ti oxides.

Distribution:

The basalt occurs as a single lava flow on a small island (Fig. 10), 30 m offshore on the harbour side of Matakana Island (U14 788 953). The basalt is irregularly jointed and exhibits curved incipient spheroidal weathering fractures. The rock is hard, competent, with only a thin weathering rind, and is the only location of basalt in the Tauranga region.

Stratigraphic Relations and Age:

The stratigraphic position of the Matakana Basalt in unknown due to lack of exposure of stratigraphic relations. Spatially associated units at Matakana Island are the Te Puna Ignimbrite interbedded with fluvial sands, lignites and lacustrine silts, and this sequence appears to overlie the basalt. The Matakana Basalt is stratigraphically placed here as pre-dating the Te Puna Ignimbrite and post-dating the Minden Rhyolite; radiometric dating is required to determine this. It has been determined as paleomagnetically normal.

Rock Character:

The Matakana Basalt is jointed and fractured with close to moderate spacing, and is a very strong rock to extremely strong rock (R5-R6).

Fig. 10 Outcrops of Matakana Basalt, western (harbour side) Matakana Island (U14 788 953).

Fig. 11 View of Kopukairua Dacite dome from Kaiwha Road.

Kopukairua Dacite

Definition and Description:

The Kopokairua Dacite was informally defined by Hughes (1993) for the youthful dacite dome and flow complex at Kopukairua (265 m), east of Welcome Bay. It was previously mapped as Minden Rhyolite by Healy *et al.* (1964). Kopukairua is a large prominent dacite volcano that is poorly exposed, and outcrops are limited to fallen boulders.

The Kopukairua Dacite (66.8 - 68.0% SiO_2, Hughes 1993; Hall 1994) ranges in lithology from light grey to dark grey glassy porphyritic hornblende dacite with phenocrysts of plagioclase, quartz, hypersthene, hornblende (up to 3 mm), Fe-Ti oxides and biotite. The groundmass varies from a spherulitic texture with coarse to fine devitrified spherulites to a fine-grained devitrified glassy groundmass containing laths of feldspar. Hornblende and biotite are strongly resorbed and have opacite rims.

Distribution:

The Kopukairua Dacite is restricted to a single dome and flow complex situated on the northern parts of the Papamoa hills (Fig. 11).

Stratigraphic Relations and Age:

The age of Kopukairua Dacite volcano is unknown. The eastern side is onlapped by the Papamoa Ignimbrite which appears to have flowed around the dome (Hughes 1993; Hall 1994). Kopukairua dome has a youthful appearance and may have a similar age to Mangatawa rhyolite dome, situated 3 km to the north, which has a K-Ar age of 2.28 - 2.36 Ma (Takagi 1995).

Rock Character:

Kopukairua Dacite is poorly exposed with outcrops limited to fallen boulders. When fresh and unweathered, the rock is very strong to extremely strong (R5 - R6) but weathers down to a firm or soft clay (S3 - S2). It has constructed a steep-sided dome but there are no bluffs exposed, and joint spacing is unknown.

Waitеariki Ignimbrite

Definition and Description:

The Waiteariki Ignimbrite was first named by Healy *et al.* (1964) and described in more detail by Healy (1969). It belongs to the Whakamarama Group established by Houghton and Cuthbertson (1989) which includes all the ignimbrites that form the Whakamarama Plateau (Aongatete and Waiteariki Ignimbrites).

Houghton and Cuthbertson (1989) defined a type section between T14 641 797 and T14 647 798 where it is 220 m thick. There it has been subdivided into three parts: (1) a 3 - 5 m thick nonwelded pumice-rich base; (2) up to 150 m of welded ignimbrite containing alternatively moderately densely welded and very densely welded glassy lenticular zones; and (3) a soft non-welded to welded upper biotite-bearing unit between 50-70 m thick with extensive vapour phase alteration. In the area of U14, mainly the upper and middle sheets are exposed.

The Waiteariki Ignimbrite is light grey-brown, varying to cream or grey, crystal rich (up to 30% crystals) and pumice rich (20%). Plagioclase is the dominant crystal with subordinate quartz, hornblende, hypersthene, biotite, Fe-Ti oxides and zircon. According to Houghton and Cuthbertson (1989), biotite is confined to the upper sheet of the Waiteariki Ignimbrite. The original glass shard texture of the matrix has been highly devitrified and spherulitic textures sometimes occur. Densely welded Waiteariki Ignimbrite contains fiamme and exhibits an eutaxitic or lenticulitic texture. In less welded samples, pumices are less flattened and are typically extensively vapour phase altered. Rhyolite and dacite are the predominant lithics found in the Waiteariki Ignimbrite with subordinate andesite. Lithic fragments (up to 4%) are generally small (up to 10 mm) but reach 30 cm in the region of Ngamuwahine Road. The matrix is comprised of cuspate and Y-shaped glass shards, variably devitrified. Whole-rock samples of the Waiteariki Ignimbrite vary from dacitic to rhyolitic in composition (67.5 - 70.1% SiO_2; Whitbread-Edwards 1994).

Fig. 12 Densely welded Waiteariki Ignimbrite in the Wairoa River at McLaren Falls (U14 783 729).
(Note Annette Rodgers in background for scale.)

Distribution:

The Waiteariki Ignimbrite is an extensive large-volume welded ignimbrite that has constructed the Whakamarama Plateau, and underlies the Tauranga Basin to depths of 50 - 150 m. It was emplaced prior to the uplift of the Kaimai Range as it is displaced by the Hauraki and Okauia Faults into the Hauraki plains where it has been located in drill-holes at a depth of 55 m (Davidge 1982). The Whakamarama Plateau dips at 3 - 5° NE towards the Tauranga Basin, and represents a tilted block uplifted to the west (Houghton and Cuthbertson, 1989). The Waiteariki Ignimbrite is generally onlapped by younger ignimbrites and terrace deposits around Tauranga Harbour, but extends as far to the east as the region south of Welcome Bay. It forms prominent jointed outcrops in the Wairoa River at McLaren Falls (Fig. 12).

Stratigraphic Relations and Age:

The Waiteariki Ignimbrite overlies the Aongatete Ignimbrite (not exposed in U14) and is in turn overlain by a thick sequence of pyroclastic deposits, and fluvial and estuarine sediments. In general terms, it forms the local basement rock of western Tauranga Basin. The Waiteariki Ignimbrite is thought to be younger and flowed around and thinned over the Minden Rhyolite domes of Kaikaikaroro, Manawata and Minden Peak (Harmsworth 1983; Whitbread-Edwards 1994).

A K-Ar age of 2.18 ± 0.15 Ma (for whole rock) and 2.13 ± 0.17 Ma (for a plagioclase separate) was determined by Takagi (1995) for a "dacite lava outcrop" under Te Ariki Falls, Kaimai (T14 642 797). However, this sample is most likely to be the crystal-rich, densely welded Waiteariki Ignimbrite which forms the only outcrops in this vicinity. This means that the Waiteariki Ignimbrite is considerably older than the previous age of 0.84 ± 0.11 Ma determined by the fission-track method by Kohn (1973), which should now be revised.

