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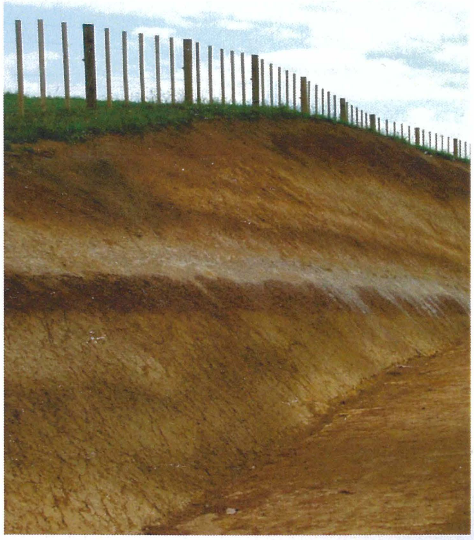

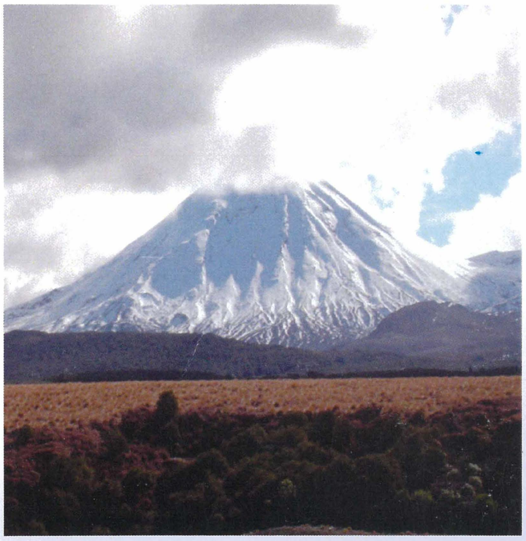

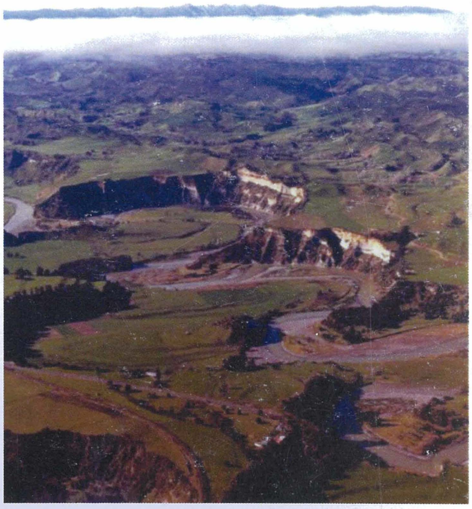

PRE-CONFERENCE NORTH ISLAND

26TH - 30th JULY, 2010

GUIDEBOOK

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NEW ZEALAND SOCIETY OF SOIL SCIENCE
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RANGAHAU AHUMĀRA KAI

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GUIDEBOOK FOR PRE-CONFERENCE NORTH ISLAND NEW ZEALAND 'VOLCANOES TO OCEAN'

26TH– 30TH JULY, 2010

NEW ZEALAND SOCIETY OF SOIL SCIENCE

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by

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Note

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Photo front cover

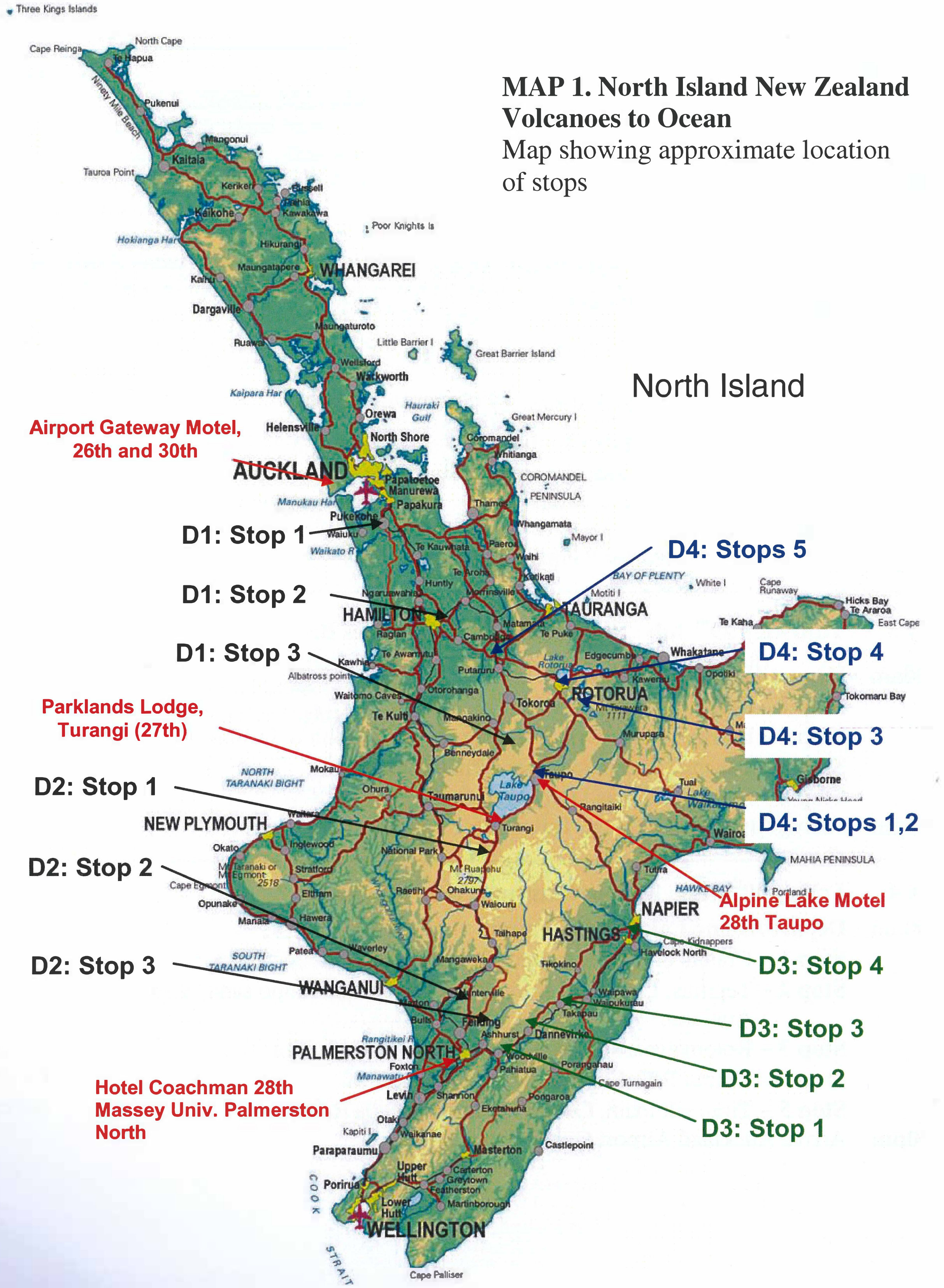
Quaternary sequence of tephras and buried soils on Gordonton Rd near Hamilton (left)
Mount Ngauruhoe, Tongariro National Park (centre)
View of Rangitikei river terraces (right)

Itinerary in brief

Day 1	**Tuesday 27th July: Auckland– Turangi**	**Map**
8:00am	**Depart Airport Gateway Motel**	
	Stop 1 - Pukekohe silt loam, Pukekohe Hill	D1 stop 1
	Stop 2 - DairyNZ Scott Farm Research Centre.	D1 stop 2
	Stop 3 - Mokai, Tuaropaki Trust's Mokai geothermal power plant	D1 stop 2
6:30pm	Arrive Parklands Motor Lodge, 15 Arahori Street Taupo	
Day 2	**Wednesday 28th July: Turangi – Palmerston North**	
8:00am	**Depart Parklands Motor Lodge**	
	Stop 1 – Mangatoetoenui Quarry, Desert Road	D2 stop 1
	Stop 2 - Stormy Point Lookout	D2 stop 2
	Stop 3 -Branch Road	D2 stop 3
5:00pm	Arrive Hotel Coachman Palmerston North	
Day 3	**Thursday 29th July: Palmerston North-Hawkes Bay- Taupo**	
8:00am	**Depart Hotel Coachman**	
	Stop 1 – Ballantrae Research Stn	D3 stop 1
	Stop 2 – Barrow Dairy farm Maharahara Road (John & Debbie Barrow)	D3 stop 2
	Stop 3 – Takapau Sheep and Beef farm and winery	D3 stop 3
	Stop 4 – Springfield Road Orchard	D3 stop 4
6.00pm	Arrive Alpine Lake Lodge Taupo	
Day 4	**Friday 30th July: Taupo–Rotorua-Tirau- Auckland**	
8:00am	**Depart Alpine Lake Lodge Taupo**	
	Stop 1 – Craters of the Moon and Huka Falls	D4 stop 1
	Stop 2 – Tephras, Loess and Buried Soil Sequence, Taupo sand, View Rd, Aratiatia.	D4 stop 2
	Stop 3 – Rotomahana silt loam, Brett Rd, Rerewhakaaitu	D4 stop 3
	Stop 4 – Kuirau Park Explosion Crater, Ranolf St	D4 stop 4
	Stop 5 – Tirau silt loam, Goodwin Farm, Tapapa Rd	D4 stop 5
7.00pm	Arrive Auckland Airport Gateway Hotel	

MAP 1. North Island New Zealand Volcanoes to Ocean

Map showing approximate location of stops



Map from www.bookin.co.nz/images/north_island_big.jpg

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Day 3: –Palmerston North-Hawkes Bay- Taupo

Day 4: Taupo–Rotorua-Tirau- Auckland

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Numerous people have contributed in various ways to this tour: planning, providing articles, information, services, speaking at various stops, and supporting or co-leading. We are very appreciative of your help – thank you.Eds.

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Introduction

Pre-tour notes and advice for tour participants

North Island, New Zealand Volcanoes to Ocean pre-conference field trip
July 26th – 30th, 2010

19thth World Congress of Soil Science, Brisbane, 2010

We look forward very much to hosting you on an interesting pre-conference field trip of North Island New Zealand. We have a group of around 22 signed up for the trip with participants from Belgium, Canada, China, Finland, France, Germany, USA and New Zealand. A warm welcome to you all from your tour leaders, Profs Vince Neall and Mike Hedley (Massey University) and Prof David Lowe (Univ. of Waikato).

Tour itinerary and themes

A provisional outline itinerary of the trip, including general route map (Map 1. p.6) is provided in these notes. More detailed descriptions will be available in your guide book. Because we have considerable distances to travel, as well as a range of stops planned, we will need to leave the hotel at 8.00 am each day.

Soils from Volcanoes

Our northern part of the tour (D1: Stop 1, Map 1.) begins with market gardening in the Pukekohe area on Pukekohe silt loam (Typic Andic Kandiudult) formed on the slopes of an old basaltic cone. Just after lunch you will examine intensive dairying (D1: Stop 2) in a flat to rolling landscape with high, short-range spatial variability in soil types ranging from Hapludands to Endoaquepts. In the afternoon we head towards Lake Taupo to view geothermally heated horticultural crops (D1: Stop 3), and a trip towards sunset around Lake Taupo to overnight in Turangi.

As we travel southwards on Day 1, towards the more recently active volcanic centres of Lake Taupo and Mt Ngauruhoe and Ruapehu in Tongario National Park, and return northwards on Day 3 and 4, to Taupo then the Okataina Volcanic Centre near Rotorua, the surficial tephra deposits and buried soils generally become successively younger and less weathered. We will see Ultisols, Andisols (including Vitrands), and Entisols on the tour, the oldest volcanic soil being possibly ~250,000 years and the youngest 15 years. The oldest buried soil dates to ~1 million years old. Tephric loess will be seen at several stops. Concepts of upbuilding pedogenesis in tephra-mantled terrains will be discussed.

On the morning of Day 2 we will climb the steep southern side of Lake Taupo and pass through the native podocarp forest on the Pihanga Saddle Road to view Mount Tongariro and the active volcanoes Ruapehu and Ngauruhoe. We will stop (D2: Stop 1) at the Mangatoetoenui Quarry to view the cover-bed succession of Holocene and Late Pleistocene Ruapehu- and Ngauruhoe-derived tephras resting on lahar deposits.

Soils from the Ocean

Leaving the volcanic plateau at Waiouru, for the southern half of our tour (Days 2 and 3) we will view actively building mountain land (the western side of the Ruahine Ranges) adjacent to dissected steep-lands giving way to river terraces and terrace remnants and alluvial plains. Over the last 400,000 yrs, tectonic uplift, coastal marine processes and erosion by the Rangitikei River have produced one of the finest flights of river aggradation terraces in the world (D2:Stop 2). The hill country we will pass through is typical of moderately and deeply incised land, Class 6e and 7e, which describes steep hills susceptible to sheet and slip erosion. Erosion control is a major focus of contemporary farm planning. The last stop of the day (D2:Stop 3) will consider the problem of extensive hill country sheep farming on highly erodible steep-land formed in Early Pleistocene marine sands and muds.

Departing Palmerston North on day 3, the route follows the Manawatu River northeastwards across alluvial terraces to the Manawatu Gorge. The headwaters of the River drain from hills and mountains on the eastern side of the Tararua and Ruahine Ranges, and since the River established its course the ranges have gradually been tectonically uplifted approximately 250m at this point (much more to the north and south), over the last 0.25-1 Ma. The first stop at AgResearch's Ballantrae Research Station (D3:Stop 1) also shows the scarp of the Wellington Fault responsible for the uplift on the eastern side.

From Ballantrae northwards the route crosses mainly rolling country which was being uplifted from the sea as recently as 1 Ma. Subsequent tectonic uplift to both the east and west has formed the Woodville and Dannevirke Synclines, in which young marine and coastal lignite deposits with pumice beds are preserved. This country has some massive and deep-seated slumps leading to much localised land sliding. Soils are either derived directly from these parent materials (mainly in the hill country) or from cover beds of both quartzofeldspathic (Mesozoic-greywacke derived) or volcanic loess. In the area south of Dannevirke and to the north of Norsewood the route traverses extensive areas of gravel terrace (the Ohakean terrace) deposited during the Last Glacial Maximum (circa. 20,000 years ago). At the Barrow Dairy farm (D3:Stop 2) we will stop to discuss farm-scale soil mapping and the development of farm management plans. As one travels northwards the topsoils on these terraces show increasing volcanic provenance (mostly andesitic) in the fine-grained accumulations above the gravels.

After visiting a sheep and beef farm plus winery at Takapau (D3:Stop 3), we take Highway 50 northwards to the Heretaunga Plains of Hawkes Bay. The pattern continues until approaching the Plains where a marked decrease in rainfall and increase in sunshine hours combines with the Holocene alluvial soils to produce the "Fruitbowl of New Zealand" (D3:Stop 4). Most of the soils on the Plains have been deposited by the combined aggradation of 3 rivers - the Tutaekuri (north), Ngaururoro (west) and Tukituki (south), discharging fine-grained sediments that have prograded the coastline in late Holocene times. Most of the soil parent materials are less than 2,000 years old, shown by extensive areas of alluvial pumice which were transported down the Ngaururoro River to inundate the lowlands of the river mouth just 1800 years ago. As the Ngaururoro River flows across the western margin of the Plains it loses half its flow into the underlying gravels which dip under the Plains providing one of New Zealand's premier artesian water systems. The buried aquiclude confining the aquifer in the lower half of the Plains is marine mud deposited by the Holocene high sea level about 6,500 years ago. Flow rates of up to 180,000 litres/hour of high quality water from a 10 cm diameter pipe are recorded. It is no wonder that the climate and soils combined with this underground water resource proved to be the successful recipe for the establishment of the food canning industry which Watties began.

From Taradale to Napier one begins to cross land that was swampy prior to the 1931 Napier Earthquake. North of Napier the current land had been a large embayment of the sea. After the Earthquake the soils remained salty for most of 50 years before the salts were leached from the profile.

Return to the Volcanoes

At the Esk Valley the route turns inland and begins to traverse typical North Island hill country. Most of the strata from the Esk to the Mohaka Rivers was under the ocean until 1 -2 Ma. Subsequent tectonic uplift has led to a general dip slope towards the east, so as we traverse westwards we pass increasingly older strata from 2 to circa 15 Ma (Miocene) years old. At the Mohaka River the route descends to the younger river terraces before climbing once more into Tertiary hill country. Soon Mesozoic greywackes appear and the land is less productive, steeper and often left in native forest or planted in pines. In the vicinity of the Tarawera Tavern, the terminus of pumiceous pyroclastic flows from the 232 AD eruption of Taupo are encountered, forming a distinct pumice terrace on the lower hillsides. As we begin to emerge from the hill country onto the Central Volcanic Plateau once more, we encounter Te Whaiti Ignimbrite from the c. 360,000 year Whakamaru eruption of the Taupo-Mangakino region which formed most of the planar landscape to Taupo. Here the soils are totally pumice dominated (Vitrudands). Nearing Taupo we pass the dacitic Tauhara dome complex.

Rising on Day 4 in Taupo, we visit “The Craters of the Moon” thermal area in Wairākei (D4:Stop 1). This is a typical acid sulfate geothermal system, with abundant fumaroles, steaming ground, mud pools, explosion craters and colourful soils. Nearby we will view Huka Falls, the largest on the Waikato River, created when the Waikato River, after flowing over a comparatively wide bed, is abruptly confined for about 220 metres to a narrow rock-bound chasm less than 15 m wide. After a short trip we will stop at a road cutting near Aratiatia Rapids (D4:Stop 2) to view a classic Taupo Pumice soil and earlier tephras and buried loess horizons. Leaving Taupo we head for the Okataina Volcanic Centre near Rotorua to view a classic layered profile with 4-5 separate tephras and buried soil horizons with unusual examples of ejected Lake Rotomahana Mud plus Mt Tarawera scoria forming the topsoils (D4:Stop 3). After a brief stop in Rotorua’s Kuirau Park to experience explosion craters with vigorous geothermal activity (D4:Stop 4) we climb over the Mamaku Plateau and head to Tirau to view a classic New Zealand Andisol (Tirau soil, Typic Hapludand) formed in distal tephras and composite tephric loess. Beneath are buried soil horizons dating back to 230,000 yrs (D4:Stop 5). To complete the tour, we travel Highway 27 from Matamata to Auckland through the heart of the Waikato and Hauraki plains, which 20,000 years ago were formed by the Waikato River as it made its way northwards into the Firth of Thames. We arrive back in Auckland around 7pm.

Land use issues

Topical issues relating to soil protection, management of intensive horticulture, pastoral farming (especially dairying), plantation forestry and sustainable land management planning will be discussed. Protection of river, lake and ground water quality from diffuse agricultural runoff and drainage will be a consistent theme throughout the tour.

Instructions for Participants:

On arrival in Auckland

Participants should plan to arrive in Auckland by early evening of Monday 26th July. Overnight accommodation is provided at Airport Gateway Motel near Auckland Airport that night (see below and Table 1). We leave the Airport Gateway Motel to start the tour at **8 am** on **Tuesday 27th July**.

Monday 26th July

All participants have been booked into **Airport Gateway Motel, 206 Kirkbridge Road, Mangere, Auckland** (very near Auckland International Airport in Mangere) for the night of Monday 26th July. [Reservations manager: *Sharin,* Email: gatewayhotel@xtra.co.nz website -- http://www.airportgateway.co.nz/]

The accommodation costs have been covered by your registration fee and include a continental breakfast on Tuesday 27th July. Any other costs on *Monday 26th July* (e.g. an evening meal on the Monday 26th , internet useage etc.) are the responsibility of participants.

Arrival and transfers Monday 26th July

On arrival at the Auckland Airport, after exiting New Zealand customs, look to your left for the **"i-site"** counter and use the free phone hotline (dial 47) to ask for a pick-up to the **Airport Gateway Motel, 206 Kirkbridge Road, Mangere, Auckland**, which operates a free airport transfer shuttle service. It operates 24 hrs every half-hour (on the hour and half-hour), or on phone request (see Table 1). The trip to the hotel takes only about 5 minutes..

Airport Gateway Motel, may be able to provide early check-in if rooms are available. If you are arriving early (before ~1 pm) and would like early check-in, please email **gatewayhotel@xtra.co.nz** and advise *Sharin* of your likely time of arrival. Tell *Sharin* that you are on the World Congress of Soil Science Tour being run by Mike Hedley (Ref # 61652). Early check-in cannot be guaranteed, however. In any event, bags can be left in secure storage at the hotel at any time.

Arriving before Monday 26th July?

If you plan on arriving in Auckland before *Monday 26th July*, you are welcome to stay at **Airport Gateway Motel, 206 Kirkbridge Road, Mangere**, at your own expense. Email **gatewayhotel@xtra.co.nz** and advise *Sharin* of your likely time of arrival. Tell *Sharin* that you are on the World Congress of Soil Science Tour being run by Mike Hedley (Ref # 61652).

Evening meal Monday 26th July

Airport Gateway Motel does provide evening meals but other eating alternatives are either a short walk or shuttle bus away to the Airport Shopping Centre, where there are additional food outlets including a 24-hr McDonald's and a 24-hr supermarket (Foodtown).

Tour meeting evening of Monday 26th July

We propose to hold a brief meeting of tour participants at Airport Gateway Hotel in either the lounge area (lobby) or conference room at 8.30 pm Thursday 27th Nov. The meeting will let us carry out a head count, introduce ourselves to one another, and provide a few final details about the tour.

Internet

Unless otherwise advised assume that there are charges for internet access at all hotels and motels, which are to be met by participants.

Getting to downtown Auckland

A blue-coloured shuttle bus "Airbus Express" operates from Auckland International Airport every 15 minutes during the day (see blue-coloured brochures available at airport or hotel)

- City to airport: 1st bus 4.30 am (from Downtown Ferry Terminal), last bus (from Downtown Ferry Terminal) 9.50 pm
- Airport to city (from International and Domestic terminals, which are adjacent): 1st bus 6.00 am, last bus 10.00 pm

- Cost for adults one way $16 or $23 return
- Tickets available from driver (reservations not required)
- Trip takes about 40-50 minutes (real-time information on next shuttle is available at key stops)
- See www.airbus.co.nz or ph 09 366-6400 or 0800 10 30 80

Note that the Airbus Express does not stop at Airport Gateway Hotel. To use Airbus Express, take the **Airport Gateway Hotel** shuttle bus to the airport (on scheduled departure times) and catch the Airbus Express shuttle to town. To return, take the Airbus Express shuttle to the airport and catch the next available **Airport Gateway Hotel** shuttle to the hotel. Alternatively, take a taxi to town and back.

Tuesday 27th July, and on tour

Please help yourself to breakfast (includes tea/coffee) at 6.30 am on Tuesday 27th July morning (available from 6.30 am). We plan to depart from **Airport Gateway Hotel** at 8.00 am sharp. Bags must be ready for loading in the lobby area by **7.45 am** please.

Accommodation, breakfast and evening meals

All participants have been booked into the accommodation listed in Table 1.
The accommodation costs covered by your registration fee include room and continental breakfasts.

Table 1: Arrival at accommodation venues

Date	Hotel/Motel	Arrival time	Dinner	Breakfast in restaurant or room
26th July	Airport Gateway Hotel 206 Kirkbride Road Auckland Airport 2022 (+64 9) 275 4079	Meeting 8.30 pm in Lobby	No meal provided	27th July, Breakfast 6.30 am have bags in Lobby by 7.45am for an 8am departure
27th July	Parklands Motor Lodge, 15 Arahori Street Turangi 3353 (+64 7) 386 7515	6.30 pm	Provided in Motor Lodge	28th July, Breakfast in room
28th July	Hotel Coachman 140 Fitzherbert Avenue Palmerston North 4410 (+64 6) 356 5065	5.00 pm	Dinner at Massey University	29th July, Restaurant from 6.30 am
29th July	Alpine Lake Lodge 141 Heuheu Street Taupo 3330 (+64 7) 378 0899	6.00 pm	Hangi at Maori concert.	30th July, Breakfast in room
30th July	Airport Gateway Hotel 206 Kirkbride Road Auckland Airport 2022 (+64 9) 275 4079	7.00 pm	No meal provided	31st July, Family restaurant

Evening meals

Evening meals have been organised for both Wednesday 28th July (Wharerata Restaurant, Massey University, Palmerston North) and Thursday 29th July (A Hangi (meal cooked in underground oven) followed by a Maori concert in Taupo). Costs for these meals, and some drinks, will be covered by your registration fee. Smart casual clothes are acceptable at restaurants. Men are generally not expected to wear suits and ties.

Lunches and morning/afternoon teas

We will provide lunches on each day of the trip. On Tuesday 27th July and Wednesday 28th lunch will be at a rural restaurant. On Thursday 29th and Friday 30th we will have packed lunches. Morning and afternoon teas will be provided from ingredients carried by us on the bus. We have short, designated stops for tea/coffee breaks and, usually, toilet access.

Weather and clothing

Late July is regarded typically as late winter/early spring in New Zealand. The weather can be rather unpredictable and range from warm and sunny (>15° C) to cold (<5° C), windy, and wet, sometimes all on the same day! It is essential therefore that you are prepared for changeable conditions and so you must pack a warm pullover/jumper or sweater and (light) windproof jacket/rainproof coat. If it is sunny or only partly cloudy you will need hats and sunblock. Because conditions underfoot could be muddy or wet in places, appropriate footwear is essential – boots are recommended. We will walk no longer than 10 minutes at any one stop so will not be hiking any distance.

Safety

At all times it is essential to be careful when we are at roadside cuttings – participants especially from right-had drive countries please look extra carefully in both directions before crossing the road (traffic in New Zealand drives on the left, UK style). Each participant will be issued with an orange Hi-Vis fluoro vest to wear during the stops. At some roadside stops we will be putting out road safety signs and traffic cones to slow traffic and minimise risk. It is essential that all participants are safety conscious and responsive if traffic comes along the road and if you are asked to move off the road or away from the road edge.

For emergencies in New Zealand the call number by phone or cell phone is **111**. You will be asked if you want (1) police, (2) ambulance, or (3) fire department. You must state where you are *including the name of the town* because calls are routed through centralised call centres.

Be careful in New Zealand and be aware of personal safety and possessions, especially after dark.

Voltage

The New Zealand electricity supply operates at 220-240 volts. You may wish to purchase an adaptor for your personal electrical devices – computer, chargers, etc – both for voltage requirements and plug style.

Quaternary volcanism, tephras, and tephra-derived soils in New Zealand: an introductory review

David J. Lowe

Department of Earth and Ocean Sciences, University of Waikato, Hamilton

Introduction

This two-part article comprises brief introductions to (1) volcanism and its products in general and to the broad pattern of Quaternary volcanism and tephrostratigraphy in North Island, and (2) the ensuing tephra-derived soils of North Island. Part 1 derives mainly from Smith et al. (2006), Leonard et al. (2007), and Lowe (2008a). Other useful reviews include those of Neall (2001), Graham (2008: Chapter 7), Wilson et al. (2009), and Cole et al. (2010). Recent reviews on tephras include Shane (2000), Alloway et al. (2007), Lowe (2008b, 2011), and Lowe et al. (2008a, 2008b). A history of tephra studies in New Zealand was reported by Lowe (1990). Part 2 describes the distribution and character of the main tephra-derived soils, these being Entisols and Andisols (mostly Vitrands and Udands) and Ultisols (Lowe and Palmer, 2005). Books on these and other soils in New Zealand include NZ Soil Bureau (1968), Gibbs (1980), McLaren and Cameron (1996), Cornforth (1998), and Molloy and Christie (1998). An excellent overview is the web-based article by Hewitt (2008), and encyclopaedic reviews by Neall (2006) and McDaniel et al. (2011) include New Zealand examples. Tonkin (2007a, 2007b, 2007c) provided a history of soil survey and soil conservation activities in New Zealand. A quantitatively-based classification of New Zealand‟s terrestrial environments was published by Leathwick et al. (2003).

Volcanoes, volcanism, and tephras

Volcanoes, magmas, and types of eruptions

Volcanoes are not only conical mountains, but span a very wide range of landforms. A volcano is any landform that results from molten rock (magma) being erupted at the Earth‟s surface. The size and shape of a volcano reflect how often it erupts, the sizes and types of eruptions, and the composition of the magma it produces. Magmas contain almost all of Earth‟s known chemical elements but typically they comprise only nine – silicon, oxygen, aluminium, magnesium, iron, calcium, sodium, potassium and titanium – that sum 98% or more by weight. Oxygen and Si together are generally the most abundant elements, making up 48–76 % by weight of most magmas. The chemistry of magma, especially Si content, is important for influencing the way it erupts, and three main magma types, and resulting volcanic rocks, are identified on the basis of their chemical composition. A fourth type, dacite, is usually grouped with andesites but is midway between andesite and rhyolite in composition.

- *Basalt* is rich in Fe and Mg and low in Si and erupts at very high temperatures (~1100–1200 °C) as a very fluid magma. Basalt magma with very little gas cools to form dark black, dense lava, but where magma erupts with lots of gas it cools to form ragged scoria or ash.

- *Rhyolite* magma is rich in Si, K and Na and erupts at temperatures between 700–850 °C as an extremely viscous magma. Rhyolite magma containing lots of gas bubbles cools to form pumice, but if the magma contains little gas it may form obsidian glass.

- *Andesite* (also *dacite*) magma is intermediate in composition and physical properties. Erupting at ~800–1000 °C it is more viscous than basalt, but much less viscous than rhyolite. Andesite magma cools to form dark grey lava if gas-poor or scoria or ash if gas-rich.

Volcanic eruptions vary remarkably in style and size. The smallest may just dust the summit of a volcano with volcanic ash, whereas the largest are capable of creating entirely new landscapes across whole countries. Although there is great diversity of volcanic behaviour, eruptions can generally be classed as one of two broad types – either explosive or effusive.

Explosive eruptions

Explosive eruptions are caused by gases violently ripping apart and shattering magma into pieces which cool and solidify into pumice (if the magma is rhyolite), scoria (if the magma is andesite or basalt), and volcanic ash (sand and dust-sized splinters mainly of volcanic glass). Explosive eruptions take place in one of two ways. The first involves gas that is contained within the magma at depth. As magma rises to the surface the drop in pressure causes these gases to bubble and expand violently. Close to the surface magma becomes like the foam that explodes out of champagne or a can of fizzy drink when first opened. The second type of explosive eruptions occurs when magma contacts water, either beneath the ground (at an aquifer) or at the land surface (either a lake or the sea). The very high temperature of magma (700–1200 °C) means that it instantly boils the water, causing violent steam explosions, which blow apart the magma, eject liquid water and steam, and rip up the ground containing the water. These types of eruptions are called phreatomagmatic eruptions (Smith et al., 2006).

In both types of explosive eruptions, the shattered magma and other rock fragments are carried violently into the air by the uprush of expanding gases, before settling back to the ground to form a pyroclastic (literally „fiery fragmental‟) deposit. The more explosive the eruption the more energetic this roaring stream of gas, and the higher the tephra and rock fragments will be carried into the air. The higher the material goes, the further from the volcano it will be blown by the wind, and so there is a close correlation or relationship between the energy of an eruption and how far the eruption products are spread.

Effusive eruptions

Effusive eruptions occur when magma contains little gas and so cannot behave explosively, but instead quietly extrudes at the surface forming flows of lava. The very fluid basalt lavas can flow long distances forming extensive, almost flat volcanoes, whereas very viscous rhyolite lava piles up around the vent, like toothpaste squeezed from a tube, forming large, steep-sided mounds called domes.

Three different types of volcanoes

Although New Zealand‟s active volcanoes look quite different from one another, all can be grouped into one of three main landform types:

- classic cones or stratovolcanoes (e.g. Mt Taranaki, Mt Ruapehu)
- volcanic fields (e.g. Auckland Volcanic Field, South Auckland Volcanic Field); and
- caldera collapse craters (e.g. Taupo caldera, Haroharo caldera)

Each of these has obvious landforms and the violence and styles of eruptions are unique to each. These differences reflect the type of magma erupted: basalt at the volcanic fields, andesite at the cone volcanoes, and rhyolite at the calderas. During our trip, we will see mainly rhyolitic or dacitic deposits and landforms but some basaltic materials are also on show at the start (South Auckland Volcanic Field) and on Day 4 near Mt Tarawera.

Caldera volcanoes and eruptions

A caldera is a large, deep crater resulting from the caving in of a rhyolite magma chamber. In places the caldera walls can be seen as steep cliffs, but many are difficult to observe in the landscape because they may be filled in with erupted material or covered by water. Calderas have extremely violent origins and form when a vast amount of viscous rhyolite magma, bubbling with gas, erupts explosively from a magma chamber that may only be a few kilometres beneath the ground. During these eruptions, so much magma is erupted that the chamber empties, leaving the ground above it unsupported. This area collapses, dropping like a piston, to form a wide, deep depression. Lake Taupo, the area to the east of Rotorua known as Okataina, and Mayor Island or Tuhua, are three examples of recently active caldera volcanoes in New Zealand. Some older calderas exist in the area between Taupo and Rotorua and on the Coromandel Peninsula (see map below) (Cole and Spinks, 2009).

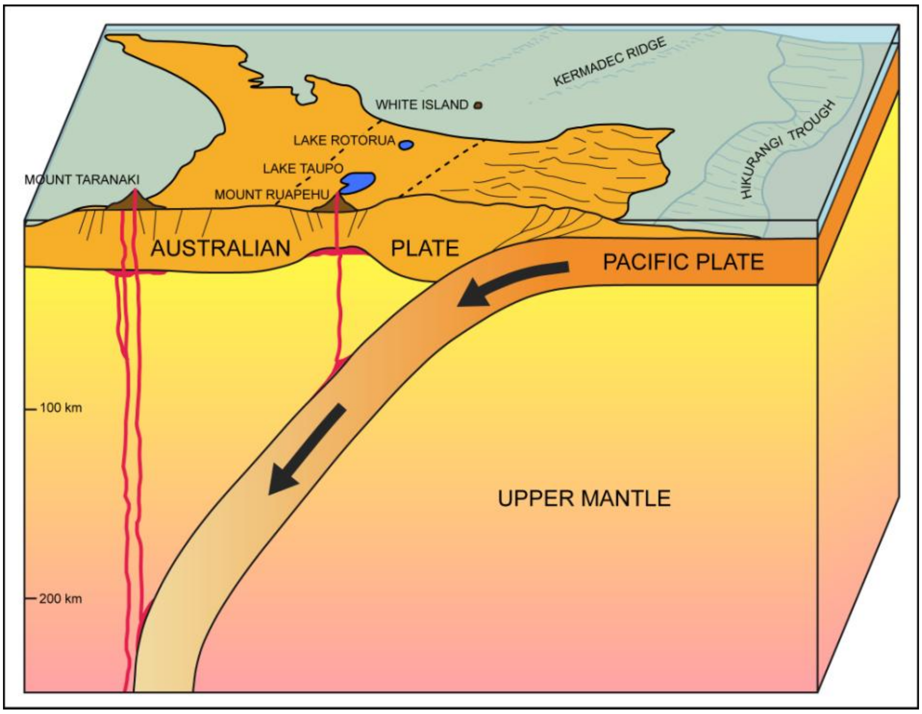
Rhyolite calderas may be active for several hundred thousand years, but large eruptions are rare, with typically thousands of years between events. Caldera collapse is not the only effect on the landscape arising from these large explosive eruptions. Huge quantities of pumice, ash and gas are pumped into the atmosphere, and through a combination of heat and momentum, a roiling column of this material may rise to over 50 km above the caldera. From this height, ash and especially aerosols – gases and tiny drops of acid – can spread around the globe, affecting the world‟s climate for several years. Closer to the caldera the landscape may be buried by metres of pumice. The most devastating process, however, occurs when this column of material falls back to earth like a fountain, then surges out in all directions from the caldera as a hurricane-like billowing, ground-hugging flow of hot pumice, ash and gas. These pyroclastic flows or „density currents‟ can travel over 100 km at the speed of a racing car, leaving behind a layer of volcanic (pyroclastic) debris that might be more than 100 metres deep. Some flows are so hot (600-700 °C) and thick that the ash and pumice fragments weld back together, forming solid rock known as partially or densely welded ignimbrite.

Dome building

Eruptions from rhyolite volcanoes are not always so explosively catastrophic. A small amount of rhyolite magma may remain after a caldera eruption, which is exhausted of all gas and so can only ooze from the volcano slowly, often along the faults and fissures opened up by earlier caldera collapse. The very high viscosity means the silica-rich rhyolite lava will not flow far, and instead, piles up around the vent, like toothpaste squeezed from a tube, to form a steep-sided dome or dome complexes. These domes are prominent landscape features amongst the caldera volcanoes of the Taupo Volcanic Zone – Mokoia Island and Mt Ngongataha are rhyolite lava domes erupted within Rotorua caldera, and Mt Tarawera comprises a collection of lava domes erupted around 1314 AD within Haroharo/Okataina caldera.

Quaternary volcanism in North Island

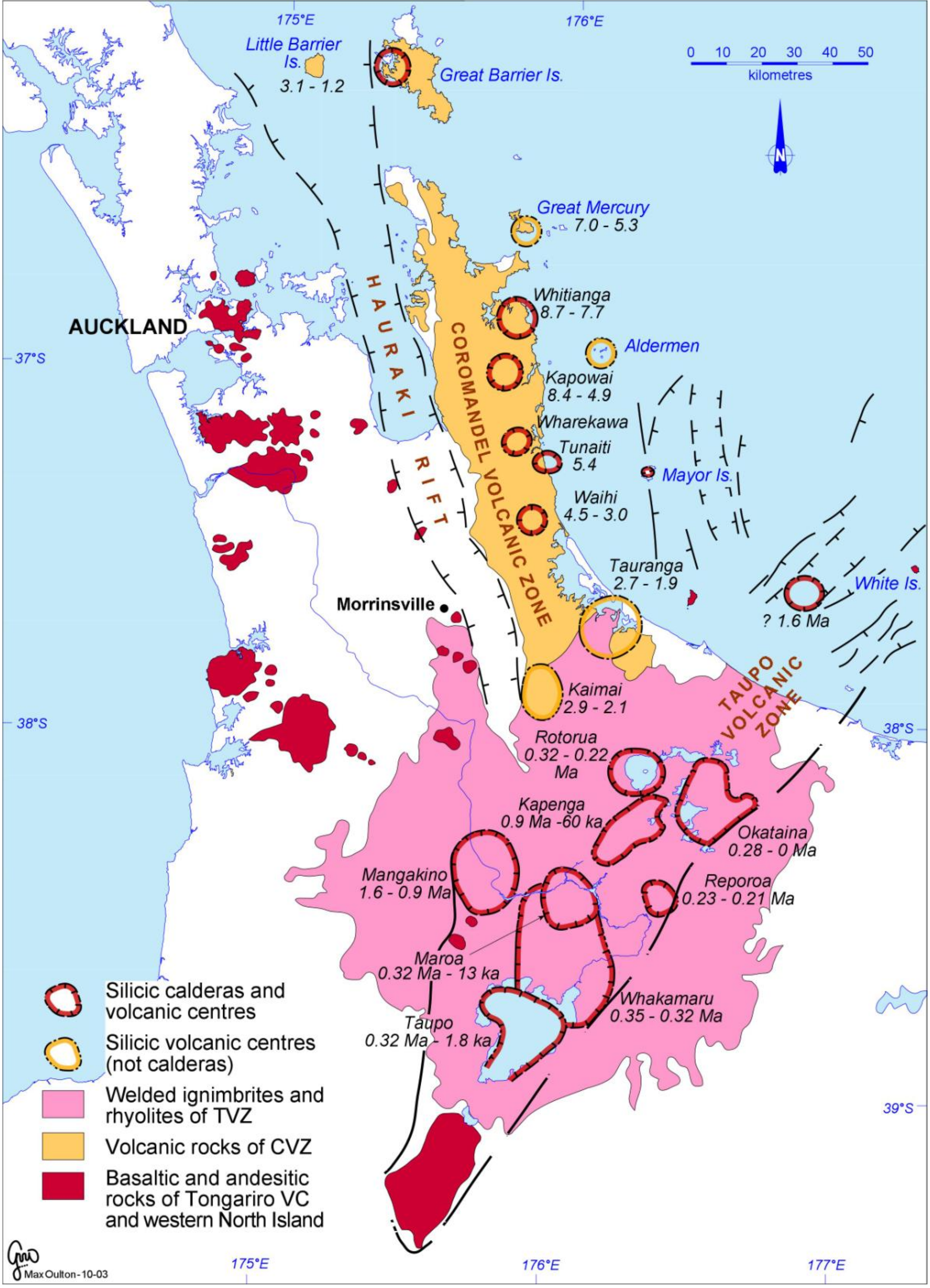
The highest concentration of Quaternary volcanic activity in New Zealand occurs in the area known as the Taupo Volcanic Zone (TVZ). This narrow band of cone and caldera volcanoes extends from Ruapehu in the south, over 240 kilometres to Whakaari (White Island) in the north, with the Taupo, Okataina, Rotorua and other calderas nestled between. Some of the planet‟s largest and most violent volcanic eruptions have occurred from this zone, as well as New Zealand‟s most recent small eruptions (Ruapehu 1995-1996, Whakaari 2000). Volcanism occurs in the TVZ, and at Taranaki, because of subduction of the Pacific tectonic plate beneath the North Island. As this plate descends and is heated, water and other fluids are boiled off and stream into the mantle rocks under the North Island. These fluids cause chemical changes that enable the otherwise solid rock of the mantle to melt, forming basaltic magma. This magma rises until, because of its higher density, it gets trapped underneath the continental crust of the North Island. Here the very hot basalt magma acts like a gigantic blow-torch, melting the crust and mixing with it to form andesite magma, which is then erupted as cone volcanoes. Where enough melting of the continental crust occurs, rhyolite magma forms, generating caldera volcanoes (Smith et al., 2006).



Simplified North Island plate tectonic setting (diagram courtesy of Adrian Pittari)

Taupo Volcanic Zone

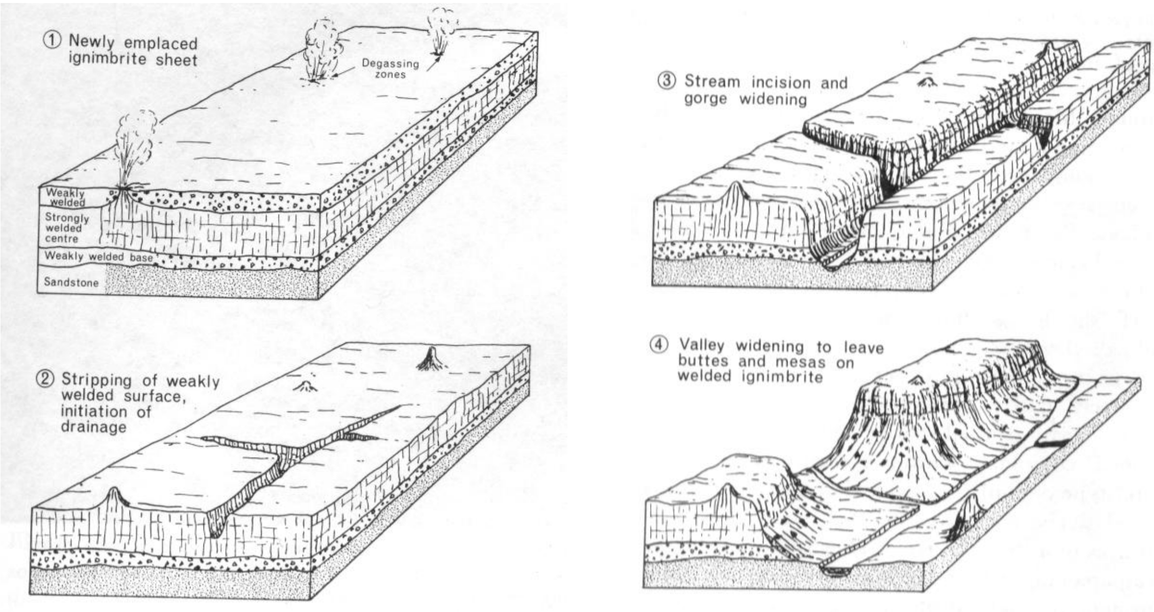
The TVZ can be thought of in three distinct parts. A southern part, dominated by andesite cones, includes the active Ruapehu and Tongariro volcanoes and the probably extinct Pihanga and Tihia-Kakaramea cones. A northern part, which is also dominated by andesite stratovolcanoes, includes the active Whakaari (White Is.) and the recently active Putauaki (Edgecumbe), and the much older, deeply eroded cones of Motuhora (Whale Is.) and Manawahe. These two stratovolcano clusters book-end the third and largest central part of the zone, extending from Turangi north to the Rotorua lakes district. This area is dominated by rhyolite calderas, including the highly active Taupo and Okataina volcanoes, and seven older calderas including Mangakino, Kapenga, Whakamaru, Reporoa, Rotorua, Maroa, and the recently-recognised Ohakuri caldera (Spinks et al., 2004; Gravely et al., 2007). The origins and extent of Rotorua caldera are debated (see W.R. Esler, this volume). Large explosive eruptions over the last 2 million years or so from this nested collection of rhyolite volcanoes have produced a huge volume of pyroclastic deposits, and many of the older volcanoes cannot be seen in the landscape because of burial underneath hundreds of metres of volcanic material from more recent eruptions. The products of these caldera eruptions are most obvious as the extensive plateaux flanking the western and eastern sides of the TVZ, which erosion reveals to be made up of many layers or sheets of ignimbrite, pumice, and tephra fallout layers. However, caldera eruption products are found far beyond the more obviously volcanic landscape of the central North Island. For instance, ignimbrite erupted from Mangakino about 1 million years ago is found 170 kilometres away in Auckland (up to 9 m thick) and rhyolite ash layers erupted from Whakamaru caldera c. 340,000 years ago are found under the seabed ~1200 km east of Napier (the Rangitawa Tephra). If we think of a volcano as including all the material erupted from it, then in a sense the entire area from Auckland to Hawkes Bay is part of a gigantic caldera volcano centred on the TVZ.



Volcanic centres and the ages of activity and rocks (including welded ignimbrites) of central North Island (diagram courtesy of Roger Briggs, after Briggs et al., 2005).

Volcanoes and landscapes

Volcanoes are both feared and revered for devastating eruptions that obliterate landscapes and terrestrial ecosystems, destroy buildings and other constructions, and injure or kill humans. Yet they provide benefits in many ways, including the formation of large areas of special, high-class soils, geothermal energy, lakes and other attractive landscape features favourable for healthy living, recreation and tourism, and materials for building and other purposes. Volcanic lakes form in calderas (e.g. Lake Taupo, Lake Rotoma), explosion craters (e.g. Lake Okaro), or in valleys dammed by lava flows (e.g. Lake Rotoehu) or pyroclastic flow deposits (e.g. Lake Rerewhakaaitu). They are especially attractive to people, and used for water supply and transport. Also appreciated are andesitic or dacitic stratovolcanoes, mountains or ranges known for their grandeur. Solitary or clustered steep-sided rhyolite domes and lava flows, and scoria cones and craters in basaltic volcanic fields (e.g. Auckland Volcanic Field), similarly provide landscape relief. Less dramatic but still impressive are the extensive layered landscapes of the central North Island and Arapuni-Putaruru, Mamaku-Rotorua, and Kaingaroa areas constructed from sheets of welded ignimbrites and characterised by cliffs and gorges, mesas and buttes (large and medium-sized flat-topped table lands), and thumb-shaped inselbergs (small steep-sided rocky mounds sometimes called tors). Draped with tephra-fallout layers and buried soil horizons (sometimes called paleosols), rolling land-surfaces have formed where the sheets become thinner.



Generalised development of land forms in an ignimbrite sheet emplaced over sandstone. In (2) the weakly welded upper part of the sheet has been stripped to leave tor-like features where, it has been suggested, fumarolic activity has caused strengthening by secondary mineral deposition (especially of silica) and alteration. However, simple erosion during glacials of softer materials is more likely and W.R. Esler (this volume) has suggested these landforms relate largely to „topographic inversion‟ when former gorges are infilled with thick, welded, erosion-resistant ignimbrite. Many of the "isolated" tor-like features are part of distinct chains, probably defining ancient watercourses (diagram from Healy, 1992.)

What is/are ‘tephra’?

„Tephra‟ comes from a Greek word *tephra* meaning ashes, and is an all-encompassing term for the explosively erupted, loose, pyroclastic (fragmental) products of volcanic eruptions. It includes all grain sizes ranging from the finest dust to blocks the size of sofas. The first recorded use of „tephra‟ in Western literature was by Aristotle c. 350 BC who described an eruption on the island of Volcano (known as Hiera in Greek) in the Lipari (Aeolian) Islands near Sicily.

The first modern useage was by Sigurdur Thorarinsson of Iceland in 1944, who resurrected the term to fit with Greek words lava and magma and to link these with classical volcanology that derives from the Roman name for the island Vulcano, the southernmost of the Lipari Islands. Both „tephra‟ and „tephras‟ are acceptable plurals. Derivative terms are tephrostratigraphy, the study of sequences of tephra layers and associated deposis and their relative and numerical ages; and tephrochronology, the use of tephras to connect, synchronize, and date sequences from place to place, and thus a powerful, widely-applied age-equivalent dating tool. In recent times, glass-shard (and crystal) concentrations preserved within peats, lake and marine sediments, and ice cores, but not visible in the field as layers, have been recognised and the term „cryptotephras‟ (from the Greek *kryptein*, to hide) has been applied to them (Lowe and Hunt, 2001; Lowe, 2008b, 2011).

What are ‘ash’ and ‘lapilli’?

„Ash‟ is not ash in the sense of a burnt residue. Rather, it consists of pulverised, jagged rock particles including pumice, mineral grains (crystals), and glass shards, all defined as smaller than 2 mm in size. Generally, fine ash is <0.06 mm, medium ash is 0.06–0.5 mm, and coarse ash is 0.5–2 mm (see also White and Houghton, 2006). Grains 2–64 mm in size are called lapilli (lapillus for a single grain), and particles larger than 64 mm are called blocks if they are sharp and angular in shape, or bombs if they are partly rounded or smooth in shape as a result of being erupted through the air whilst still hot and semi-plastic.

Tephra layers blanket the landscape

As well as erupting lavas and other materials, and modifying or building landforms comparatively close to vents, North Island volcanoes have blasted huge volumes of tephra into the air to be blown over northern New Zealand and in some cases far out to sea, more than 1000 km from source. The accumulation of layer-upon-layer of tephra-fallout deposits has helped volcanologists work out the history of volcanism and the distribution of their far reaching airborne products. In many parts of North Island natural cliffs along terraces, river banks or at the coast, together with cuttings made during road construction or quarrying, reveal blanketing layers of tephra fallout from numerous eruptions. A feature of such layers is that they drape the landscape on which they fall, following the contours of hills, terraces and valleys, although they can also be washed into valleys by rain and rivers, slump off hillsides, and be blown by the wind if forest cover has been damaged or is missing, for example during glacial periods. Landscapes draped with tephras, such as in the Taranaki and Waikato regions, tend to have slopes generally smoother than those without tephra mantling.

Mapping tephras ‘hand-over-hand’

A law in geology states that the oldest deposits in a layered sequence occur at the bottom and are overlain progressively by younger deposits, the most recent therefore being right at the top (Law of Superposition). This natural arrangement means that quite often only the youngest deposits are seen in a road cutting because the earlier layers are too deeply buried and therefore accessible only by drilling, especially near volcanoes where the deposits are very thick. Tephra layers are mapped by tracing each layer from cutting to cutting across the landscape and by drilling holes, digging pits, or coring lakes or peat bogs to fill any gaps. A tephra deposit from a single eruption may be tens of metres thick near its source but beyond about 100 km it thins quickly to only a few centimetres or millimetres. As well, the shattered rock fragments, crystals, and glass shards making up tephra layers are typically biggest near source but become finer with increasing distance away from it because smaller grains are able to be carried further by the wind. Consequently, mainly ash-size particles (<2 mm) are found in tephra deposits at localities several hundred kilometres or more from the source volcano.

Distribution of tephras in North and South islands

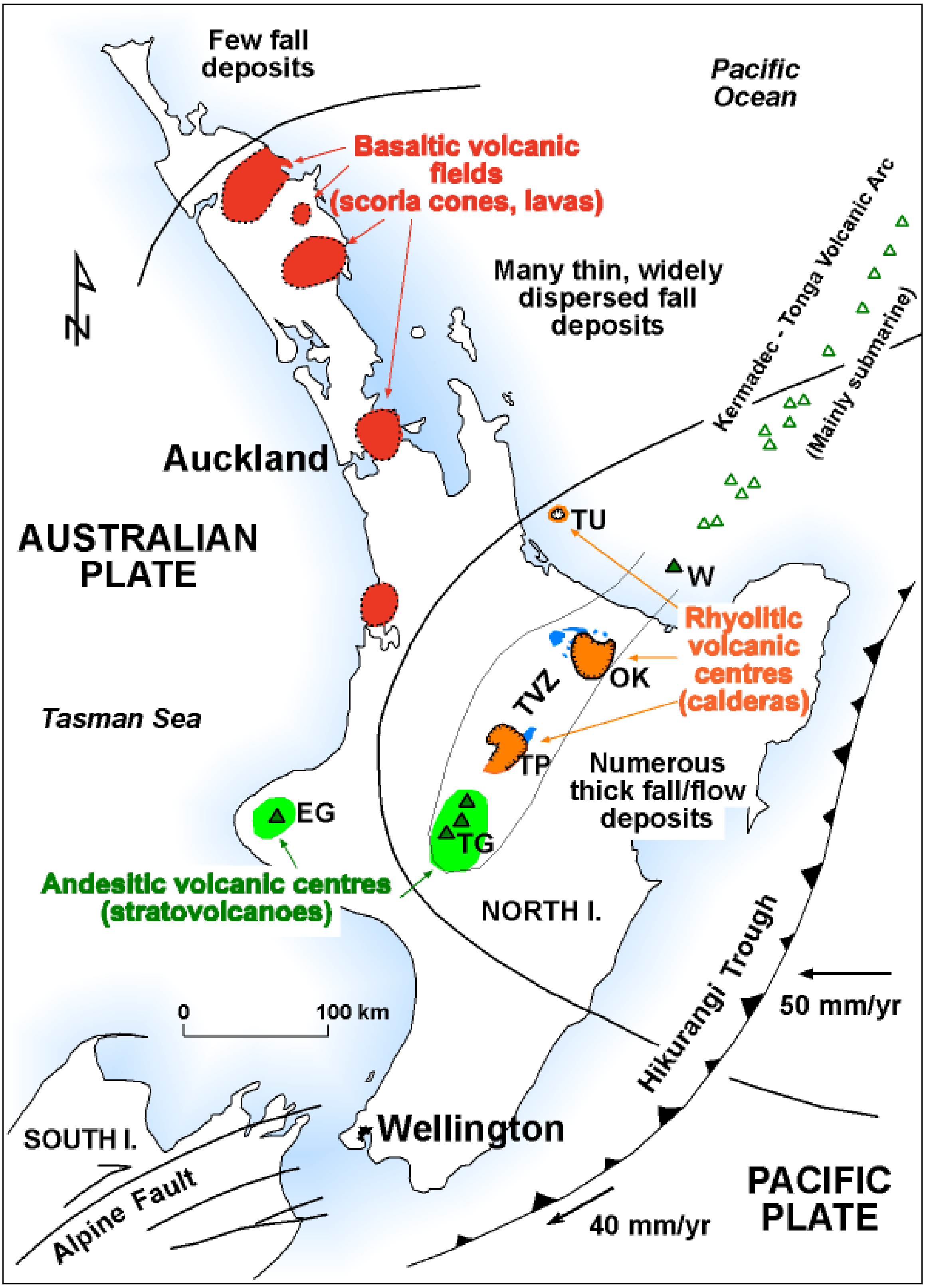
The thickest tephra sequences occur downwind of the TVZ in the Rotorua-Taupo area, Bay of Plenty, East Coast-Poverty Bay, and Hawke‟s Bay. Moderately thick deposits are found in Wanganui-Taranaki, King Country-Waikato-Coromandel and Auckland regions. Fewer tephra layers occur in other parts of the North Island. Only a handful of tephras has been recognised so far in the South Island. They include Rangitawa Tephra, erupted c. 340,000 years ago from Whakamaru volcano, and Kawakawa Tephra, erupted c. 27,100 cal. years ago from Taupo volcano.

Tephra as a unique dating tool (tephrochonology)

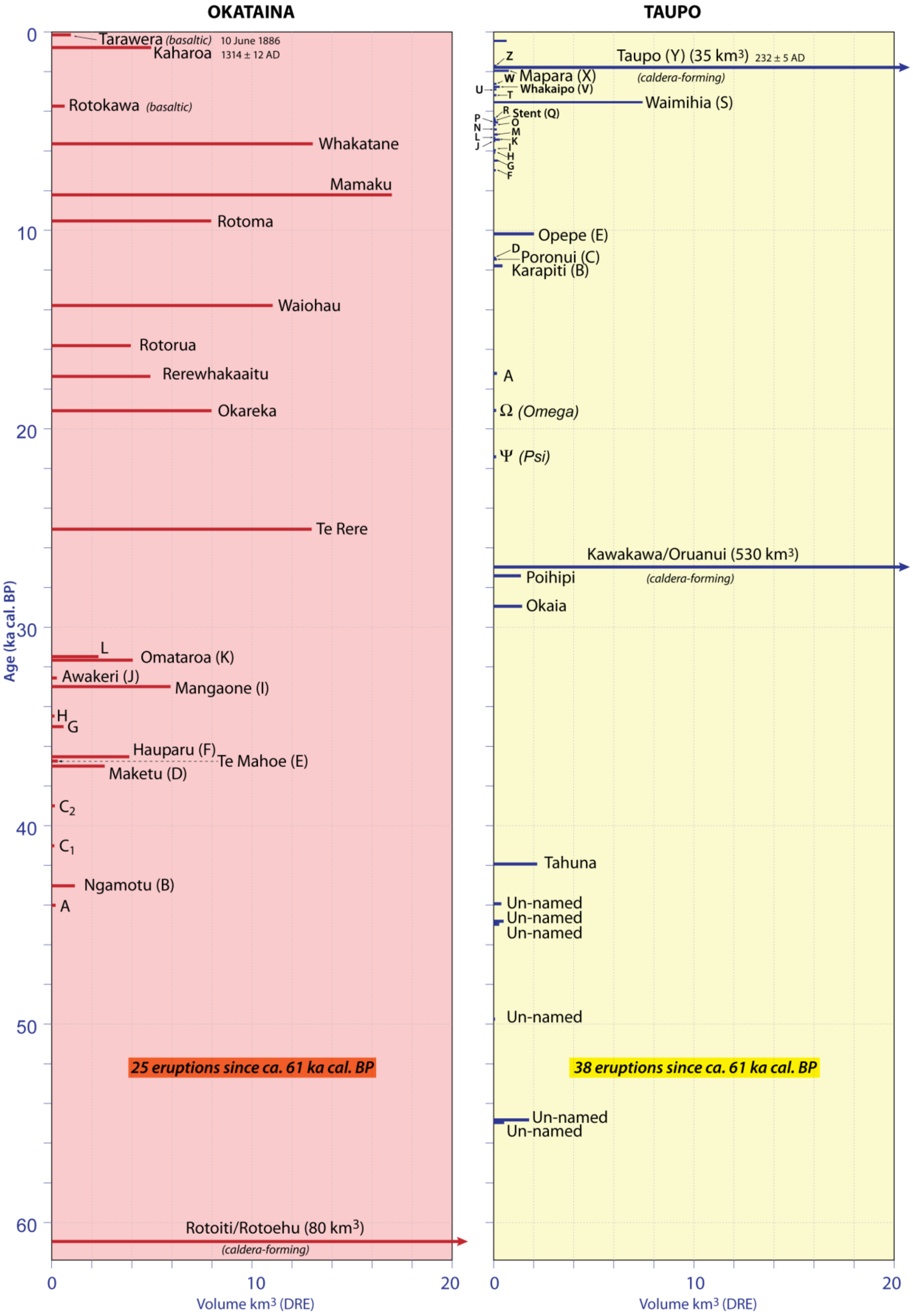
Tephra-fallout layers have two special features: (1) they are erupted over very short time periods, geologically speaking, usually a matter of only hours or days to a few weeks or months (Lowe, 2011); and (2) they can be spread widely over land and sea to form a thin blanket that has effectively the same age *wherever it occurs*. Therefore, once it is identified by mineralogical or geochemical analysis, a tephra layer provides a marker bed for an „instant‟ in time (an isochron), that instant being the date of the eruption that produced the layer. In New Zealand and elsewhere many studies have used tephra layers or isochrons as a dating tool, a science called tephrochronology. These studies include examining climatic and environmental change during glaciations, sea-level changes, pre-historic earthquake events, flooding and landsliding history, and archaeology (for example, helping to answer the question of timing of Polynesian settlement in New Zealand; see D.J. Lowe, this volume).

Fingerprinting tephras

How can one tephra layer be distinguished from another? Tephrochronologists use many methods to characterise each layer, both in the landscape and laboratory. In the landscape, colour, thickness and position of the tephra in the sequence are important. The palaeoenvironmental or palaeoecological context in which a tephra occurs may also be useful for correlational purposes. Sometimes the type of pumice is useful in identifying it. For example, pumice from the Taupo eruption (c. 232 AD) is usually cream-coloured and relatively easy to crush between fingernails whereas pumice from the Kaharoa eruption (c. 1314 AD) is white, dense and hard to crush. In the lab, the types of minerals (crystals) present sometimes allow the tephra to be identified and matched to a source volcano. A widespread tephra erupted from Tuhua volcano (Mayor Is.) c. 7000 cal years ago (Tuhua Tephra), for example, contains very unusual minerals including aegirine that allow it to be identified instantly with a microscope, even if just a few grains are present. Chemical analysis of volcanic glass in tephra layers using the electron microprobe is perhaps the best way of fingerprinting them. This is because most tephras, except where strongly weathered and therefore altered to clay, contain abundant glass shards which can be analysed using the electron microprobe or laser ablation-mass spectrometry to provide a chemical signature. Another way of helping identify tephras is by dating them (see Lowe, 2011).



Map showing plate tectonic setting, the main volcanic centres that produced parent materials for many of todays" tephra-derived soils, and the general dispersal of tephra on North Island (from Lowe and Palmer, 2005). EG, Egmont or Taranaki volcano; TG, Tongariro Volcanic Centre (includes Ngauruhoe, Tongariro, and Ruapehu volcanoes); TP, Taupo Volcanic Centre; OK, Okataina Volcanic Centre (includes Mt Tarawera and Haroharo volcanic complexes); TU, Tuhua Volcanic Centre (Mayor Is.); W, Whakaari (White Is.); TVZ, Taupo Volcanic Zone.



Stratigraphic relationships, ages and volumes (as magma or dense-rock equivalent, DRE; multiply by ~3 to obtain approximate bulk volumes) of tephras erupted from Taupo and Okataina volcanic centres since c. 61,000 cal years ago (from Lowe, 2011, after Wilson et al., 2009).

Volcanic topdressing

The frequent but usually localised eruptions from the volcanoes of Tongariro Volcanic Centre and also Taranaki but less often, have added small but markedly beneficial amounts of many nutrients to soils downwind from the volcano. For example, the 1995-1996 eruptions of Mt Ruapehu added 30–1500 kg ha^{-1} of sulphur and small quantities of other useful elements (including cobalt) to large areas of land in central and eastern North Island. By coring lakes and bogs in Waikato, Auckland and Hawke"s Bay regions and identifying many thin tephras preserved within them (and, most recently, cryptotephras expressed typically as glass-shard concentrations), it has become clear that such topdressing by andesitic tephras has continued over tens of thousands of years in the past, helping to maintain soil fertility in northern and eastern North Island.

Painting with *kokowai*

Early Maori used yellowish to reddish iron oxides called kokowai, or „red ochre", derived from seepages and stream beds in volcanic areas as a pigment or paint. The most important site was Kokowai Springs, Mt Taranaki. Kokowai was used for facial or body decorations, paint for buildings and canoes, and as an insect repellent. Its colours could be altered by heating over several steps, becoming bright red after strong heating (to form haematite). Kokowai has been identified as ferrihydrite, a tiny clay mineral with a huge surface area (200-500 m^2/g) and strong „pigmenting power" (i.e. it permanently stains clothing or other surfaces). Haematite, another iron oxide from red scoriaceous soils, was also an important ceremonial pigmenting agent used mainly for facial decorations on high-ranking chiefs (Lowe et al., 2002).

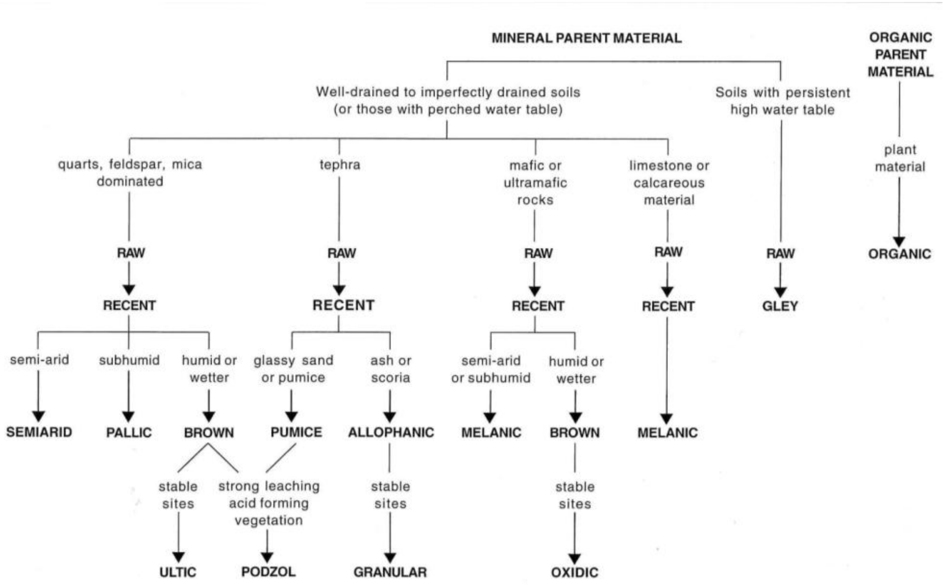
Photo (left) shows ferrihydrite seepage near Waikato River, Hamilton (see Lowe and Percival, 1993). Photo: David Lowe

Tephra-derived soils of New Zealand

The relatively young landscapes of much of central North Island, especially the Bay of Plenty-Taupo-Tongariro area, are predominantly of volcanic origin. Consequently, the nature and distribution of the soils contained in these landscapes are very strongly influenced by the volcanic history. Variations in the age, thickness, and mineralogical composition of the tephra deposits in which the soils are forming have significantly contributed to the soil patterns evident today. Post-depositional erosion and reworking of tephra deposits have helped to shape the landscape and, in turn, has created „genetic" links of varying strengths between the soils and landforms of the region. To a certain extent, climatic and indigenous vegetation gradients have also been imprinted upon the characteristics of the soils and their patterns of distribution (Molloy and Christie, 1998).

Classification of tephra-derived soils

Soils formed from tephra deposits are represented by five orders of the New Zealand Soil Classification (*NZSC*) which reflect increasing age and development: (Tephric) Recent Soils (~1% of North Island soils), Pumice Soils (~15%), Allophanic Soils (~12%), and Granular Soils (~3%) and (rarely) Ultic Soils (Hewitt, 1998; Lowe and Palmer, 2005; see also table below for relative abundances of New Zealand soils).



Major taxonomic development paths of New Zealand soils (from A.E. Hewitt in Molloy and Christie, 1998, p.235).

Tephric Recent Soils (Entisols)

These soils occur on very young, mainly andesitic or basaltic eruptives (~100–600 years old) close to the volcanic centres of Taranaki, Tongariro-Ruapehu, Rangitoto Island, and Mt Tarawera. They are typically gravelly or sandy and have few nutrients – the result of insufficient time for weathering to release them – and cannot store much water.

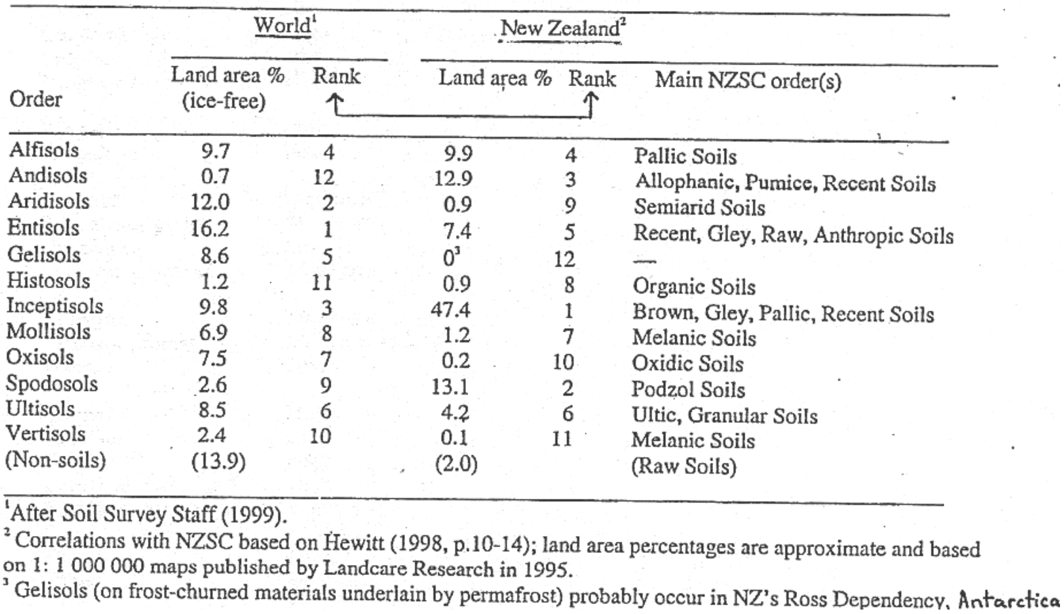
Pumice Soils (mainly Vitrands)

Covering a large swath of the central and eastern North Island, these shallow soils are made up of coarse rhyolitic pumice deposits derived mainly from the Taupo (c. 232 AD) and Kaharoa eruptions (c. 1314 AD). The young and weakly developed soils formed from these deposits (~700–1800 years old) are extremely deficient in many elements essential for animal health including copper, selenium, and cobalt. The Californian Monterey pine (*Pinus radiata*) grew fast and vigorously on the problematic Pumice Soils, partly by tapping into nutrients and moisture in the paleosols and soil horizons formed in tephras buried beneath them.

Allophanic Soils (mainly Udands)

These deep, versatile soils are formed typically on accumulating sequences of thin, fine-grained interfingering tephra layers from both rhyolitic and andesitic volcanoes, and occur in the Ohakune-Waiouru area, Taranaki, King Country-Waikato, and western Bay of Plenty-Coromandel. Small patches are found on basaltic scoria cones in Auckland-Northland. Most Allophanic Soils have taken between 10,000 and 25,000 years to form, with some as old as c. 60,000 years, and clearly are irreplaceable, yet they are undervalued by most people. Their name comes from the tiny nanocrystalline clay mineral formed in them, allophane, which dominates their physical and chemical properties because of its positive charge and huge surface area: a single teaspoon (about 5 g) of allophane has the surface area of a rugby field (400-900 m^2/g) (Lowe and Palmer, 2005; Neall, 2006; McDaniel et al., 2011).

Abundances of 12 soil orders of the world (of* Soil Taxonomy*) vs abundances In New Zealand (rank = relative abundance) (after Lowe et al., 2000a).



	World[1]		New Zealand[2]		
Order	Land area % (ice-free)	Rank	Land area %	Rank	Main NZSC order(s)
Alfisols	9.7	4	9.9	4	Pallic Soils
Andisols	0.7	12	12.9	3	Allophanic, Pumice, Recent Soils
Aridisols	12.0	2	0.9	9	Semiarid Soils
Entisols	16.2	1	7.4	5	Recent, Gley, Raw, Anthropic Soils
Gelisols	8.6	5	0[3]	12	—
Histosols	1.2	11	0.9	8	Organic Soils
Inceptisols	9.8	3	47.4	1	Brown, Gley, Pallic, Recent Soils
Mollisols	6.9	8	1.2	7	Melanic Soils
Oxisols	7.5	7	0.2	10	Oxidic Soils
Spodosols	2.6	9	13.1	2	Podzol Soils
Ultisols	8.5	6	4.2	6	Ultic, Granular Soils
Vertisols	2.4	10	0.1	11	Melanic Soils
(Non-soils)	(13.9)		(2.0)		(Raw Soils)

[1] After Soil Survey Staff (1999).

[2] Correlations with NZSC based on Hewitt (1998, p.10-14); land area percentages are approximate and based on 1: 1 000 000 maps published by Landcare Research in 1995.

[3] Gelisols (on frost-churned materials underlain by permafrost) probably occur in NZ's Ross Dependency, Antarctica

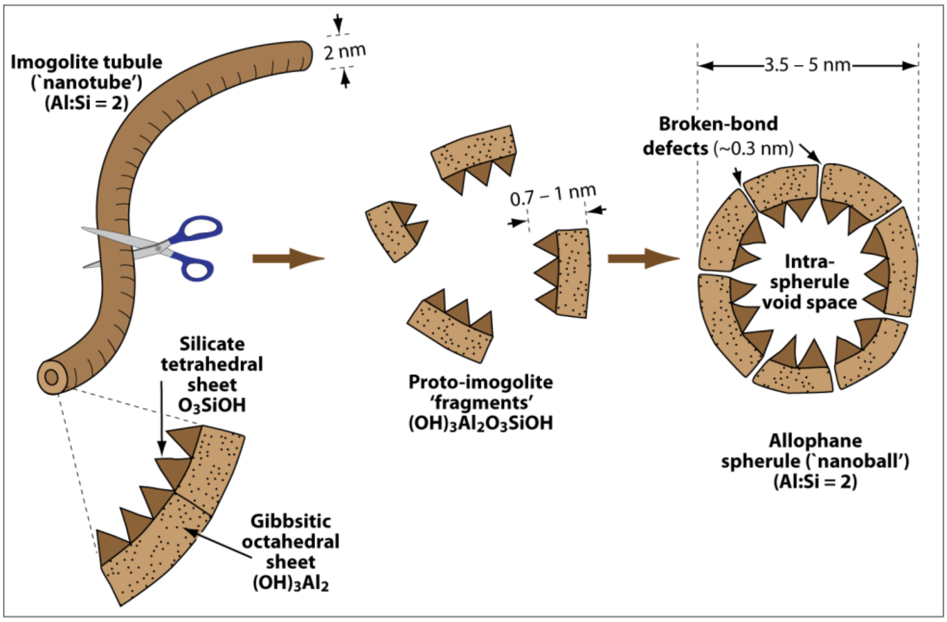
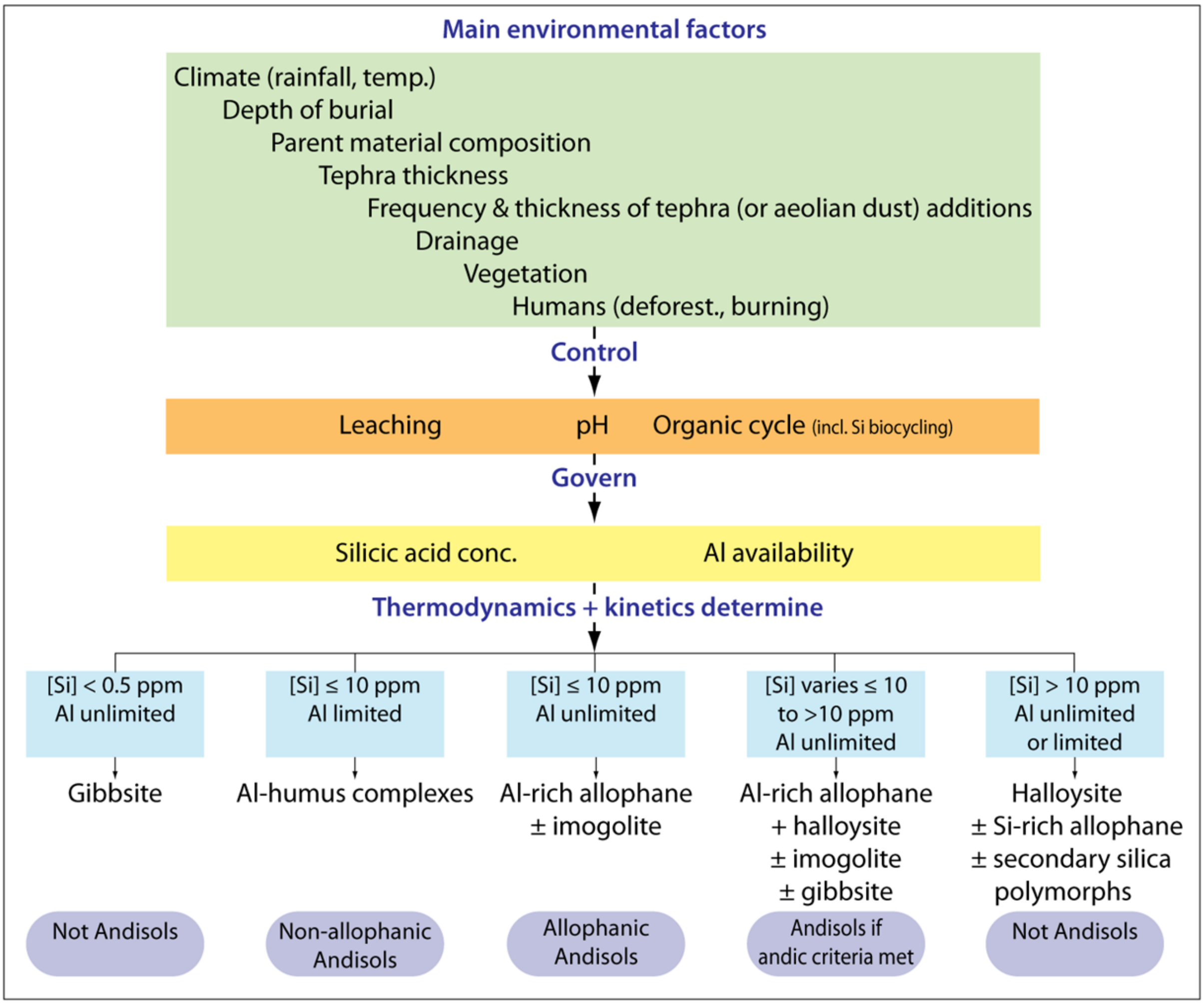


Diagram of imogolite nanotubes and Al-rich allophane nanospheres, which have similar structures at the atomic scale (from McDaniel et al., 2011, after Lowe, 1995).

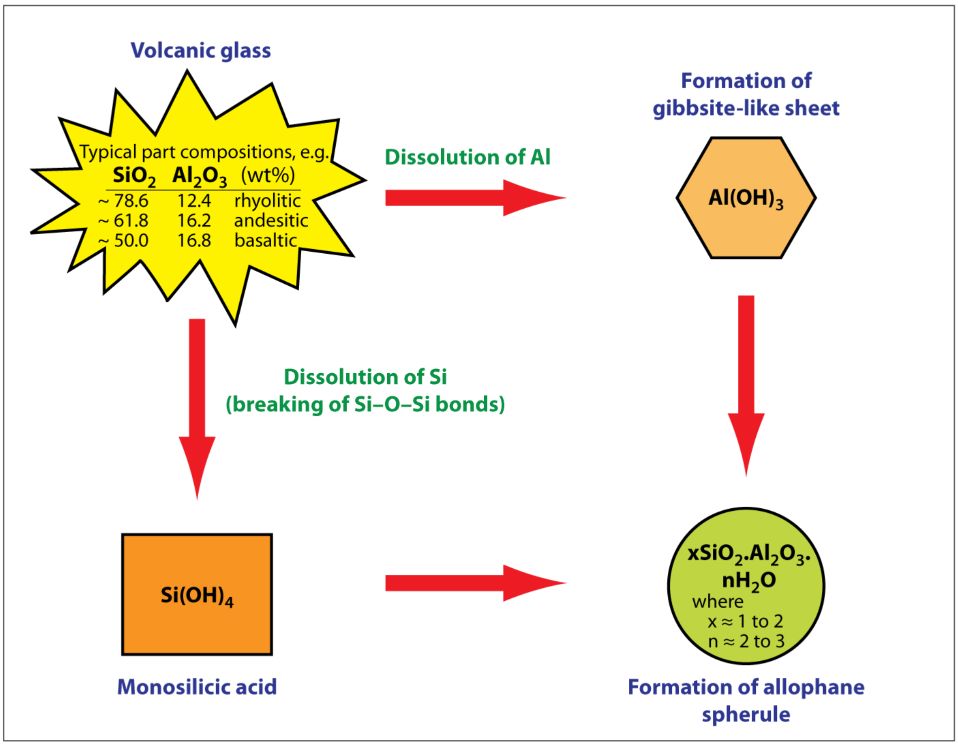
Forming allophane

The essential conditions for the formation of allophane are the activity of silicic acid in the soil solution, the availability of Al species, and the opportunity for co-precipitation (see figure below). These conditions are controlled largely by the leaching regime, the organic cycle, and pH, which, in turn, are potentially influenced by numerous environmental factors including rainfall, drainage, depth of burial, parent tephra composition and accumulation rate, dust accession, type of vegetation and supply of humic substances, and human activities (such as burning vegetative cover), together with thermodynamic and kinetic factors (Lowe, 1986; Parfitt, 2009; McDaniel et al., 2011). Availability of Al, derived mainly from the dissolution of glass or feldspars, is assumed to be unlimited in this model, though potentially more is available from andesitic and especially basaltic tephras than rhyolitic tephras. In contrast, in pedogenic environments rich in organic matter and with pHs ≤ 5, humus effectively competes for dissolved Al, leaving little Al available for co-precipitation with Si to form allophane or halloysite. In these environments (such as in parts of Japan), Al-humus complexes are formed instead of allophane (McDaniel et al., 2011).



Environmental influences and controls that govern the critical conditions leading to the formation of different clays from the weathering of tephras, and the likely occurrence or not of Andisols as a result (from Churchman and Lowe, 2011, modified after Lowe, 1986, 1995). ± indicates that the clay mentioned may also be present.

In New Zealand, both mineralogical and soil-solution studies on soils derived from tephras extending across a rainfall gradient showed that rainfall, coupled with through-profile drainage, helps govern Si concentration [Si] in soil solution and thus the likelihood of allophane being formed or not (Parfitt et al., 1983; Singleton et al., 1989; Parfitt, 1990, 2009). The Si leaching model is summarized as follows: where [Si] is less than ~10 ppm (mg l^{-1}), allophane is formed; where [Si] is greater than ~10 ppm, halloysite is formed. If [Si] is close to ~10 ppm then either allophane or halloysite may predominate. A profile throughflow threshold of approximately 250 mm per year of drainage water likely controls [Si] – less than ~250 mm means that the loss of Si is insufficient for Al-rich allophane to form and halloysite (or Si-rich allophane) forms instead (Parfitt et al., 1984; Lowe, 1995; McDaniel et al., 2011).