Rock Character:

The Waiteariki Ignimbrite varies in welding from non-welded to densely welded, and the wall strength consequently also varies widely from very weak to very strong rock (R1 - R5). Joints with a wide to very wide spacing (0.2 - 3 m) occur in the welded zones, but are absent in non-welded ignimbrite. In many places the rock erodes by rock fall.

Papamoa Ignimbrite

Definition and Description:

The Papamoa Ignimbrite was defined by Healy *et al.* (1964) for a dacitic ignimbrite that resembles the Waiteariki Ignimbrite and overlies the Te Puke Breccias. The Te Puke Breccias outcrop on the Papamoa hills and are described by Healy *et al.*, (1964) as white to brown pumice breccias and tuffs with interbedded freshwater siltstones and sandstones. Hughes (1993) remapped the eastern sector of the Tauranga Basin and considered that the "Te Puke Breccias" were flow units and interbeds within the Papamoa Ignimbrite. Hughes (1993) also divided the Papamoa Ignimbrite into a Lower Papamoa Ignimbrite, with a type section between U14 973 795 and U14 973 804 where it is 50 m thick, and an Upper Papamoa Ignimbrite with a type section at U14 944 777 exposed as 60 m high bluffs along the valley wall (Fig. 13).

Hughes (1993) distinguished the Lower Papamoa Ignimbrite as a complex ignimbrite that contains a total of six different kinds of juvenile components: five intermediate to acidic pumice types and one basic scoria type. The pumice and scoria types vary in abundance with stratigraphic height and range in composition from basaltic andesite (55 wt % SiO_2) to andesite to dacite (dominant composition) to rhyolite (70.8 wt.% SiO_2), and are described in detail by Hughes (1993). The Lower Papamoa Ignimbrite is a light brownish-grey to buff-brown, pumice-rich (15-30%), crystal-rich (15-20%) ignimbrite (Fig. 14). The matrix contains crystals of plagioclase, quartz, hornblende, hypersthene, Fe-Ti oxides (ilmenite and titanomagnetite) and rare biotite in some pumices. Lithics are sometimes concentrated into lithic-rich zones of grey to pink rhyolite and black to dark grey andesite (up to 10%) (and small rare metaquartzites), but the matrix is predominantly lithic-poor (~1%). The Lower Papamoa Ignimbrite is variably welded, often exhibits case hardening where exposed in bluffs and steep cliffs, and may be lenticular with dark brown to grey to black lenticles set in a buff to grey matrix. At the type section on the eastern side of the Rocky Cutting Road valley, Welcome Bay (U14 973 804), the Lower Papamoa Ignimbrite overlies a sequence of fine ash beds containing accretionary lapilli and light brown pumice-rich (25%) flow units that might be the equivalent of the "Te Puke Breccias" of Healy *et al.* (1964).

Fig. 13 Bluffs of Upper Papamoa Ignimbrite, Waitao Road.

Fig. 14 Lower Papamoa Ignimbrite, Rocky Cutting Road (U14 962 794). Note the pumice-rich character with dark greyish-brown basaltic andesite/andesite scoria/pumice, pale buff-brown to greyish-white dacitic/rhyolite pumice, and lithics of dark grey to black rhyolite and andesite.

The boundary between the Lower and Upper Papamoa Ignimbrites is gradational (Hall 1994). The Upper Papamoa Ignimbrite contains only a single pumice type (rhyodacite), and is dense, cream to grey, with white pumices and crystals of plagioclase, quartz, hornblende, hypersthene and Fe-Ti oxides. Pumice sizes are small (av. 5 - 15 mm, max. 25 mm) compared with pumice clasts in the Lower Papamoa Ignimbrite (e.g. 190 x 150 mm). Lithics are mainly pink rhyolite with lesser amounts of dark grey andesite.

Distribution:
The Papamoa Ignimbrite is confined to the northeastern sector of the Tauranga region where it outcrops within the foothills of the Papamoa Ranges and infills valleys. Broadly, it forms a fan, emanating from the Papamoa Ranges, that dips gently and thins to the north. It typically forms prominent bluffs in the region of Rocky Cutting Road, Reid Road, road-cuts on Welcome Bay Road (U14 967 818), a 10 m waterfall in Kaitemako Stream at U14 919 768, and the Upper Papamoa Ignimbrite is well exposed along Kaitemako Road and Waitao Road.

Stratigraphic Relations and Age:
The age of the Papamoa Ignimbrite is unknown but overlies older andesites of the Papamoa Range which have K-Ar ages of 2.94 Ma and 2.54 Ma (Stipp 1968). It also appears to have onlapped the Kopukairua Dacite and flowed around this dome (Hughes 1993; Hall 1994). Healy *et al.* (1964), Skinner (1986) and Houghton and Cuthbertson (1989) noted its dacitic nature similar to the Aongatete and Waiteariki ignimbrites of the Whakamarama Group, and an age similar to the Waiteariki Ignimbrite appears likely.

Rock Character:
The Papamoa Ignimbrite is typically a medium strong to strong rock (R3 - R4) with a wide to very wide joint spacing (1 - 3 m). Outcrops occur as bluffs and ledges, and case hardening of the outer surfaces is typical.

Ongatiti Ignimbrite

Definition and Description:

The Ongatiti Ignimbrite is a major caldera-forming welded ignimbrite erupted from the Mangakino Volcanic Centre (Wilson *et al.* 1984; Houghton *et al.* 1995). It is among the most voluminous eruptive units known in the Taupo Volcanic Zone. The Ongatiti Ignimbrite is a non-welded to partially to densely welded pumice-rich, crystal-rich ignimbrite that has been described by Briggs *et al.* (1993). At Tauranga it is a partially to densely welded rhyolitic ignimbrite with whitish-cream, dense fibrous pumice (up to 20% and 50 mm in size) set in a buff brown matrix. The ignimbrite contains up to 25% crystals of plagioclase, quartz, hornblende, hypersthene, Fe-Ti oxides and zircon. It has a distinctive coarse vitroclastic texture comprising clean, weakly devitrified glass shards of cuspate and platy shapes.

Distribution:

The Ongatiti Ignimbrite outcrops as columnar jointed cliffs in the middle reaches of the Wairoa River north of McLaren Falls and around Tebbutt Road (Fig. 15). On a regional scale, the Ongatiti Ignimbrite has a wide distribution which extends from its source at Mangakino to north of Morrinsville and to the west coast of the North Island, but this is the only locality known in the Tauranga or Bay of Plenty regions.

Stratigraphic Relations and Age:

The Ongatiti Ignimbrite stratigraphically overlies the Waiteariki Ignimbrite. Sections of Ongatiti Ignimbrite overlying weathered Waiteariki Ignimbrite are exposed along Tebbutt Road. It has been dated by Ar/Ar methods by Houghton *et al.* (1995) at 1.21 ± 0.04 Ma.

Rock Character:

The Ongatiti Ignimbrite varies from weak to very strong rock (R2 - R5) depending on the degree of welding. It typically outcrops in bluffs that show subvertical joints varying from 0.3 - 4 m in width, and erosion by rock fall is typical. Case hardening on the outer exposed surfaces of the ignimbrite is a ubiquitous feature.

Fig. 15 Outcrops of columnar jointed Ongatiti Ignimbrite, Tebbutt Road (U14 800 790).

Te Puna Ignimbrite

Definition and Description:

The Te Puna Ignimbrite was first described by Harmsworth (1983), and studied in more detail by Whitbread-Edwards (1994) who proposed a type section at Te Puna Station Road (U14 828 859), Te Puna. The Te Puna Ignimbrite is a non-welded to partially welded buff brown ignimbrite containing white to grey fibrous pumice (15 - 25%). The matrix is crystal-rich (25%) with crystals of plagioclase, quartz, hornblende, hypersthene, Fe-Ti oxides and altered biotite. The groundmass consists of cuspate, lunate and Y-shaped glass shards in a yellowish matrix, and lithic types (1 - 2%) are grey, red and green rhyolites, occasional charcoal and obsidian, and fragments of Ongatiti Ignimbrite. Single pumice clasts range in composition from 72.6 - 75.7 wt.% SiO_2 (Whitbread-Edwards 1994).

Distribution:

The Te Puna Ignimbrite is exposed on Te Puna Station Road (Fig. 16) next to the Wairoa River (>16 m thickness) and in coastal sections at Omokoroa (3 m thick) and Pahoia Point (10 m), and also on the harbour side of Matakana Island. Outcrops are confined to the vicinity of Tauranga Harbour and it is not known in eastern Tauranga Basin, and hence is classified here as a small volume ignimbrite (<5 km^3), derived from a local Tauranga source.

Stratigraphic Relations and Age:

The age of the Te Puna Ignimbrite is unknown but its primary magnetisation is reversed (Kamp and Turner, pers. comm.) which suggests an age older than 0.78 Ma (e.g. Berggren *et al.* 1995) Lithic fragments of Ongatiti Ignimbrite with an Ar/Ar age of 1.21 ± 0.04 Ma (Houghton *et al.* 1995) give a maximum age for the Te Puna Ignimbrite. At Omokoroa (U14 797 928), the Te Puna Ignimbrite overlies lignite and fluvial pumiceous sands which suggests it flowed into a swamp, estuarine or lake environment (Whitbread-Edwards 1994; Hollis 1995). The top of the ignimbrite is eroded and overlain by cross-bedded fluvial pumiceous sands, lacustrine diatomaceous silts and sands, lignites, and tephras (Pahoia Tephras, Hamilton Ash). On Motuhoa Island (U14 805 906), the Te Puna Ignimbrite is unconformably overlain with a wavy erosional contact by the Te Ranga Ignimbrite, which in turn has an erosional contact with the Pahoia Tephras (Hollis 1995).

Rock Character:

The Te Puna Ignimbrite varies from non-welded, very weak rock to partially welded medium strong rock (R1 - R3). It is typically massive, joints and discontinuities are absent, and weathers to firm clay (S3). At Omokoroa Point, Pahoia Point and Matakana Island the Te Puna Ignimbrite is intercalated with Matua Subgroup lignites, fluvial and estuarine sands, and Pahoia Tephras, and is very prone to marine cliff and platform erosion and landslides, especially under wet conditions. Numerous rotational shallow and deep landslides are found along the extent of the cliffs at these localities.

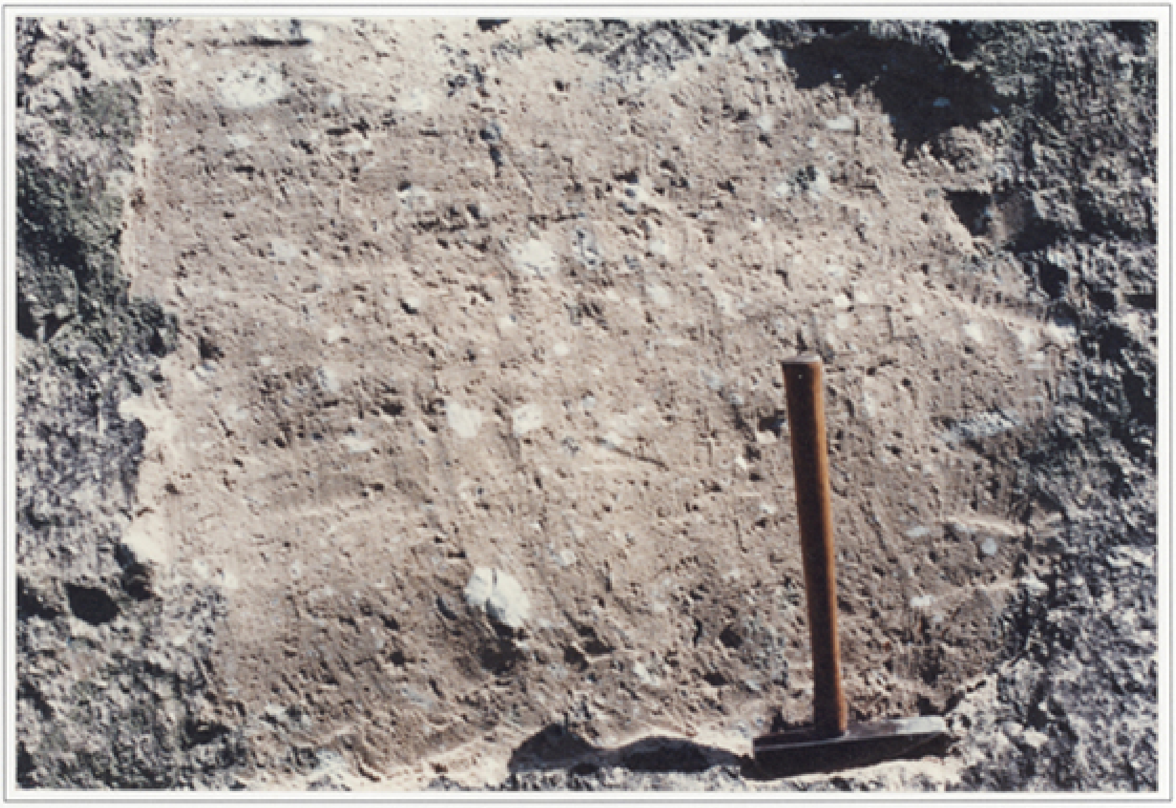


Fig. 16 Te Puna Ignmbrite at Te Puna Station Road (U14 828 859). Note abundant white pumice in buff brown matrix.

Te Ranga Ignimbrite

Definition and Description:

The Te Ranga Ignimbrite was informally defined by Harmsworth (1983), and studied in more detail by Hollis (1995) who proposed a type section near Chadwick Road, Greerton, at U14 856 818. The Te Ranga Ignimbrite is a light grey, non-welded, crystal-poor, sandy textured ignimbrite (Fig. 17), containing 5 - 25% pumice, 1-5% lithics (dominantly obsidian and rhyolite), and 7 - 12% crystals of plagioclase, hypersthene, Fe-Ti oxides, quartz, hornblende and augite. It is notable for containing a moderately coarse glass shard texture displaying cuspate, lunate, Y-shaped and platy shapes that are little deformed. Whole intact glass bubble textures are sometimes found, and the shards are only slightly devitrified, colourless or tinted light brown.