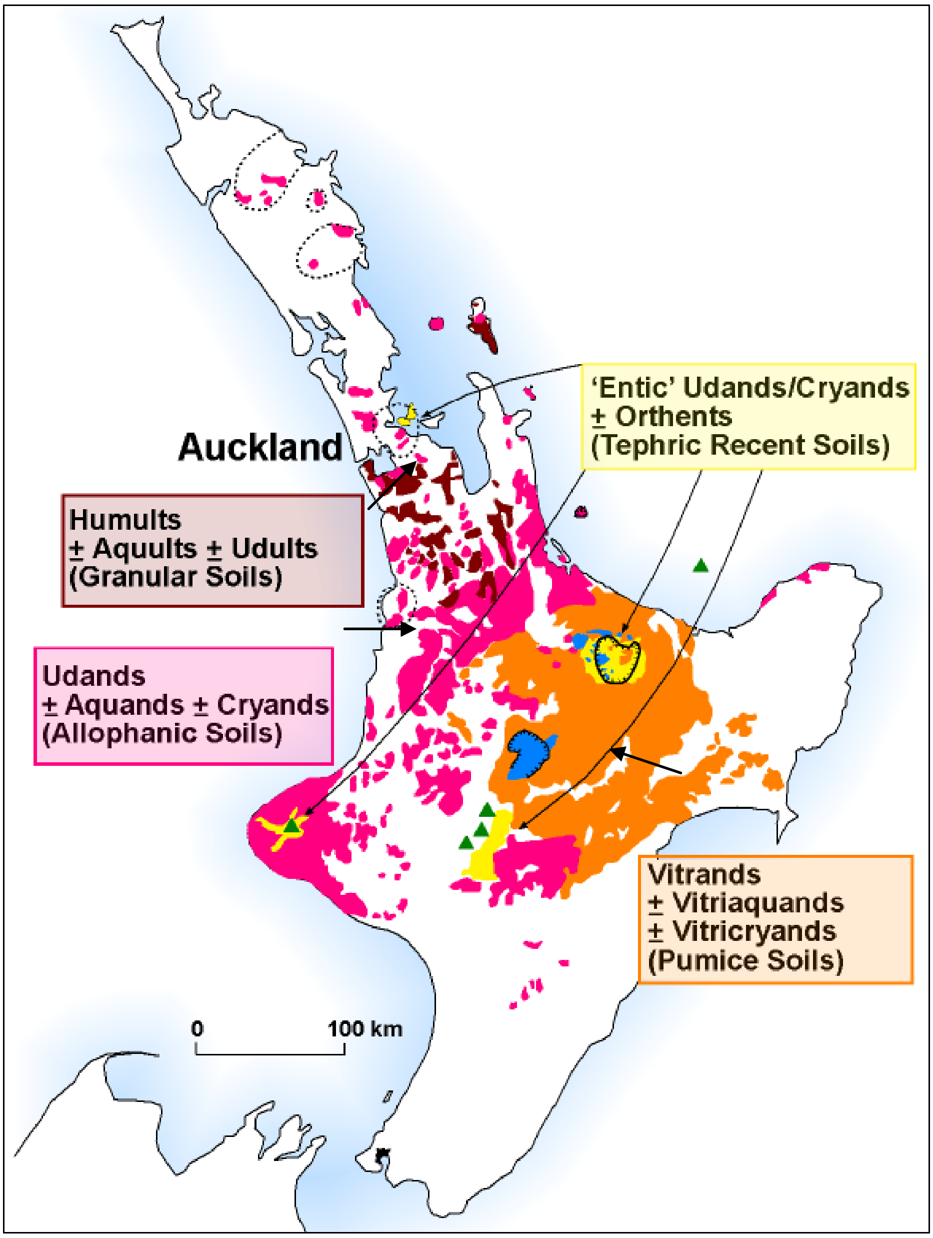


Various volcanic glass compositions and dissolution of Al and Si and their reprecipitation to form allophane spherules or „nanoballs" (from McDaniel et al., 2011, after Hiradate and Wada, 2005; see also Theng and Yuang, 2008).

Allophanic Soils are supreme in New Zealand for food, fibre, and water production because of their outstanding physical properties. Friable and free draining, even after heavy rain, yet resilient to repeated cropping or stock treading, they have good aeration and very stable soil aggregates, a high organic carbon content, and they can store large amounts of water (Molloy and Christie, 1998). These features and their distribution on smooth, easily manageable tephra-mantled landscapes make them ideal for pasture production and grazing in humid climates. Allophanic Soils are unmatched for almost any land-use: cropping, horticulture, effluent irrigation, forestry, and sports fields. However, contrary to popular opinion, these soils (especially those more siliceous) are not normally „rich and fertile" – many have low natural fertility, and need regular „topping up" with various nutrients especially phosphorus (because of P fixation) and potassium to maintain high productivity (Lowe and Palmer, 2005). Sensitivity and thixotropy, properties that cause them to behave in a fluid-like manner when loading pressures are applied, can also pose engineering problems (Neal, 2006).

Granular Soils (mainly Udults, Humults)

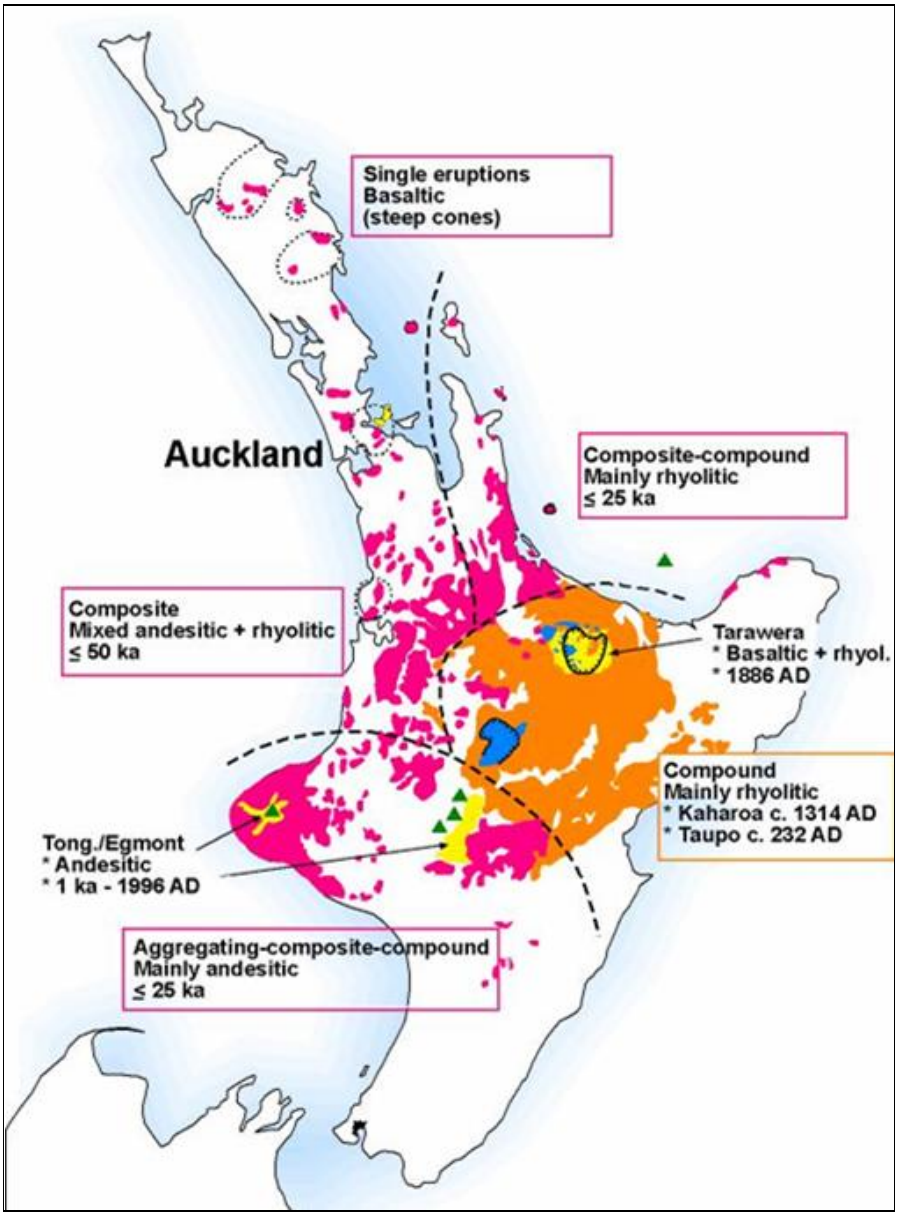
These sticky and clayey but well-structured soils have formed on older, strongly weathered tephra layers erupted from central TVZ between about 100,000 and 350,000 years ago (Lowe et al., 2001). They occur in the northern Waikato and South Auckland regions – for example in the Pukekohe-Bombay Hills area – where the younger mantling tephra layers so predominant in central North Island have become sufficiently thin to allow these older deposits to emerge at the land"s surface. The clay mineral dominant in these soils (halloysite) has proven suitable for cricket pitches in the northern North Island partly because it dries out and shrinks relatively quickly in humid climates. An example of these soils will be seen at Stop 1 on Day 1 of the tour and along road cuts in the Hamilton Basin.



Distribution of four main groupings of tephra-derived soils in North Island (after Kirkpatrick, 1999, based on Rijkse and Hewitt, 1995; modified from Lowe and Palmer, 2005).

Upbuilding pedogenesis

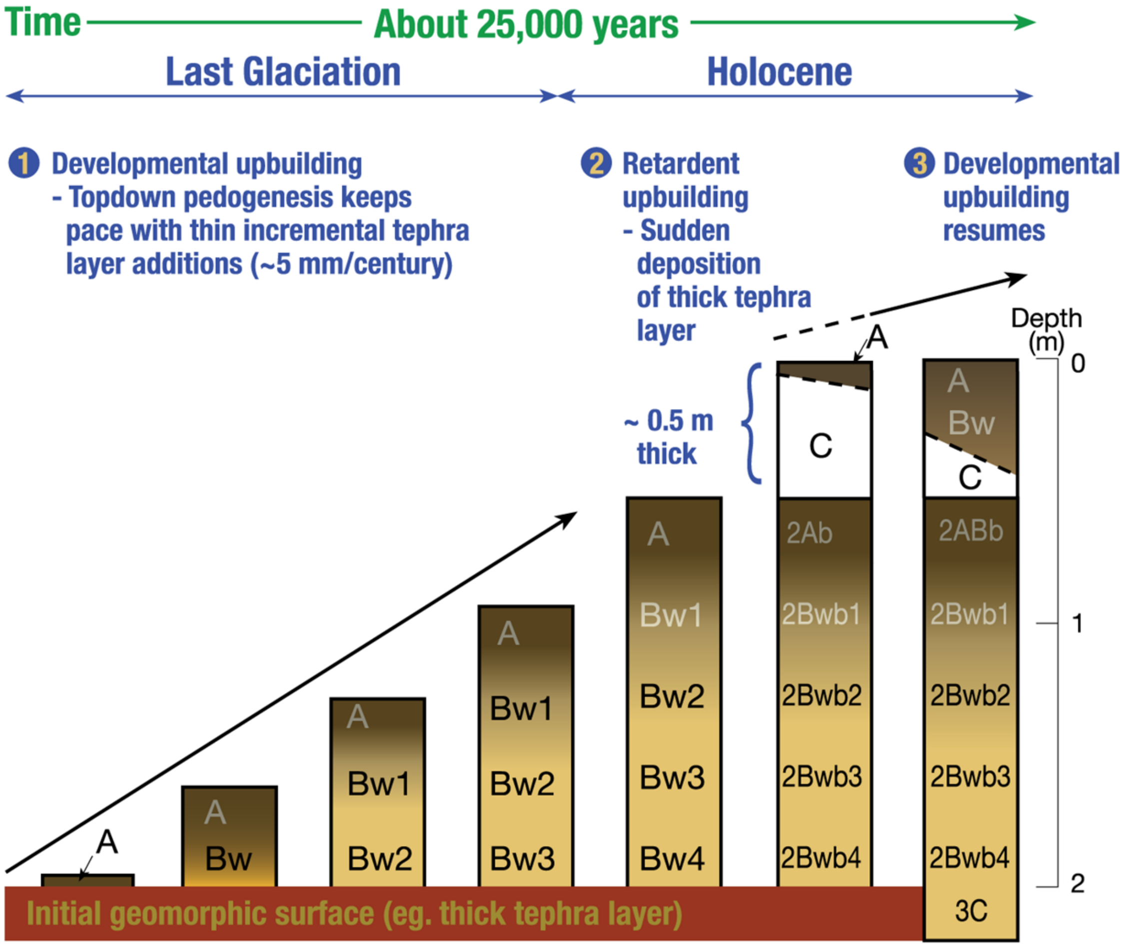
A distinctive feature of many volcanic ash-derived soils is the „multisequel" or layered nature of their profiles which attests to the up-building of the landscape via the deposition of tephras from numerous eruptions. During periods of quiescence between major eruptions, soil formation takes place, transforming the characteristics of the unmodified tephra via *topdown pedogenesis* (Almond and Tonkin, 1999). Soil processes alter the underlying material in a downward-moving front, forming generally well-developed subsoil horizons – i.e., classical pedogenesis. However, where tephras are added to the land surface, *upbuilding pedogenesis* takes place and the rate of upbuilding determines the rate and impact of pedogenesis. Two scenarios can be considered: (1) tephra accumulation is incremental or relatively slow, leading to „developmental upbuilding"; (2) tephra accumulation is rapid, e.g. burial by a thick deposit (which may become a stratigraphic marker bed), leading to „retardant upbuilding" (Lowe and Tonkin, 2010; McDaniel et al., 2011).



General subdivision of the main groupings of Andisols in North Island into six zones according to their multisequal soil character (soil stratigraphy), the primary compositions of component tephras, and approximate ages of the 1-m deep soil profiles (from Lowe and Palmer, 2005). Ages on Kaharoa and Taupo tephras from Hogg et al. (2003, 2009). Note: „Aggregating" should read „Aggrading".

Scenario 1 Where successive tephra deposits are thin and accumulate relatively frequently (e.g. at distal locations), the material deposited from each eruption will become incorporated into the existing soil via soil mixing and other process. When tephras (and tephric loess) are accumulating incrementally, topdown soil formation does not stop, but its effects are lessened because any one position in the tephra deposits is not exposed to soil processes for long before it becomes buried too deeply for these processes to be effective as the land surface gently rises. Nonetheless, this upbuilding history leaves the tephra deposit with a soil fabric inherited from when the tephra was part of the surface A horizon or subsurface Bw horizon. The maximum development of subsurface soil horizons occurs when soil formation has a greater impact during phases of topdown pedogenesis. In developmental upbuilding, subsurface horizons are typically weakly expressed.

Scenario 2 Where a tephra deposited on the land surface surface is of sufficient thickness, or more rapid, to quickly bury the antecedent soil below the range of soil forming processes (i.e., it becomes isolated), the buried soil becomes part of the underlying regolith and is recognised as a buried paleosol (a soil of a landscape or environment of the past) or more typically a buried soil horizon. A new soil will begin forming at the new land surface in the freshly deposited material. Thus, retardant upbuilding recognises that the development of the newly-buried soil has been stopped or retarded, and the pedogenic „clock" reset to zero for soil formation to start on the new land surface.



Model of upbuilding pedogenesis and evolving horizonation over ~25,000 years in the Waikato region, North Island, with contrasting developmental and retardant upbuilding episodes (from Lowe and Tonkin, 2010)

The terms „developmental upbuilding" and „retardant upbuilding" were used by Johnson and Watson-Stegner (1987) and Johnson et al. (1990) as part of their dynamic-rate model whereby soils evolve by „ebb and flow" through time (Schaetzl and Anderson, 2005). A complication is that loess (wind-blown sediment) was widely generated in the central North Island during glacial periods. Unstratified tephric loess deposits of about three metres thickness (e.g. on Mamaku Plateau – see Stop 5, Day 4) were derived largely from thick rhyolitic tephra-fall and ignimbrite deposits, which eroded during glacial periods to form valley fill and fan deposits. These were supplemented probably by glassy dust blown directly from primary tephra fall deposits. Tephric loess deposition slowed and petered out generally at around the time of deposition of Rerewhakaitu tephra (c. 17,600 cal years ago) after which climate began ameliorating and full forest cover returned (Vucetich and Pullar, 1969; Newnham et al., 2003). Today tephric loess is found as subsurface layers in tephra-soil sequences, being buried by tephra deposition during the Holocene. The fastest rates of loess accretion in New Zealand were during the cold glacial periods and especially during marine oxygen isotope stage 2, when rivers aggraded very rapidly (Lowe et al., 2008c). The fastest rates were 0.15–0.23 millimetres per year (15-23 mm/century) where deposition was enhanced by turbulence and the slowest was less than 0.01 mm per year (<1 mm/century). Accretion rates for tephric loess in the Waikato region, ~0.03–0.08 millimetres per year (3-8 mm/century), are similar to those for loess in south Westland, 0.04–0.12 mm per year (4-12 mm/century). In an „upbuilding‟ phase, soil formation thus occurs simultaneously with slow loess accumulation, forming a „soil-sediment‟ (Lowe et al., 2008c).

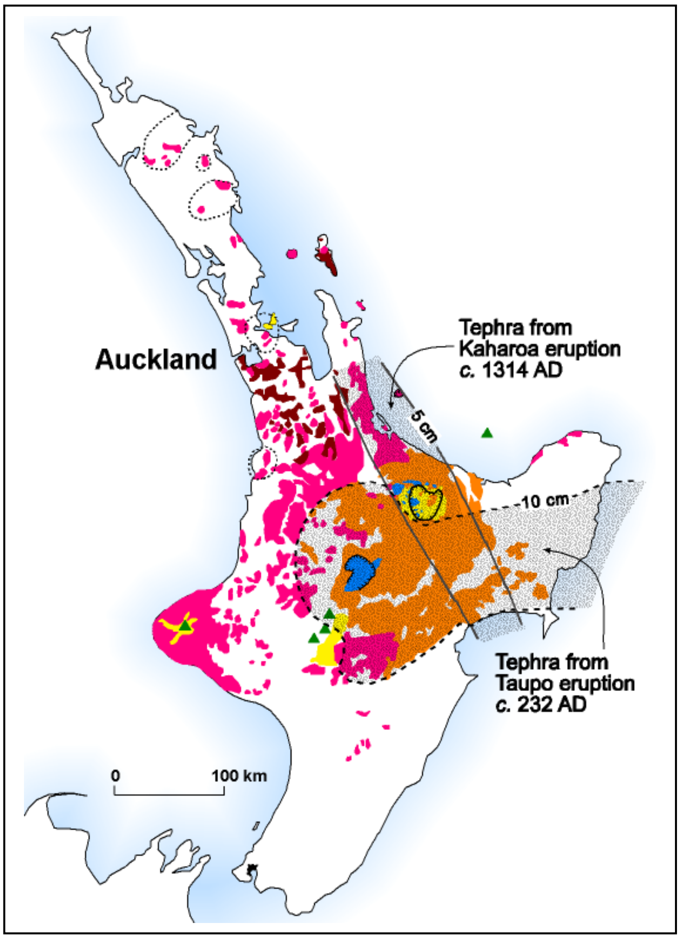
Ages and rates of soil formation can be assessed for the tephra-derived soils through tephrochronology, the use of tephra layers to link and date sequences (Lowe and Tonkin, 2010). Where Allophanic or Pumice soils (Andisols) comprise upbuilding sequences of tephras and soil horizons, the maximum age of the soil profile constituents depends on the depth at which the profile „base‟ is drawn. In considering the uppermost 1 to 2 m of Andisols, some generalizations about their composite ages can be made. In situations where just a single eruption event has taken place to produce a parent deposit, then Andisols developed in that material have the same age as the eruption. In New Zealand, there is a wide range of ages on Andisols depending on location (see figure above). Most of the Pumice Soils (Vitrands) are between ~700 and ~1800 cal years old; extensive Allophanic Soils (Udands) date back ~20,000–25,000 cal years and some are as old as ~60,000 years.

Tephra-derived soils and land use

Although many of the tephra-derived soils are of supreme quality, some are not. In the early part of the 20th century – at a time when large tracks of land were being prepared for pastoral agriculture – many of the soils on the central plateau were found to be deficient in trace elements crucial for animal health (i.e. cobalt, copper, and selenium), causing the so-called “bush sickness” problem. Early surveys of soils and tephra deposits (“soil-forming ash-showers”) showed a link between Kaharoa and Taupo deposits and the occurrence of bush sickness, but it was not recorded on Tarawera eruptives. The worst bush-sick area was on Kaharoa Tephra and the soils were regarded (even into the 1950s) as „despised soils‟ (Vucetich and Wells, 1978). Note that some other areas of New Zealand also had bush sickness, typically under high rainfall, but that was a deficiency acquired from leaching rather than inherent. Ironically, the cobalt deficiency led to the development of the large pine forest plantations of central North Island. These forests were to become the foundation of New Zealand‟s exotic timber industry (Molloy and Christie, 1998). The land-use debate has been recently renewed with substantial areas of forest land being converted to dairy pastures and concerns being raised regarding the impacts of the land use change on the soils and water quality (see Day 4).

Soil classification

Soil classifications throughout this guide are given in terms of both the *New Zealand Soil Classification* (NZSC) by Hewitt (1998) and Clayden and Webb (1994), and *Soil Taxonomy* by Soil Survey Staff (1999, 2010).



Map of North Island showing single isopachs of tephras deposited from Taupo and Kaharoa eruptions, soils on which were deficient in Co which resulted in „bush sickness" (from Lowe and Palmer, 2005). Cartoon from Nick Kim, Environment Waikato.

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Day 1: Auckland–Turangi

Outline for Day 1 (Tuesday 27th July 2010)

8.00 am Depart Airport Gate Motel, 206 Kirkbridge Road, Mangere, Auckland

8.50-9.50 am STOP 1 Pukekohe Hill Reserve (Massey Memorial Lookout), Pukekohe: overview, market gardening, Pukekohe soil
- Introduction to tour
- Soil-related environmental issues: Dr Peter Singleton (Environment Waikato)
- Market gardening in Pukekohe area
  - Soil resilience, erosion, urbanisation issues
- Franklin Sustainability Project (growers‟ perspective): Monty Spencer (A.S. Wilcox and Sons: growers, packers, distributors of fresh produce)
- Pukekohe silt loam (Typic/Andic Kandiudult)

9.50-10.10 am Morning tea/coffee, Pukekohe Hill Reserve

10.40-10.50 am Toilet stop, Bombay services, State Highway (SH) 1

11.50 am -12.40 pm LUNCH Willow Glen Cafe, Gordonton Road

12.50-2.00 pm STOP 2 DairyNZ Scott Farm Research Centre, Newstead, Hamilton

Research focussed on twin challenges of reducing the environmental impact of intensive dairying and increasing productivity. Milking 350 cows on 120 ha (effective) on a mixture of Udands and Aquepts and also (possibly) Haplohemists or Humaquepts
- Overview Scott Farm research: Chris Roach and Chris Glassey (DairyNZ)
- Horotiu–Bruntwood–Te Kowhai soils (Vitric Hapludand-Aquic Hapludand-Typic Humaquept)

2.40-2.50 pm Toilet stop, Tirau

3.50 pm - 5.00pm STOP 3 Mokai, Tuaropaki Trust's Mokai geothermal power plant

Afternoon Tea (mobile)

6.30 pm Arrive Parklands Motor Lodge, Turangi. Dinner at Motel

Rest of evening free.

Day 1 – Route and scientific stops

A, Airport Gateway Motel; T, toilet stop; L, lunch; 1, 2, 3, scientific stops; I, Parklands Motor Lodge, Turangi

1.1 Background to Stop 1

Progress in understanding erosion rates and management at Pukekohe

Les Basher
Landcare Research, Lincoln
Craig Ross
Landcare Research, Palmerston North

Introduction

Soil erosion in the Pukekohe area has been a concern to vegetable growers and environmental managers for many decades. Many local farmers have periodically used scrapers to transport soil back upslope within their fields. Clearing of sediment from drains and roadways, particularly after large storms, is a significant cost to both farmers and local authorities. Concerns about erosion were highlighted by the impacts of large storms in May 1996 and January 1999, which caused widespread soil loss within fields as well as flooding and sedimentation within Pukekohe town, and led to the establishment of the Franklin Sustainability Project (http://www.ew.govt.nz/Environmental-information/Land-and-soil/Land-use-in-the-Waikato/Soil-Management-in-the-Franklin-District/)

Although there was some small plot research in the early 1970s by Water and Soil Division of Ministry of Works, until recently there has been little scientific study of rates and processes of soil erosion (Basher at al., 1997). Most accounts of the types and magnitude of erosion in the area had been anecdotal. Rills on steeper slopes and deposition at the base of slopes were commonly observed within fields after storms. The terracetted nature of the landscape, with large steps in height at paddock boundaries, was cited as evidence of soil movement within fields. Molloy and Christie (1998) suggested from such evidence that up to 1 m depth of soil has been transported downslope in ~100 years of intensive market gardening. This report provides a brief summary of erosion studies carried out by Landcare Research, and their management implications. These studies have made major advances in:

- quantifying the rates of soil erosion at a range of scales (plot, field, and small catchment);
- evaluating the impacts of high intensity storms;
- investigating the mechanisms of soil erosion;
- characterising soil physical properties that are important to runoff and sediment generation; and
- evaluating management practices to reduce soil erosion.

The main soils in the area, the Patumahoe and Pukekohe series, are clayey and well structured and have clay mineral assemblages dominated by kandite group minerals (chiefly halloysite) and varying amounts of gibbsite and secondary iron oxides; some contain allophane (see soil data below). The soils have demonstrated capacities for supporting intensive horticultural cropping without serious structural damage (Hewitt and Shepherd, 1997). Gradwell and Aldridge (1971) and Gradwell (1973) showed, however, that a reduction in aggregate porosity and hence deterioration in soil functioning at some sites was attributable to particular cultivation practises rather than length of time under cultivation.

Rates of soil erosion

Measured export of sediment from a small (1.8 km^2) catchment, used predominantly for market gardening, was very low, averaging 0.5 t ha^{-1} yr^{-1} over a 3-year measurement period (Basher *et al.,* 1997). Bedload was negligible compared with the suspended sediment load. Sediment yields during winter and spring storms were higher than during storms with the same peak runoff in other seasons.

By contrast, soil loss from small plots (13 m by 3 m) of continuously bare soil was two orders of magnitude higher, averaging 57 t ha^{-1} yr^{-1} over a 2.5 year measurement period (Basher et al., 1997). Soil loss during individual storm events reached more than 10 t ha^{-1}. A small proportion (32 %) of the storms was responsible for most (87 %) of the soil loss, and these storms were concentrated in the winter and spring. When two of the four plots were grassed down, soil loss reduced to 0.4 t ha^{-1} yr^{-1}.

Both the plot and small catchment studies showed the importance of the winter and spring periods for sediment generation. These times of the year are characterised by a high frequency of storms, poor ground cover and increased sediment concentrations in storm runoff. Attempts to reduce sediment load and soil movement need to target this time of the year. The difference in yields between the plot and catchment scale suggested large quantities of soil were mobilised within fields by storms, but little of this sediment was transported into streams. The within-paddock soil redistribution (by both water erosion and tillage) has been investigated using the radionuclide tracer caesium-137 (^{137}Cs) to calculate net rates of soil erosion and deposition, by both water and tillage, since 1953 (Basher and Ross, 2002). Results from three fields within the small catchment where sediment yield was measured are summarised in Table 1. In each field there was:

- An extremely wide range of measured ^{137}Cs values indicative of both erosion and deposition (at rates up to 100 t ha^{-1} yr^{-1});
- Net soil loss from all fields, with the highest net loss from the steepest field (field 1); >30 cm of soil has been lost from the upper parts of these fields (7.4 mm yr^{-1}), and up to 45 cm deposited in the lower parts (10.2 mm yr^{-1}), since 1953. The high soil deposition rates are consistent with observed accumulations of topsoil >1 m deep in the lower parts of fields.
- A characteristic pattern of soil redistribution with most of the field dominated by erosion, and a small area near the base of each field (where slope gradient was lower) with very high rates of deposition (Fig. 1). Sediment delivery ratios in the three fields ranged from 28 to 73 %.
- Only a small proportion of the soil redistribution was by tillage. Most was caused by water erosion and deposition.

Table 1 Water and tillage erosion rate estimates from ^{137}Cs data for three fields at Pukekohe (reference value for ^{137}Cs in an undisturbed site is 774 Bq m^{-2})

	Field 1	**Field 2**	**Field 3**
Slope angle (mean and range)	7.0 (2-10)	5.0 (2-8)	3.3 (1-4)
Slope length (m)	120	135	280
Mean ^{137}Cs areal activity (Bq m^{-2})	520	688	659
Range (Bq m^{-2})	253–1488	171–2144	419–1438
Mean ^{137}Cs residual (%)*	-32.8	-11.1	-12.9
Range (%)	-67 to 92	-78 to 177	-45 to 90
Net erosion rate (t ha^{-1} yr^{-1})	-29.7	-11.3	-7.1
Mean water erosion rate (t ha^{-1} yr^{-1})	-31.4	-8.2	-7.3
Mean tillage erosion rate (t ha^{-1} yr^{-1})	1.7	-3.1	0.2
Sediment delivery ratio (%)#	73	28	57
Mean topsoil depth (cm)	46.9	46.9	37.3
Range of topsoil depth (cm)	25–110	26–120	26–68

* Represents the proportional loss of ^{137}Cs relative to the reference value – negative values represent erosion, positive values deposition.

Ratio of soil erosion to soil deposition.

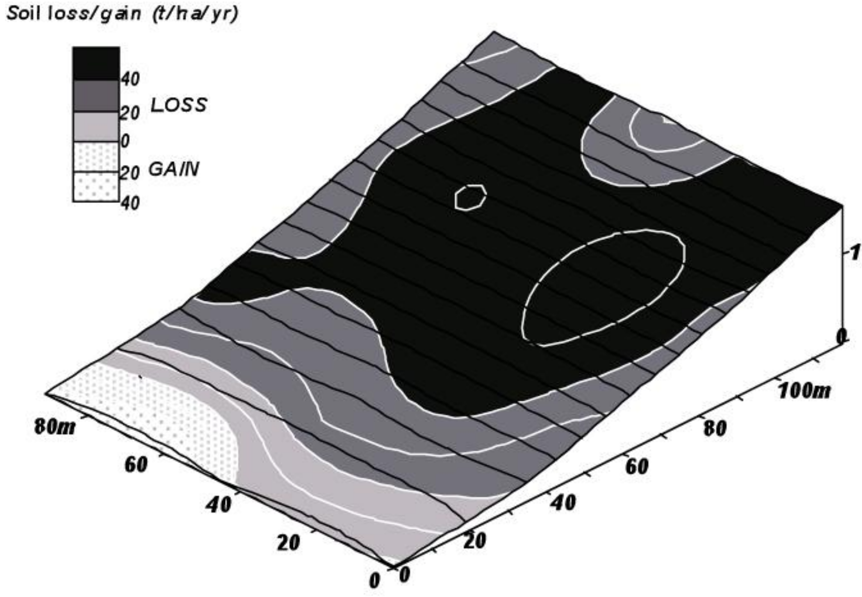

Fig. 1 Pattern of soil redistribution in field 1

While there was massive redistribution of soil from upper slopes to lower slopes within fields, in each field the area *gaining* soil was far smaller than the area *losing* soil and there was a net loss of soil over the three fields of 21 t ha^{-1} yr^{-1}. This value represents a total net loss of 9.8 cm of soil since 1952 (~2.4 mm yr^{-1}). From discussions with Franklin District Council staff, we estimated 5 t ha^{-1} yr^{-1} (~0.6 mm/yr) of soil was being removed each year from drains and roads – the ^{137}Cs data suggest the loss could be higher, because sediment export only accounts for 0.5 t ha^{-1} yr^{-1} of the net loss of soil of 21 t ha^{-1} yr^{-1}. The small proportion of sediment being generated by erosion that is delivered into streams is a function of both the small proportion of fields that deliver sediment directly into the drainage system, and strongly aggregated soils. The major loss of soil appears to occur by removal in trucks.

Storm impacts

On 21 January 1999 a short-duration, high-intensity storm caused widespread soil erosion on market gardening lands in the Pukekohe area and extensive sedimentation in drains and on roads. No erosion damage occurred in fields in other land uses (e.g., pasture, orchards), except where water had overflowed from drains. Problems with the regional drainage system which contributed to the overflows were identified (e.g. under-sized culverts, inadequate drain maintenance) and are being rectified. About 145 mm of rain fell in four hours, at intensities up to 125 mm hr^{-1}. While the peak 10-minute rainfall intensities were very high, they were not that unusual at Pukekohe (15-20 year recurrence interval). However, it is rare for such high-intensity rainfall to continue for such a long period of time. Total rainfall for the storm had a recurrence interval >100 years.

Fields damaged by erosion and sedimentation were identified from interpretation of colour vertical aerial photographs (scale 1: 10,000) taken five days after the storm, supplemented by oblique aerial photos taken between one and four days after the storm. Erosion severity was assessed using a semi-quantitative technique (based on area of the field affected by erosion, and degree of disruption of topsoil or subsoil), supplemented by a ground–based survey to provide field measurements of erosion for some of the fields. Results of the storm damage survey were reported in Basher and Thompson (1999).

Within the Pukekohe area, damage was localised to certain fields and roads. Many cropping fields (c. 52%) remained largely unaffected by runoff and erosion, despite the very high rainfall intensities. The main form of damage was by rill erosion, typically formed along wheel tracks or the shallow surface depressions resulting from cultivation. Rills were typically incised to 10–20 cm depth to the top of the tillage pan, with a maximum depth of 50 cm. The rate of erosion in some fields was extremely high, and was closely related to soil tilth, the impact of uncontrolled runoff from drains, and the degree of ground cover. Erosion rates ranged from c. 30–600 t ha^{-1} and sediment delivery ratio from near zero to 100 %, depending on the variation in slope within the field, and the presence of barriers (such as hedges) to trap sediment. In most fields a large proportion of the eroded sediment was redeposited at the bottom of the field, and in many cases deposition also occurred in adjacent fields. In only four of the 18 fields examined was the sediment delivery ratio estimated to be greater than 50%. The most severe erosion damage was associated with uncontrolled runoff entering fields from drains (Fig. 2), and on bare soils cultivated to a fine tilth by rotary hoeing. No erosion was observed where cover crops were growing, while incorporation of stubble from previous cover crops also significantly reduced the severity of erosion. Contour drains were effective in controlling runoff and erosion in some fields, but exacerbated the problem in others suggesting that more attention needs to be paid to the most effective design (particularly slope and spacing) of contour drains.

Fig. 2 Severe rill erosion where uncontrolled runoff from a drain has entered a field in which onions have just been planted

There was little evidence of sheet erosion suggesting infiltration rates were not exceeded by rainfall intensities, except locally in compacted areas such as wheel tracks and headlands. Runoff was also generated where soils became completely saturated. The survey suggested that if drains had been adequate to transport runoff safely, the erosion damage within fields would have been very limited.

Management of soil erosion

At Pukekohe, most of the vegetable crops (onions, cabbages, lettuces, broccoli, squash, carrots) are grown in beds planted up-and-down slope, and the wheel tracks between the beds appear to be the key zones for initiation of surface runoff and erosion. Field observations after the very wet July in 1998 suggested that most of the runoff and erosion was occurring on wheel tracks (Fig. 3), with no obvious erosion in the beds of onion or greens crops. Erosion along wheel tracks was observed both in crops that had recently been planted and „greens" crops that were being harvested. The wheel tracks form natural channels for water to flow down, and the soils under the wheel tracks are highly compacted and have low infiltration rates. Wheel tracks cover about 18% of paddocks where crops are being grown in beds.

Fig. 3 Field evidence of runoff and erosion along compacted wheel tracks, July, 1998

Two trials have been undertaken to quantify the role of wheel tracks in processes of infiltration and erosion, and to assess the utility of a simple management practice to reduce erosion (Basher et al., 1999, 2000; Basher and Ross, 2001). The trials were carried out over two years under natural rainfall. Net rates of erosion from onion beds with cultivated or uncultivated wheel tracks were measured using a combination of silt fences, erosion pins, and repeat topographic surveys. Infiltration rates in onion beds, cultivated and uncultivated wheel tracks, and changes in infiltration rates through winter, spring, and summer, were measured using the double-ring, ponded-water method. Wheel tracks were cultivated by dragging a single tyne down each track to depth of c. 30 cm.

When wheel tracks were uncultivated the erosion rate was 21 t ha^{-1} compared with 1 t ha^{-1} when wheel tracks were cultivated. Most erosion occurred in the winter/early spring period when storm frequency and rainfall intensity was highest, and infiltration rates in the uncultivated wheel tracks lowest. Erosion occurred through mobilisation of soil along the edge and base of the wheel tracks, with no evidence of erosion of the onion beds. Most of the eroded soil comprised soil aggregates, with 75% between 0.25 and 4 mm in diameter, suggesting soil was transported in runoff along the wheel tracks as stable aggregates.

Uncultivated wheel tracks had very low infiltration rates compared with those of onion beds and cultivated wheel tracks (Table 2).

The differences between cultivated and uncultivated wheel tracks were consistent in both trials, with minor differences due to rainfall patterns and the implements used to cultivate wheel tracks. There were clear trends in infiltration rates through time, with rates in the uncultivated wheel tracks increasing through the growing season from 0.5 to 77 mm hr^{-1} and in onion beds from 400 to 900 mm hr^{-1}, whereas rates in the cultivated wheel tracks decreased from 60,000 to 8500 mm hr^{-1}. The major increase in uncultivated wheel tracks occurred after October when the soil surface began to dry out, and frequent wetting and drying cycles caused the compacted surface soil to crack and break up.

Table 2 Infiltration rates (mean ± standard deviation) measured at June and October 1999, and January 2000

	Infiltration rate (mm hr^{-1})		
	June	October	January
Uncultivated wheel track	0.5 ± 0.5	12.7 ± 21.9	77.2 ± 53.7
Cultivated wheel track	60,312 ± 45,341	12,456 ± 10,668	8582 ± 4256
Onion beds	411 ± 243	485 ± 394	907 ± 674

Both trials were carried out in onion crops but we believe the results would also apply to other crops grown in beds such as greens crops, carrots and squash. We are uncertain of their application to potato crops but this could be easily assessed by measuring infiltration rates in potatoes. Cultivating wheel tracks is a simple and highly effective practice to increase infiltration of rainfall and reduce erosion rates on these clay-rich, strongly structured soils.

Soil physical properties

In many soils breakdown of soil aggregates to smaller particles is a major contributor to the erosional susceptibility of the soils. However, at Pukekohe analysis of aggregate size and stability indicates the soils are resistant to structural breakdown by slaking and dispersion into sand, silt, and clay particles that would contribute to suspended load. Physically, the soils are characterised by high clay content, strong macro- and micro-aggregation, and structural stability (i.e. low structural vulnerability; see Hewitt and Shepherd, 1997). Clay contents in surface horizons are >60 %, and up to 10% of the clay fraction is allophane.

Mean weight diameters of soil aggregates sampled from under a variety of crops, and from within drains (representing transported sediment), were in the 1 to 2.5 mm range. All samples were moderately to strongly water stable, with between 73 and 91 % of aggregates remaining on 0.5–2 mm sieves (Fig. 4) after wet sieving. The samples from the drains had a higher cumulative net percentage retained (87–91 %) than the samples from the fields (73–81 %). The drain samples also tended to have a higher proportion of coarser water stable aggregates (retained on the 2-mm sieve) than samples from the fields. These trends probably reflect loss of a small proportion of unstable soil aggregates by abrasion and dispersion during bedload transport in the drainage system. The laboratory measurements of aggregate stability, and field observations during the wheel track trials and after storms, both suggest breakdown of soil aggregates is not a significant contributor to the erosion problem.

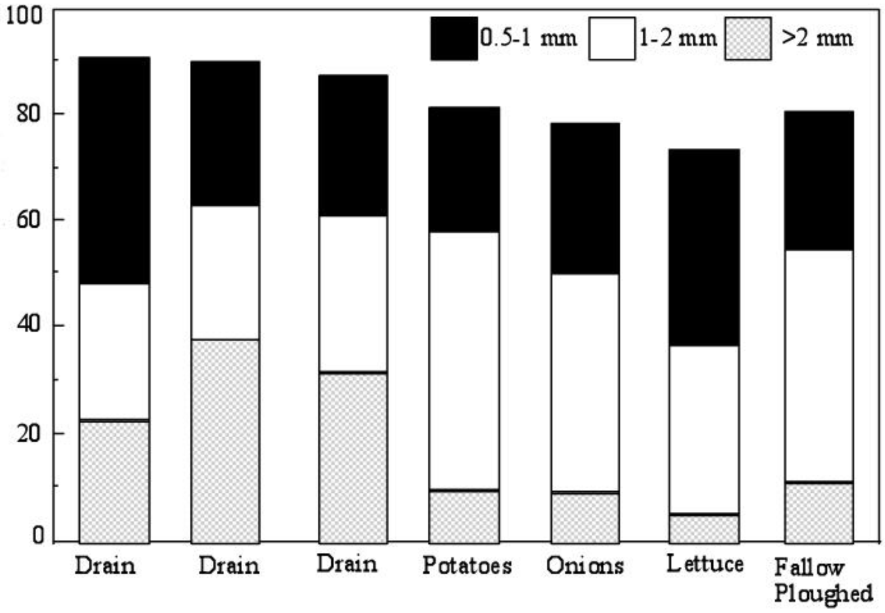

Fig. 4 Aggregate stability analysis of soils under a range of crops and sediments in drains – percentage of aggregates remaining on 2, 1 and 0.5 mm sieves after wet sieving

The Granular Soils (Ultisols) used for cropping have strongly developed tillage pans at a depth of 20-35 cm and these could limit water movement into and through the soil. To investigate the role of the tillage pan in percolation of water and runoff generation and assess the influence of cropping on soil physical properties, hydraulic conductivities have been compared in soils under cropping and pasture (Table 3). These results suggested:

- cropping has led to a reduction in saturated hydraulic conductivities in A horizons, but the measured values are still high compared to typical rainfall intensities;
- the B horizon below the tillage pan is the limiting layer for water movement;
- differences in the upper B horizon (33-43 cm) probably reflect the impact of erosion.