The Te Ranga Ignimbrite is unconsolidated and non-welded and in places could be mistaken for a fluvially derived pumiceous sand, but its characteristic texture and presence of charcoaled logs indicate a hot emplacement and pyroclastic flow origin. It has formed both veneer and valley pond structures, as seen at Jack Shaw's Pumice Pit, Tauriko, where it unconformably overlies eroded Matua Subgroup fluvial sands, silts and gravels.

Distribution:

The Te Ranga Ignimbrite covers an area of about 30 km^2, a thickness of 6 m at the Chadwick Road section and 25 m at Shaw's Quarry, Tauriko (U14 834 798), and is a small volume (<5 km^3) ignimbrite. It covers most of the area between Maungatapu and the Wairoa River, including parts of Matakana and Motuhoa Islands in the Tauranga Harbour, typically forming the steep sided interfluves or flat topped ridges along which pass Cameron, Cambridge and Pyes Pa roads. The Te Ranga Ignimbrite is not known outside the central Tauranga Basin, and a local Tauranga volcanic source is suggested.

Stratigraphic Relations and Age:

The Te Ranga Ignimbrite stratigraphically overlies the Te Puna Ignimbrite (Motuhoa Island) and underlies the Waimakariri Ignimbrite. However, none of these ignimbrites have been radiometrically dated.

At the Chadwick Road section, the stratigraphic sequence consists of lacustrine silts, Te Ranga Ignimbrite, horizontally bedded fine-medium ash, Te Ranga Ignimbrite-derived reworked fluvial sands, overlain in turn by Hamilton Ash, Rotoehu Tephra, and younger TVZ-derived tephra (Hollis 1995). The intercalation of the Te Ranga Ignimbrite between underlying lake sediments and overlying volcanogenic fluvial sands indicates that it might have been emplaced subaqueously, at least in part, into a lake (cf. Cas and Wright 1991; Bailey and Carr 1994), which is consistent with the absence of welding (Hollis 1995).

Rock Character:

The Te Ranga Ignimbrite is unconsolidated, non-welded and varies from extremely weak to weak rock (RO-R2). It is massive, sandy textured with occasional white pumice, lacks any jointing or discontinuities, and is prone to gully erosion.

Fig. 17 Te Ranga Ignimbrite exposed in Shaw's Pumice Pit, Tauriko (U14 834 798).

Waimakariri Ignimbrite

Definition and Description:

The Waimakariri Ignimbrite was informally named by Fransen and Briggs (1981) and Fransen (1982) for a voluminous, partially welded, rhyolitic ignimbrite that underlies the Mamaku Ignimbrite. The Waimakariri Ignimbrite probably corresponds to the lower Mamaku Ignimbrite as described by Healy (1957) and Lloyd (1965), but Fransen and Briggs (1981) and Fransen (1982) recognised it as a distinct unit from the Mamaku Ignimbrite. It probably also corresponds to the Pokai Ignimbrite south and southeast of the Mamaku Plateau as described by Karhunen (1993) and others. The Waimakariri Ignimbrite is a buff brown (e.g. at Merrick Road U14 842 743) varying to light grey (e.g. bluffs near Ruahihi Power Station and Ruahihi Canal) pumice-rich, crystal-rich ignimbrite (Fig. 18). It contains brown to dark brown or whitish-grey pumices (sometimes with pinkish-brown rims) which range from fibrous to dense to highly vesicular (Fig. 19). The pumices typically contain glomerocrysts or crystal clots (up to 5 mm) of plagioclase and quartz. Pumice abundance is variable, typically 15 - 20%, but sometimes reaches 50% in pumice concentration zones. Pumices range in size from 10 - 400 mm (average 30 - 80 mm) but in some places pumices up to 2 m across have been reported (Hollis 1995). Crystal abundance also varies (10 - 20%), and is dominated by plagioclase with lesser amounts of quartz, Fe-Ti oxides (mainly titanomagnetite), hypersthene and hornblende (generally trace amounts), biotite (rare), zircon and apatite (accessory). Lithic fragments vary from <1 (common) to 8% and are mainly rhyolite with rare greywacke. The Waimakariri Ignimbrite has a fine-grained vitroclastic matrix with platy, cuspate, lunate and Y-shaped glass shards, some with complete glass bubble walls still intact. There are various degrees of devitrification, vapour phase alteration and weathering. Welding is highly variable but it is generally partially welded with densely welded zones occurring in places where it flowed into paleotopographic lows (Morgan 1986). The Waimakariri Ignimbrite commonly outcrops as vertical cliffs, sometimes displaying columnar jointing, and with case hardening on the outer surface due to weathering.

Distribution:

The Waimakariri Ignimbrite is extensive and outcrops between the Wairoa River and eastwards to the Papamoa Hills. To the south, it gradually becomes obscured and covered by the overlying Mamaku Ignimbrite. It is thickest in the area of the Wairoa River and Ruahihi (>40 m), and is exposed in cliffs along the sides of broad valleys which run north-south into the southern parts of the Tauranga Basin. It is well exposed in cliffs at Belk Road Quarry (U14 822 765), along the Ruahihi Canal (Fig. 18) south of McLaren Falls (U14 784 728), Pyes Pa Road (U14 847 760), Merrick Road (U14 845 743), and Merrick Farm Youth Camp (U14 840 735; cliffs up to 50 m high). Hughes (1993) constructed a stratigraphic column at Merrick Farm accessway (U14 845 743) which is proposed here as a type section for the Waimakariri Ignimbrite.

Stratigraphic Relations and Age:

The Waimakariri Ignimbrite is a large volume (up to 100 km^3, Houghton *et al.* 1995) welded ignimbrite that stratigraphically overlies the Whakamaru Ignimbrites (in the western Mamaku Plateau, Fransen and Briggs 1981) and the Waiteariki and Te Ranga ignimbrites (near Ruahihi at U14 794 760, Hollis 1995), and is overlain by the Mamaku Ignimbrite. The upper surface of the Waimakariri Ignimbrite is eroded, and a paleosol is developed at Merrick Farm accessway (U14 844 743, Hughes 1993). However, at localities where it is overlain by the Mamaku Ignimbrite, the Waimakariri surface is only weakly dissected (Fransen 1982; Morgan 1986) which suggests only a small time period before the emplacement of the Mamaku Ignimbrite.

The age of the Waimakariri Ignimbrite is unknown but is bracketed by other ignimbrites with ages

The age of the Waimakariri Ignimbrite is unknown but is bracketed by other ignimbrites with ages of 0.32 (Whakamaru) and 0.22 Ma (Mamaku) (Houghton *et al.* 1995; Wilson *et al.* 1995). The weak degree of erosion on the upper Waimakariri surface would imply an age closer to that of the Mamaku is more likely. The Waimakariri Ignimbrite is suggested as coming from the Rotorua caldera (Fransen and Briggs 1981). The Pokai Ignimbrite, probably equivalent of the Waimakariri to the south and southeast, is also considered to have erupted from a Rotorua source (Wood 1992) or alternatively the Kapenga Volcanic Centre by Houghton *et al.* (1995).