Table 3 Comparison of saturated hydraulic conductivity (mean ± standard deviation) measured under cropping and pasture

		Hydraulic conductivity (mm hr^{-1})	
Horizon	Depth (cm)	Cropping	Pasture
Upper A	7-17	85 ± 65	134 ± 191
Lower A*	25-35	55 ± 62	261 ± 382
Upper B	33-43	2 ± 2	58 ± 107
B	53-63	2 ± 0.9	2 ± 1
B	75-85		3 ± 6

* Tillage pan under cropping

Conclusions

These results suggested that erosion is largely an on-site problem with a high rate of soil redistribution within fields, but that relatively little soil is being transported into streams. The average net loss of soil is c. 20 t ha^{-1} yr^{-1} (from both the ^{137}Cs data and the wheel track trials), with most of this soil deposited close to source in drains and on roads. This finding indicates the market gardening lands are unlikely to be a significant source of sediment into the Manukau Harbour. The ^{137}Cs data suggest net soil losses up to c. 30 cm since 1953 in the upper parts of these fields, and net gains c. 40 cm in small areas of the lower parts of the fields. This result implies in the upper parts of fields all the original topsoil has been lost and that the present topsoil, with low organic matter content, was formerly part of the subsoil.

The hydraulic data indicates that infiltration rates and saturated hydraulic conductivities in topsoils in the crop beds will not generally limit water movement. Much of the erosion problem is due to the practice of growing crops in beds with highly compacted wheel tracks between the beds. Runoff is generated in compacted areas of the fields (wheel tracks and headlands) and entrains sediment from the edge of the crop beds. Cultivation of wheel tracks can be used to improve infiltration rates and reduce erosion rates to negligible levels. It is likely to be effective in reducing erosion rates even in high intensity storms.

Erosion risk is greatest in the winter and spring periods when storm frequency tends to be high, ground cover is relatively poor, and infiltration rates in wheel tracks are at their lowest. An integrated drainage system to safely discharge runoff into streams is essential to erosion control, particularly in high intensity storms.

Acknowledgements

We thank the Foundation for Research, Science and Technology, Franklin Sustainability Project, and Auckland Regional Council for providing funding to carry out this research. We are very grateful to the many growers who have assisted with our studies, allowed access to their properties, and shared their knowledge about vegetable growing and erosion in the Pukekohe area.

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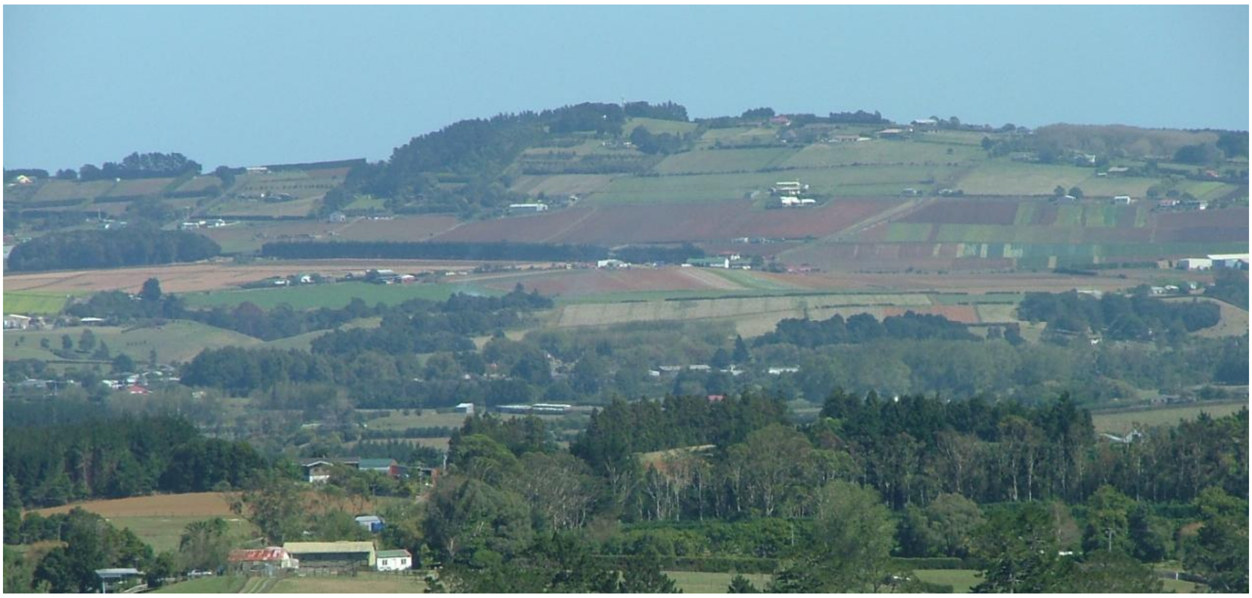


Vegetable growing on Ultisols on the Bombay hills east of SH1 in late summer (23 March 2007) – irrigators were operating in some fields. Photo: David Lowe

Potatoes growing in Pukekohe soils on gently sloping shoulder of Pukekohe Hill, 10 October, 2008. View towards southwest where the hills (some basaltic) are bounded by Waikato Fault. Waikato River flows in valley with its mouth at top right (Port Waikato). Photo: David Lowe

1.2 Stop 1 – Pukekohe silt loam, Pukekohe Hill

Location Q12 & R12 783397, elevation 210 m asl, rainfall 1280 mm pa

Introduction

Pukekohe Hill is an excellent starting point for the tour in various ways: it provides a commanding view of important market gardens developed within Ultisols, and associated landuse issues, and the Massey Memorial on the hilltop commemorates Irish-born, South Auckland identity William („Big Bill") Fergusson Massey (1865-1925), Prime Minister of New Zealand 1912-1925, after whom Massey University is named. Pukekohe town has a population of about 23,000.

Pukekohe Hill

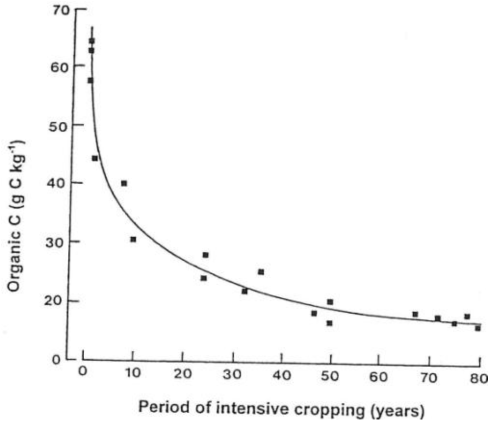
Pukekohe Hill forms a high point (222 m above sea level) within the basaltic South Auckland volcanic field active between c. 1.6 and 0.5 Ma. The hill is underlain by basalt lavas erupted about 0.56 Ma (Briggs et al., 1994; Edbrooke, 2001) and is the youngest effusive centre in the field. But the intensively used, dominantly brown (7.5YR), clayey, strongly structured Ultisols in the area are in most places formed mainly in stongly weathered, distal tephras derived from rhyolitic eruptions in far-off central North Island. The distal weathered tephras, with 60–90 % clay content, comprise a composite sequence with the collective name Hamilton ash beds. They drape over the basalts on which dark reddish-brown (5YR–2.5YR) buried soil horizons are found. The Hamilton ash beds are ~1.1 m to ~3.5 m thick in this area (Rae, 1995). They have an age span of c. 350,000 to c. 100,000 years and in turn are overlain with a patchy, thin (~0.3–0.4 m), composite cover bed veneer of intermixed tephras that have accumulated incrementally millimetre-by-millimetre over the past c. 60,000 years – the base of the cover bed being identified as c. 60 cal ka Rotoehu Ash (Lowe, 1981). The soils thus reflect upbuilding pedogenesis for the last c. 60 ka, and also probably for substantial periods before then (Bakker et al., 1996). An important initial point here regarding parent materials is that the lithological units shown on geological maps are *not* necessarily the parent materials of the modern soils associated with a geological map unit. The volcanic terrains within northern and central North Island are usually layered and so a stratigraphic approach, as will be demonstrated during the tour, is essential to understanding the soils and their relationship with the landscape.

Pukekohe Hill (*pukekohe* means „hill with kohekohe", the latter being a distinctive „tropical-looking" tree with large leaves, *Dysoxlum spectable*) was cleared of native broad leaved forest between 1876 and 1900, the development of the main trunk railway generating a demand for sleepers. The hard, dense timber from puriri trees (*Vitex lucens*), common in the Pukekohe area and on Pukekohe Hill, was utilised for railway sleepers. With the forest clearance, horticultural crops of potatoes and onions were grown, although these were first grown in the wider area from the 1850s. Specialised gardening of onions began in 1892 with the first significant commercial crops produced in 1904 (Rae, 1995, after Morris, 1962). The first potatoes were grown on Pukekohe Hill in 1893 (Flynn, 2005). Other vegetables grown on the easy rolling to rolling landscapes include greens (cabbage, lettuce, broccoli, cauliflower, silver beet, snow peas), squash, pumpkin, carrots, spring onions, and asparagus. Production yields are among the highest in New Zealand: onions 55 t/ha; potatoes 60 t/ha; cabbage 30 t/ha (after Molloy and Christie, 1998). Many fields been used continuously or semi-continuously for >30 years, some for >60 years, and some for >100 years, often with more than one crop each year. The vegetables grown in the Pukekohe area are essential for the large Auckland market, and provide about one-third of New Zealand"s fresh vegetable production. The total area in vegetable production is about 8000 ha.

Soils

A soil survey of the area (1: 63,360), together with a larger-scale soil map of Pukekohe town (1: 25,000), was published in 1977 to assist the agricultural development and to provide fundamental planning data for future land use – and especially to show the importance of the soils in the Pukekohe area for food production in response to a proposal to relocate the Auckland motorway through Pukekohe (Orbell, 1977). Rae (1995) undertook a soil survey and drilling programme in a small area (0.26 km^2) to the northwest of Pukekohe Hill near Hilltop Rd and Blake Rd to determine the thickness of the Hamilton Ash and depth to the paleosols on the underlying basalts. He then developed GIS-based models to analyse modern and buried paleosol surfaces to examine relationships between drainage and the underlying paleosols (only a weak relationship was found, the modern topography being more important with poorly-drained soils occurring in drainage sinks or depressions) (Rae, 1995).

The bulk of the Patumahoe and Pukekohe soils in the area, formed mainly from Hamilton ash beds, are possibly aged c. 250,000 years (± ~50,000 years?), but as noted above the thin topmost parts of the profile are younger and date from c. 60 ka. The soils become more weathered with depth, probably a result of the accumulatory character of deposition of tephra materials combined with effectively continuous soil formation on them, i.e., upbuilding pedogenesis has dominated (Bakker et al., 1996). Unlike the denser, heavier halloysite-dominated Ultisols further to the south in the Hamilton area, the Pukekohe and Patumahoe soils contain moderate allophane, gibbsite, and kaolinite, and relatively high amounts of crystalline Fe oxides, as well as halloysite and vermiculite. The soils contain clay coatings in the subsoils. The fine-clay/total-clay ratio in the Patumahoe soil (0.7-0.8; fine clay = <0.02 μm) indicates that clay illuviation has occurred but the lobed appearance and non-laminated character of the clay coatings also suggests neoformation (Bakker et al., 1996). The Patumahoe soil has a well developed pedal microstructure with 90 % of the material finer than 20 μm, and many small, irregular iron oxide nodules (10-50 μm) (Bakker et al., 1996). The peds in the B horizons tend to be tightly packed but separate easily (Gibbs et al., 1968). The soils are sticky when wet and topsoils have limited workability then, but they are more friable and have more even moisture contents than the firm, compacted Ultisols around Hamilton (Gibbs et al., 1968). The soils are slowly permeable, resulting in periods of perching (Hewitt, 1998). They are effectively self-mulching, i.e., after cultivation the surface tends to re-aggregate into a strong granular structure which is quite persistent. Differences between the Pukekohe and Patumahoe soils are subtle but local growers suggest that the Pukekohe soils on the hill behave differently from the Patumahoe soils on the lower rolling slopes, being much easier to cultivate and holding their structure better (G.E. Orbell, pers. comm., 2008). However, although the soils are highly suited to vegetable production and are very resilient, frequent cultivation over a long period has increased soil erosion (as described above by Basher and Ross, this volume), reduced soil organic matter and soil biological activity, and degraded soil structure (Barratt, 1971; Basher and Ross, 2002).



Decline in organic C over time in Patumahoe soils under intensive vegetable cropping, Pukekohe (from Haynes and Tregurtha, 1999)

Other environmental issues include nitrogen leaching and groundwater contamination in a peri-urban environment, increases in diseases and pests and use of herbicides, fungacides, pesticides, and insecticides, and loss of soils to urban encroachment (C.W. Ross pers. comm., 2008). Onion white rot has become established in the Pukekohe district and fungicide resistance is widespread (Holland and Rahman, 1999). The production system for onions in this district is regarded as unsustainable because of the disease and insect problems combined with degradation of the soil resource, erosion and leaching.

Both Pukekohe and Patumahoe soils have medium to low fertility status: P-retention is low to medium but can be high (99 % in lower subsoils of Patumahoe soil), K and Mg reserves are low, sulphate tends to be strongly adsorbed on B horizons, and C and N levels are moderate (Hewitt, 1998; Molloy and Christie, 1998). Large amounts of N can be leached through fertilizer use on crops over winter, especially potatoes which are the single biggest contributer to nitrate leaching in the area (Francis et al., 2003). Potatoes planted in early winter receive ~480 kg N/ha, with 70% applied at planting. However, because potato plants do not take up N until at least 30 days after planting, fertilizer N applied at the time of planting is at risk of being leached (around 114 kg N/ha). Similarly, winter cabbages receive 150 kg N/ha at the time of planting in May, with much of this being leached before the plants are large enough to take up the N. August is a better time to apply N fertilizer when the plants are big enough to utilise it. The growing of cover crops during autumn fallowing adds organic matter to the soil and the cover crops will also take up potentially-leachable N from the soil. Francis et al. (2003) showed that oats and ryegrass as a cover crop produced significant quantities of dry matter below ground (roots) campared with sorghum, and 145 kg N/ha of N uptake compared with 62 kg N/ha uptake for sorghum.

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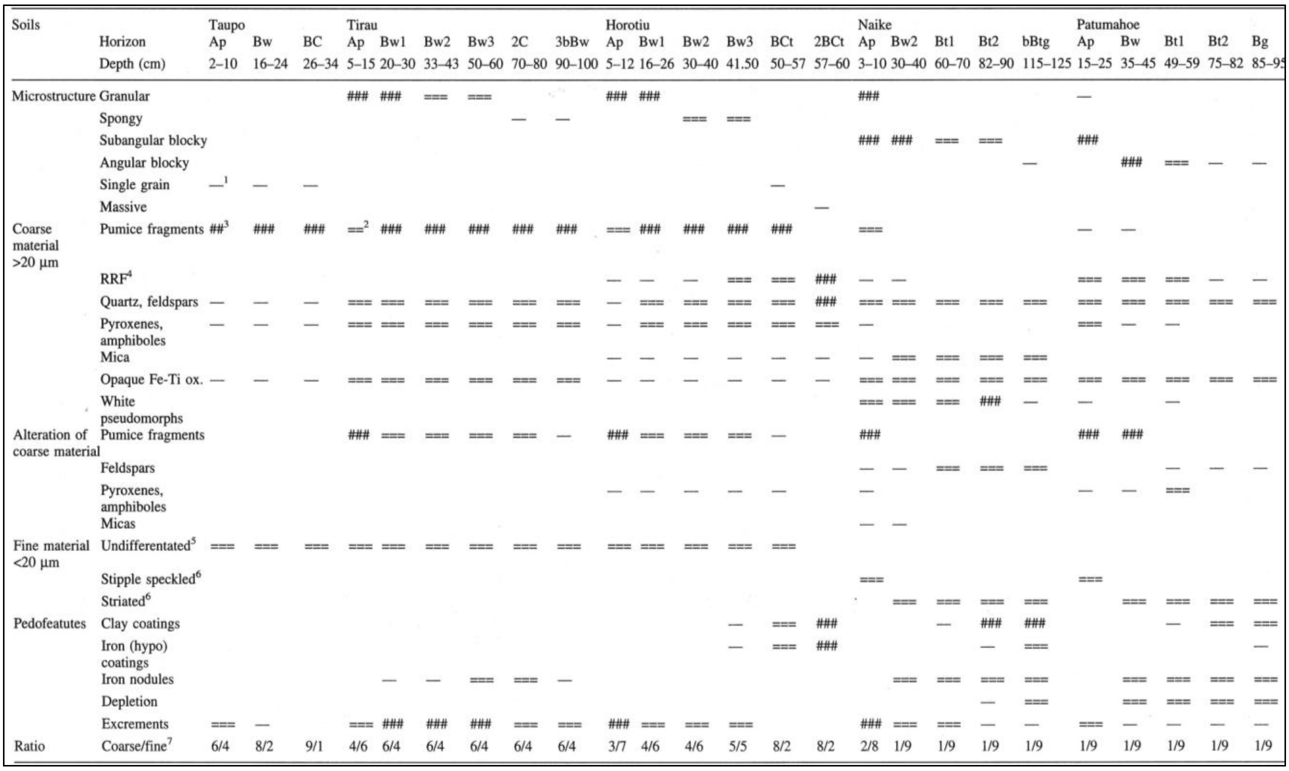
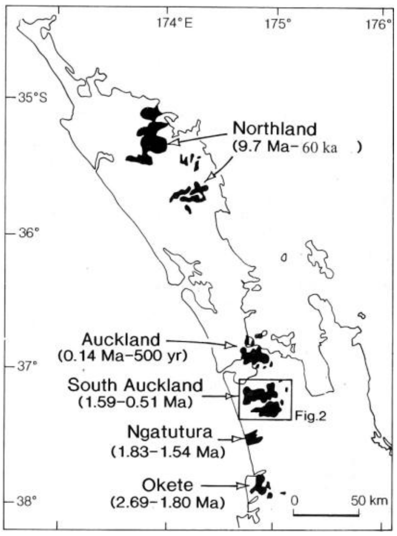
Micromorphological features in a range of tephra-derived soils in North Island including Patumahoe (from Bakker et al., 1996)

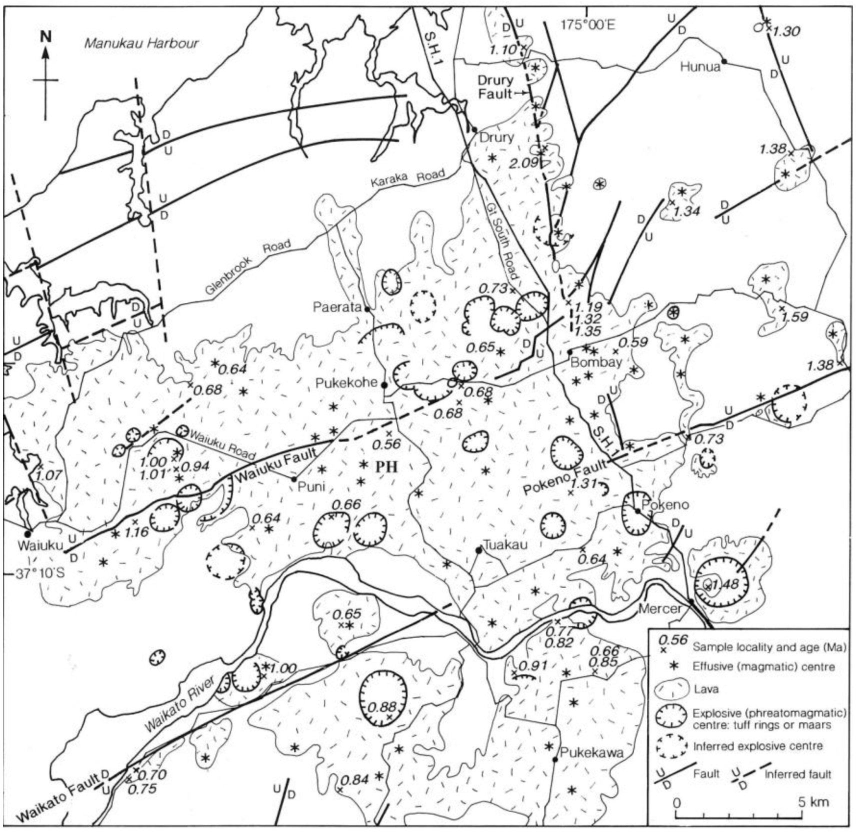


Soils		Taupo			Tirau						Horotiu						Naike					Patumahoe				
	Horizon	Ap	Bw	BC	Ap	Bw1	Bw2	Bw3	2C	3bBw	Ap	Bw1	Bw2	Bw3	BCt	2BCt	Ap	Bw2	Bt1	Bt2	bBtg	Ap	Bw	Bt1	Bt2	Bg
	Depth (cm)	2–10	16–24	26–34	5–15	20–30	33–43	50–60	70–80	90–100	5–12	16–26	30–40	41.50	50–57	57–60	3–10	30–40	60–70	82–90	115–125	15–25	35–45	49–59	75–82	85–9
Microstructure	Granular				###	###	===	===			###	###					###					—				
	Spongy								—	—			===	===												
	Subangular blocky																###	###	===	===		###				
	Angular blocky																				—		###	===	—	—
	Single grain	—[1]	—	—											—											
	Massive															—										
Coarse material >20 µm	Pumice fragments	##[3]	###	###	==[2]	###	###	###	###	###	===	###	###	###	###		===					—	—			
	RRF[4]										—	—	—	===	===	###	—	—				===	===	===	—	—
	Quartz, feldspars	—	—	—	===	===	===	===	===	===	—	===	===	===	===	###	===	===	===	===	===	===	===	===	===	===
	Pyroxenes, amphiboles	—	—	—	===	===	===	===	===	===	—	===	===	===	===	===	—					===	—	—		
	Mica										—	—	—	—	—	—	—	===	===	===	===					
	Opaque Fe-Ti ox.	—	—	—	===	===	===	===	===	===	—	—	—	—	—	—	===	===	===	===	===	===	===	===	===	===
	White pseudomorphs																===	===	===	###	—	—		—		
Alteration of coarse material	Pumice fragments				###	===	===	===	===	—	###	===	===	===	—		###					###	###			
	Feldspars																—	—	===	===	===			—	—	—
	Pyroxenes, amphiboles										—	—	—	—	—		—					—	—	===		
	Micas																—	—								
Fine material <20 µm	Undifferentated[5]	===	===	===	===	===	===	===	===	===	===	===	===	===	===											
	Stipple speckled[6]																===					===				
	Striated[6]																	===	===	===	===		===	===	===	===
Pedofeatutes	Clay coatings													—	===	###			—	###	###			—	===	===
	Iron (hypo) coatings													—	===	###				—	===					—
	Iron nodules					—	—	===	===	—								===	===	===	===		===	===	===	===
	Depletion																			—	===		===	===	===	===
	Excrements	===	—		===	###	###	###	===	===	###	===	===	===			###	===	===	—	—	===	—	—	—	—
Ratio	Coarse/fine[7]	6/4	8/2	9/1	4/6	6/4	6/4	6/4	6/4	6/4	3/7	4/6	4/6	5/5	8/2	8/2	2/8	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9

Key

[1] Few –
[2] Common ===
[3] Many ###
[4] Rhyolitic rock fragments
[5] Isotropic
[6] Anisotropic
[7] Coarse >20 µm/fine<20 µm

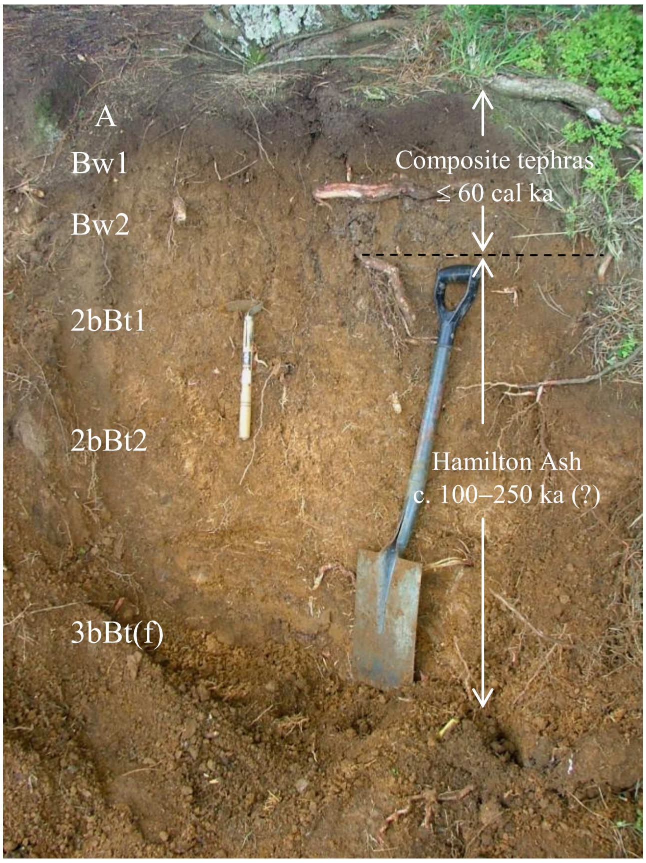




Maps of northern North Island showing locations of intraplate basalt volcanic fields (above) and South Auckland volcanic field including ages and structural patterns (right) (both from Briggs et al., 1994). PH, Pukekohe Hill

Freshly exposed Pukekohe soil at top of Anzac Rd, Pukekohe Hill, on 10 October, 2008. Leo provides the scale for new road turn-around under construction. Photo: David Lowe

Pukekohe silt loam on edge of Massey Memorial Lookout reserve, Pukekohe Hill. Location V16 783397 (bordering Ken Balle's fields)



Mangans in lower subsoil of Pukekohe soil (in close up below, cutting blade is 10 cm long)

Provisional stratigraphy, ages and horizonation. Data for Pukekohe and Patumahoe soils are given below. Pukekohe data (unpublished) from Landcare Research National Soils Database; Patumahoe data from Parfitt et al. (1981). Modern horizonation of Pukekohe soil profile SB8432 (below): B1 = BA; B2 = Bt; 'C' = another Bt horizon. Photos: David Lowe.

Soil Name: PUKEKOHE SILT LOAM Elite Lab No: SB08432

Description of Profile No: 8432 for Project No: SB

Author: GEO Date: 17-Feb-1969

Map reference: 0 0 Map Series: Grid ref unknown
Classification: Brown granular loam,
US Taxonomy:
NZSC: Mottled-acidic Orthic Granular Soil
Survey: Franklin County (part) FRAN Region: Auckland
Location: Northerly facing slope, Upper Queens Street roadside cutting.
Topdressing:
Annual Rain: 1143mm Elevation: 137 m Mean Temp - Annual: 12 C
Landform: Slope Landform Genesis:
Microrelief: Slope: 7 deg Aspect: 45 deg
Rock outcrops:
Slope Movement:
Drainage: Moderately well Land Use: Horticulture
Improvements: fertilised,
Vegetation: BRACKEN-PASPALUM-MARSHMELLOW-ROUGH ROADSIDE
Parent Materials: moderately weathered, ANDESITIC VOLCANIC ASH

Notes

SEE CARD FOR DETAILED ADDITIONAL NOTES. GROSSLY OVERDEEPENED A.P HOR

Horizon	Depth (cm)	Horizon Description
Ap	0-15	dark reddish brown (5YR 3/2) gritty silt loam; moderately weak soil strength; weakly developed medium nut breaking to coarse crumb structure; many live roots; structure - crushing to. crumb described as strong; distinct boundary.
B1	15-25	yellowish red (5YR 4/6) clay loam; moderately weak soil strength; strongly developed fine blocky structure; many faint mottles; many live roots; mottles diffuse, pale grey in patches, together with darker red cont mottles; diffuse boundary.
B2	25-40	brown to dark brown (7.5YR 4/4) clay loam; moderately firm soil strength; strongly developed medium nut structure; few faint mottles; few clay coatings; few live roots; roots tend to follow incipient prismatic struct, thin coatings are aggregate faces, mottles diffuse & reddish; diffuse boundary.
C1	40-63	strong brown (7.5YR 5/8) clay loam; moderately weak soil strength; moderately developed medium nut breaking to strongly developed coarse crumb structure; few live roots; structure crushing easily to. many f, few med white (?Gibbsite) flecks;

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	pH H2O	pH 1M KCl	pH 1M NaF	pH CaCl2	H2O Moist	C (%)	N (%)	C/N	Truog P (ug/g)	Phosphorus fractions (mg %) 0.5 M H2SO4	Inorg.	Organic	Total	P retn (%)
				A1A	A1A	A1B	A1A		A3A	A4A		A5A	A5B		A5D	A5E	A5C
Ap	0-15	A	-					5.9	2.70								60
B1	15-25	B	-					5.0	0.70								73
B2	25-40	C	-					4.8	0.60								77
C1	40-63	D	-					4.9	0.60								78

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	Cation exchange (NH4OAc @ pH7 me %) CEC	Sum bases	%BS	Ca	Mg	K	Na	KCl Ex. Al (me. %)	Titratable acidity (me. %)	Reserve Mgr (me. %)	Reserve Kc (me. %)	S Total (ug/g)	Phosphate ext. (ug/g) S	SO4
				A6E	6A3	6A5	A6B				A6H	A6I	A7B	A7A		A11	A11
Ap	0-15	A	-	19.4	10.3	53	8.6	1.00	0.10	0.55							
B1	15-25	B	-	14.7	4.24	29	2.4	0.92	0.11	0.81							
B2	25-40	C	-	13.1	2.54	19	0.9	0.83	0.17	0.64							
C1	40-63	D	-	13.2	1.69	13	0.2	0.70	0.05	0.74							

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	Pyrophosphate-extractable (%) Fe	Al	C	Acid oxalate-extractable (%) Fe	Al	Si	Mn	ODOE	Dithionite-citrate extractable (%) Fe	Al	Stones >2mm (%)	Moisture factor
				A8B			A8A					A8C			A2
Ap	0-15	A	-				0.53	0.39						n.d	1.045
B1	15-25	B	-				0.26	0.30						n.d	1.080
B2	25-40	C	-				0.29	0.29						n.d	1.063
C1	40-63	D	-				0.25	0.31						n.d	1.060

Soil Name: PUKEKOHE SILT LOAM Elite Lab No: SB08432

Mineralogy: Treated Clay Fraction (see Analysis Summary) (%) PART 1

Horizon	Lab letter	Sample depth (cm)	Clay (%)	Mica	Chlorite	Vermiculite	HIV	Smectite	Kandite	Kaolinite	Halloysite	Gibbsite	Goethite	Hematite	VG Am.SiO2	Serpentines	Pyrophylite	Zeolite	Talc
Ap	A	-		8	0	15	0	0	65			1	0	0		0	0	0	
B1	B	-		9	0	3	9	0	65			1	0	0		0	0	0	
B2	C	-		4	0	8	0	0	65			8	0	0		0	0	0	
C1	D	-		4	0	0	4	0	65			20	0	0		0	0	0	

Mineralogy: Treated Clay Fraction (see Analysis Summary) (%) PART 2

Horizon	Lab letter	Sample depth (cm)	Clay (%)	Interstratified minerals Mica-Vermiculite	Mica-HIV	Mica-Smec	Mica-Chlorite	Chlorite-Vermic	Chlorite-Smec	Kaolin-Smec	IHM	Allophane +Imogo	Quartz	Feldspar	Cristobalite
Ap	A	-		0	8	0	0	0	0	0	0	<1	0	0	2
B1	B	-		6	3	0	0	0	0	0	0	<1	0	0	3
B2	C	-		8	0	0	0	0	0	0	0	<1	0	0	5
C1	D	-		3	2	0	0	0	0	0	0	<1	0	0	3

Soil Name: PUKEKOHE SILT LOAM Elite Lab No: SB08432

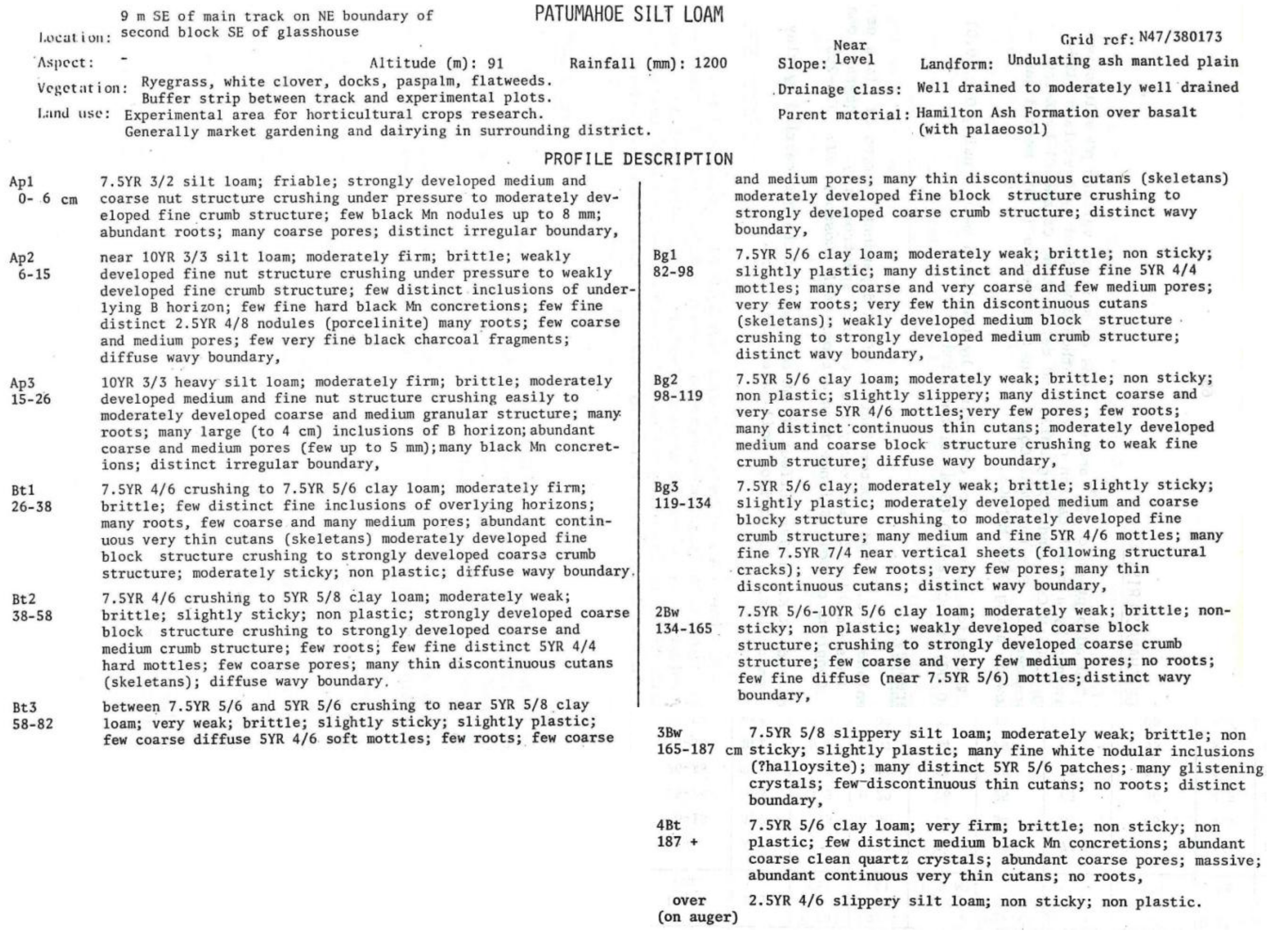
WHOLE SOIL MINERALOGY (%)

Horizon	Lab letter	Sample depth (cm)	Carbonate min. (CaCO3)	Allophane+Imogolite	Ferrihydrite	Mica	Chlorite	Quartz	Feldspar	Kandite	Gibbsite	Hematite	Goethite	Lepidocrocite	Serpentine group	Extractable (%) -Dithio Fe	Pyro phos. Al	Acid-oxalate Fe	Al	Si
Ap	A	-			<1													0.53	0.39	
B1	B	-			<1													0.26	0.30	
B2	C	-			<1													0.29	0.29	
C1	D	-			<1													0.25	0.31	

Classification: Pukekohe silt loam

NZSC: Allophanic [or Acidic] Orthic Granular Soils; tephric, rhyolitic; silty/loamy; slow
Soil Taxonomy: Clayey, mixed, thermic Typic Kandiudults [or Andic if in upper profile BD ≤1.0 g/cm^3 and Alo + 1/2Feo >1.0]

Build-up of redistributed (eroded) soil along hedge line forming an artificial terrace (Pukekohe soils). Photo: David Lowe

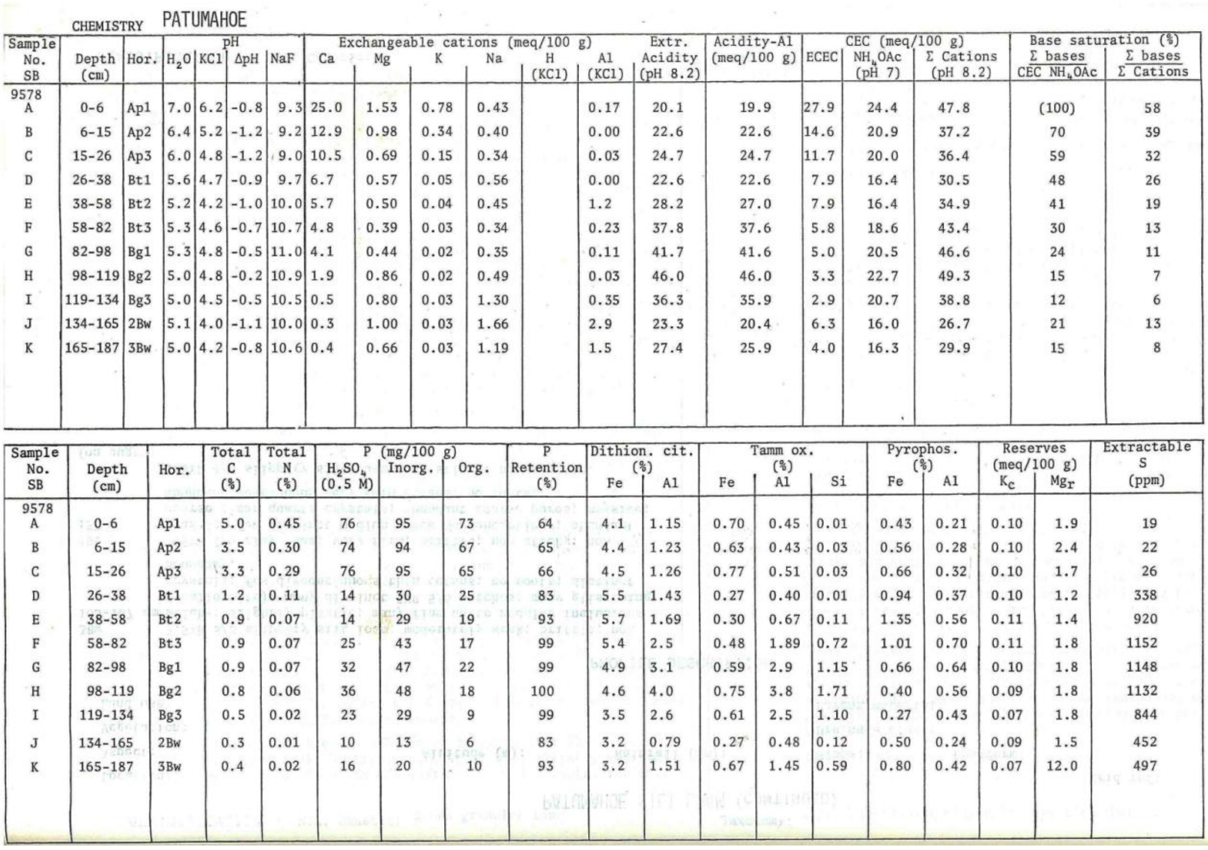


PATUMAHOE SILT LOAM

Location: 9 m SE of main track on NE boundary of second block SE of glasshouse
Grid ref: N47/380173
Aspect: -
Altitude (m): 91
Rainfall (mm): 1200
Slope: Near level
Landform: Undulating ash mantled plain
Vegetation: Ryegrass, white clover, docks, paspalm, flatweeds. Buffer strip between track and experimental plots.
Drainage class: Well drained to moderately well drained
Land use: Experimental area for horticultural crops research. Generally market gardening and dairying in surrounding district.
Parent material: Hamilton Ash Formation over basalt (with palaeosol)

PROFILE DESCRIPTION

Ap1 0- 6 cm	7.5YR 3/2 silt loam; friable; strongly developed medium and coarse nut structure crushing under pressure to moderately developed fine crumb structure; few black Mn nodules up to 8 mm; abundant roots; many coarse pores; distinct irregular boundary,
Ap2 6-15	near 10YR 3/3 silt loam; moderately firm; brittle; weakly developed fine nut structure crushing under pressure to weakly developed fine crumb structure; few distinct inclusions of underlying B horizon; few fine hard black Mn concretions; few fine distinct 2.5YR 4/8 nodules (porcelinite) many roots; few coarse and medium pores; few very fine black charcoal fragments; diffuse wavy boundary,
Ap3 15-26	10YR 3/3 heavy silt loam; moderately firm; brittle; moderately developed medium and fine nut structure crushing easily to moderately developed coarse and medium granular structure; many roots; many large (to 4 cm) inclusions of B horizon; abundant coarse and medium pores (few up to 5 mm); many black Mn concretions; distinct irregular boundary,
Bt1 26-38	7.5YR 4/6 crushing to 7.5YR 5/6 clay loam; moderately firm; brittle; few distinct fine inclusions of overlying horizons; many roots, few coarse and many medium pores; abundant continuous very thin cutans (skeletans) moderately developed fine block structure crushing to strongly developed coarse crumb structure; moderately sticky; non plastic; diffuse wavy boundary.
Bt2 38-58	7.5YR 4/6 crushing to 5YR 5/8 clay loam; moderately weak; brittle; slightly sticky; non plastic; strongly developed coarse block structure crushing to strongly developed coarse and medium crumb structure; few roots; few fine distinct 5YR 4/4 hard mottles; few coarse pores; many thin discontinuous cutans (skeletans); diffuse wavy boundary.
Bt3 58-82	between 7.5YR 5/6 and 5YR 5/6 crushing to near 5YR 5/8 clay loam; very weak; brittle; slightly sticky; slightly plastic; few coarse diffuse 5YR 4/6 soft mottles; few roots; few coarse and medium pores; many thin discontinuous cutans (skeletans) moderately developed fine block structure crushing to strongly developed coarse crumb structure; distinct wavy boundary,
Bg1 82-98	7.5YR 5/6 clay loam; moderately weak; brittle; non sticky; slightly plastic; many distinct and diffuse fine 5YR 4/4 mottles; many coarse and very coarse and few medium pores; very few roots; very few thin discontinuous cutans (skeletans); weakly developed medium block structure crushing to strongly developed medium crumb structure; distinct wavy boundary,
Bg2 98-119	7.5YR 5/6 clay loam; moderately weak; brittle; non sticky; non plastic; slightly slippery; many distinct coarse and very coarse 5YR 4/6 mottles; very few pores; few roots; many distinct continuous thin cutans; moderately developed medium and coarse block structure crushing to weak fine crumb structure; diffuse wavy boundary,
Bg3 119-134	7.5YR 5/6 clay; moderately weak; brittle; slightly sticky; slightly plastic; moderately developed medium and coarse blocky structure crushing to moderately developed fine crumb structure; many medium and fine 5YR 4/6 mottles; many fine 7.5YR 7/4 near vertical sheets (following structural cracks); very few roots; very few pores; many thin discontinuous cutans; distinct wavy boundary,
2Bw 134-165	7.5YR 5/6-10YR 5/6 clay loam; moderately weak; brittle; non-sticky; non plastic; weakly developed coarse block structure; crushing to strongly developed coarse crumb structure; few coarse and very few medium pores; no roots; few fine diffuse (near 7.5YR 5/6) mottles; distinct wavy boundary,
3Bw 165-187 cm	7.5YR 5/8 slippery silt loam; moderately weak; brittle; non sticky; slightly plastic; many fine white nodular inclusions (?halloysite); many distinct 5YR 5/6 patches; many glistening crystals; few discontinuous thin cutans; no roots; distinct boundary,
4Bt 187 +	7.5YR 5/6 clay loam; very firm; brittle; non sticky; non plastic; few distinct medium black Mn concretions; abundant coarse clean quartz crystals; abundant coarse pores; massive; abundant continuous very thin cutans; no roots,
over (on auger)	2.5YR 4/6 slippery silt loam; non sticky; non plastic.