<u>Rock Character</u>:
The rock character of the Waimakariri Ignimbrite is highly variable, and ranges from weak rock (R2) where non-welded to weakly welded, to strong rock where partially or densely welded (R4). Case hardening on surface outcrops and bluffs is common. Joints occur in partially and densely welded zones, varying in spacing from wide to very wide (1 - 4 m), but many outcrops such as at Ruahihi Canal or Merrick Farm accessway which are weakly to partially welded, there are no joints or discontinuities (Fig. 18).

Fig. 18 Waimakariri Ignimbrite exposed in walls and ledges along Ruahihi Canal (U14 784 728).

Fig. 19 Pumice-rich, crystal-rich Waimakariri Ignimbrite, Ruahihi Canal (U14 784 728).

Mamaku Ignimbrite

Definition and Description:

The Mamaku Ignimbrite was named by Martin (1961) who designated the gorge of the Mangorewa River at the Pyes Pa Road - Tauranga Direct Road bridge as the type site (U15 887 554) where it is 130 m thick.

The Mamaku Ignimbrite varies in colour from light grey to light brown to pinkish-purple to purplish-grey, and is generally a pumice-poor, crystal-poor, lithic-poor vapour phase altered welded ignimbrite. The degree of welding is highly variable, ranging from weakly welded to partially welded, and densely welded where the ignimbrite is thick. In the Raparapahoe Stream south of Te Puke, the Mamaku Ignimbrite has a dark grey-black basal vitrophyre which is a very densely welded lenticulite. The basal lenticulite contains black obsidian lenses representing strongly flattened pumice, and has a moderate crystal abundance (~10%) of quartz, plagioclase, hypersthene and hornblende, and rare andesitic lithics. Columnar jointing is generally characteristic of the partially to densely welded zones. The pumice (7 - 20% abundance) is usually powdery, grey, and extensively vapour phase altered (Fig. 20), and the ignimbrite often contains spotty brown patches that are weathered ferromagnesian crystals. The crystal assemblage is plagioclase, quartz, hypersthene, augite (trace), hornblende (trace), biotite (rare), Fe-Ti oxides, and accessory apatite and zircon. The matrix is generally strongly devitrified and vapour phase altered so that the relict shard texture is destroyed. Incipient spherulitic textures are sometimes observed (Morgan 1986). Lithic fragments constitute less than 2% and are argillite, ignimbrite and rhyolite.

Distribution:

The Mamaku Ignimbrite forms the upper surface of the Mamaku Plateau, which in the Tauranga region dips about 2° to the north. It has an erupted volume estimated at about 300 km^3 (Wilson *et al.* 1984) and thicknesses around Lake Rotorua reach 180 m (drill-hole data, Nathan 1976). The Mamaku Ignimbrite takes the form of an extensive thick fan spreading to the south, west and north of Lake Rotorua (Healy *et al.*, 1964). To the north, it extends to the southern Tauranga region and forms a rolling surface cut and dissected by major drainage patterns. It is generally 70- 80 m thick but has flowed around several topographic highs which are the older rhyolite domes that include Puwhenua and Otanewainuku (645m, U14 919 616). The Mamaku Ignimbrite partially covers the southern extension of the Papamoa Ranges and also covers part of the Waimakariri Ignimbrite surface.

Stratigraphic Relations and Age:

The Mamaku Ignimbrite stratigraphically overlies the Waimakariri Ignimbrite, and has an Ar/Ar age of 0.22 ± 0.01 Ma determined by Houghton *et al.* (1995). Various authors (e.g. Healy 1957; Lloyd 1965; Nathan 1976; Wilson *et al.* 1984) recognise and agree that the source of the Mamaku Ignimbrite is from Rotorua caldera.

Rock Character:

Within the Tauranga Basin, the Mamaku Ignimbrite generally varies from very weak to medium strong rock (R1-R3), but in some sections, e.g. in Raparapahoe Stream, the Mamaku Ignimbrite is 80 m thick, partially to densely welded and columnar jointed, and locally has a dense dark grey-black vitrophyre at its base. The vitrophyre forms waterfalls in the stream and is very strong to extremely strong rock (R5 - R6).

Fig. 20 Mamaku Ignimbrite exposed in road-cuts on No. 4 Road, south of Te Puke (U14 002 726). Note the grey to brownish-grey vapour phase altered pumice and fine spotty patches of weathered ferromagnesian crystals.

Matua Subgroup

Definition and Description:

Matua Subgroup is defined as all terrestrial and estuarine sedimentary deposits formed after the deposition of the Waiteariki Ignimbrite but excluding those of the recent fluvial regimes (Houghton and Cuthbertson 1989). The Matua Subgroup is part of the Tauranga Group as defined by Kear and Schofield (1978). It contains a wide variety of lithologies which change rapidly laterally and vertically (Houghton and Cuthbertson 1989). Lithologies within the Matua Subgroup include fluvial pumiceous and rhyolitic silts, sands and gravels (Fig. 21), lacustrine (diatomaceous) and estuarine muds, lignites and peats, intercalated with airfall tephras and thin distal ignimbrites (Figs. 22, 23, 24). A variety of sedimentary structures are found including cross-bedding, planar stratified and massive units, and post-depositional slump and water escape structures. A large proportion of the sediments are derived from reworked ignimbrites, lava domes and flows, and tephras, from both the Tauranga region and Taupo Volcanic Zone. Processes of erosion, transportation and re-deposition of consolidated and unconsolidated volcanic debris constitutes a major phase of most volcanic terranes, and it is therefore logical to expect to find deposits which are evidence of these processes in the Tauranga Basin.

Distribution:

Matua Subgroup sediments form a number of terraces ranging in height up to 80 m in the Tauranga Basin, and are exposed in coastal cliff sections at Maungatapu, Matapihi and Omokoroa Peninsulas, the base of Mt Maunganui, and many other localities around Tauranga Harbour. Matua Subgroup deposits infill the Tauranga Basin to a depth observed in drill-holes of about 150 m (Harmsworth 1983). Most sections show lateral and vertical variations of individual beds, so that it is not possible to construct reliable fence diagrams across the Basin. For example, the lignites vary from a few cm to 5 m at Omokoroa (Fig. 23), average 2 - 3 m, and may provide marker horizons (see detailed description of lignites including pollen analyses in Harmsworth, 1983), but correlation of thin distal ignimbrites across the basin has so far proved unproductive because of re-working of deposits and lack of suitable exposures.

Stratigraphic Relations and Age:

Matua Subgroup sediments have a range in age, and are defined as all the sedimentary deposits that post-date the Waiteariki Ignimbrite (2.18 Ma) and pre-date the Hamilton Ash (0.35 Ma), following the usage of Harmsworth (1983) and Houghton and Cuthbertson (1989). However, Houghton and Cuthbertson (1989) suggested it should be extended up to the age of the Mamaku Ignimbrite, now with a revised age of 0.22 Ma (Houghton *et al.* 1995).

The Matua Subgroup sediments are overlain by a thick sequence of tephra beds, often 3 - 5 m, of Hamilton Ash, Rotoehu Ash, and other post-Rotoehu tephras derived from the Taupo Volcanic Zone.

Fig. 21 Planar and cross-bedded fluvial silts, sands and gravelly sands of the Matua Subgroup, Shaw's Pumice Pit, Tauriko (U14 834 798).

Fig. 22 Te Puna Ignimbrite (pale brownish-white, approximately 2 m thick at position of hammer) at Omokoroa Point (U14 797 928) overlying dark brown fluvial sands (1 - 1.5 m thick) and black lignites (on shore platform) of the Matua Subgroup. Te Puna Ignimbrite is in turn overlain by white pumiceous fluvial sands and silts (Matua Subgroup) intercalated with Pahoia Tephras. The upper and lower surfaces of the Te Puna Ignimbrite are wavy and erosional.

Fig. 23 Lignite beds containing large fossilised logs on shore platform, Omokoroa Point (U14 797 928). Bedding in the lignites is slightly deformed and forms localised basinal depressions several metres across, possibly resulting from differential compaction.

Pahoia Tephras

Following Harmsworth (1983), the Pahoia Tephras (Pahoia Tuffs of Pullar *et al.* 1973) are included within the Matua Subgroup and consist of all the tephras older than Hamilton Ash Formation in the Tauranga Basin. The Pahoia Tephras are intercalated with fluvial and other sediments of the Matua Subgroup (Fig. 24), and include distal ignimbrites. A number of paleosols are interbedded within the Pahoia tephra sequence. The Pahoia Tephras are a group of tephras and may in part be correlatives of the Kauroa Ash Formation, a sequence of extremely weathered, clay-rich, rhyolitic tephra deposits recognised largely in the Waikato region that underlies the Hamilton Ash. The Kauroa Ash Formation has a possible age range between 2.26 Ma and 0.95 Ma (Briggs *et al.* 1994). As defined here, the Pahoia Tephras have a range in age from 2.18 Ma (age of the Waiteariki Ignimbrite from Takagi, 1995) to 0.35 Ma (age of the Hamilton Ash), H1, from Kohn *et al.* 1992).

Pahoia Tephras are exposed in coastal sections of the terraces at Greerton, Maungatapu, Matapihi, the base of Mt Maunganui, Matua, along the Waikareao expressway, Omokoroa (Fig. 22, 24) and Pahoia Peninsulas, and on Matakana and Motuhoa Islands.

Fig. 24 Sequence of beds (Matua Subgroup sediments; Te Puna Ignimbrite; Pahoia Tephras) on northern side of Omokoroa Point (U14 795 928): dark brown (shaded) fluvial sands and gravels at base (~1 m), bioturbated estuarine muds (protruding unit, ~0.8 m), Te Puna Ignimbrite (~0.6 m, at position of hammer head), cross-bedded and planar bedded fluvial sands and silts intercalated with pale brownish-white and white Pahoia Tephras with associated paleosols (vertical cracks, darker colour).

Hamilton Ash

The Hamilton Ash Formation consists of a sequence of strongly weathered, clay-textured tephra beds and paleosols well represented in the Waikato-South Auckland-Tauranga regions (Ward 1967; Pain 1975). The sequence has been divided into eight units numbered H1 (bottom) to H8 (top), although at any particular site, usually much fewer than eight units are found. At Omokoroa, the Hamilton Ash reaches a thickness of about 2.5 m (Fig. 25), but it is usually only about 1 m, presumably because of erosion of beds and paleosols. H1 has been identified as the Rangitawa Tephra (in southern North Island) which has a zircon fission track age of 0.35 ± 0.04 Ma (Kohn *et al.* 1992). The Rangitawa Tephra is probably a distal correlative of the Whakamaru-group ignimbrites erupted from Whakamaru caldera in the Taupo Volcanic Zone and dated at 0.32 ± 0.02 Ma by Houghton *et al.* (1995).

Fig. 25 Tephra section in road-cut (eastern side of road) at Omokoroa (U14 788 915), showing 2.5 m of orange-brown Hamilton Ash beds at base, with a strongly developed dark brown paleosol on their upper surface (position of spade handle), overlain by Rotoehu Ash (~0.7 m, prominent white protruding bed), and an undifferentiated composite sequence of younger post-Rotoehu Ash tephras (pale brown, ~0.2 m) derived from Taupo Volcanic Zone. (Annette Rodgers for scale.)

Taupo Volcanic Zone Tephras

Rotoehu Ash:

Overlying the Hamilton Ash are a sequence of younger tephras derived from the Taupo Volcanic Zone. The most conspicuous is the Rotoehu Ash which has an age >c.50 ka (Froggatt and Lowe 1990; Lowe and Hogg 1995). The Rotoehu Ash is a distinctive, widespread, shower-bedded airfall unit that in the Tauranga region varies from 0.3 to 2.4 m (av. 0.3 - 0.5 m) in thickness (Vucetich and Pullar, 1969). Part of the Rotoehu Ash is considered to be deposited from large phreatic eruptions which occurred when the Rotoiti Ignimbrite entered the sea (Walker 1979). The Rotoehu Ash is typically whitish-grey, fine to coarse ash textured, and directly overlies the Hamilton Ash (Fig. 25).

Post-Rotoehu Ash Tephras:

There is a thick cover of younger tephras overlying the Rotoehu Ash in the Tauranga Basin (Fig. 25). They are listed below, with thicknesses determined from isopach maps from Vucetich and Pullar (1969), Pullar and Birrell (1973a, b), and Hogg and McCraw (1983):

Mangaone Tephra (0.6 - 3 m); Kawakawa Tephra (0.3 - 0.6 m); Te Rere Tephra (0.15 - 0.3 m); Okareka Tephra (0.15 - 0.5 m); Rotorua Tephra (0.15 - 0.45 m); Mamaku Tephra (0.1 m); Tuhua Tephra - derived from Mayor Island - 6,130 years old (Froggatt and Lowe 1990) (0.1 m); Waimihia (0.1 m); Taupo (0.1 m); and Kaharoa (0.1 m).

The tephras of the Tauranga Basin are highly significant because they are the dominant parent materials of the productive soils in the region. They are also useful for dating land surfaces and correlating terrace heights. Their ages are summarised in Froggatt and Lowe (1990). All the tephras, except for the Tuhua Tephra, were derived from the Taupo Volcanic Zone.

Holocene Sediments

Tauranga Harbour is a large barrier-enclosed estuary, confined by the Bowentown (northern entrance) and Mt Maunganui (southern entrance) tombolos, and the barrier island complex of Matakana Island (Healy and Kirk 1982). The tombolos of Bowentown and Mt Maunganui have been tied to the mainland by a system of progradational dune ridges, comprised of a combination of fixed and moving dune sands, and formed during the Holocene and mainly since the post-glacial marine transgression or stillstand of c.6500 years ago (Wigley 1990; Munro 1994).

The harbour is generally shallow and lagoonal, and tidal gorges, ebb-tide and flood-tide deltas are well developed at both the northern and southern entrances (Healy and Kirk 1982). The exposed intertidal area of the estuarine lagoon is largely composed of marine sand (Healy and Kirk 1982). Davies-Colley (1976) observed that the freshwater input into the Tauranga Harbour is small compared to the tidal flow.

River and stream alluvium and peat deposits have formed low terraces of Holocene and late Pleistocene age. They are composed of silts, sands, clays, gravels and carbonaceous material.