CHEMISTRY PATUMAHOE

Sample No. SB	Depth (cm)	Hor.	pH				Exchangeable cations (meq/100 g)						Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	CEC (meq/100 g)			Base saturation (%)	
			H_2O	KCl	ΔpH	NaF	Ca	Mg	K	Na	H (KCl)	Al (KCl)			ECEC	NH_4OAc (pH 7)	Σ Cations (pH 8.2)	$\frac{\Sigma \text{ bases}}{\text{CEC } NH_4OAc}$	$\frac{\Sigma \text{ bases}}{\Sigma \text{ Cations}}$
9578 A	0-6	Ap1	7.0	6.2	-0.8	9.3	25.0	1.53	0.78	0.43		0.17	20.1	19.9	27.9	24.4	47.8	(100)	58
B	6-15	Ap2	6.4	5.2	-1.2	9.2	12.9	0.98	0.34	0.40		0.00	22.6	22.6	14.6	20.9	37.2	70	39
C	15-26	Ap3	6.0	4.8	-1.2	9.0	10.5	0.69	0.15	0.34		0.03	24.7	24.7	11.7	20.0	36.4	59	32
D	26-38	Bt1	5.6	4.7	-0.9	9.7	6.7	0.57	0.05	0.56		0.00	22.6	22.6	7.9	16.4	30.5	48	26
E	38-58	Bt2	5.2	4.2	-1.0	10.0	5.7	0.50	0.04	0.45		1.2	28.2	27.0	7.9	16.4	34.9	41	19
F	58-82	Bt3	5.3	4.6	-0.7	10.7	4.8	0.39	0.03	0.34		0.23	37.8	37.6	5.8	18.6	43.4	30	13
G	82-98	Bg1	5.3	4.8	-0.5	11.0	4.1	0.44	0.02	0.35		0.11	41.7	41.6	5.0	20.5	46.6	24	11
H	98-119	Bg2	5.0	4.8	-0.2	10.9	1.9	0.86	0.02	0.49		0.03	46.0	46.0	3.3	22.7	49.3	15	7
I	119-134	Bg3	5.0	4.5	-0.5	10.5	0.5	0.80	0.03	1.30		0.35	36.3	35.9	2.9	20.7	38.8	12	6
J	134-165	2Bw	5.1	4.0	-1.1	10.0	0.3	1.00	0.03	1.66		2.9	23.3	20.4	6.3	16.0	26.7	21	13
K	165-187	3Bw	5.0	4.2	-0.8	10.6	0.4	0.66	0.03	1.19		1.5	27.4	25.9	4.0	16.3	29.9	15	8

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g)			P Retention (%)	Dithion. cit. (%)		Tamm ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)
					H_2SO_4 (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K_c	Mg_r	
9578 A	0-6	Ap1	5.0	0.45	76	95	73	64	4.1	1.15	0.70	0.45	0.01	0.43	0.21	0.10	1.9	19
B	6-15	Ap2	3.5	0.30	74	94	67	65	4.4	1.23	0.63	0.43	0.03	0.56	0.28	0.10	2.4	22
C	15-26	Ap3	3.3	0.29	76	95	65	66	4.5	1.26	0.77	0.51	0.03	0.66	0.32	0.10	1.7	26
D	26-38	Bt1	1.2	0.11	14	30	25	83	5.5	1.43	0.27	0.40	0.01	0.94	0.37	0.10	1.2	338
E	38-58	Bt2	0.9	0.07	14	29	19	93	5.7	1.69	0.30	0.67	0.11	1.35	0.56	0.11	1.4	920
F	58-82	Bt3	0.9	0.07	25	43	17	99	5.4	2.5	0.48	1.89	0.72	1.01	0.70	0.11	1.8	1152
G	82-98	Bg1	0.9	0.07	32	47	22	99	4.9	3.1	0.59	2.9	1.15	0.66	0.64	0.10	1.8	1148
H	98-119	Bg2	0.8	0.06	36	48	18	100	4.6	4.0	0.75	3.8	1.71	0.40	0.56	0.09	1.8	1132
I	119-134	Bg3	0.5	0.02	23	29	9	99	3.5	2.6	0.61	2.5	1.10	0.27	0.43	0.07	1.8	844
J	134-165	2Bw	0.3	0.01	10	13	6	83	3.2	0.79	0.27	0.48	0.12	0.50	0.24	0.09	1.5	452
K	165-187	3Bw	0.4	0.02	16	20	10	93	3.2	1.51	0.67	1.45	0.59	0.80	0.42	0.07	12.0	497

PARTICLE SIZE DISTRIBUTION (<2 mm) Patumahoe

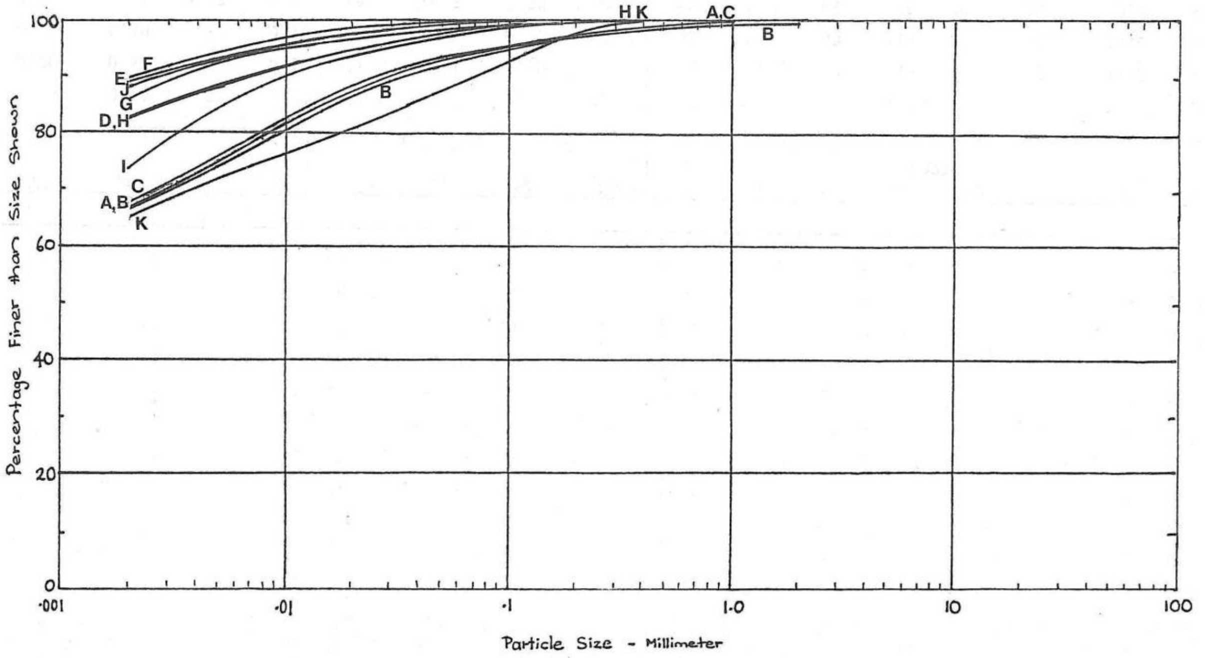
Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9578A	0-6	Ap1	4	3	27	66	45	0.68	(<1)
B	6-15	Ap2	4	3	26	67	46	0.69	(1)
C	15-26	Ap3	4	2	27	67	46	0.69	(<1)
D	26-38	Bt1	2	1	15	82	68	0.83	
E	38-58	Bt2	1	1	9	89	75	0.84	
F	58-82	Bt3	0	1	9	90	68	0.76	
G	82-98	Bg1	1	2	10	87	61	0.70	
H	98-119	Bg2	1	0	16	83	54	0.65	
I	119-134	Bg3	1	2	23	74	42	0.57	
J	134-165	2Bw	0	2	10	88	63	0.72	
K	165-187	3Bw	7	6	21	66	45	0.68	

PHYSICS

Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	15 bar water Air Dry (%)
0-6	Ap1	30.8	24.8
6-15	Ap2	29.8	23.8
15-26	Ap3	30.2	23.7
26-38	Bt1	45.8	31.0
38-58	Bt2	53.4	33.2
58-82	Bt3	64.4	31.4
82-98	Bg1	71.0	31.4
98-119	Bg2	75.5	30.8
119-134	Bg3	68.2	34.4
134-165	2Bw	64.4	42.2
165-187	3Bw	55.2	31.7

Core Depth (cm)	Dry bulk density (T/m^3)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
0-6	1.04					
7-10	1.00					
16-19	0.95					
20-23	0.90					
31-34	0.78					
–	–					
	1.06					
	0.94					
	0.81					
	0.78					
	–					
	–					

SB 9578 Patumahoe



Mineralogy Patumahoe

Sample No. SB	Depth (cm)	Hor.	Clay Fraction (%)															Sand Fraction (%)													
			Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Hematite	Quartz	Feldspar (acid)	Andesine	Glass	Kaolinite	Biotite	Horneblende	Augite	Hypersthene	Epidote	Cristobalite	Quartz Ag.	Magnetite	Plant opal
9578A	0-6	Ap1			2	9			42	17	20	1	1	7				a		C	C		R	S	tr	R	tr	S		S	S
B	6-15	Ap2			4	23			31	19	15	1	1	6				a		c	a			S	tr	R		S	R	S	S
C	15-26	Ap3			5	20			30	20	17	1	1	5				a		c	C			S/R	tr	R		S	R	R	S
D	26-38	Bt1			4	20			17	33	15	tr	tr	10				a/A		c	C			S		S		S		S	S
E	38-58	Bt2			2	14			11	35	22	tr	tr	16				a		c	c	C		R			tr	S	S	S	R
F	58-82	Bt3				16			11	40	21	tr	tr	11				a/A		c/S	c	S		R		tr	tr	S		S	R/S
G	82-98	Bg1				12			5	42	21	tr		19				a/A	tr	S	c	C		R			tr	S	S	S/c	R
H	98-119	Bg2				15				46	16			23				a		R		a						S/c	S	S/c	
I	119-134	Bg3				11				65	5			15				C			R	A	tr					S	S	c	
J	134-165	2Bw								88	tr			12				A	tr		R	C	R					S	S/c	c/C	
K	165-187	3Bw				24				60	4							C	R	R		a	a					S	S	S	

Total Element Analysis

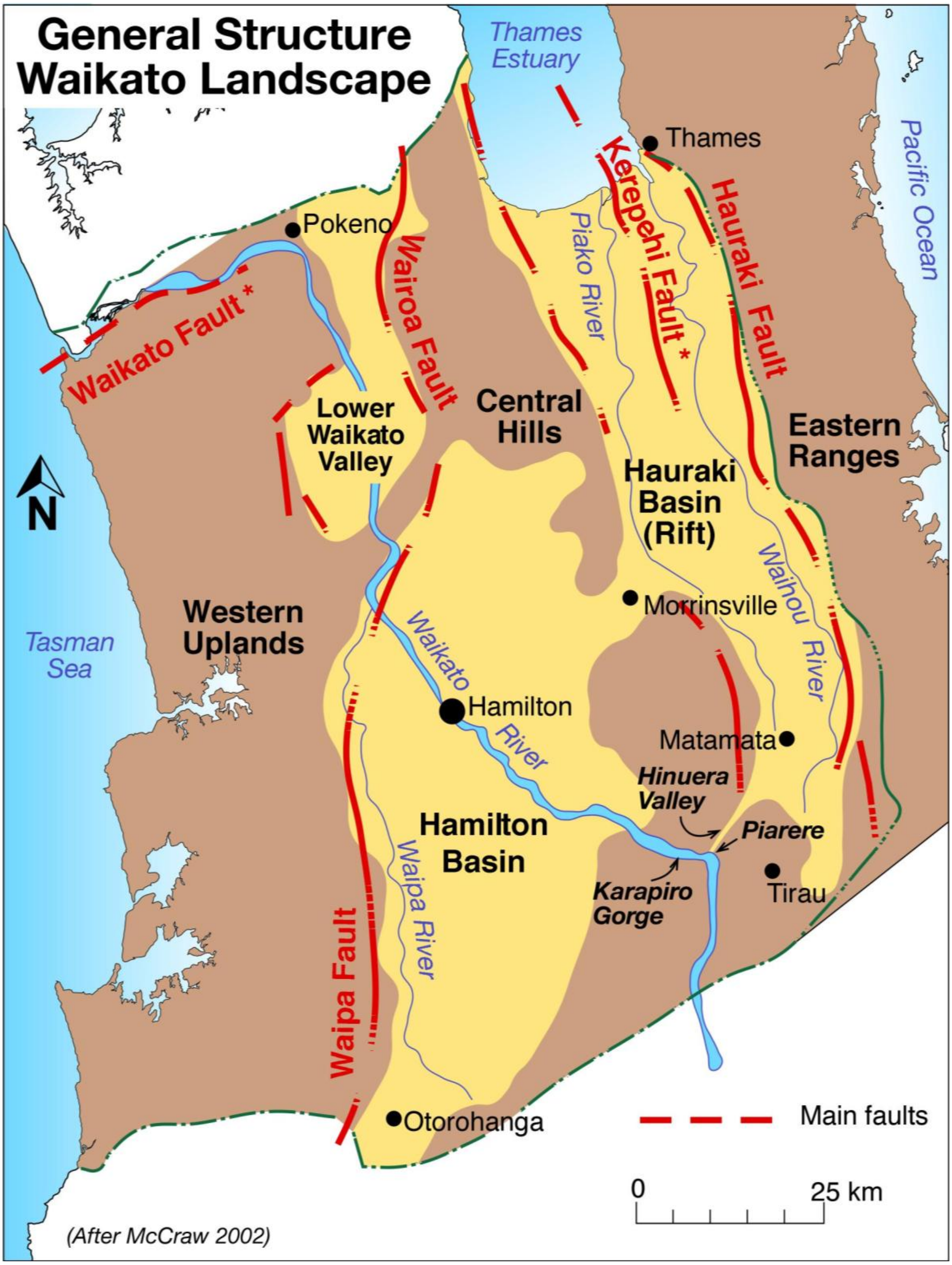
Sample No. SB	Hor.	Fe	Mn	Ti	Ca	K (%)	P	Si	Al	Mg	Na	Cr	Ni	Cu	Zn (ppm)	Rb	Sr	Y	Ba	Ign. loss (%)
9578A	Ap1	5.53	0.48	0.68	0.78	0.38	0.17	21.1	11.7	0.31	<0.2	67	21	69	125	36	46	14.7	344	19.6
B	Ap2	5.79	0.46	0.70	0.44	0.38	0.17	21.8	12.1	0.30	<0.2	63	5.0	68	117	37	53	14.5	354	17.5
C	Ap3	5.74	0.42	0.70	0.39	0.39	0.16	22.0	12.0	0.26	<0.2	66	7.7	69	117	33	52	13.0	341	17.0
D	Bt1	6.70	0.06	0.71	0.19	0.22	0.05	18.2	16.3	0.22	<0.2	62	7.7	65	95	25	46	9.2	351	17.4
E	Bt2	6.32	<0.02	0.70	0.24	0.26	0.10	18.7	18.3	0.32	<0.2	58	14.4	70	86	21	21	7.6	369	19.0
F	Bt3	6.70	<0.02	0.67	0.10	0.14	0.06	14.5	19.7	0.26	<0.2	49	12.8	78	84	23	9.9	6.9	366	20.0
G	Bg1	6.06	<0.02	0.61	0.08	0.12	0.07	14.0	20.2	<0.20	<0.2	48	13.8	73	83	22	12.3	5.3	430	21.0
H	Bg2	5.88	<0.02	0.57	0.03	0.12	0.07	14.3	20.4	<0.20	<0.2	37	13.1	75	89	19.2	5.9	6.6	616	20.0
I	Bg3	4.64	<0.02	0.46	<0.01	0.12	0.04	17.3	19.7	0.26	<0.2	27	10.0	59	104	14.8	7.9	3.9	1060	16.4
J	2Bw	4.81	<0.02	0.48	<0.01	0.12	<0.02	19.7	17.9	<0.20	<0.2	30	8.5	46	84	14.1	8.2	5.7	1100	14.3
K	3Bw	4.65	<0.02	0.46	0.05	0.50	0.03	19.5	17.3	0.27	<0.2	22	<4.0	32	69	16.7	18.6	6.5	936	15.2

Classification: Patumahoe clay loam

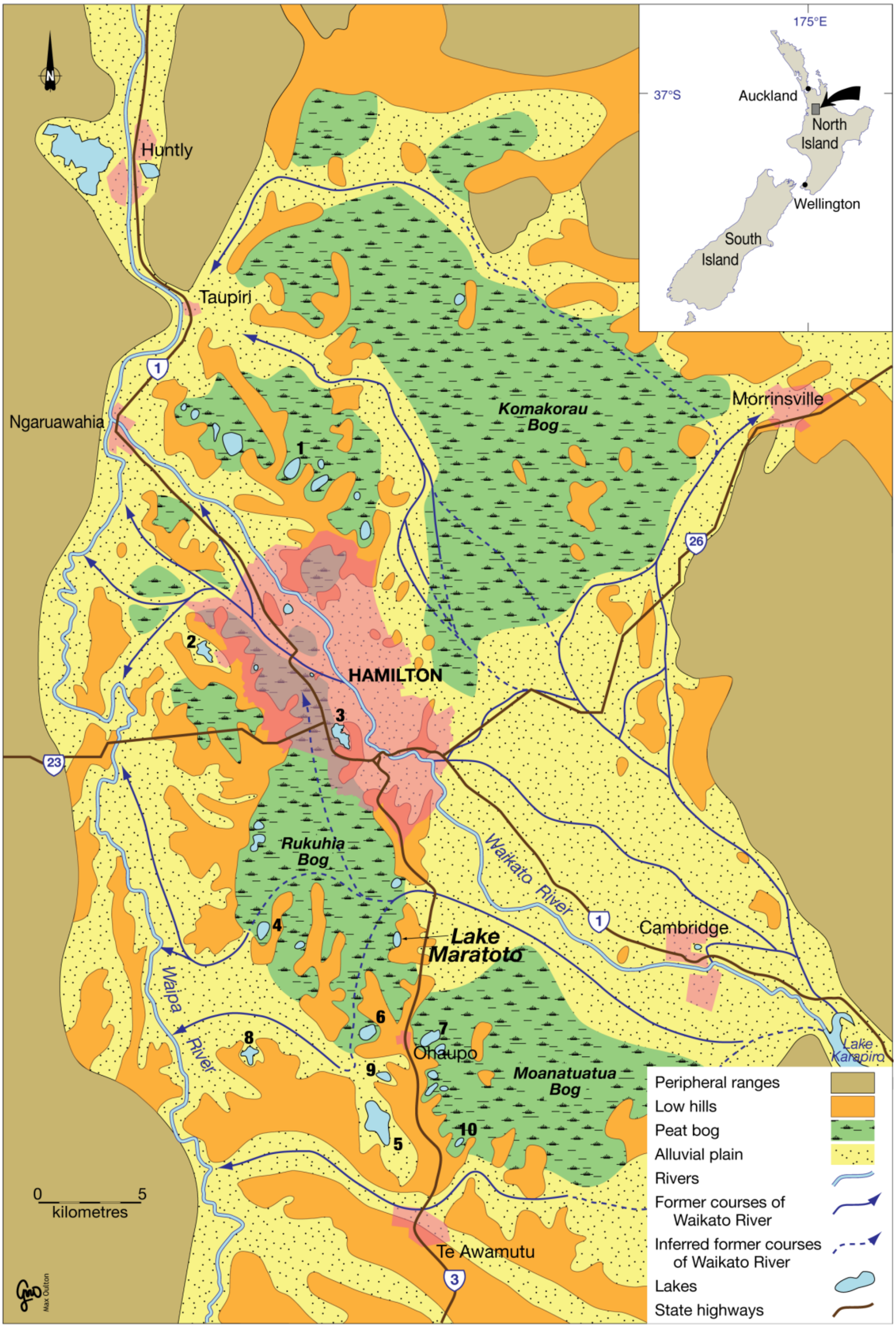
NZSC: Allophanic Oxidic Granular Soils; tephric, rhyolitic; clayey; slow
Soil Taxonomy: Clayey, mixed, thermic Andic Palehumults

"We're taking soil samples today ...
in other words, FIELD TRIP!"

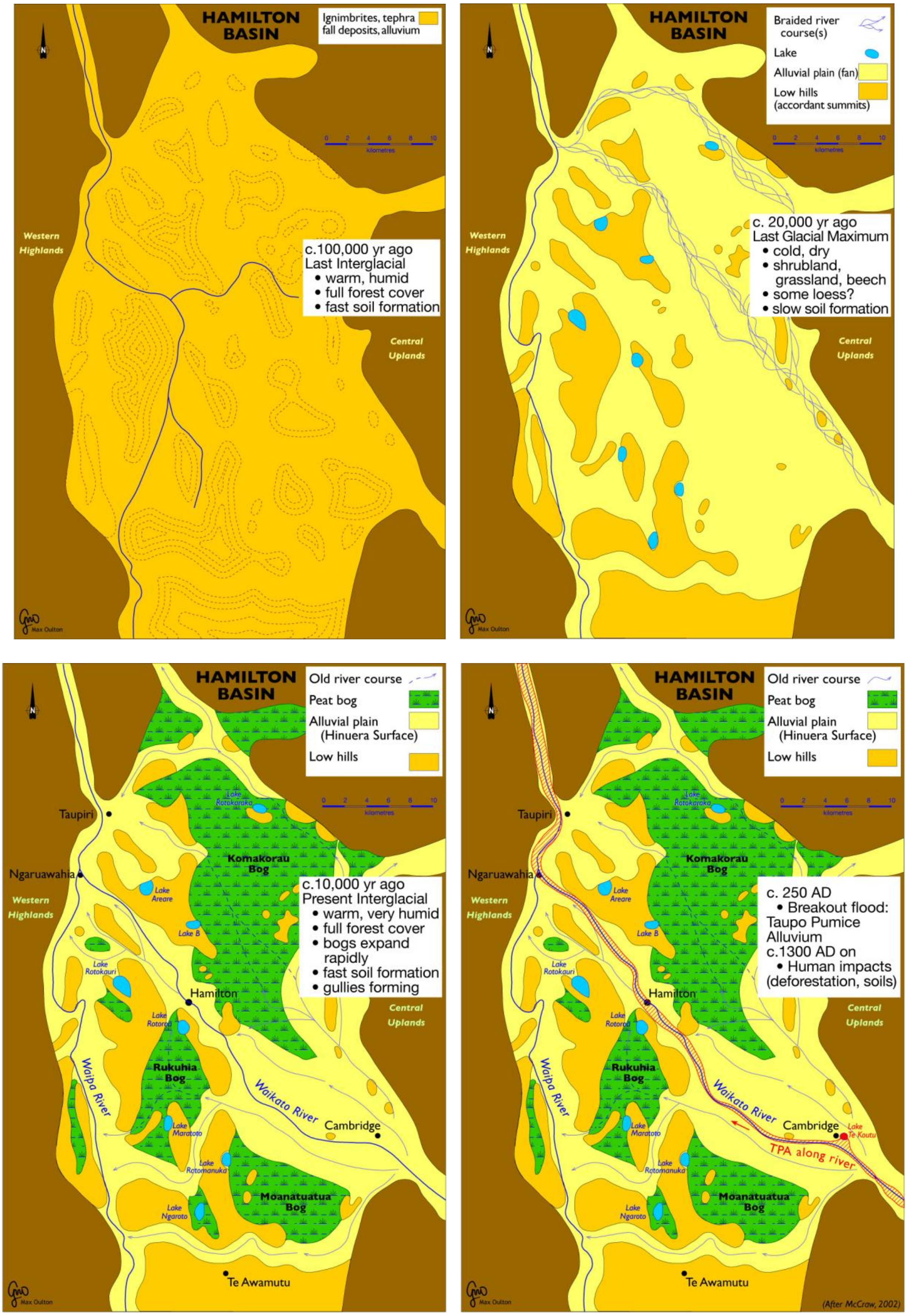
1.3 Transit from Pukekohe Hill (Stop 1) to Dairy NZ Scott Farm (Stop 2) through the Hamilton Basin, central Waikato region



General structure of the Waikato landscape and location of Hamilton Basin (after McCraw, 2002).



Modern landscape features of the Hamilton Basin showing antecedent hills partly buried by volcanogenic alluvium (Hinuera Formation) and post-Hinuera lakes and peat bogs (diagram by D.J. Lowe after McCraw, 2002). Note that the ancestral Waikato River migrated widely in building the low-angle alluvial fans (plain) in the basin; the paleochannels represent just the final stages of river migration and failed downcutting prior to its final incision into the modern channel.



Snapshots at 4 different times since c. 100-125 ka showing the general development of landscape features of the Hamilton Basin. The geology and geomorphic development of the landscape are strongly reflected in the modern soil pattern (diagrams by D.J. Lowe).

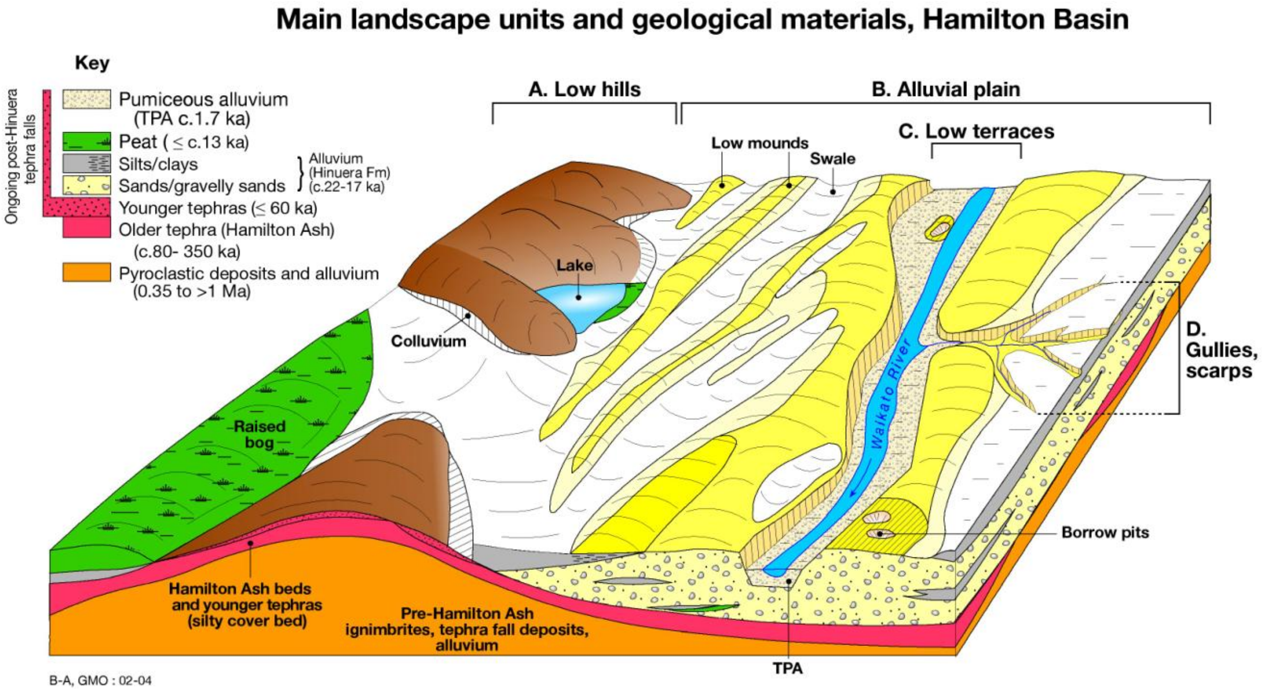
General landscape pattern and soils of the Hamilton Basin

The Hamilton Basin area is characterised by four main landscape units or landforms as depicted in the block diagrams below (McCraw, 1967, 2002; Bruce, 1979; Selby and Lowe, 1992), and these provide a soil-landscape model to predict the soil pattern. The four units are:

- **Low rolling hills** – the so-called „Hamilton hills“
- **Flattish alluvial plains** with micro-relief of low mounds (bars) and swales (depressions)
- **Low terraces** adjacent to the modern Waikato River
- **Gullies** cut into the alluvial plain or low terraces and draining to the Waikato River

A. The low rolling hills represent the remnants of a landscape dating back around more than a million years. A drill hole through a hill will typically show the following sequence of deposits (from top down):

- Silty cover bed of post-Hamilton-Ash tephras from multiple sources; ~0.5 m thick; ≤*c*. 60 ka[*]
- Red-brown, clayey weathered tephra beds (Hamilton Ash); ~1–3 m thick; top bed *c*. 80–125 ka, basal *c*. 350 ka (the dark reddish-brown uppermost buried soil horizon probably represents soil formation during the last interglacial)
- Orange/reddish/cream gravelly alluvial clays (Karapiro Formation); variable thickness (few metres); *c*. 500 ka
- Very dark red-brown, clayey weathered tephra beds (part of Kauroa Ash Formation); patchy; older than *c*. 0.78 Ma (magnetically reversed)
- Cream-coloured ignimbrite (deposit from pyroclastic flows); up to 10–20 m thick. Three main units: Ongatiti Ig., Rocky Hill Ig., Kidnappers Ig., aged from *c*. 1.2 to c. 1.0 Ma, respectively.



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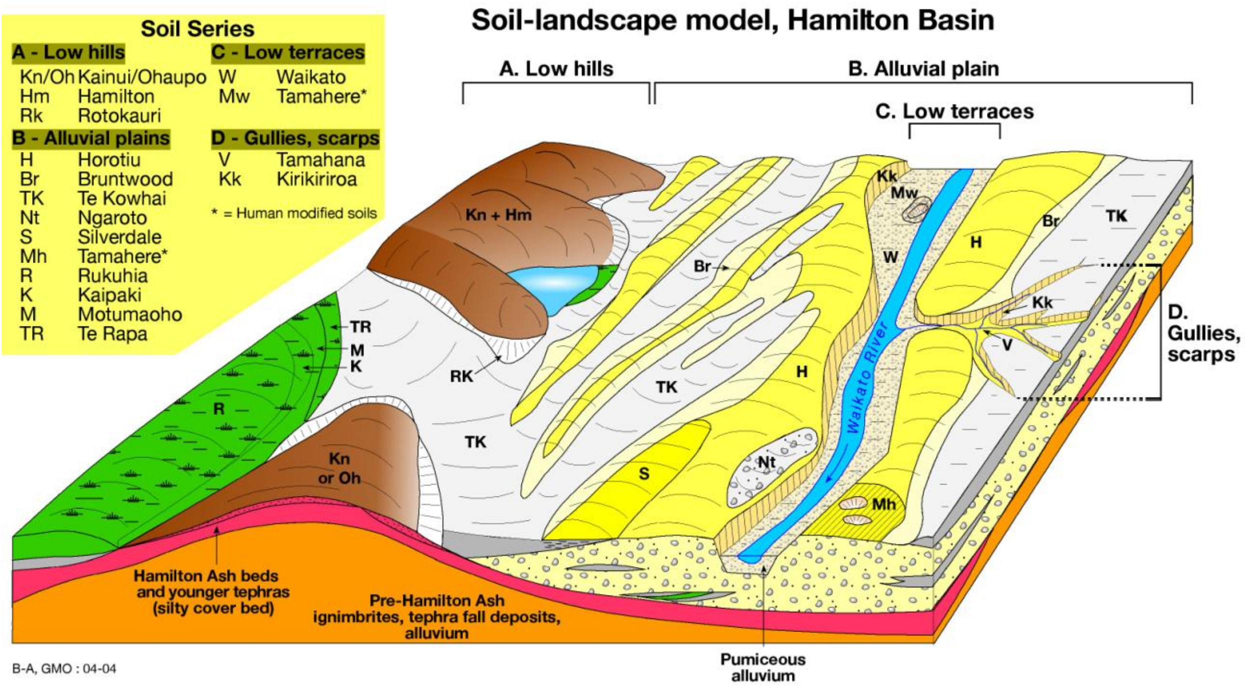
[*] *Note*: ka = thousands of years ago; Ma = millions of years ago



(Previous page) Main landscape units A-D and geological materials and ages in the Hamilton Basin and (above) associated soil series (constructed by D.J. Lowe after McCraw, 1967; Bruce, 1979; Singleton, 1991). The regional geology was described by Kear and Schofield (1978) and Edbrooke (2005); the geomorphology was described by Selby and Lowe (1992).

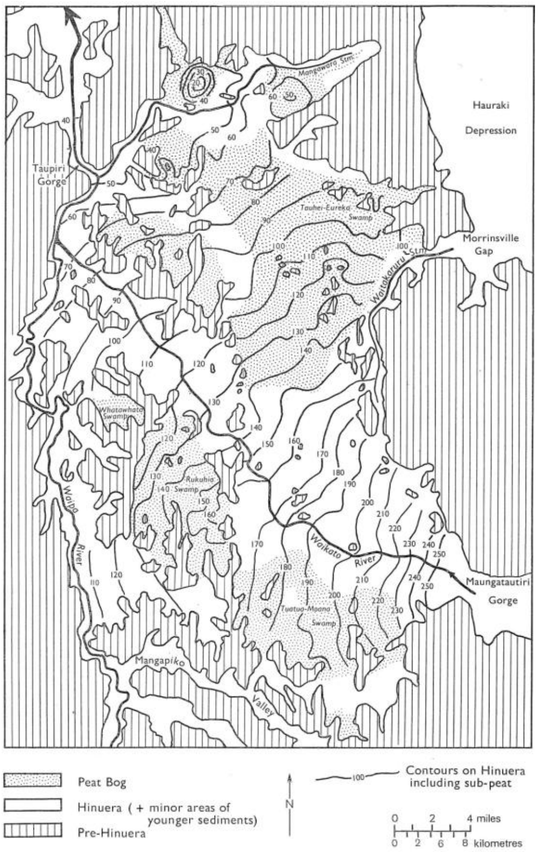
B. The plains represent alluvium derived ultimately from the mainly volcanic catchments of the central North Island and deposited by the ancestral Waipa River and then the ancestral Waikato River system in a series of depositional episodes over the past *c*. 100 ka or so (see maps above). These deposits swept around and over the pre-exisiting hilly landscape in the Waikato, partly burying it so that today we find just remnants of the accordant hills protruding through the essentially flat-lying alluvial surface. The alluvial surface comprises a series of low ridges/bars and swales or depressions; it also slopes very gently in a fan form, the apex at Maungatautari and the toe at Taupiri, ~1 m vertically for every 1 km horizontally (Manville and Wilson, 2004). The ancestral Waikato River was predominantly a high energy, braided system that until c. 22,000 cal. years ago flowed through the Hauraki Basin via the Hinuera Valley to the Thames Estuary/Firth of Thames. It then switched (avulsed) at Piarere near Karapiro to flow into the Hamilton Basin (Manville and Wilson, 2004).

The name of the volcanogenic alluvium deposited by the ancient Waipa and Waikato rivers is the Hinuera Formation, and the surface of the plains is called the Hinuera Surface (Kear and Schofield, 1978; Edbrooke, 2005). The deposits of the Hinuera Formation are up to 60 m thick. The latest depositional episode in the Hamilton Basin was between *c*. 22,000-20,000 and 17,000 cal. years ago (Manville and Wilson, 2004). Some time after, the ancestral Waikato River began to entrench, forming terraces, into its modern channel after a series of 'failed' downcutting episodes manifest today as shallow paleochannels in the Hinuera Formation (see map above). Thin but numerous tephra layers (each a few millimetres to a few centimetres in thickness) have blanketed much of the Hinuera Surface in the Hamilton Basin since the surface was abandoned *c*. 17,000 cal. years ago by the entrenching Waikato River. The tephra layers are well preserved in lake sediments (e.g. cores from lakes contain numerous tephra layers: Lowe, 1988) and peat bogs that developed on or alongside the Hinuera deposits (see below).

Slightly undulating surface of the Hinuera Formation – the low gravelly ridge (levee) in foreground (Horotiu soils) drops away to a flat swale towards the right (Te Kowhai soils) and background (note effluent sprayers). Despite being mantled with numerous thin tephras since c. 18 cal ka (~0.4 to ~0.6 m thick in total, see photo below), the subtle ridge-and-swale features derived from braided river channels of the ancestral Waikato River are clearly evident today. Site at Hautapu near Cambridge. Photo: David Lowe

Cross stratified fluvial gravelly sands of c. 18 cal. ka Hinuera Formation overlain by ~0.6 m of thin, intermixed tephras near Hautapu (associated landscape shown in photo above). Sediments comprise mainly quartzo-feldspathic assemblages with rhyolitic rock fragments and subordinate pumice and heavy minerals. Modern soil is Horotiu sandy loam. Cutting tool ~0.3 m in length. Photo: D.J. Lowe.

The soil pattern on the tephra-draped Hinuera Surface mimicks the alluvial depositional environments: well drained soils occur on the slightly raised channel/bar deposits (Horotiu soils comprise tephra fallout cover on coarse alluvium) and poorly drained soils occur on lower-lying 'swales' containing volcanogenic overbank flood deposits (Te Kowhai, Ngaroto, and Matangi soils). Of these, the silt-rich Te Kowhai soils are most common. In between are the Bruntwood soils (well drained upper, poorly drained lower horizons) and Silverdale soils (moderately well drained upper and poorly drained lower horizons). We aim to see examples of the Horotiu-Bruntwood-Te Kowhai soils at Stop 2 that mark a low-elevation toposequence across raised channel/bar deposits through to a swale.



Contours in feet on the Hinuera Surface in the Hamilton Basin showing fan form (from Kear and Schofield, 1978). Slope of fan surface is ~1 m per km.
(1 foot = 0.305 m hence 250 ft = 76 m, 100 ft = 31 m, 50 ft = 15 m).

To the north and south of Hamilton, large raised bogs have developed on the Hinuera Surface. Initially low-lying wet areas, including near lakes, the peats spread and thickened and coalesced into raised bogs when net precipitation in the region increased at c. 13,000 cal years ago (Green and Lowe, 1985). Soils on the deepest parts of the bogs, entirely formed in deep peat, are the Rukuhia soils; those towards the margins are the Kaipaki soils (peat ~1 m thick), and those on the margins are the Motumaoho or Te Rapa soils (~30-40 cm of peat on volcanogenic alluvium). Te Rapa soils are present on Scott Farm at Stop 2.

Along the Waikato and Waipa rivers are numerous examples of human-modified soils (Tamahere series) adapted for growing tropical sweet potato (kumara) by early Maori (Gumbley et al., 2004). These soils typically have overthickened, charcoal-bearing topsoils to which gravels and sands have been added, these being excavated from adjacent small quarries or 'borrow pits' in the Hinuera Formation. The soils were mounded into small hillocks called *puke* to provide perfect drainage conditions, increase soil temperatures, and provide an interface for better tuber development. The growing conditions were adapted from yam-growing practises in the Pacific islands. *Puke* means 'yam-growing mound' in proto-Polynesian. The kumara was imported to temperate New Zealand by early Polynesian sailors.