STRUCTURE

Waitearìki Ignimbrite forms the local basement in the Tauranga Basin and overlies the Aongatete Ignimbrite (not exposed in the map area of U14) and presumably older Pliocene-Miocene andesitic volcanics and Mesozoic greywacke. The Waiteariki Ignimbrite has been tilted during uplift of the Kaimai Ranges, and dips 3 - 5° to the NE into the Tauranga Basin where it is unconformably overlain by a subhorizontal, mainly undeformed younger volcanic and sedimentary sequence.

Our studies have shown that very little faulting has occurred within the Tauranga Basin since the deposition of the Waiteariki Ignimbrite approximately two million years ago. In fact, no faults have been observed in outcrop within the Basin. The only faults that have been mapped are the two faults in the Papamoa Ranges postulated by Healy *et al.* (1964). However, the basis of these two faults is the alignment of rhyolite domes that strike NNE at 010 - 030°, but neither of these faults have actually been observed. The rhyolite domes of Kaikaikaroro, Manawata and Minden Peak also show an 030° alignment which may be structurally controlled (Whitbread-Edwards 1994), possibly by deeper-seated faults in the basement.

It appears quite likely that deeper-seated faulting occurs, but the faults have been obscured by a thick cover of sedimentary and pyroclastic rocks. This cover would be dominated by the welded ignimbrites of the Waiteariki, Waimakariri and Mamaku, and also by the non-welded ignimbrites of the Te Puna and Te Ranga intercalated with a variety of fluvial, estuarine and lacustrine sediments. The marine seismic reflection data by Davey *et al.* (1995) is significant since it shows that offshore of Tauranga and in the region west of the Tauranga Fault Zone, the structure is characterised by a deeper highly block-faulted unit that is overlain by a flat-lying, relatively undeformed sedimentary sequence.

Hence, for onshore Tauranga, we postulate that there may be a series of predominantly NNE-striking normal faults which occur in the basement (comprised of older volcanics and Mesozoic greywacke), but which have been covered by the Waiteariki and younger pyroclastic and sedimentary rocks. These faults may have controlled the localisation of volcanic vents, and even possibly controlled the NNE alignment of the terraced peninsulas of the Tauranga Harbour (e.g. Omokoroa, Tauranga City) and the dominant NNE direction of major rivers (e.g. Wairoa River, Te Puna Stream, Waipapa River).

Some terraces have a 1 - 2° dip to the NE or N which may have been imparted by late stage rejuvenation of NNE-striking faults and associated minor tilting. There are also numerous warm springs in the Tauranga district which may be associated and partly controlled by NNE-trending faults.

Caldera Structures:
The rhyolite domes and flows in the Taupo Volcanic Zone are generally associated with calderas, and restricted to intracaldera or caldera rim locations, or at least are never located far outside the caldera rim (Briggs and Fulton 1990). Hence by this analogy, the numerous rhyolite domes and flows of the Tauranga area may be associated with late Pliocene caldera structures. There is also a negative gravity anomaly in the northwestern region between Aongatete and Matakana Island (Woodward and Ferry 1973) which could indicate a caldera or collapse structure infilled with low density volcanic material. Lake sediments are found in many places in the Tauranga region, e.g. Matakana Island, although there is no direct evidence that these were caldera lakes.

However, arcuate or circular structures of possible rhyolitic caldera origin, similar to that seen in the Coromandel Volcanic Zone (e.g. Skinner 1986), have not been observed by remote sensing or landsat images in the Tauranga region. Also, lithic lag breccia facies, indicative of proximity to source, have not been found in any of the ignimbrites in the Tauranga district.

Some calderas in Taupo Volcanic Zone, e.g. the Reporoa caldera, have only recently been recognised (Nairn *et al.* 1994) even though they are relatively young features (230 ka, Houghton *et al.* 1995), because burial by younger volcanic material has largely obscured them. Hence it is even more unlikely that the recognition of caldera structures in the Tauranga region, which would be Pliocene in age, are not possible to define.

In summary, there is no conclusive evidence for rhyolitic caldera structures in the Tauranga area. However, the presence of numerous eroded rhyolite domes and flows (including buried rhyolite lavas - Harmsworth 1983) of late Pliocene age, associated with ignimbrites and lake sediments, and a negative gravity anomaly in the northwest near Aongatete, may suggest that calderas existed in the late Pliocene but have been obscured and buried by younger volcanic and sedimentary infill.

Applied Geology:
The rocks and soils of the Tauranga district are extremely variable in their physical and engineering properties, and mass failure is well known in many different localities (e.g. Bird 1981). This work by no means attempts to evaluate the soil and rock mechanical properties of the materials in the Tauranga region, but merely records some preliminary data on wall strength and spacing of discontinuities using the methods in the ISRM (International Society for Rock Mechanics) booklet (Brown 1981) on rock characterisation testing and monitoring (see Appendix for scales used).

Slope instability and mass failure may vary from deep-seated to superficial, and rotational slumps are common. Many of the pyroclastic rocks are strong, welded ignimbrites that are jointed and erode by rock fall, but others particularly in the central Tauranga Basin are very weak non-welded ignimbrites which lack any major discontinuities, and may erode by large and small scale rotational slides. Slope failures can be catastrophic events associated with high intensity rainstorms, and superficial failures can be common that involve failure of the soil, tephra and sometimes weathered bedrock, especially on steeper slopes.

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APPENDIX

Terminology used for Rock Characterization (after Brown 1981)

(a) Spacing of joints or discontinuities

Description	Spacing
Extremely close spacing	< 20 mm
Very close spacing	20 - 60 mm
Close spacing	60 - 200 mm
Moderate spacing	200 - 600 mm
Wide spacing	600 - 2000 mm
Very wide spacing	2000 - 6000 mm
Extremely wide spacing	> 6000 mm

(b) Manual index test of wall strength.

Grade	Description	Field Identification	Approx. Range of uniaxial compressive strength (M Pa)
S1	Very soft clay	Easily penetrated several inches by fist	<0.025
S2	Soft clay	Easily penetrated several Inches by thumb	0.025-0.05
S3	Firm clay	Can be penetrated several inches by thumb with moderate effort	0.05-0.10
S4	Stiff clay	Readily indented by thumb but penetrated only with great effort	0.10-0.25
S5	Very stiff clay	Readily indented by thumbnail	0.25-0.50
S6	Hard clay	Indented with difficulty by thumbnail	>0.50
R0	Extremely weak rock	Indented by thumbnail	0.25-1.0
R1	Very weak rock	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife	1.0-5.0
R2	Weak rock	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer	5.0-25
R3	Medium strong rock	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer	25-50
R4	Strong rock	Specimen requires more than one blow of geological hammer to fracture it	50-100
R5	Very strong rock	Specimen requires many blows of geological hammer to fracture it	100-250
R6	Extremely strong rock	Specimen can only be chipped with geological hammer	>250

Note: Grade S1 to S6 apply to cohesive soils, for example clays, silty clays, and combinations of silts and clays with sand, generally slow draining. Discontinuity wall strength will generally be characterized by grades R0-R6 (rock) while S1-S6 (clay) will generally apply to filled discontinuities (see Filling).
Some rounding of strength values has been made when converting to S.1 units.

ACKNOWLEDGEMENTS

We are indebted to the Land Resources section of Environment B·O·P for their cooperation and financial assistance to the research students in the Department of Earth Sciences, University of Waikato, who have been involved in this project. In particular, we would like to thank Tony Hall and Lawrie Donald for their continued support and understanding over the last 5 years. During the compilation and production of the map we have been fortunate to receive the expertise from members of the GIS group at Environment B·O·P, namely Stuart Halliday and Scott Lillas who have done an outstanding job in producing the map. We would also like to thank Norm Ngapo for his support in the latter part of this project, and to Joanne Deely and Norm Ngapo for editing the manuscript.

Further collaborative work with the Institute of Geological and Nuclear Sciences is also being carried out, particularly a programme of Ar/Ar dating of the volcanic rocks of the Tauranga region and southern Coromandel Volcanic Zone.

We are grateful to the many farmers, landowners and quarry managers of the Tauranga district who have given us access to their land and property.

Elaine Norton typed the manuscript and the figures were draughted by Frank Bailey. We would like to thank Lloyd Homer (IGNS) for his spectacular photographs on the front and back cover, and figures 1 and 5.

GLOSSARY

Aggradation — upbuilding of a surface by deposition of sands, gravels and silts by a stream.

Andesite — a dark grey coloured, fine-grained, extrusive or volcanic rock that is porphyritic and contains phenocrysts of plagioclase, ± pyroxene (e.g. hypersthene, augite) ± hornblende in a fine-grained groundmass.

Basalt — a black to dark grey coloured, fine-grained extrusive or volcanic rock that is generally porphyritic and contains phenocrysts of ± olivine, ± pyroxene (hypersthene, augite), ± calcic plagioclase in a glassy or fine-grained groundmass.

Bioturbation — the churning and stirring of a sediment by organisms.

Breccia — a coarse-grained clastic sedimentary rock composed of large (greater than sand size, or 2 mm in diameter) angular rock fragments that are cemented together by a finer-grained matrix. Breccia is similar to <u>conglomerate</u> except a conglomerate is composed of large rounded rock fragments.

Carapace (volc.) — a shield or thick cover over a lava dome, usually composed of pumiceous breccia and obsidian.

Cross-bedding — the internal arrangement of the layers in a stratified rock, characterised by minor beds or laminae inclined in sloping lines or concave forms at various angles to the original depositional surface. It is characteristic of sedimentary rocks, especially sandstones, deposited by swift water (or air) currents.

Dacite — a medium to light grey, fine-grained extrusive or volcanic rock with a composition between that of a rhyolite and an andesite.

Devitrified (devitrification) — conversion of the glassy texture of a rock to a crystalline texture.

Diatom — a microscopic, single-celled plant growing in marine or fresh water.

Diatomaceous — composed of numerous diatoms or their siliceous remains. (Forms a fine-grained white rock that feels slightly gritty and has a light weight or low density).

Distal — a deposit formed far from source. (Compare with <u>proximal</u>: a deposit formed near to its source area.)

Eutaxitic — banded structure in volcanic rocks resulting from parallel alignment of minerals and layers.

Fiamme — dark, glassy lenses in densely welded ignimbrite formed by collapse of pumice fragments.

Foliated — a planar arrangement of textural or structural features in a rock.

Glomerocryst — an aggregate of crystals.

Hyalopilitic — a groundmass texture in a volcanic rock where the spaces between the feldspar laths and ferromagnesian minerals in the groundmass are occupied by glass.

Ignimbrite — the deposits formed from pumiceous pyroclastic flows.

Intercalated — thin layers or strata of one kind of material that alternate with layers or strata of another kind of material.

K-Ar ages — a method of dating rocks or minerals by measuring their potassium (K) and argon (Ar) contents.

Lacustrine — formed in or deposited in a lake.

Lapilli a pyroclastic fragment between 2 - 64 mm in size.
Laths long and thin shaped crystals.
Lenticular resembling a lens in shape.
Lenticulite a densely welded ignimbrite made up of lenticular dark coloured dense obsidian fragments formed from collapsed pumice.
Lignite brownish-black carbonaceous material intermediate between peat and subbituminous coal.
Lithology the description or characteristics of a rock in hand specimen and in outcrop.
Mesotidal a tidal range between 2 m and 4 m.
Microlites minute crystals only visible under the microscope.
Non-welded pyroclastic deposits in which there is no sintering together of the originally hot, glassy fragments; the deposits are soft and porous, and easily crumbled in the hand.
Opacite aggregates of opaque, microscopic grains in a volcanic rock.
Paleosol a buried soil horizon of the geologic past.
Perlitic texture of a glassy volcanic rock that has curved or arcuate cracks due to contraction during cooling.
Phenocryst a large crystal in a volcanic rock.
Phreatic a volcanic eruption or explosion of steam, mud or other material.
Porphyritic common texture of a volcanic rock in which large crystals (phenocrysts) are enclosed in a fine-grained groundmass (which may be finely crystalline, glassy, or both).
Progradation the building forward or outward toward the sea of a shoreline by near-shore deposition of river-borne sediments.
Pyroclastic fragmental aggregates formed by explosive volcanic activity and deposited by transport processes resulting directly from this activity.
Radiometric measurement of geologic time by using the decay rate of radioactive elements.
Rhyolite a light coloured siliceous volcanic rock that may be porphyritic, exhibit flow textures, or may be entirely glassy (obsidian). May contain phenocrysts of quartz, feldspar, ± biotite, ± hornblende, ± hypersthene, ± augite.
Spheroidal weathering a form of chemical weathering in which spherical or concentric shells of decayed rock (varying from 2 cm to 2 m in diameter) are formed and successively loosened.
Spherulitic texture of a rock (usually rhyolite) composed of numerous spherulites. Spherulites are rounded or spherical masses of radiating, fine, needle-like (acicular) and fibrous minerals or glass.
Subgroup a formally defined assemblage of formations within a Group.
Tephra a collective term for all the unconsolidated, primary pyroclastic products of a volcanic eruption.
Tombolo a sand or gravel bar that connects an island with the mainland.
Trachytic texture of a volcanic rock in which the feldspars are oriented in a sub-parallel manner as a result of flow of lava.
Vitroclastic texture of the matrix of an ignimbrite composed of fine ash-sized (less than 2 mm) broken glass shards.
Vitrophyre a densely welded ignimbrite which has a glassy appearance in hand specimen.

Volcaniclastic a fragmental aggregate of volcanic origin.

Volcanogenic having a volcanic origin.

Welding the sintering together of hot pumice fragments and glass shards under a compactional load. Welding may occur in three zones of dense welding, partial welding and non-welding. Densely welded ignimbrites are hard, dense, strong to very strong rocks with low porosity and permeability, which are generally well jointed.

Back cover: The terraced peninsula of Omokoroa Point, Tauranga Harbour.
Photo: D L Homer

Digital terrain model of U14
GIS, Environment BOP

The terraced peninsula of Omokoroa Point, Tauranga Harbour
Photo:D.L.Homer

ISSN0110-0947