C. The lowermost terraces adjacent to the modern Waikato River mark deposition from a dramatic break-out flood event about 250 AD ago following the latest eruption of Taupo Volcano (in 232 ± 5 AD). Huge quantities of pumiceous deposits were swept down the Waikato River, which rose several metres to tens of metres, and then left stranded as terrace deposits adjacent to the main river channel and up tributary valleys or gullies that drained into it (Manville et al., 1999; Manville, 2001, 2002). The deposits are known as the Taupo Pumice Alluvium and are up to ~30 m thick. Soils developed on these materials (Waikato series) are weakly formed because of their young age. On SH 1, the Cambridge Golf Course boasts that it was „sculptured by the Waikato River 15,000 years ago‟. This is untrue: the course is dominated by deposits and paleochannels of the Taupo Pumice Alluvium of *c.* 250 AD, only *c.* 1750 cal. years ago (the earlier Hinuera Formation materials are well buried underneath or were cannibalized during the Taupo break-out flood event).

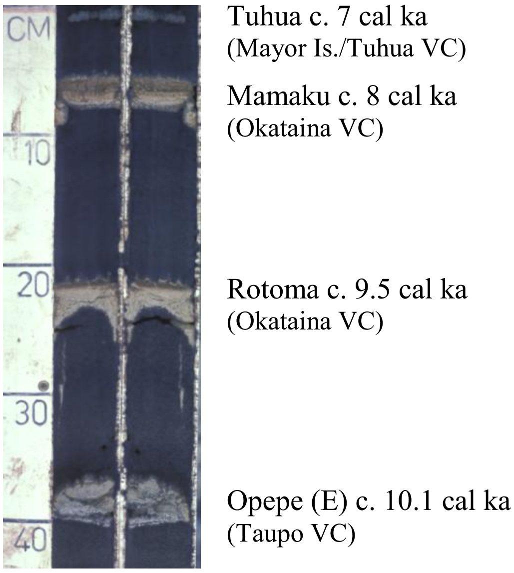
D. Gullies are occasionally cut into the Hinuera Surface, usually draining towards the modern Waikato River. Soils of the gully sides, and terrace scarps, are Kirkiriroa series and soils on the recent alluvium in gully bottoms are Tamahana series. Many gullies in the Hamilton area, some previously used as rubbish dumps, are being restored with native forest as an important and distinctive part of the landscape and to increase native bird life.

(Above)
Lake Maratoto, south of Hamilton, was formed c. 20 cal ka. It is a world reference locality for the Pleistocene-Holocene boundary (marked by Konini Tephra c. 11,700 cal BP).

(Above right)
The first core of 33 eventually taken from the lake (April 1979). Grey layer near base is alluvium overlying dark proto-lake lake sediment (near tape head) and pre-lake soil (Green and Lowe, 1985). Photo: Rex Julian

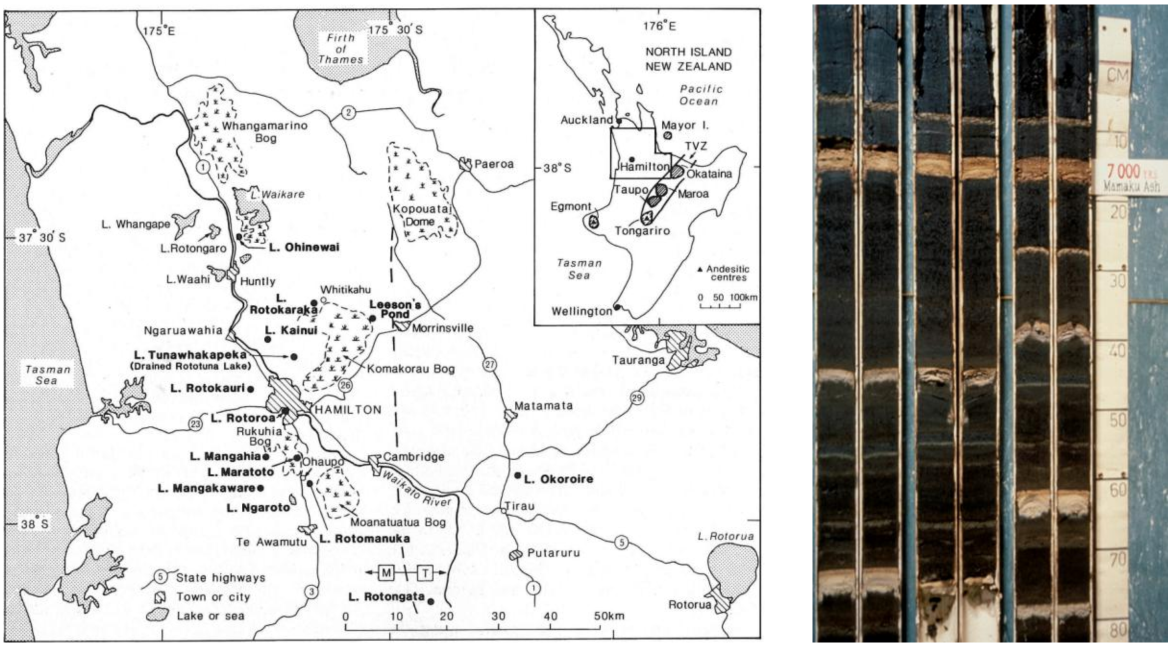
(Right)
Close up of tephras in core from Lake Rotongata (SW of Putaruru). VC = volcanic centre.

Photos: David Lowe



Lakes and peat bogs as tephra archives

Numerous lakes were formed as a result of deposition of sediments (Hinuera Formation) by the ancestral Waikato River system c. 20,000 to 17,000 cal. years ago. Where sediment was deposited alongside an embayment in the antecedent hills, a small basin was able to form and drainage from the hills eventually resulted in it being filled with a lake. Examples include Lake Maratoto (see photo above), Lake Rotoroa (Hamilton Lake), Lake Ngaroto, Lake Rotokauri, Lake Kainui (D), and Lake Rotomanuka. Most of the lakes in the Hamilton Basin date to this time (Lowe and Green, 1992). All contain about 2–4 m of lake sediment within which are preserved >40 multiple, thin, visible tephra layers within their sediments (e.g. Green and Lowe, 1985; Lowe, 1988). These tephras, derived from six volcanic centres, each range in thickness from a few millimetres to several centimetres and in this area amount to an estimated ~40 cm in total thickness (Lowe, 1988). The average rate of tephra accumulation in the Hamilton Basin since c. 18 cal. ka is ~4 mm per century. Numerous cryptotephras (glass-shard or crystal concentrations preserved in sediments but not visible as a layer to the naked eye) (Alloway et al., 2007a) are also present. From recent work on lake cores and peat bogs, such cryptotephras are confirmed in the Waikato region (Gehrels et al., 2006, 2008) and thus probably were assimilated into modern soils as „dustings‟ from small-scale eruption plumes.

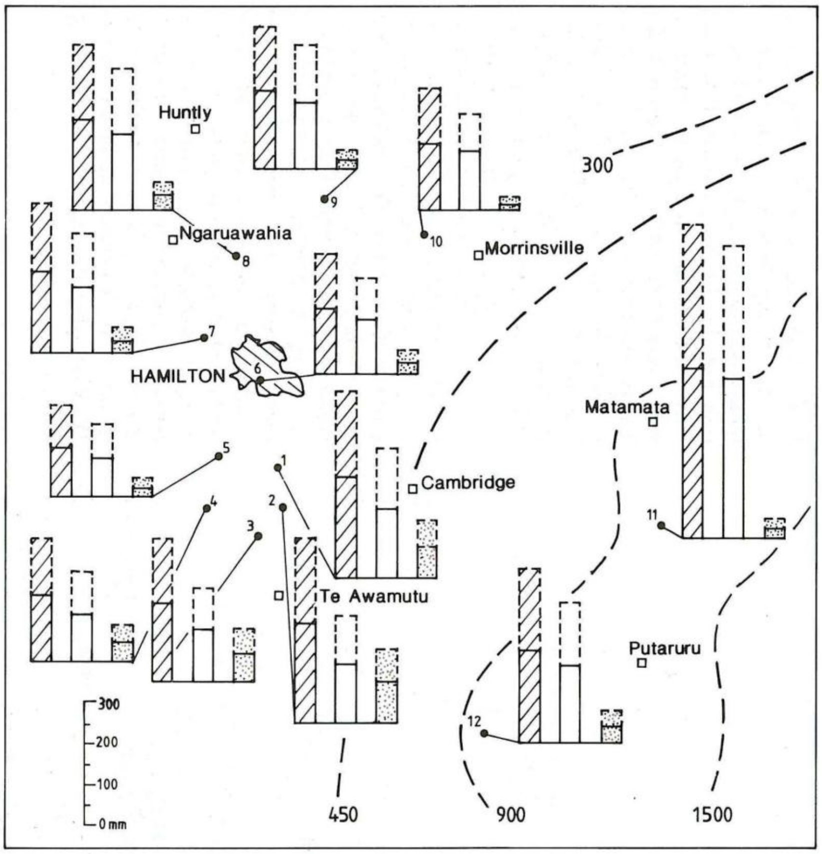


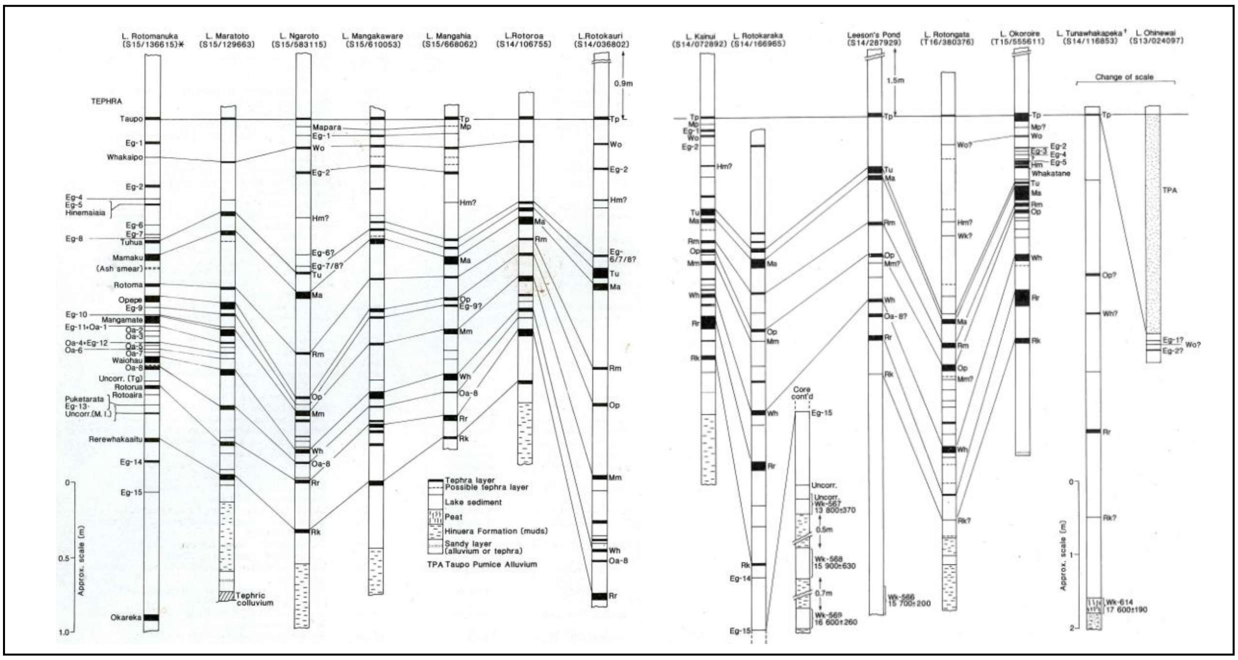
(Left) Waikato area showing locations of lakes cored to obtain detailed post-c. 20 cal ka tephra record. Scott Farm site is just above the word 'HAMILTON' by SH 26. (Right) Cores from Lake Rotomanuka opened to show tephra layers preserved in dark lake sediments (from Lowe, 1988).

Many lakes, including L. Rotoroa, were deepened by the growth of peat on top of the Hinuera Formation from *c.* 13,000 cal. yes ago, which formed a second „storey‟ to the dam impounding the lake waters. Lake Maratoto has been identifed recently as the Australasian reference site (parastratotype) marking the boundary between the Pleistocene and the Holocene in this part of the world, dated at 11,700 cal. yrs BP (the global reference site, called the global stratotype section and point, for this boundary is the Greenland ice core NGRIP) (Walker et al., 2009). Vegetation studies using lakes and peats as archives show that prior to c. 17.5 cal ka the region was dominated by shrubland-grassland with patches of beech and rare podocarps. Full broadleaf-podocarp forest became re-established at c. 17.5 cal ka (Newnham et al., 1989, 1999, 2003; see also Alloway et al., 2007b).

Lake sites are: 1, L. Maratoto; 2, L. Rotomanuka; 3, L. Ngaroto; 4, L. Mangakaware; 5, L. Mangahia; 6, L. Rotoroa; 7, L. Rotokauri (thickness measurements do not include Rerewhakaaitu Ash); 8, L. Kainui; 9, L. Rotokaraka; 10, Leeson's Pond; 11, L. Okoroire; 12, L. Rotongata.

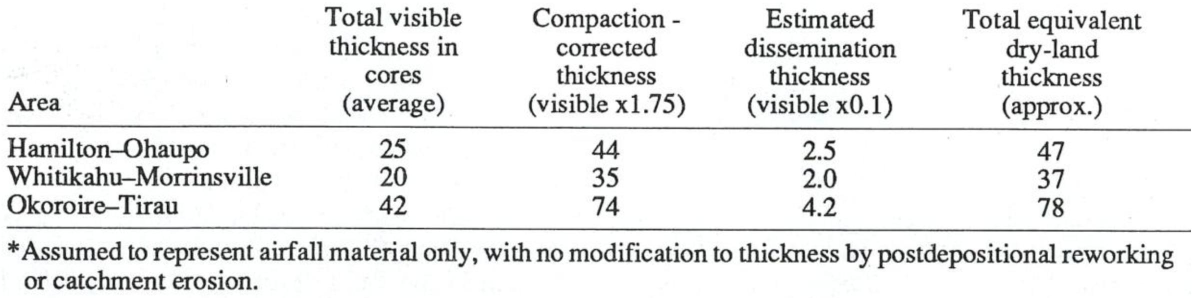
Thickness and compositional relationships based on measurements of tephras in lake cores. Bars with hatching = total thickness of all tephras ≤ c. 20 cal ka; blank bars = rhyolitic tephras; stippled bars = andesitic tephra. Solid bars = actual measurements, dashed bars = thicknesses corrected for compaction and dissemination in sediment cores. Dashed lines = isopachs (in mm) of sum of tephras at subaerial sites deposited since c. 20 cal ka (from Lowe, 1988).





Stratigraphy and correlation of post- c. 20 cal ka visible tephras in cores from 14 Waikato lakes (from Lowe, 1988). It is likely that numerous cryptotephras are also present in the sequences.

Total thicknesses of visible tephras < c. 20 cal ka in central Waikato area based on lake core measurements and estimated 'dry-land' (subaerial) thicknesses (values in cm) (from Lowe, 1988)



Area	Total visible thickness in cores (average)	Compaction - corrected thickness (visible x1.75)	Estimated dissemination thickness (visible x0.1)	Total equivalent dry-land thickness (approx.)
Hamilton–Ohaupo	25	44	2.5	47
Whitikahu–Morrinsville	20	35	2.0	37
Okoroire–Tirau	42	74	4.2	78

*Assumed to represent airfall material only, with no modification to thickness by postdepositional reworking or catchment erosion.

Deposition of the break-out flood deposits of the Taupo Pumice Alluvium at *c*. 250 AD resulted in the formation of several young lakes, including Lake Hakanoa at Huntly and Lake Te Koutu at Cambridge.

Peat bogs are extensive in the Hamilton Basin, as noted earlier. They began as sparse, isolated, scattered swampy hollows on top of the Hinuera Surface in low-lying spots and adjacent to lakes, but massive peat bog formation and coalescence began as regional water tables rose when net rainfall began increasing from about *c*. 13,000 cal. years ago. Especially fast rates of growth occurred because of warm and wet conditions until *c*. 8000 cal. yrs ago when they slowed (Green and Lowe, 1985).

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1.4*A* Issues in the Waikato Region: water and soil quality

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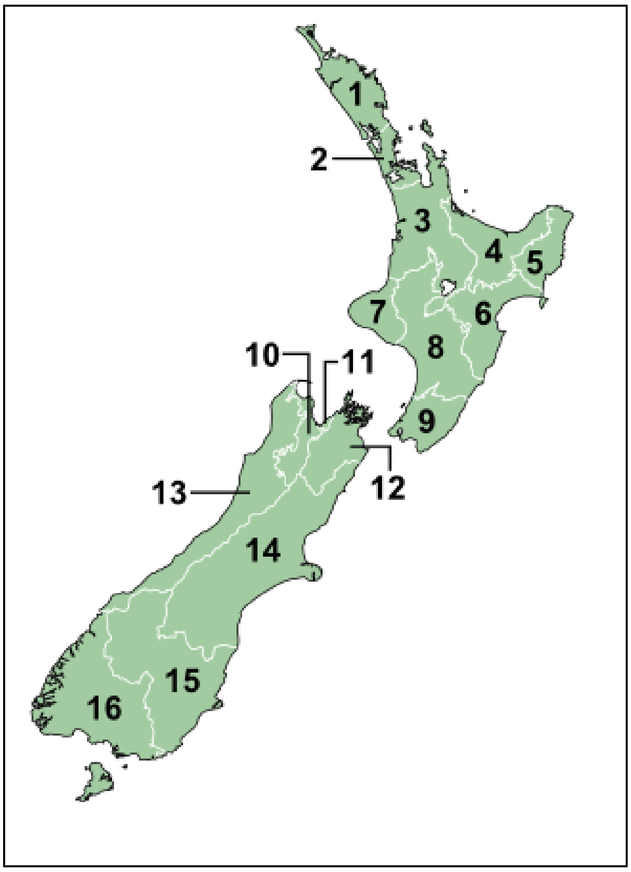
Introduction: regional councils and their role

There are 16 regions in New Zealand. Twelve are governed by an elected regional council (the first tier of local government); four smaller areas are governed by territorial authorities (the second tier of local government), which perform the functions of a regional council and thus are known as unitary authorities. Regional councils are listed in the Local Government Act 2002. That act requires regional councils to promote sustainable development – the social, economic, environmental and cultural well-being of their communities. The current regions and their councils were formed in 1989 as a result of an amalgamation procedure carried out under the Local Government Act 1974. The geographic extent of the regions was based largely on river catchments and major watersheds.



1 Northland
2 Auckland
3 Waikato
4 Bay of Plenty
5 East Cape*
6 Hawke Bay
7 Taranaki
8 Manawatu-Wanganui
9 Wellington
10 Tasman*
11 Nelson*
12 Marlorough*
13 West Coast
14 Canterbury
15 Otago
16 Southland

* These regions are unitary authorities (local councils)

Regional authorities are primarily responsible for environmental management, including water, contaminant discharge and coastal management, river and lake management including flood and drainage control, and regional land management; regional transport (including public transport); and harbours, biosecurity or pest management. Territorial authorities are responsible for local-level land use management (urban and rural planning); network utility services such as water, sewerage, stormwater and solid waste management; local roads; libraries; parks and reserves; and community development. Property rates (land taxes) are used to fund both regional and territorial government activities.

Water quality and soil issues in the Waikato Region

Water quality and soil health in rural areas are declining in the Waikato because of ongoing intensification in farming and the associated losses of nutrient and bacteria into waterways. This intensification affects groundwater, streams, rivers and the coast. Monitoring of rivers and streams shows that bacteria levels could make water unsuitable for stock to drink in 75 per cent of sites, and may be too high for people to swim safely in 70 per cent of sites (Environment Waikato, 2008).

Since the 1990s there has been a 7-fold increase in nitrogen use on dairy farms and nitrogen leaching on dairy and sheep and beef farms has increased by 25 per cent. The increase in fertiliser use and in soil fertility means that higher quantities of nutrients are now entering waterways. The nutrients nitrogen and phosphorus are increasing in many rural Waikato streams. About 80 to 90 per cent of nutrients in streams comes from agricultural land. Point sources, such as factories, contribute 3 to 7 per cent. The remainder is from areas in forest.

Previously the Waikato River had shown reductions in nutrient levels because of improvements in waste management by point sources such as factories and sewage plants. But now we are seeing the effects of higher nutrient loss from farmland and this is causing nutrient levels in the Waikato River to increase.

It can take decades before groundwater draining from the land reaches a stream. As a result the full effects of intensification are yet to be seen in our waterways and things are likely to get worse before they get better, even if nitrogen losses stopped today. This problem is exacerbated by continued intensification.

Large increases in intensification, such as forestry to farming, or big increases in stock numbers (the Waikato region"s dairy herd numbers over one million cows), will require new management approaches if further decline in water quality is to be prevented. Current best practise will not be enough to prevent a decline in water quality in some areas and new methods are needed. For example, a potential 37,000 ha of plantation forest could be converted to pastoral farming (see Day 4). This conversion would increase nitrogen leaching losses from the current 48 tonnes under forest to 822 tonnes per year. And phosphorus losses would increase by 46 tonnes.

Cadmium in phosphate fertiliser is accumulating in the soil and if the trends continue it will limit the use of the soil and could affect the quality of the food produced. Cadmium occurs naturally in the rock deposits from which phosphate fertilisers are made. Cadmium does not break down in the soil so levels can increase over time as more phosphate fertiliser is applied. Highest levels are found on dairy land and some horticultural land. If current rates of accumulation continue then most dairy land would exceed a recommended cadmium guideline of 1 mg/kg (1 mg of Cd per kg of soil) in about 15 years time. Monitoring of the soils of the Waikato region shows that 11 per cent of samples already exceed the 1 mg/kg level. While not posing an immediate threat, cadmium needs to be actively monitored and managed, with a strategy developed to mitigate and manage the risks. The multi-agency cadmium working group led by the Ministry of Agriculture and Forestry (MAF) has just released a cadmium report summarising the issues (see http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/land-management/cadmium-in-nz/risks/index.htm).

Farmers want sustainability, they want clean water and healthy soil, and so does the community. Twenty-five thousand Waikato jobs directly depend on agricultural production. Environment Waikato will continue working with industry leaders to find the new solutions that are needed, and to ensure they are adopted fast enough and extensively enough to make a difference. The biggest risks to trade will be from any reluctance to seriously acknowledge these sustainability issues. We need agriculture to be successful and sustainable. It will be neither without clean water and healthy soil.

Reference

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The Waikato Region has an area of 25,000 km², and a population of 402,200 (June 2008 estimate), the main city being Hamilton (population ~135,000).

1.4*B* Issues in the Waikato Region: trace-element accumulation

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Cadmium

Based on recent sampling, it is estimated that perhaps 11% of the Waikato Region‟s pastoral soils and 17% of its horticultural soils already exceed 1 mg/kg soil cadmium. For horticultural soils, this would represent approximately 1775 hectares of land. For pastoral soils (sheep, beef and dairy land), this would represent about 157,000 hectares. Within the pastoral soils sample set, all soil samples that have so far exceeded the 1 mg/kg agricultural guideline have been from dairy farms. An estimated 8.3 tonnes of the heavy metal cadmium is currently applied to Waikato soils each year, with the largest single source being superphosphate fertiliser. Cadmium is a naturally occurring, toxic, non-essential and biologically cumulative heavy metal. Concentrations of cadmium in Waikato soils have been gradually increasing since the advent of aerial topdressing in the late 1940-early 1950s.

There are three means by which existing and foreseeable uses of the productive soil resource may be lost as a result of cadmium accumulation in soils. These are:

1. Soil cadmium concentrations become such that the property can no longer be subdivided for residential or rural-residential use without some form of investigation and/or remediation. This threshold is also 1 mg/kg in the Waikato Region
2. Possible market access restrictions for produce; and
3. Non-compliance with food standards for crops grown on a property because of soil contamination.

The average cadmium concentration in Waikato dairy soils is projected to reach the recommended guideline in under 15 years. At current loading rates, the average cadmium concentration over all pastoral surface soils in the Waikato Region is expected to reach the 1 mg/kg guideline in under 40 years.

The New Zealand fertiliser industry has also reported that preventing further accumulation in New Zealand soils would require an 80% reduction in the cadmium content of superphosphate fertiliser, to approximately 24 mg Cd/kg P_2O_5. The current voluntary limit for cadmium in New Zealand phosphate fertilisers is 122 mg Cd/kg P_2O_5.

Cadmium is a toxic heavy metal that accumulates in the body over time. The main source is from food. The most common effects of cadmium poisoning are kidney damage, cirrhosis of the liver and lung disease Exposure of the general population to cadmium is mainly through food. Of all contaminants in the diet, cadmium is the one that comes closest to its provisional tolerable weekly intake. A current impact associated with the presence of cadmium in drystock farming is the rejection of offal meat. As a result of its high cadmium content, offal from animals older than 2.5 years is not permitted to be sold for human consumption.

Soil cadmium concentrations (in combination with other soil conditions), become such that food standards would be routinely broken in specific crops grown on a property. This impact relates to the capacity of any land to be used, either currently or in the future, for production of specific vegetable and grain crops.

Fluorine/fluoride

The largest single source for fluorine in soil is from superphosphate fertiliser. With another 60 years of fluorine accumulation, it is unlikely we could continue to graze stock. The natural background was under 200 mg/kg as total fluorine. Today about 25% of surveyed Waikato soils exceed a 500 mg/kg threshold for fluorine above which Massey University studies suggested that fertiliser and grazing management may be advisable to prevent the onset of chronic fluorosis. In addition, the high inputs of fluorine (superphosphate contains about 15,000 mg/kg) appear to be changing soil chemistry, because fluorine attacks aluminosilicate minerals. Fluorine is the most electronegative element (making it highly reactive with aluminium and silicon), and loadings to soil from superphosphate appear to be roughly equivalent to what you would get deposited around an aluminium smelter. Dissolved aluminium species in porewater of fertilised soils are predominantly present as aluminium fluoride complexes.

Zinc

Zinc in soil is largely from facial eczema remedies used to treat stock. Animals are dosed with zinc oxide or sulphate to disrupt the protein structure of the fungal toxin responsible for liver damage. Dosing can involve spraying on pasture, use in stock water, or ingestion of a bolus; in all cases most of the ingested zinc eventually ends up in excreted form, back on the soil. Zinc is applied at about 1000 times the rate for cadmium, and concentrations in soil are increasing. Use of zinc for facial eczema started with our very own Gladys Reid in Te Aroha. Although this is not an issue for stock or human health, zinc is quite phytotoxic. Guidelines for protection of plant species are, therefore, quite low. Other subtleties exist with essential elements like zinc, for example an excess of zinc may cause a deficiency in copper, or may increase the rate of cadmium leaching - because all three elements can interact. Zinc is often regarded as an storm-water contaminant, but on an a farm property where facial eczema remedies have been used, annual zinc loading rates can exceed urban loadings, and have been estimated as 5 kg/ha/yr for a beef farm, 5.8 kg/ha/yr for a sheep farm, and 6.7 kg/ha/yr for a dairy farm. Other sources of zinc in pastoral soils become insignificant in relation to this.

Widespread use of facial eczema remedies appears to have caused a significant increase in average zinc in Waikato soils from a background concentration of 30 mg/kg to a current average of 60 mg/kg, and with over 10% of properties exceeding 100 mg/kg. The estimated annual average accumulation rate is 700 µgZn/kg/yr. Loss of a proportion of the zinc from pastoral farming also appears to be causing zinc to accumulate in rural lake sediments.

Phosphate fertilisers

Over recent years, New Zealand soils have received over 2 million tonnes of superphosphate fertiliser per annum. Superphosphate is 40% gypsum (calcium sulphate). The major constituents added from superphosphate fertiliser are phosphorus (P), calcium (Ca), sulphate (SO_4^{2-}). In terms of trace elements, use of superphosphate results in gradual accumulation of cadmium (Cd), fluorine (F) and uranium (U). Historically, this source has account for virtually all (over 95% of) additional cadmium and fluorine in pastoral soils, and about two-thirds of the uranium. For example, historic accumulation rates of Cd, F and U in Waikato soils are estimated to have averaged 2600 µgF/kg/yr, 5-7 µgCd/kg/yr and 19 µgU/kg/yr.

Single superphosphate contains up to 24 mg/kg cadmium, which in this product corresponds to a voluntary industry limit of 280 mgCd/kgP, although concentrations in recent years may have been less than this. More refined phosphates such as diammonium phosphate (DAP) generally have a lower cadmium content.

The fluorine content of superphosphate is in the region of 1–3% (10,000–30,000 mg/kg), with a typical New Zealand estimate being about 15,000 mg/kg. (At this concentration, ingestion of superphosphate by grazing stock is sufficient to cause “phosphate poisoning.”)

Various sources suggest that 60 mg/kg would be a reasonable upper estimate of the average historic U content of New Zealand superphosphate fertilisers. The current average may be significantly higher than this depending on the main source of phosphate rock. The reported uranium content of phosphate rock from Morocco is about 140 mg/kg.

Nitrogen fertilisers tend to have a fairly low trace element content, because they are manufactured from natural gas (mainly the methane, CH_4) and air (dinitrogen, N_2) (Fig. 1), though some exceptions will exist (Table 1).

Horticultural and grazing soils

Further work on trace-element and ΣDDT concentrations in horticultural and grazing soils in the Auckland and Waikato regions was reported by Gaw et al. (2006). They showed that there were elevated levels of arsenic (<2 to 58 mg/kg), cadmium (<0.1 to 1.5 mg/kg), copper (5 to 523 mg/kg), lead (5 to 243 mg/kg) and ΣDDT (<0.03 to 34.5 mg/kg) in soils in both regions. With the exception of cadmium and zinc, significantly higher levels of contaminants were generally detected in horticultural than in grazing soils. The degradation of DDT in New Zealand horticultural soils (and in soils in pip and stonefruit orchards: Gaw et al., 2003) may be inhibited by the co-contamination with trace elements (Gaw et al., 2006).

Table 1 Concentration ranges (mg/kg) of selected trace elements in limestones, manures, nitrogen fertilisers, phosphate fertilisers and sewage sludges (after Kabata Pendias and Pendias, 2001).

Element	Limestones	Manures	Nitrogen fertilisers	Phosphate fertilisers	Sewage sludges
Arsenic	0.1—24.0	3—25	2.2—120	2—1,200	2—26
Cadmium	0.04—0.1	0.3—0.8	0.05—8.5	0.1—170	2—1,500
Chromium	10—15	5.2—55	3.2—19	66—245	20—40,600
Copper	2—125	2—60	<1—15	1—300	50—3,300
Mercury	0.05	0.09—0.2	0.3—2.9	0.01—1.2	0.1—55
Manganese	40—1,200	30—550	—	40—2,000	60—3,900
Nickel	10—20	7.8—30	7—34	7—38	16—5,300
Lead	20—1,250	6.6—15	2—27	7—225	50—3,000
Uranium	—	—	—	30—300	—
Zinc	10—450	15—250	1—42	50—1,450	700—49,000

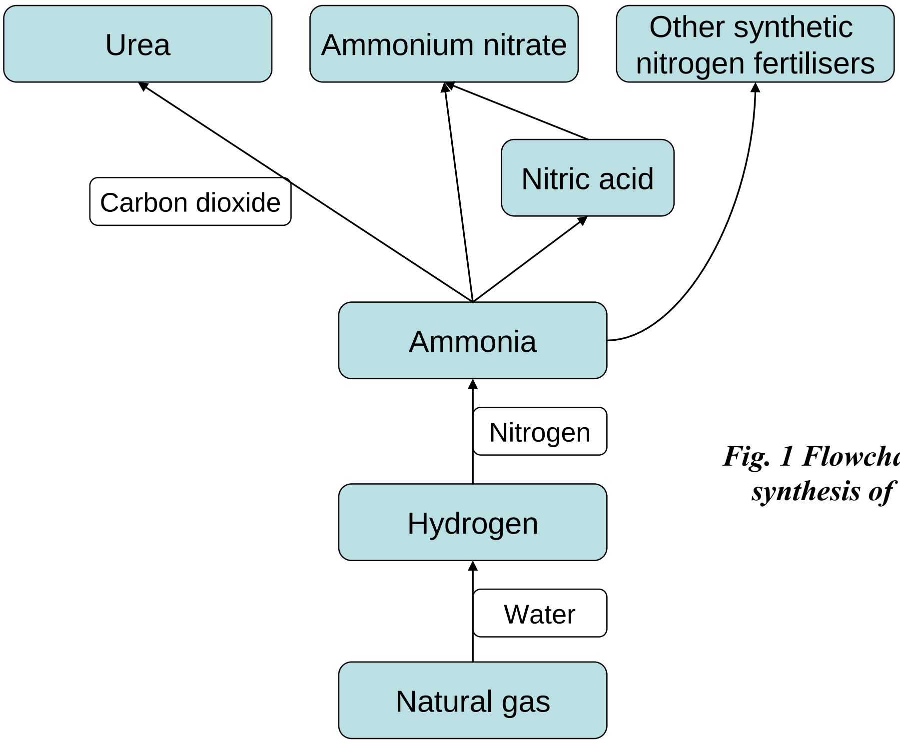

Fig. 1 Flowchart showing steps to synthesis of nitrogen fertilisers.

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1.4*C* Issues in the Waikato Region: groundwater

The Hinuera Formation in a broad flat basin containing 50% water and 50% sediment: lake or land?

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The entire Hamilton Basin can be described as a simple reservoir with groundwater storage provided in the sediments of the Tauranga Group (Schofield, 1972; Edbrooke, 2005). Within this group the volcanogenic Hinuera Formation is by far the most significant for groundwater resources. The Hinuera Formation provides a great abundance of groundwater for municipal and rural domestic supply, for irrigation and industrial use (such as the Hautapu Dairy Factory) and for rural stock watering. Groundwater levels occur between 2 m and 6 m below the ground surface. Groundwater movement is northwest, matching the flow direction of the modern Waikato River. Most of the tributary streams become entrenched as they approach the Waikato River whereby a rapid increase in groundwater flow occurs due to the increased piezometric gradient. The annual recharge is over late winter and spring with seasonal water table fluctuations between 0.5 m to 1 m. The main recharge zones are broad essentially flat areas of undissected Hinuera Surface with free draining soils. In these areas minimum runoff and maximum rainfall infiltration can be expected. Groundwater discharge is dominated by outflow to the numerous incised surface streams and intermittent paleochannels that are often lined by numerous springs and seepages. The Mangaone Stream located north of Cambridge is one of the major drainage pathways for groundwater to the Waikato River (this stream flows in an abandoned paleochannel immediately adjacent to the denitrification wall at Stop 4). Tritium results show that waters from the shallow unconfined aquifers of the Hinuera Surface are of recent origin originating as precipitation within the last 5 years. Water is discharged rapidly from these shallow aquifers with losses most likely to surface streams.

Lithological control

Deposition of the Hinuera Formation is influenced by regular changes in the channel position as the Waikato River migrated across the developing low-angle fan surfaces (e.g. McCraw, 1967; Hume et al., 1975; Selby and Lowe, 1992). As a consequence, the Hinuera sequence is characterised by a lack of lithological continuity. Rapid changes in lithology occur in both vertical and horizontal directions. This spatial variability in turn influences the behaviour of groundwater and causes changes in the water table level and storage capacity over relatively short distances – numerous small zones of higher permeability rather than single well defined aquifers. For example, water-producing bores often require long screens in order to intercept a number of smaller and narrower aquifers to achieve the required yields. Locating water supply bores is a tricky exercise in order to ensure interception of high yielding aquifers.

Occasional large continuous aquifers exist in several areas – for example, at the Hautapu Dairy Factory near Cambridge a series of bores intersecting a well-defined aquifer supply the factory with 2.5 m^3/day. These aquifers may represent thick valley deposits or unconsolidated porous deposits of distal ignimbrites. The most productive aquifers are found in the coarser grained materials particularly where the sediments are well sorted.

Precious resource

The groundwater resource within the Hinuera Formation is essential for municipal domestic supply and, like many groundwater supplies elsewhere, is becoming increasingly important for horticultural supply. The prosperous dairying industry in the Waikato threatens the groundwater resource via direct runoff from dairy herd effluent ponds and via soil leaching from land sprinkle application of cowshed waste. The greatest challenge from a resource management perspective is to maintain the quality of the supply: there are abundant quantities of groundwater but the quality of supply is of critical importance.

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1.5 Stop 2 – DairyNZ Scott Farm Research Centre Prototype farmlets, Horotiu-Bruntwood-Te Kowhai soils

Location S14 ~186785, elevation 45 m asl, rainfall 1200 mm pa

A 120 ha dairy farm milking 350 cows on a mixture of Allophanic, Gley, and Organic/peaty Gley soils, which vary markedly in their drainage characteristics from well drained to poorly drained. Research programmes are focussed on reducing the environmental impact of intensive dairying.

Two Scott Farm Projects

Dairy farmers continue to challenge researchers to increase on-farm productivity, especially in feed production and conversion of feed to milksolids to maintain New Zealand"s competitive advantage. Prior to the start of this project the Parliamentary Commissioner for the Environment (PCE) challenged the dairy industry to redesign dairy farm systems for future economic and environmental sustainability.

As new technologies emerge they need to be tested in a farm system to help determine how results from plot scale experiments can be successfully integrated into paddock scale farm systems.

Two projects set out to demonstrate how:

1. high levels of milksolids production per ha (1750 kg MS per ha) could be achieved by growing all the feed within the farm area, rather than bringing it in from other sources;
2. a productive dairy farm system (1200 kg MS per ha) might operate with the requirement to reduce N leaching losses per ha by 50%. This is similar to operating under a nutrient discharge allowance cap, which is now occurring on dairy farms in the Lake Taupo and Lake Rotorua catchments (see Day 4).

Two prototype farmlets commenced operation on 1 June 2006: 1."**Super Productivity Farm**" and 2."**Tight Nitrogen Farm (Tight N farm**)".

Super Productivity (Super P) Prototype Farmlet

The **Super Productivity** farm aims to lift milksolids (MS) production per total hectare used by 20% to 1750 kg MS per total ha, using forages and crops grown entirely within the farm area. It also addresses the industry requirement to improve our ability to convert sunlight into MS.

Super Productivity Farm Description (8 ha)
Production target is 1750 kg MS per total hectare, 486 kg MS per cow. (1.0 kg MS/kgLwt) from 29 crossbred cows (F12 J4; expected average cow in the national herd in 2016) at 3.6 cows per total ha and 5.0 cows per grassed ha. Comparative stocking rate, 82 kg lwt/tDM. Herd $BW 210 and $PW 258 compared to national average for crossbreds of 111 and 123.
Pastures: 4.5 ha of novel endophyte (AR1&AR37) perennial ryegrass
Cultivars are: Revolution AR1, Alto AR1, Extreme AR37

Forage Crops: The farmlet includes a 2 ha cropping area on which we will need to grow 28 tonnes of dry matter to meet feed budget targets
Main findings (completed 2009**)**
Measurements of feed eaten per ha, and feed conversion efficiency, have proved to be comparable with the highest performing commercial and research herds in New Zealand at more than 16 tonnes of DM per ha, but remain short of the stretch target gains. The high $BW herd has not shown any characteristics that might be of concern for farming in the future in a pastoral farming system, (e.g. low fertility, excessive body condition score loss). The challenge remains to provide them with sufficient feed to allow them to increase their production towards their economic potential.

New pastures established at the start of the Super P farmlet grew an additional 8% total DM in year 1 and 11% in year 2 compared to the control farmlet pastures established 8-10 years ago. Converting high crop yields achieved on plot scale experiments to high paddock yield remains a challenge. Total annual energy and dry matter production should not be the sole target for feed supply. Progress to targets so far has also been limited by the distribution of feed throughout the season. The farm benefits from good winter feed production from annual ryegrasses and new perennial ryegrasses. Because of this there is potential to include a plant that provides a greater supply of suitable summer and autumn feed (but lower winter feed production).

A comparison of profitability of the Super P farmlet with the control herd shows that for the prices, costs and conditions in year 1 the system was less profitable than the control herd, but this changed to being more profitable than the Control in year 2, with higher payout (from $4.50 to $7.90 per kg MS) outstripping the cost of obtaining additional feed. Super P target 1750 kg MS per total ha used. All feed grown within the farm area, 8 ha, 29 cows. Herd $BW 170 (5 July 2008), 3.6 cows per ha. This farm aims to identify methods of incorporating high yielding crops and pastures into a profitable high milksolids production per ha farm and be self contained for feed.

Tight Nitrogen Farm (Tight N farmlet)

The **Tight N farm** aims to reduce nitrate leaching to ground water by 50% from current levels. Our aim is to produce 1200 kg MS/ total ha from a typical Waikato self contained farm, but with half the kg N leached into ground water per 100 kg MS produced compared to the levels measured over the past 4 years on the adjacent Resource Efficient Dairying trial on Scott Farm. This is a **Control**. The Control farmlet (7 ha and 21 cows) allows comparison with a typical Waikato pasture- only system using up to 200 kg N fertiliser per ha.

Tight N Farm Description (7 ha)
Production target is 1200 kg MS/ha from 3.0 cows per ha with no brought in feed with half the nitrate leaching previously measured in earlier trials. This farm combines the most promising nitrogen management technologies such as nitrification inhibitors, stand-off pads for wintering, and a "Herd Home" will be used as nutrient management option. Forages will be grown with high condensed tannin (CT). The system will be grass-based and will use technologies to reduce nitrogen concentration in cows‟ urine, the amount of urine deposited in high risk months (e.g. in stand-off areas), and nitrogen leaching from urine patches (inhibitors).

Main findings
Nitrogen (N) leaching can be reduced in this environment by up to 26 % compared with the control farmlet at little cost to milksolids production per ha, but with a significant reduction in farm profit per ha. This reduced profit is because the N mitigation strategies used to date have a cost associated with them with no extra production gained. Climatic variation between seasons has an influence on N leaching and the mitigation strategies were effective in both years.

Farmers will require decision rules to determine the N mitigation strategies that provide the best fit to the seasonal conditions prevailing at the time if the aim is to minimise monetary losses from seeking N leaching reductions. Results to date are in close agreement with predictions from the Overseer model. This trial is continuing with a “Tight N Target” of reducing nitrate leaching by 50% compared to a commercial farm producing 1200 kg milksolids per ha. This farmlet aims to provide information on how N leaching might be reduced from a productive dairy without affecting farm profit.

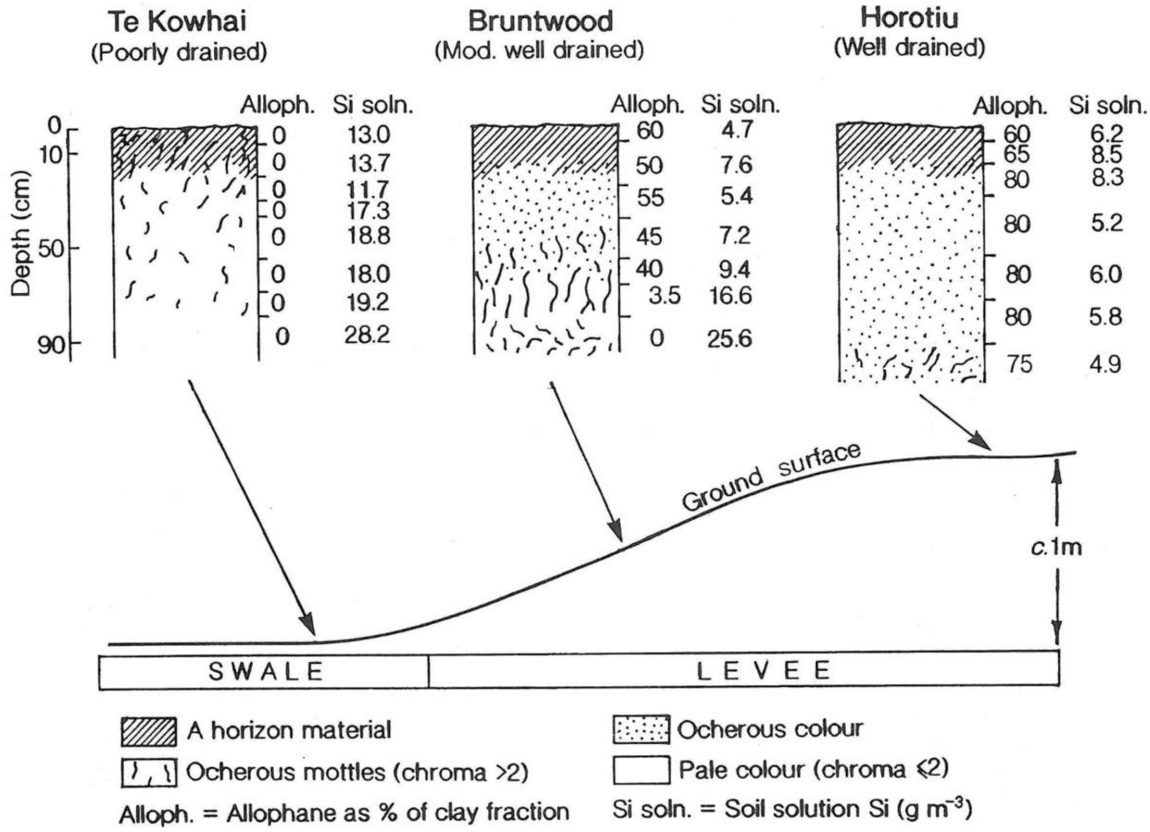
Soils

Soils on Scott Farm include mineral soils in both well-drained to poorly-drained landscape positions on the ash-mantled Hinuera Surface, as well as organic-rich soils developed on shallow peat (~30 cm or more thick) over alluvium. Although the farm soil map indicates that soils on the peaty materials, mapped as Te Rapa series, are Podzol Soils (Spodosols), in my opinion (DJL) they are much more likely to be either Organic Soils or Gley Soils in NZSC depending on the thickness of peat and its organic carbon content. The Te Rapa soils do not have podzolic-B (spodic) horizons. Instead, they are probably either Acid/Mellow Humic Organic Soils (Haplohemists?) or Peaty Acid Gley Soils (Humaquepts?).

Horotiu soils (Vitric or Typic Hapludands) occur in slightly elevated levees or channel bar positions, manifest as low ridges or mounds, over coarse textured volcanogenic alluvium. They are free-draining and hence have lost silicon in soil solution by leaching and have predominantly allophanic properties. Measurements of Si in soil solution in this soil show concentrations <10 g/m^3 (ppm), therefore favouring the formation of Al-rich allophane (Singleton et al., 1989). **Te Kowahi soils** (Typic Humaquepts) in contrast occur in adjacent depressions or swales where overbank alluvial deposits have finer textures, the soils are less free draining with fluctuating and often high water tables. These soils are non-allophanic because silicon is retained and thus halloysite is the dominant clay. In Te Kowhai soils, measurements of Si in soil solution show concentrations >10 g/m^3 (ppm), therefore favouring the formation of halloysite (Singleton et al., 1989).

In the intermediate landscape positions are the **Bruntwood soils** (Aquic Hapludands) which have allophane in upper horizons and halloysite in lower horizons. Low [Si] levels in soil solution are found in the leached upper horizons and high [Si] levels occur in the poorly drained lower horizons. Thermodynamically, imogolite (and by implication allophane) is more stable than halloysite over a wide range of silicon concentrations (see stability diagram below). Halloysite is more stable than imogolite/allophane only at high silicon activity, with the threshold/cross-over point being about 10-15 ppm Si in soil solution (Singleton et al., 1989; Lowe, 1995; Churchman and Lowe, 2010).

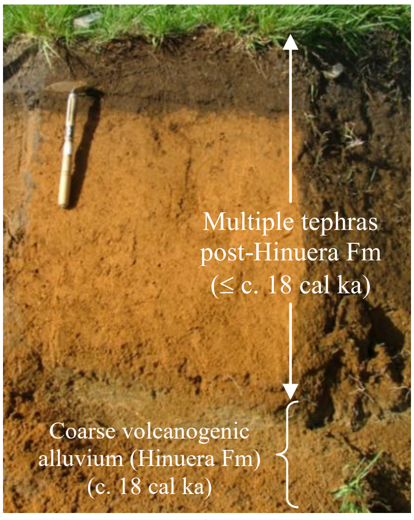
Mineralogically, sand fractions of all three soils are dominated by very abundant volcanic glass and very common plagioclase, with quartz and cristobalite common in Te Kowhai soils (see data sheets below). The alluvium in each soil is identical in age (c. 18 cal ka). Thin intermixed tephras mantle the alluvium for Horotiu and Bruntwood soils, but for Te Kowhai soils the ash mantle seems to have been removed (or blended into upper alluvial materials).



Horotiu–Bruntwoood–Te Kowhai soil drainage leaching sequence and associated mineralogical and soil-solution analyses at Ruakura (after Singleton et al., 1989) (from Lowe and Percival, 1993). The soil solution studies confirmed the general leaching model proposed by Parfitt et al. (1983, 1984) and Lowe (1986). The threshold value of about 10 to 15 ppm of silicon in soil solution matches closely thermodynamic stability diagrams (see diagram below; Lowe, 1995; Churchman and Lowe, 2010). Cutting tool is ~30 cm long.

Te Kowhai

Bruntwood



Horotiu

Allophane and halloysite contents, and measurements of silicon in soil solution, in Horotiu, Bruntwood, and Te Kowhai soils near Scott Farm (from Lowe and Percival, 1993, after Singleton et al., 1989)

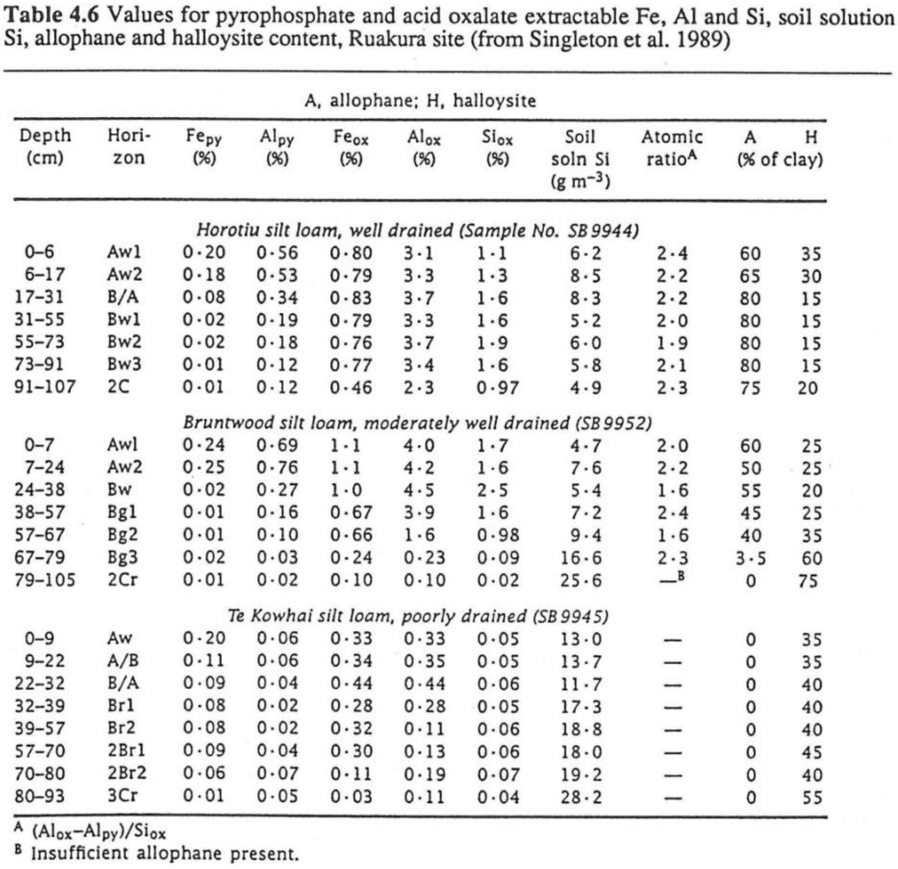


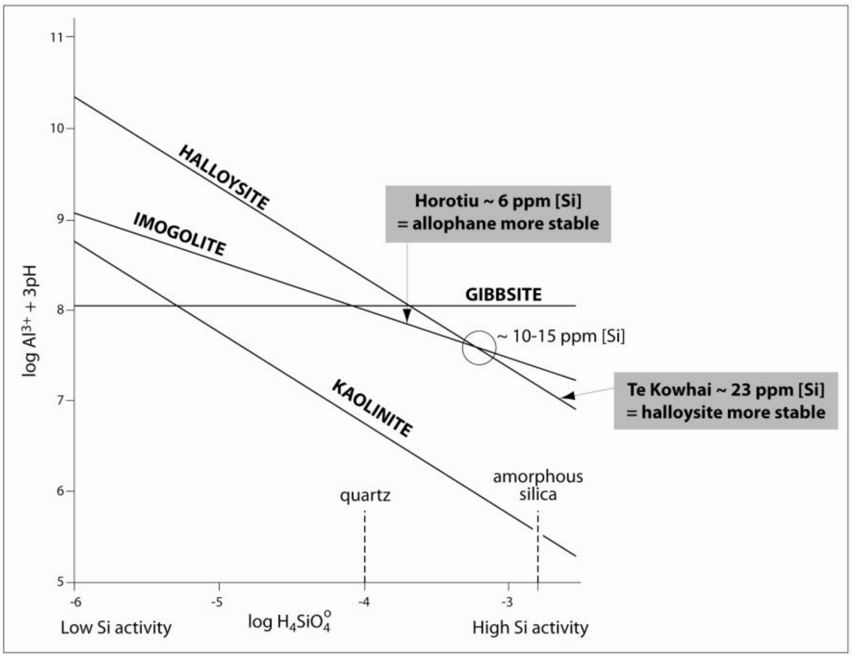
Table 4.6 Values for pyrophosphate and acid oxalate extractable Fe, Al and Si, soil solution Si, allophane and halloysite content, Ruakura site (from Singleton et al. 1989)

A, allophane; H, halloysite

Depth (cm)	Hori- zon	Fe_{py} (%)	Al_{py} (%)	Fe_{ox} (%)	Al_{ox} (%)	Si_{ox} (%)	Soil soln Si (g m^{-3})	Atomic ratio[A]	A (% of clay)	H (% of clay)
Horotiu silt loam, well drained (Sample No. SB 9944)										
0–6	Aw1	0·20	0·56	0·80	3·1	1·1	6·2	2·4	60	35
6–17	Aw2	0·18	0·53	0·79	3·3	1·3	8·5	2·2	65	30
17–31	B/A	0·08	0·34	0·83	3·7	1·6	8·3	2·2	80	15
31–55	Bw1	0·02	0·19	0·79	3·3	1·6	5·2	2·0	80	15
55–73	Bw2	0·02	0·18	0·76	3·7	1·9	6·0	1·9	80	15
73–91	Bw3	0·01	0·12	0·77	3·4	1·6	5·8	2·1	80	15
91–107	2C	0·01	0·12	0·46	2·3	0·97	4·9	2·3	75	20
Bruntwood silt loam, moderately well drained (SB 9952)										
0–7	Awl	0·24	0·69	1·1	4·0	1·7	4·7	2·0	60	25
7–24	Aw2	0·25	0·76	1·1	4·2	1·6	7·6	2·2	50	25
24–38	Bw	0·02	0·27	1·0	4·5	2·5	5·4	1·6	55	20
38–57	Bg1	0·01	0·16	0·67	3·9	1·6	7·2	2·4	45	25
57–67	Bg2	0·01	0·10	0·66	1·6	0·98	9·4	1·6	40	35
67–79	Bg3	0·02	0·03	0·24	0·23	0·09	16·6	2·3	3·5	60
79–105	2Cr	0·01	0·02	0·10	0·10	0·02	25·6	—[B]	0	75
Te Kowhai silt loam, poorly drained (SB 9945)										
0–9	Aw	0·20	0·06	0·33	0·33	0·05	13·0	—	0	35
9–22	A/B	0·11	0·06	0·34	0·35	0·05	13·7	—	0	35
22–32	B/A	0·09	0·04	0·44	0·44	0·06	11·7	—	0	40
32–39	Br1	0·08	0·02	0·28	0·28	0·05	17·3	—	0	40
39–57	Br2	0·08	0·02	0·32	0·11	0·06	18·8	—	0	40
57–70	2Br1	0·09	0·04	0·30	0·13	0·06	18·0	—	0	45
70–80	2Br2	0·06	0·07	0·11	0·19	0·07	19·2	—	0	40
80–93	3Cr	0·01	0·05	0·03	0·11	0·04	28·2	—	0	55

[A] $(Al_{ox}-Al_{py})/Si_{ox}$

[B] Insufficient allophane present.



Stability of kaolinite (Al: Si = 1: 1), halloysite (Al: Si = 1: 1), and imogolite (Al: Si = 2: 1) compared with that of gibbsite (after Lowe and Percival, 1993, after Percival, 1985). An Al-rich allophane line is likely to parallel the imogolite line and to be in a similar position, i.e., have similar or possibly slightly greater stability (Lowe and Percival, 1993). Generally, stability increases downwards in the figure (solubility decreases). Soil solution data from Singleton et al. (1989).

Clay skins in an Andisol

Note that Bakker et al. (1996) reported micro-laminated, anisotropic, clay coatings bridging rounded grains of fluvial origin in BCt and 2bBCt horizons of the Horotiu soil at Pony Club pit (Gordonton Rd) in Hamilton. The undisturbed character of the delicate coatings indicated that illuviation took place after deposition of the sediment. Such illuviation had not previously been reported in soils of the Horotiu series, nor, possibly, in Andisols (McDaniel et al., 2010).

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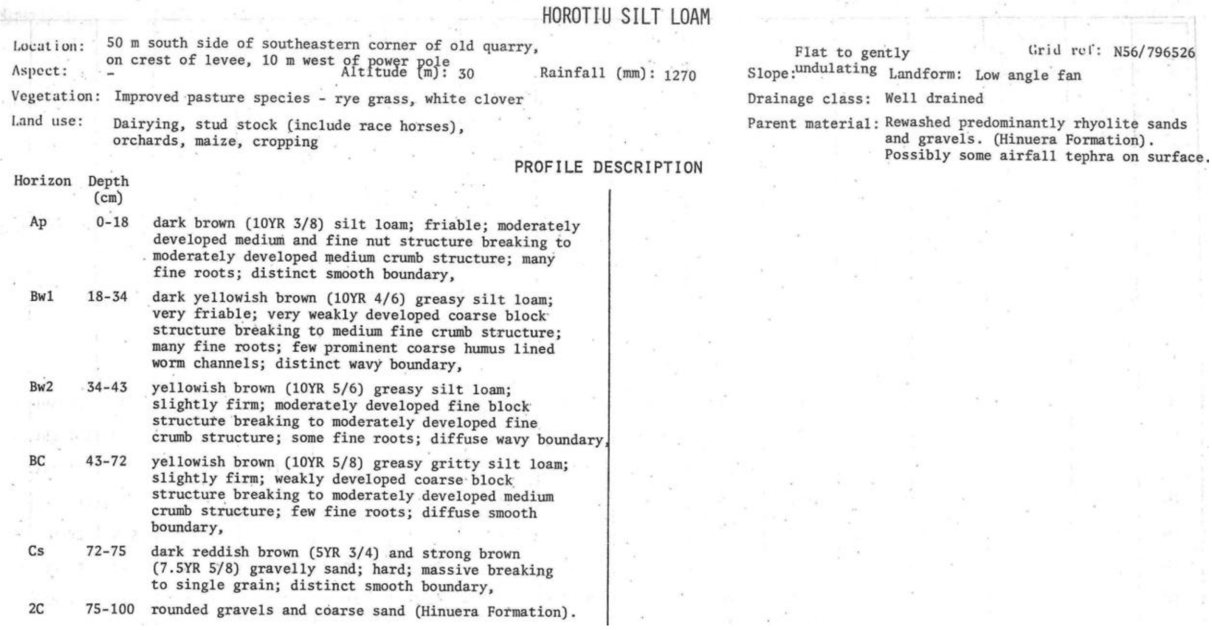
Description of Horotiu soil at former Hamilton East Pony Club pit, Gordonton Rd (S14 119820), from Parfitt et al. (1981) (see also Bakker et al., 1996)



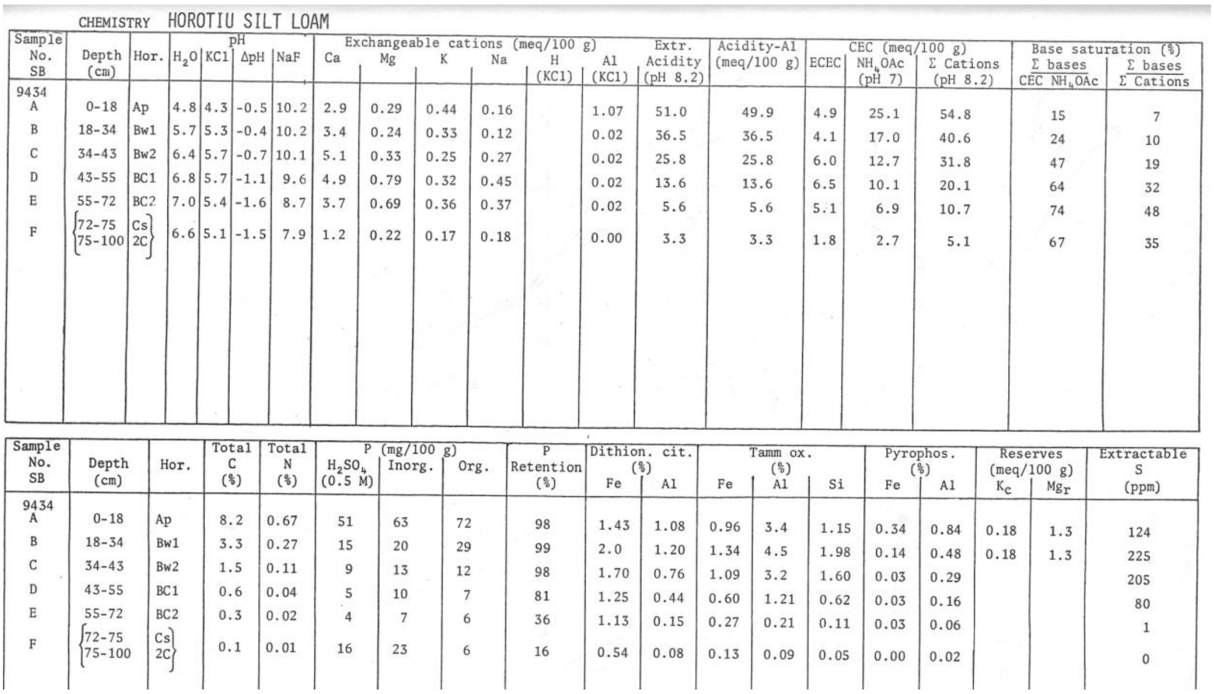
HOROTIU SILT LOAM

Location: 50 m south side of southeastern corner of old quarry, on crest of levee, 10 m west of power pole
Aspect: -
Altitude (m): 30
Rainfall (mm): 1270
Vegetation: Improved pasture species - rye grass, white clover
Land use: Dairying, stud stock (include race horses), orchards, maize, cropping

Grid ref: N56/796526
Slope: Flat to gently undulating
Landform: Low angle fan
Drainage class: Well drained
Parent material: Rewashed predominantly rhyolite sands and gravels. (Hinuera Formation). Possibly some airfall tephra on surface.

PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-18	dark brown (10YR 3/8) silt loam; friable; moderately developed medium and fine nut structure breaking to moderately developed medium crumb structure; many fine roots; distinct smooth boundary,
Bw1	18-34	dark yellowish brown (10YR 4/6) greasy silt loam; very friable; very weakly developed coarse block structure breaking to medium fine crumb structure; many fine roots; few prominent coarse humus lined worm channels; distinct wavy boundary,
Bw2	34-43	yellowish brown (10YR 5/6) greasy silt loam; slightly firm; moderately developed fine block structure breaking to moderately developed fine crumb structure; some fine roots; diffuse wavy boundary,
BC	43-72	yellowish brown (10YR 5/8) greasy gritty silt loam; slightly firm; weakly developed coarse block structure breaking to moderately developed medium crumb structure; few fine roots; diffuse smooth boundary,
Cs	72-75	dark reddish brown (5YR 3/4) and strong brown (7.5YR 5/8) gravelly sand; hard; massive breaking to single grain; distinct smooth boundary,
2C	75-100	rounded gravels and coarse sand (Hinuera Formation).



CHEMISTRY HOROTIU SILT LOAM

Sample No. SB	Depth (cm)	Hor.	pH H_2O	pH KCl	pH ΔpH	pH NaF	Exchangeable cations (meq/100 g) Ca	Mg	K	Na	H (KCl)	Al (KCl)	Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g) NH_4OAc (pH 7)	Σ Cations (pH 8.2)	Base saturation (%) $\frac{\Sigma \text{ bases}}{\text{CEC } NH_4OAc}$	$\frac{\Sigma \text{ bases}}{\Sigma \text{ Cations}}$
9434 A	0-18	Ap	4.8	4.3	-0.5	10.2	2.9	0.29	0.44	0.16		1.07	51.0	49.9	4.9	25.1	54.8	15	7
B	18-34	Bw1	5.7	5.3	-0.4	10.2	3.4	0.24	0.33	0.12		0.02	36.5	36.5	4.1	17.0	40.6	24	10
C	34-43	Bw2	6.4	5.7	-0.7	10.1	5.1	0.33	0.25	0.27		0.02	25.8	25.8	6.0	12.7	31.8	47	19
D	43-55	BC1	6.8	5.7	-1.1	9.6	4.9	0.79	0.32	0.45		0.02	13.6	13.6	6.5	10.1	20.1	64	32
E	55-72	BC2	7.0	5.4	-1.6	8.7	3.7	0.69	0.36	0.37		0.02	5.6	5.6	5.1	6.9	10.7	74	48
F	72-75 75-100	Cs 2C	6.6	5.1	-1.5	7.9	1.2	0.22	0.17	0.18		0.00	3.3	3.3	1.8	2.7	5.1	67	35

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g) H_2SO_4 (0.5 M)	Inorg.	Org.	P Retention (%)	Dithion. cit. (%) Fe	Al	Tamm ox. (%) Fe	Al	Si	Pyrophos. (%) Fe	Al	Reserves (meq/100 g) K_c	Mg_r	Extractable S (ppm)
9434 A	0-18	Ap	8.2	0.67	51	63	72	98	1.43	1.08	0.96	3.4	1.15	0.34	0.84	0.18	1.3	124
B	18-34	Bw1	3.3	0.27	15	20	29	99	2.0	1.20	1.34	4.5	1.98	0.14	0.48	0.18	1.3	225
C	34-43	Bw2	1.5	0.11	9	13	12	98	1.70	0.76	1.09	3.2	1.60	0.03	0.29			205
D	43-55	BC1	0.6	0.04	5	10	7	81	1.25	0.44	0.60	1.21	0.62	0.03	0.16			80
E	55-72	BC2	0.3	0.02	4	7	6	36	1.13	0.15	0.27	0.21	0.11	0.03	0.06			1
F	72-75 75-100	Cs 2C	0.1	0.01	16	23	6	16	0.54	0.08	0.13	0.09	0.05	0.00	0.02			0

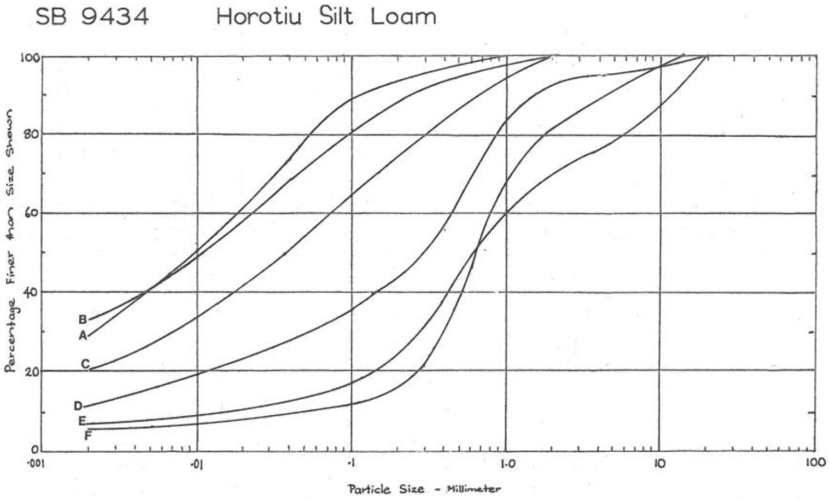
PHYSICS

Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	15 bar water Air Dry (%)
0-18	Ap	25.6	22.3
18-34	Bw1	43.9	20.5
34-43	Bw2	37.5	18.3
43-55	BC1	23.4	14.8
55-72	BC2	13.5	10.5
75-100	2C	3.7	3.3

Core Depth (cm)	Dry bulk density (T/m^3)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
2-9	0.80					
20-27	0.62					
35-42	0.72					
}49-56	0.96					

PARTICLE SIZE DISTRIBUTION (<2 mm) Horotiu Silt Loam

Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9434A	0-18	Ap	12	12	56	20			
B	18-34	Bw1	8	12	67	13			
C	34-43	Bw2	9	14	63	14			
D	43-55	BC1	11	17	50	22			
E	55-72	BC2	30	15	35	20			
F	75-100	2C	83	5	7	5			



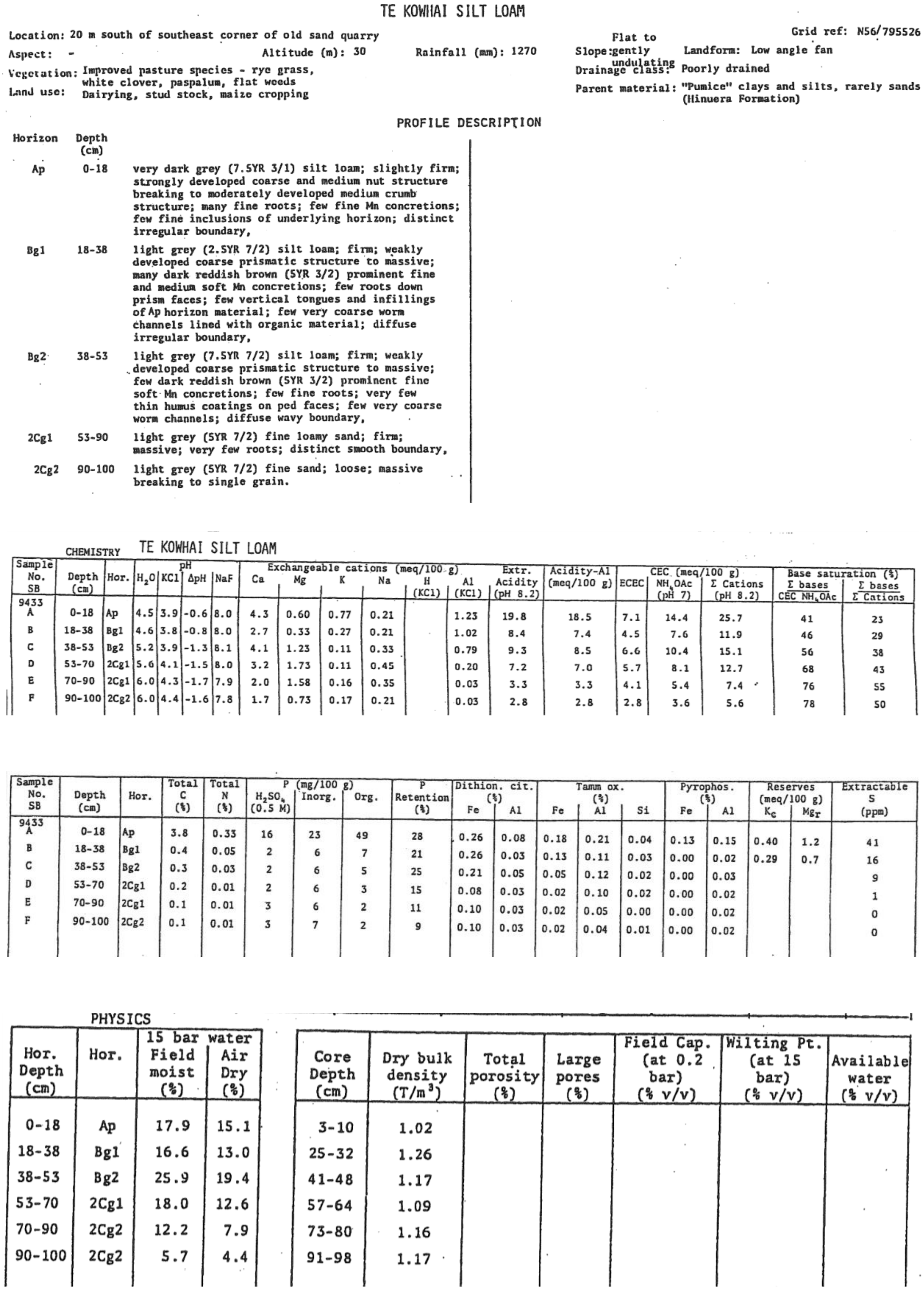
Mineralogy HOROTIU

Sample No. SB	Depth (cm)	Hor.	Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass
			Clay Fraction (%)														
9434A	0-18								12	18	2		2	50			16
B	18-34								9	18	1		2	62			8
C	34-43								9	21	tr		6	55			9
D	43-55								8	42	tr		4	20			26
E	55-72									67	tr		5	8			20
F	75-100									72			tr	8			20

Classification: Horotiu sandy loam [Pony Club site]

NZSC: Typic Orthic Allophanic Soils; tephric, mixed rhyolitic and andesitic; silty/sandy; moderate/rapid
Soil Taxonomy: Medial/sandy-skeletal, thermic Vitric Hapludands

Description of Te Kowhai soil near former Hamilton East Pony Club pit, Gordonton Rd (S14 118820), from Parfitt et al. (1981)



TE KOWHAI SILT LOAM

Location: 20 m south of southeast corner of old sand quarry
Grid ref: N56/795526
Aspect: -
Altitude (m): 30
Rainfall (mm): 1270
Slope: Flat to gently undulating
Landform: Low angle fan
Drainage class: Poorly drained
Vegetation: Improved pasture species - rye grass, white clover, paspalum, flat weeds
Land use: Dairying, stud stock, maize cropping
Parent material: "Pumice" clays and silts, rarely sands (Hinuera Formation)

PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-18	very dark grey (7.5YR 3/1) silt loam; slightly firm; strongly developed coarse and medium nut structure breaking to moderately developed medium crumb structure; many fine roots; few fine Mn concretions; few fine inclusions of underlying horizon; distinct irregular boundary,
Bg1	18-38	light grey (2.5YR 7/2) silt loam; firm; weakly developed coarse prismatic structure to massive; many dark reddish brown (5YR 3/2) prominent fine and medium soft Mn concretions; few roots down prism faces; few vertical tongues and infillings of Ap horizon material; few very coarse worm channels lined with organic material; diffuse irregular boundary,
Bg2	38-53	light grey (7.5YR 7/2) silt loam; firm; weakly developed coarse prismatic structure to massive; few dark reddish brown (5YR 3/2) prominent fine soft Mn concretions; few fine roots; very few thin humus coatings on ped faces; few very coarse worm channels; diffuse wavy boundary,
2Cg1	53-90	light grey (5YR 7/2) fine loamy sand; firm; massive; very few roots; distinct smooth boundary,
2Cg2	90-100	light grey (5YR 7/2) fine sand; loose; massive breaking to single grain.

CHEMISTRY TE KOWHAI SILT LOAM

Sample No. SB	Depth (cm)	Hor.	pH H_2O	pH KCl	pH ΔpH	pH NaF	Exchangeable cations (meq/100 g) Ca	Mg	K	Na	H (KCl)	Al (KCl)	Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g) NH_4OAc (pH 7)	Σ Cations (pH 8.2)	Base saturation (%) Σ bases / CEC NH_4OAc	Σ bases / Σ Cations
9433 A	0-18	Ap	4.5	3.9	-0.6	8.0	4.3	0.60	0.77	0.21		1.23	19.8	18.5	7.1	14.4	25.7	41	23
B	18-38	Bg1	4.6	3.8	-0.8	8.0	2.7	0.33	0.27	0.21		1.02	8.4	7.4	4.5	7.6	11.9	46	29
C	38-53	Bg2	5.2	3.9	-1.3	8.1	4.1	1.23	0.11	0.33		0.79	9.3	8.5	6.6	10.4	15.1	56	38
D	53-70	2Cg1	5.6	4.1	-1.5	8.0	3.2	1.73	0.11	0.45		0.20	7.2	7.0	5.7	8.1	12.7	68	43
E	70-90	2Cg1	6.0	4.3	-1.7	7.9	2.0	1.58	0.16	0.35		0.03	3.3	3.3	4.1	5.4	7.4	76	55
F	90-100	2Cg2	6.0	4.4	-1.6	7.8	1.7	0.73	0.17	0.21		0.03	2.8	2.8	2.8	3.6	5.6	78	50

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g) H_2SO_4 (0.5 M)	Inorg.	Org.	P Retention (%)	Dithion. cit. (%) Fe	Al	Tamm ox. (%) Fe	Al	Si	Pyrophos. (%) Fe	Al	Reserves (meq/100 g) K_c	Mg_r	Extractable S (ppm)
9433 A	0-18	Ap	3.8	0.33	16	23	49	28	0.26	0.08	0.18	0.21	0.04	0.13	0.15	0.40	1.2	41
B	18-38	Bg1	0.4	0.05	2	6	7	21	0.26	0.03	0.13	0.11	0.03	0.00	0.02	0.29	0.7	16
C	38-53	Bg2	0.3	0.03	2	6	5	25	0.21	0.05	0.05	0.12	0.02	0.00	0.03			9
D	53-70	2Cg1	0.2	0.01	2	6	3	15	0.08	0.03	0.02	0.10	0.02	0.00	0.02			1
E	70-90	2Cg1	0.1	0.01	3	6	2	11	0.10	0.03	0.02	0.05	0.00	0.00	0.02			0
F	90-100	2Cg2	0.1	0.01	3	7	2	9	0.10	0.03	0.02	0.04	0.01	0.00	0.02			0

PHYSICS

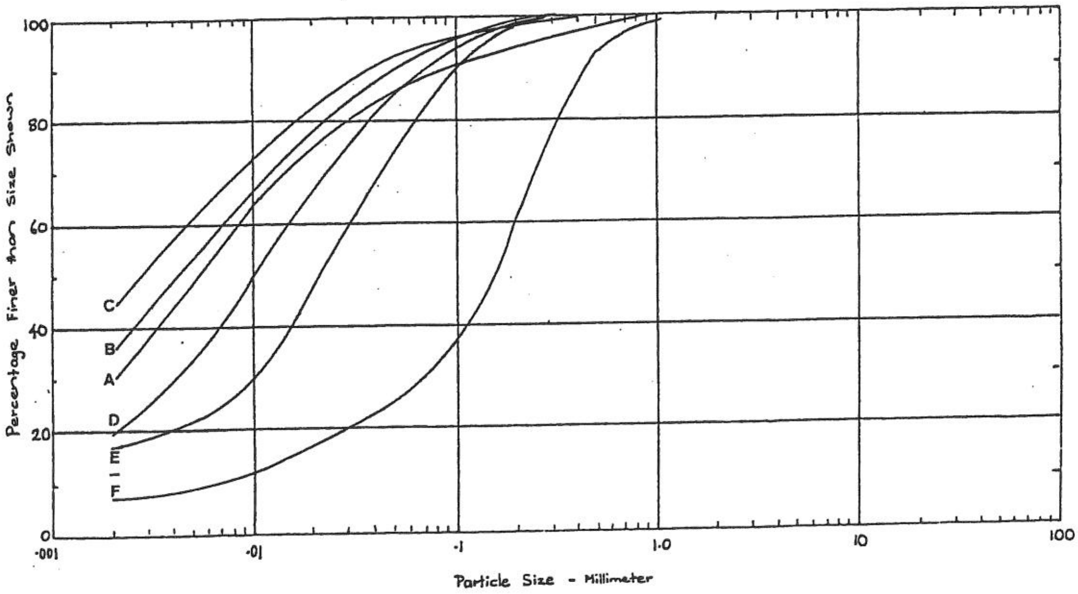
Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	Air Dry (%)
0-18	Ap	17.9	15.1
18-38	Bg1	16.6	13.0
38-53	Bg2	25.9	19.4
53-70	2Cg1	18.0	12.6
70-90	2Cg2	12.2	7.9
90-100	2Cg2	5.7	4.4

Core Depth (cm)	Dry bulk density (T/m³)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
3-10	1.02					
25-32	1.26					
41-48	1.17					
57-64	1.09					
73-80	1.16					
91-98	1.17					

PARTICLE SIZE DISTRIBUTION (<2 mm) Te Kowhai Silt Loam

Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9433A	0-18	Ap	9	6	55	30			
B	18-38	Bg1	5	6	53	36			
C	38-53	Bg2	4	4	47	45			
D	53-70	2Cg1	5	10	66	19			
E	70-90	2Cg1	8	19	56	17			
F	90-100	2Cg2	64	11	18	7			

SB 9433 Te Kowhai Silt Loam



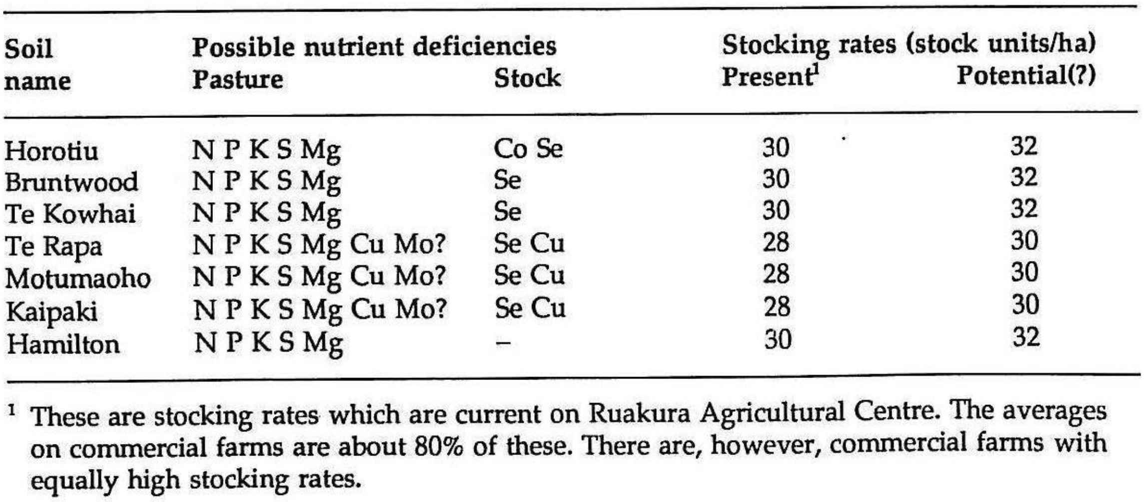
Mineralogy TE KOWHAI

Sample No. SB	Depth (cm)	Hor.	Clay Fraction (%) Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass	Sand Fraction (%) Quartz	Feldspar (acid)	Andesine	Glass	Muscovite	Biotite	Horneblende	Augite	Hypersthene	Epidote	Zoisite	Apatite	Magnetite	Plant opal
9433A	0-18								27	33			6	8			26														
B	18-38								24	36			4	8			28														
C	38-53								20	50			2	8			20														
D	53-70								13	52			1	8			26														
E	70-90									63			tr	10			26														
F	90-100									62			tr	8			30														

Classification: Te Kowhai silt loam [Pony Club site]
NZSC: Acidic Orthic Gley Soils; tephric, rhyolitic; silty; slow
Soil Taxonomy: Fine/fine silty, mixed, thermic Typic Humaquepts

Classification: Bruntwood silt loam [Pony Club site, no data available]
NZSC: Mottled Orthic Allophanic Soils; tephric, mixed rhyolitic and andesitic; silty; moderate/slow
Soil Taxonomy: Medial/fine-silty, thermic Aquic Hapludands

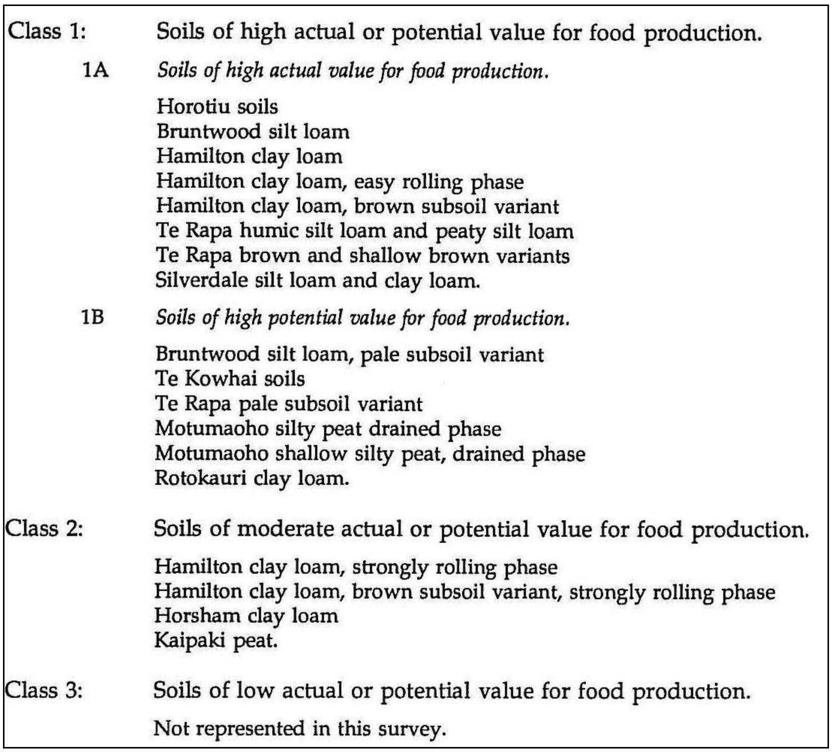
Summmary of possible nutrient deficiencies under pastoral farming (from W.M.H. Saunders in Singleton, 1991)



Soil name	Possible nutrient deficiencies Pasture	Stock	Stocking rates (stock units/ha) Present[1]	Potential(?)
Horotiu	N P K S Mg	Co Se	30	32
Bruntwood	N P K S Mg	Se	30	32
Te Kowhai	N P K S Mg	Se	30	32
Te Rapa	N P K S Mg Cu Mo?	Se Cu	28	30
Motumaoho	N P K S Mg Cu Mo?	Se Cu	28	30
Kaipaki	N P K S Mg Cu Mo?	Se Cu	28	30
Hamilton	N P K S Mg	–	30	32

[1] These are stocking rates which are current on Ruakura Agricultural Centre. The averages on commercial farms are about 80% of these. There are, however, commercial farms with equally high stocking rates.

Classification of soils according to their actual or potential value for food production (from Singleton, 1991)



Class 1:	Soils of high actual or potential value for food production.
1A	*Soils of high actual value for food production.*
	Horotiu soils Bruntwood silt loam Hamilton clay loam Hamilton clay loam, easy rolling phase Hamilton clay loam, brown subsoil variant Te Rapa humic silt loam and peaty silt loam Te Rapa brown and shallow brown variants Silverdale silt loam and clay loam.
1B	*Soils of high potential value for food production.*
	Bruntwood silt loam, pale subsoil variant Te Kowhai soils Te Rapa pale subsoil variant Motumaoho silty peat drained phase Motumaoho shallow silty peat, drained phase Rotokauri clay loam.
Class 2:	Soils of moderate actual or potential value for food production.
	Hamilton clay loam, strongly rolling phase Hamilton clay loam, brown subsoil variant, strongly rolling phase Horsham clay loam Kaipaki peat.
Class 3:	Soils of low actual or potential value for food production.
	Not represented in this survey.

Land-use suitability classifications of Waikato soils for various uses are given by Singleton (1990); one example is shown above. The Horotiu soils are highly versatile soils (classed as* 1s1 *in LUC) that are able to successfully grow most horticultural (and other) crops provided they are climatically suited to the Waikato region (the main limiting factor can be water availability, and irrigation is desirable and essential for some permanent crops). Horotiu soils are especially good for the production of asparagus (which requires a free root run and good drainage), and stone and pip fruit, cereals, vegetables and berry fruit (S.J. Franklin in Singleton, 1991).

Under old legislation, these soils were generally not able to be urbanised but more recently under the Resource Management Act (1991) prescriptive land use is not generally allowed and urbanisation with lifestyle blocks has become an issue. However, the tide may be turning. Proposed regional plans in the Waikato are to protect LUC class 1, class 2 (except peat), and some class 3 soils (allophanic on rolling land) from residential development. Development is to either avoid these soils or go in a direction that has the least impact on the soils (P.L. Singleton pers comm., July 2010).

1.6 Transit from Scott Farm (Stop 2) to Mokai (Stop 3), Taupo

After leaving Scott Farm at Newstead near Hamilton, the road to Cambridge gradually climbs (rising about 1 metre every kilometre travelled) up the very low-angle alluvial fans of the (composite tephra-draped) Hinuera Surface towards the eastern margins of the Hamilton Basin. We briefly descend onto the younger Taupo Pumice Alluvium (c. 250 AD) past the Cambridge Golf Course (with the false advertising) before returning to the Hinuera Surface. Andesite-dacite Maungatautari stratovolcano (797 m, age 1.8 Ma) features near Lake Karapiro. The forested upper slopes of Mt Maungatautari have been totally enclosed with a predator-proof fence as part of a new project to restore animal life to New Zealand forests using the concept of 'ecological islands' of which the Maungatautari Trust project is the leading example. An enclosure within the main fenceline on the southern slopes (off Tari Rd) is being stocked with kiwi in an attempt to halt their rapidly declining numbers.

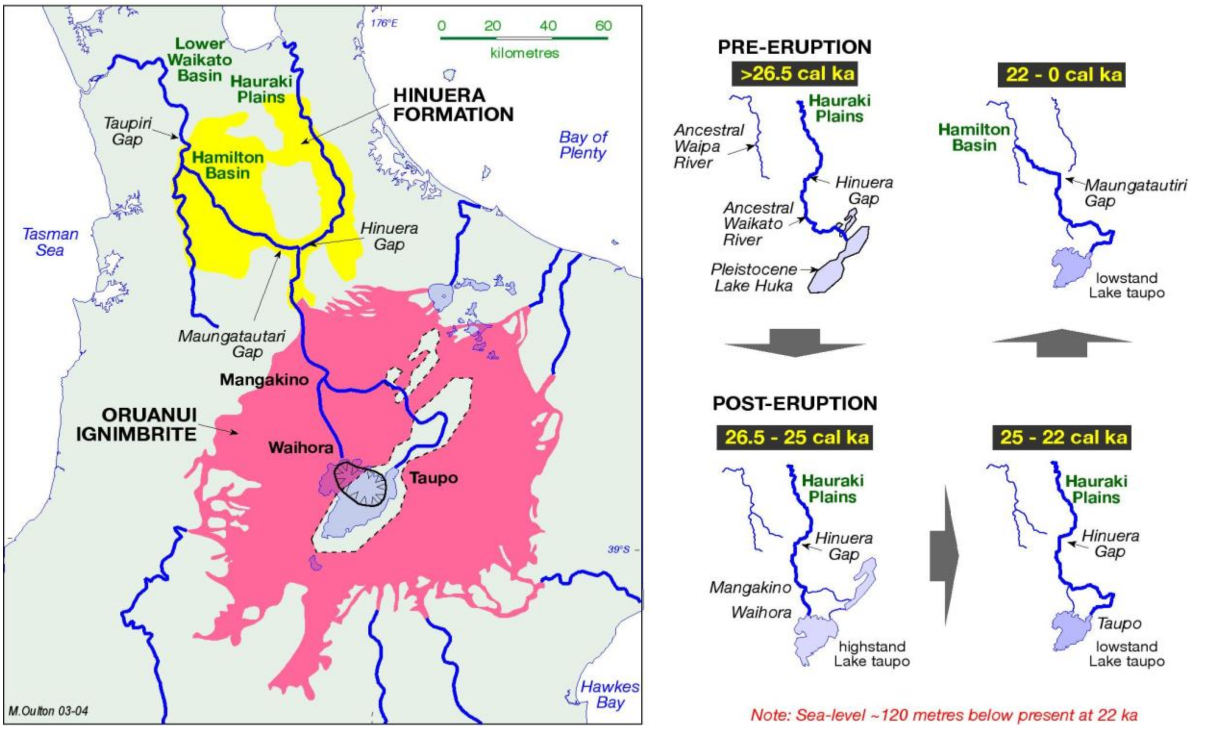


Diagram depicting the impacts of the Oruanui/Kawakawa eruption of Taupo caldera volcano (c. 27,100 cal. yrs BP) on the ancestral Waikato River (after Manville, 2001). Note distribution of Hinuera Formation (volcanogenic sediments) in both Hauraki and Hamilton basins. Hinuera Formation sediments in the Hauraki Plains extend well beyond the marked area into the Firth of Thames and are more voluminous than those in the Hamilton Basin (Manville and Wilson, 2004).

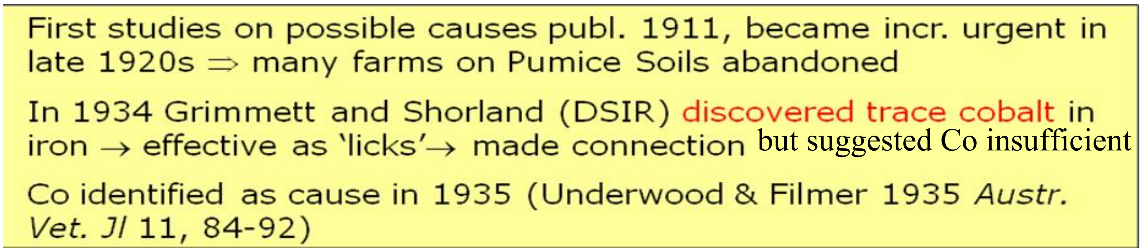
Gradually the landscape becomes steeper and hillier as the underlying ignimbrites become thicker. Tephra layers amounting to several metres or more in thickness drape most of the landscape and become thicker as we get closer to their source volcanoes in central TVZ. The impacts of mass movement, especially slumping and soil creep, become evident in the hillsides. Such slumping (on pasture) can be triggered by high intensity storms every c. 20-30 years on average (under native forest slumping occurs every c. 100 yrs) (Selby, 1974, 1976).

At Piarere the geological framework of the hills becomes obvious as a three-tiered landscape repesenting three welded ignimbrite units all derived from Mangakino caldera volcano in TVZ: Ongatiti (1.23 Ma), Ahuroa (~1.1 Ma), and Rocky Hill (~1.0 Ma). The Ongatiti

Ignimbrite is quarried nearby (Hinuera) and sold as brick used for cladding: 'Hinuera Stone'. The cliffs of Ongatiti Ignimbrite marking the Hinuera Valley margins featured in the first of the *Lord of the Rings* film series. Tirau soils (Typic Hapludands) drape the landscape and an example will be seen at Stop 5 on Day 4. Note that the famous hypothetical **nine-unit landscape model** was developed in this area by Dalrymple et al. (1968).

Triple-tier landscape at Piarere relating to three welded ignimbrite sheets aged c. 1.2 to 1.0 Ma. Photo: D.J. Lowe

From Tirau southward the road climbs gradually onto more sheets of ignimbrites derived from a number of sources. The soils in this region are the result of upbuilding pedogenesis, mainly developmental but occasionally retardant when thicker tephras are emplaced (see diagram and photo below). At Litchfield, just south of Putaruru, the distal feather edge of the nonwelded Taupo Ignimbrite (c. 232 AD) forms the uppermost soil-forming parent material in many places from here until we reach Lake Taupo. The low Co content of soils developed on Taupo Tephra led to a vitamin-B12 related stock wasting disease of ruminants (especially sheep and cattle) in the early part of the 20th Century ("bush sickness") in this and other parts of central North Island (see Day 4) and the remedy, discovered in the mid 1930s by Australian and New Zealand scientists, was first employed in this area on K.S. Cox's farm. Cobalt is an essential requirement for red blood cell production.

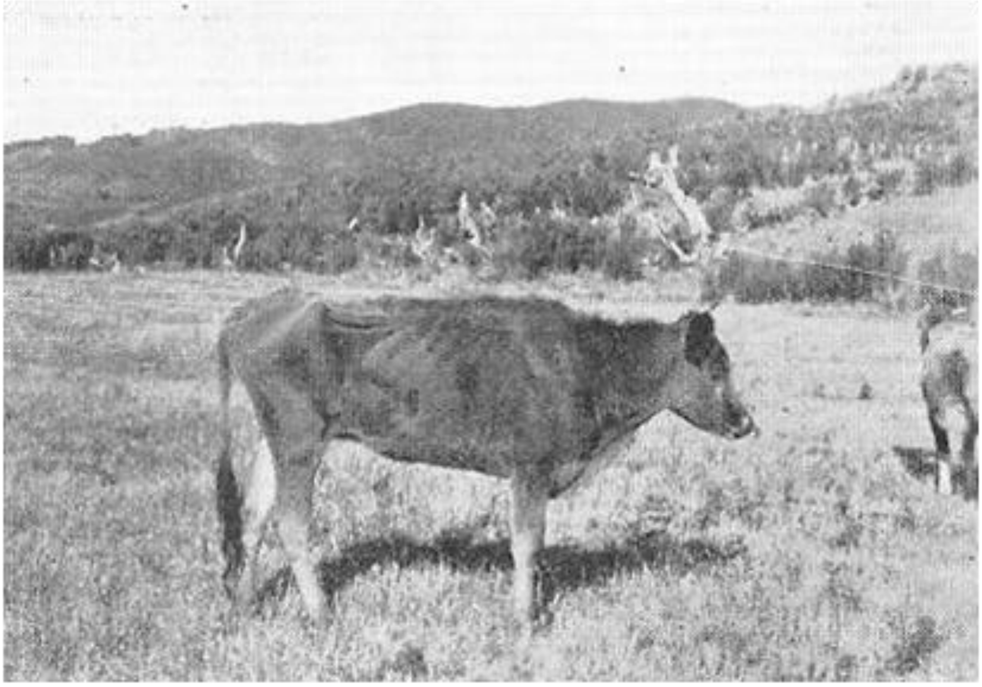


First studies on possible causes publ. 1911, became incr. urgent in late 1920s ⇒ many farms on Pumice Soils abandoned

In 1934 Grimmett and Shorland (DSIR) discovered trace cobalt in iron → effective as 'licks'→ made connection but suggested Co insufficient to be effective

Co identified as cause in 1935 (Underwood & Filmer 1935 *Austr. Vet. Jl* 11, 84-92)

Landscape at Litchfield underlain by Taupo soils and associated Co-deficiency. The deficiency is remedied by topdressing with cobaltalised superphosphate (100-200 g per ha), spraying pastures, oral dosing or drinking-water additives, salt licks, or long-lasting injections. Photo: David Lowe



'Bush–sick' cow on Taupo soil at Ngaroma, South Waikato (from Grange & Taylor 1932)

Partly as a result of these agricultural problems, a forestry industry became established, the mainstay tree being *Pinus radiata* from California (known as Monterey pine). *P. radiata* has been very successful, it matures rapidly in about 27 years on average, and can grow on 'clapped out' soils with little problem. Its roots can easily punch through surficial pumice deposits to reach nutrients and water in buried soil horizons. The soils to the east of SH1 between Putaruru and Tokoroa are now growing their 4th crop (rotation) of *P. radiata*. The importance of this tree to New Zealand will become very evident as we head to Tokoroa and on to Taupo! Palmer et al. (2005) used a P-based nutrient model to establish that *P. radiata* was growing sustainably after two rotations on Spodosols developed on Taupo Ignimbrite in elevated areas on the southern Mamaku Plateau to the east of Tokoroa. Models to predict *Pinus radiata* productivity throughout New Zealand have recently been developed by Watt et al. (2010). Various spatial prediction techniques for developing *Pinus radiata* productivity surfaces across New Zealand were compared by Palmer et al. (2010).

As we head towards Mokai north of Taupo, the landscape steepens with numerous rhyolite lava domes evident within this central part of the TVZ.

Young pines growing in raw pumice (from Molloy and Christie, 1998)

Logs stacked at Tokoroa in 2007

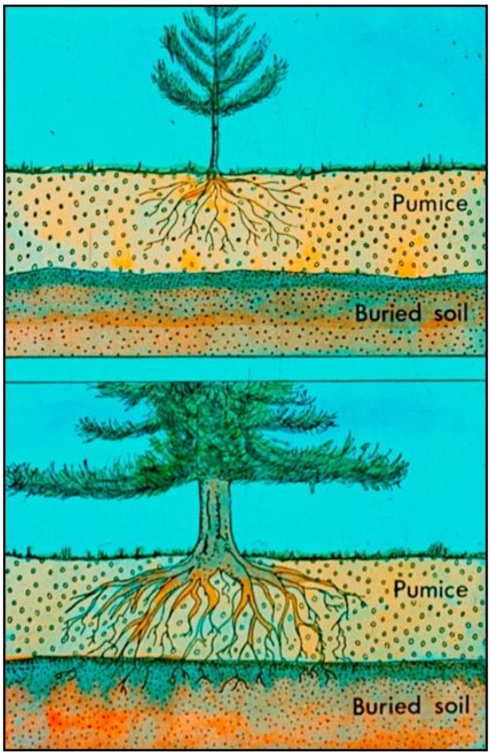


Diagram showing how* P. radiata *can exploit buried soils (courtesy of J.D. McCraw)

Eucalyptus *spp. are also planted in central North Island for the paper industry.*

Photo: Putaruru Timber Museum

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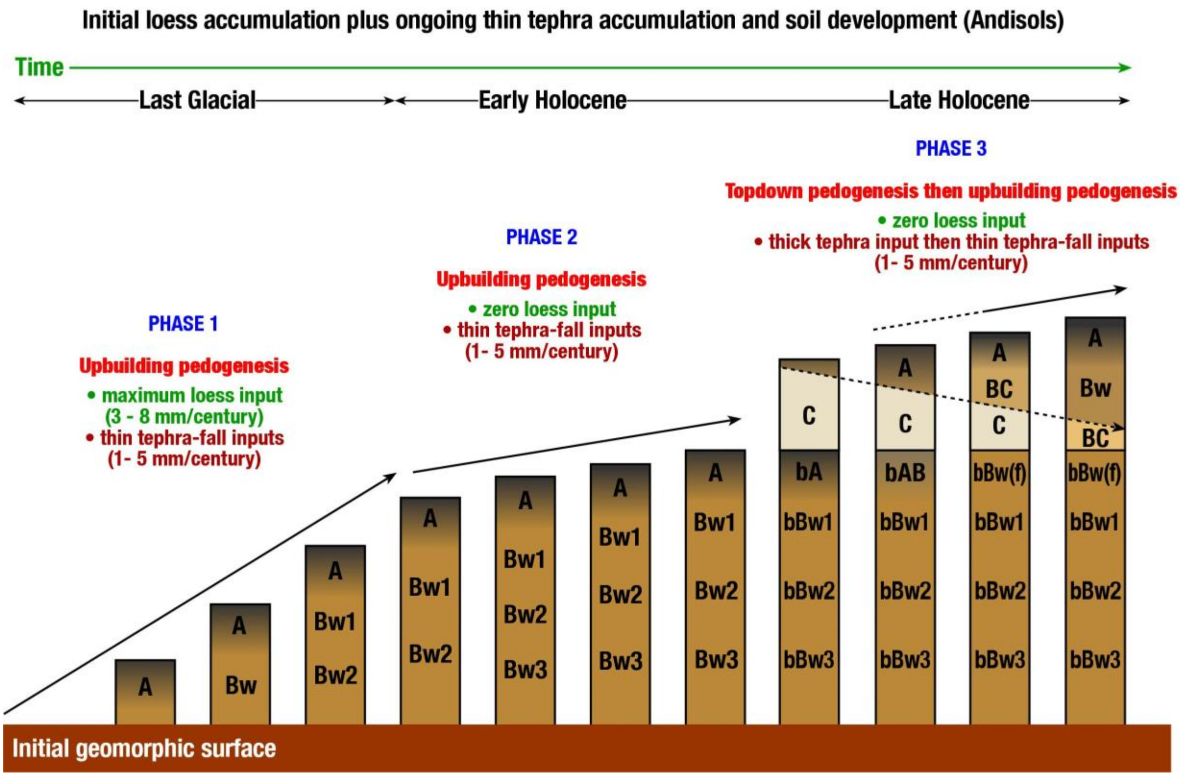
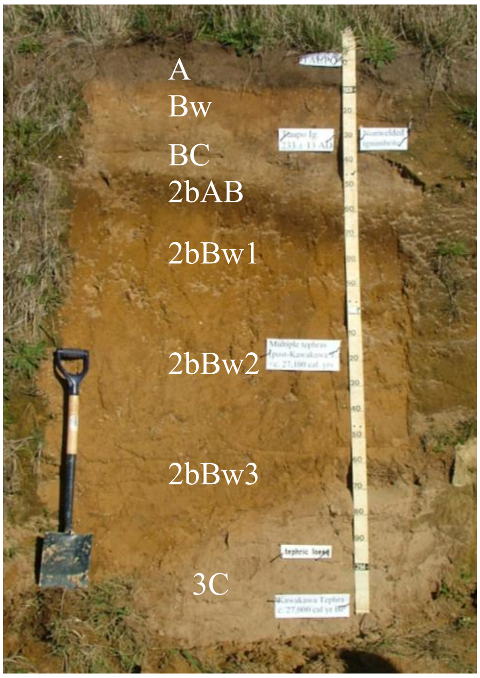


Model of soil development in the eastern Waikato area near Tirau-Putaruru via upbuilding pedogenesis (after Lowe, 2000; Lowe et al., 2008). Most parts of the soil columns have at some time been 'temporary' A horizons. Rates of tephra and tephric loess accumulation in the Putaruru-Tapapa area since c. 27 cal ka average about 7 mm per century (cf. ~4 mm per century for the Horotiu soil since c. 18 cal. ka). Most of the time the upbuilding is developmental as the rates of addition are sufficiently slow to allow topdown pedogenesis to continue as the land surface gently rises, but occasionally a thicker deposit, such as Taupo ignimbrite as depicted above in phase 3, effectively seals off the antecedent soil and soil formation begins anew on the fresh parent materials (i.e. retardant upbuilding). To what extent the properties of the buried soil horizons change subsequently depends on a range of factors including the depth of burial and whether the horizons are effectively isolated or within range of various soil-forming process, and diagenesis.



Soil profile at Kokako Rd near Litchfield showing results of upbuilding pedogenesis. Photo: D.J. Lowe

Taupo Ignimbrite c. 232 AD

Multiple thin intermixed tephra layers deposited after Kawakawa Tephra & before Taupo Ignimbrite (i.e. between c. 27 cal ka and 1.8 cal ka)

Kawakawa Tephra c. 27,100 cal yr BP

1.7 Stop 3 – Mokai, Tuaropaki Trust's Mokai geothermal power plant

Mokai geothermal system

Visit to the Tuaropaki Trust‟s Mokai geothermal power plant, now generating 2% of New Zealand‟s electricity. The Mokai geothermal system is one of the seven systems classified for development in the Waikato region. The Tuaropaki Power Company, which is 75% owned by the Tuaropaki Trust owns two geothermal power stations at Mokai, and wishes to sustainably manage and use the Mokai system for as long as possible.

The Mokai geothermal system lies 25 km north west of Taupo.

Map of Geothermal fields in Taupo-Rotorua Region

The natural features of the Mokai system include warm and hot springs, mud pools, a rare mud geyser, and fumaroles. It also has one of the largest populations of a rare geothermal plant, the fern *Christella* sp. 'thermal'.

The Tuaropaki Trust owns a large area of land overlying the Mokai geothermal system. The Mokai geothermal system is classified for development by Environment Waikato. At Mokai a single development body (the Tuaropaki Trust) has access to the majority of the resource. Mighty River Power now has a 25 per cent stake in the Tuaropaki Power Company.

Developing the system

In 1999 the Trust built a 55 megawatt geothermal power station on the site. In 2005 they completed another station beside it. With current capacity producing 110 MW, the plant reinjects all fluids back underground with minimal environmental impact. Associated with the project is a geothermally heated 11.7 hectare glasshouse which began producing capsicum and tomato for the export market and is now diversifying into a range of vegetables. This venture employs 50 people from Mokai and Mangakino. This has had a significant positive effect on the socio-economic well-being of the two areas.

The Trust believes that developing the Mokai geothermal system is a unique opportunity for Maori to take the initiative and create a project that allows for self-determination.

The Trust is staging the development to minimise adverse environmental effects and accommodate the needs of existing users and potential needs of future generations. They recognise geothermal taonga (treasures) such as therapeutic and cooking pools. A key part of the development is re–injecting used geothermal fluid back into the deep geothermal aquifer to minimise the impact on existing geothermal features and natural ecosystems.

Geothermal Energy and extraction

Geothermal energy is an important contributor to New Zealand‟s electricity supply. But extracting geothermal energy affects the geothermal features and the surrounding environment. Reusing and reinjecting geothermal energy and fluid, and managing the geothermal system as an integrated whole to development helps to minimise the effects.

How much we use

Primary energy – In 2005, New Zealand‟s total primary energy supply was 702 petajoules (PJ). Twelve percent (85 PJ) of New Zealand‟s primary energy came from geothermal sources[1].

Primary energy comes directly from natural sources such as the sun, gas and oil, wood, coal and geothermal energy:

- Industries use it for process heat.
- Gas is used in vehicles and for cooking and heating.
- Households use it for heating (burning wood and coal, using geothermal heat and water).
- It is also turned into electricity.

Primary energy obtained from geothermal sources is forecast to increase to 150 PJ in the next 25 years[2]. Estimates say we could extract between 30,000 and 57,000 PJ per year of geothermal energy using present technology[3]. But this could lead to irreversible effects, such as the destruction of geysers and other surface features, and land subsidence.

Electrical energy - In 2005, New Zealand‟s total electrical energy supply was 150 PJ per year. Geothermal energy provided around 6.5 percent of our national electricity supply, most of it coming from the seven geothermal power stations in the Waikato region[1].

Waikato region - The Waikato region provides 90 percent of the primary geothermal energy extracted in New Zealand[4]. Of the geothermal energy extracted, only 10 percent is converted to a useable form[1]. The rest is re-injected or disposed of into the environment as heat. In the Waikato region there are about 40 separate industries, accommodation facilities and tourist facilities take small amounts of heat for direct uses.

Where the power stations are

New Zealand has nine geothermal power stations. Seven are in the Waikato region. There are plans to build others and expand existing stations, in the Waikato, Bay of Plenty, and Northland regions. See map above and the table below lists the stations in our region.

Geothermal power stations

Geothermal System	Site	Owner(s)	Productive output (MW)	Year built
Wairakei-Tauhara	Wairakei	Contact Energy	140	1958
	Wairakei Binary	Contact Energy	14	2005
	Poihipi Rd	Contact Energy	30	1997
	Tauhara	Contact Energy	(15)	Planned
	Tukairangi Rd	Geotherm	(60)	Planned
Mokai	Mokai A	Tuaropaki Power Company	55	2000
	Mokai B	Tuaropaki Power Company	37	2005
Rotokawa	Rotokawa	Rotokawa Joint Venture	30	1998
Rotokawa	Rotokawa B	Tauhara North No. 2 Trust	(30)	Planned
Ohaaki	Ohaaki	Contact Energy	30	1988

As well as these large power stations, about 40 commercial operations extract small or medium quantities of geothermal water and energy in the region. Most operations take the water from wells or springs, but others take water from hot streams such as the Onekeneke at Taupo. This heated water is used mainly for public baths or motel pools.

Geothermal systems extend under large areas of land. To find, develop and extract these economic sources of geothermal energy and fluid resources (sometimes as deep as five kilometres below the Earth‟s surface) requires large capital investment and complex infrastructures.

What extraction does

Although only a fraction of geothermal energy is currently used, the environmental effects have been dramatic.

Since the 1950s, the number of geysers in the region has dwindled because of heat and fluid extraction and the effects of overlying land uses. When water extraction prevents pressure from reaching the level necessary to fuel the geysers, they disappear. As a result, many sinter-depositing springs and geysers and their associated ecosystems have been lost with the development of the Wairakei Geothermal Power Station.

Use our map to find out more about the state of geothermal features in the Waikato region.

The extraction of heat and fluid also causes land subsidence. For example, a marae near Ohaaki Geothermal Power Station is sinking and runs the risk of being inundated by the Waikato River, as the ground around and under it subsides.

Effects on other parts of the natural environment are summarised in the table below.

Environmental effects of geothermal contaminants[5]

Contaminant	Adverse effects	Source of contaminant
Arsenic	Lethal at high levels. Lower doses cause a wide range of illnesses including cancer. Toxic to humans, fish and plants. Levels in the Waikato River from Wairakei to the sea exceed drinking water standards. Levels in water cress exceed food standards. The beds of some of the Waikato hydro lakes are identified as contaminated land because of high concentrations of arsenic in the sediment.	Natural geothermal discharges. Separated water from geothermal wells discharged into water.
Boron	Toxic to humans at high levels. Toxic to some crops at low levels.	Natural geothermal discharges. Separated water from geothermal wells discharged into water.
Heat	Elevated water temperatures may kill fish and aquatic life. Fish may avoid water if the temperature rises even slightly above their preferred level.	Separated water and condensed steam from geothermal wells discharged into water. Cooling water passed through geothermal power stations.
Hydrogen sulphide	The „rotten egg" smell. This discharge can cause death if concentrations build to dangerous levels in enclosed areas and are inhaled. It can also cause corrosion. Toxic to fish.	Discharges to air from the de–gassing of geothermal fluid. Natural geothermal discharges.
Carbon dioxide	A greenhouse gas. This can kill if found in high concentrations in enclosed spaces, such as in power stations.	Released by geothermal powerstations at a rate of about 1/10 that of fossil fuel powerstations[6].
Mercury	A toxic element. Accumulates in the food chain. Mercury concentrations in some fish from the Waikato River exceed recommended levels for human consumption[7].	Discharged into air from geothermal cooling towers and into water from geothermal wells.

Reducing the effects

In the past, once geothermal fluid extracted for electricity generation had been through the power station, any excess heat and fluid was discarded. Now increasingly, other industrial and domestic processes use the discarded heat and fluid. This means less of the energy extracted is wasted, and less heated water is produced as a by-product. For example:

- A prawn farm near Taupo heats its own freshwater by running it across pipes containing geothermal water used by its neighbour, the Wairakei Geothermal Power Station.
- At Ohaaki, geothermal heat is used to treat timber.

Developers must obtain resource consents prior to developing geothermal areas. The resource consent process requires consultation with iwi and considers potential effects on waahi tapu and other significant sites. Significant adverse environmental effects must be avoided, remedied, or mitigated.

Each power station needs a set of about 15 resource consents to cover such activities as taking geothermal fluid and fresh water, and discharging steam and other gases to air, reinjection of geothermal fluid to ground or its discharge to land or water, drilling geothermal wells, and building and maintaining roads.

Find out about how the Mokai Geothermal System is being managed.

Footnotes

1. New Zealand Energy Data File January 2006, Ministry of Economic Development
2. NZ Energy Outlook to 2030, August 2006, Ministry of Economic Development
3. Lawless, J. and Lovelock, B, 2001. New Zealand‟s Geothermal Resource, in New Zealand Geothermal Association 2001 Seminar Proceedings.
4. Sinclair Knight Merz Ltd, 2006: Regional renewable energy assessment : Waikato region, Sinclair Knight Merz Ltd.; Energy Efficiency and Conservation Authority (EECA), 2006
5. Drinking water standards referred to in this table are defined in: Ministry of Health.2005: Drinking Water Standards for New Zealand 2005. Ministry of Health, Wellington.
6. New Zealand Geothermal Association Submission to Government on Climate Change Consultation Paper, May 2002.
7. National Institute of Water and Atmospheric Research. 1995: Mercury and Arsenic in Waikato River Fish. NIWA Consultancy Report SCJ129/06. NIWA, Hamilton.

Article Source: http://www.ew.govt.nz/environmental-information/geothermal-resources/energy-and-extraction/

1.8 Transit around Lake Taupo

Lake Taupo, with an area of ~ 620 km^2, is the largest freshwater lake in Australasia. It has a volume of ~60 km^3 and a maximum depth of ~185 m (Lowe and Green, 1992). The lake has a maximum length of 41 km and maximum width of 30 km. The lookout point provides an overview of the eastern half of Taupo volcano and emphasises the contrast in morphologies and eruptive styles between Taupo and the composite stratovolcanoes (cones) to the south (Wilson, 1994). Taupo is the archetypal „inverse volcano", as described by the late Prof George Walker, from which, in general, eruptions have been so explosive and the products so widely dispersed that the accumulation of material around the vents has not compensated for collapse associated with caldera formation and regional extension. Consequently, the lake bed near Horomatangi Reefs, site of the youngest eruption, is the lowest point for over 40 km in any direction (Wilson, 1994).

In contrast, the andesitic composite cones to the south-south-west have produced numerous relatively small and weakly- to non-explosive eruptions that have piled up material around the vents to produce high cones not affected by caldera collapse. Mt Tauhara (dacitic) is visible to the southeast, and beyond and to its right the land slopes gently at 1-2° from the Kaingaroa Plateau (700 m) down to Lake Taupo (357 m), forming the eastern side of the volcano. The active andesitic composite cones are dominated by Tongariro (1967 m), Ngauruhoe (2287 m, also known informally as „Mt Doom" from *Lord of the Rings*), and Ruapehu (2797 m). In comparing the andesitic cones and Taupo volcano, the DRE volume of the c. 27 cal ka Kawakawa/Oruanui eruption (~530 km^3, nearly 1200 km^3 as loose material) exceeds the combined volumes of all the andesitic edifices visible at the south end of the lake.

The soils developed in loose Taupo Tephra around Lake Taupo are susceptible to severe gully erosion. The erodibility of the soils under three classes of vegetation – pasture grasses, ungrazed grass, and scrub – was assessed by Selby and Hoskins (1973) with the use of a specially designed flume which simulated gully erosion. Erosion was found to be significantly higher beneath scrub than beneath grass vegetation when the same erosive stress was applied in each case. Under natural conditions, however, greater runoff, and therefore greater erosive power, always occurs on pasture grasses than under scrub. In spite of the greater inherent erodibility of scrub, actual erosion is therefore greater on pasture lands (Selby and Hoskins, 1973). Under pasture grasses, plant roots and organic matter bind the soil particles and inhibit erosion. This effect is less under scrub. Gully erosion is attributable largely to the low density and easy entrainment of pumice particles. 'Retirement' of such gullies with tree planting has been successful in stabilising them.

References

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Selby, M.J., Hoskins, P.J. 1973. The erodibility of pumice soils of the North Island, New Zealand. *Journal of Hydrology (NZ)* 12, 32-56.

Wilson, C.J.N. 1994. Post-conference tour day 1: Hamilton-Tokaanu. *In*: Lowe, D.J. (ed) Conference Tour Guides. *International Inter-INQUA Field Conference on Tephrochronology, Loess and Paleopedology.* University of Waikato, Hamilton: 74-100.

(Left) Gully formed in loose pumice deposits (note person for scale at headwall) and (right) gully stabilised with* P. radiata *plantings (photos courtesy of M.J. Selby)

1.9 Background and development of rules affecting land use in the Lake Taupo catchment

Chris McLay
Environment Waikato, Hamilton

Introduction

The Waikato Regional Plan Variation 5 – Lake Taupo Catchment (“RPV5”) – adds a new section to the Waikato Region Plan to provide policies and methods to protect the water quality of Lake Taupo. This section arose in response to increasing pressures for land-use intensification in the catchment during the late 1990s, along with signs that lake water quality is starting to decline. The variation has been appealed to the Environment Court and a decision is pending in the near future. Many staff within Environment Waikato and other organisations have contributed to the development of the Variation. This summary is taken from other Environment Waikato reports.

Land use and ownership in the Lake Taupo catchment

Lake Taupo is 622 square kilometres in area. The lake‟s catchment (watershed) has an area of 3487 square kilometres (including the lake). In addition to the urban centres at Taupo and Turangi, there are several smaller settlements around the lake, some of which are in the process of expansion and development. Land uses in the catchment can be broadly divided into pastoral farming, planted production forestry, and undeveloped land (including indigenous forest). Most farms are drystock, mainly mixed sheep and beef, with some farms also running deer. There are six dairy farms in the catchment with four located entirely within the catchment and two partly within the catchment.

NASA space shot of Lake Taupo and its catchment (from Nathan, 2007).

Nathan, S. 2007. Lakes. Te Ara – the Encyclopedia of New Zealand. NZ Ministry for Heritage and Culture. Updated 5-Nov-2007.
URL:
http://www.TeAra.govt.nz/TheBush/Landscapes/Lakes/en

NASA JSC Digital Image Collection
(reference ISS005-E-21107)

Ngati Tuwharetoa is the iwi with mana whenua (traditional land tenure) in the lake"s catchment. Its rohe (territory) includes the catchment of Lake Taupo and stretches further on all sides. Collectively, Ngati Tuwharetoa represents the largest private land owner in the catchment. Approximately 110,000 ha or 40 percent of land in the catchment is in Maori ownership.

Threat to water quality

Scientific evidence gathered over the last 30 years shows that the water quality in Lake Taupo is under threat. The lake currently has excellent water quality, reflected by extremely low levels of plant nutrients and phytoplankton. This means that the lake has very clear water. The excellent water quality is threatened by increasing nitrogen loads entering the lake, particularly from farming activities, but also from wastewater from community sewage treatment plants and septic tanks. Nitrogen is a nutrient which increases tiny, free-floating algae in the lake water, and these algae make the water look murky. Increased nitrogen in the lake also can cause an increase in some lake weeds and an increase in slimy growths on the lake bed.

If the water quality of Lake Taupo were allowed to continue to deteriorate, it would eventually result in adverse impacts on the economy of the Taupo area, given its dependence on tourism and recreation.

Consultation and partnerships

In response to concern about changes in the lake and the potential for future intensification, Waikato Regional Council (Environment Waikato) commissioned technical investigations in mid-2000 to learn more about lake water quality and the influence of catchment land uses. It also circulated an issues and options paper amongst key stakeholders and the general public and invited local people to public meetings. In 2001, Environment Waikato resolved to take steps to protect the lake from any further long-term decline in water quality. The principal objective was to maintain current water quality in Lake Taupo in the long-term. The time scale was intended to allow for the fact that groundwater in the catchment takes many years (decades) to reach the lake.

Following this, Environment Waikato began a further extensive period of consultation with stakeholders including central Government, the Taupo District Council, Ngati Tuwharetoa, and other landowner groups in the catchment, to formulate a strategy to achieve the objective stated above. The strategy that was developed involves a two-pronged approach, each equally important. (1) A planning or resource management approach under the Resource Management Act (RMA), and (2) the establishment of a public fund to assist landowners to reduce their outputs of manageable nitrogen. The first appproach has resulted in Variation 5 to the proposed Waikato Regional Plan. The second has resulted in the formation of the Lake Taupo Protection Trust. This trust has been established through consultation with local and regional communities to establish rating contributions from Environment Waikato and Taupo District Council and a central Government taxpayer-funded contribution. This fund is administered by the Lake Taupo Protection Trust, which is a council -controlled crganisation established under the Local Government Act 2002. The trust is overseen by a joint committee comprising two representatives from Government, Ngati Tuwharetoa, Taupo District Council and Environment Waikato.

The regional plan variation

Nitrogen can enter the lake from a variety of sources including animal urine, rainfall, nitrogen-fixing plants such as clover, planted production forest, sewage, and urban runoff. Some of these sources can be managed to reduce the amount of nitrogen entering the lake. RPV5 focuses on controlling the amount of nitrogen from these manageable sources. Pastoral farming is responsible for 93 percent of the manageable load of nitrogen to the lake, and sewage and stormwater for 7 percent.

The main objective of RPV5 is for 2001 water quality levels in Lake Taupo to be maintained by 2080. The reason for the long time-frame is that it takes many decades for nitrogen to travel from where it enters the ground until it reaches the lake. Because land was less intensively farmed in the catchment 50 years ago, the nitrogen currently entering the lake is at a lower concentration than it will be in years to come. Therefore, nitrogen levels in the lake are likely to get worse before they get better. The most important thing that the RPV5 rules do is to cap the amount of nitrogen entering the catchment at current levels. It does this through a series of policies and rules that manage land-use activities and wastewater discharges.

To cap nitrogen from land uses, the rules ensure people in the lake catchment manage their land-use activities so that nitrogen leaving their land (that is, leaching through soil) does not exceed the average nitrogen leaching from their land over the period 2001 to 2005. People‟s nitrogen allowance is said to be „grandparented‟. This means, for example, that if a farm was leaching 14 kilograms of nitrogen per hectare per year in the past, then it can continue to do so. Most farmers will need to obtain a resource consent from Environment Waikato to remain farming under RPV5. Through the consent process they will be given a nitrogen discharge allowance (NDA) which will be equivalent to the amount of nitrogen per hectare per year that their land leached on the most favourable year for the land owner in the benchmark period between 2001 and 2005. Their NDA will be „benchmarked‟ at this level using a computer model called Overseer. Farm information such as stock numbers and fertiliser rates for the farm during this benchmark period will be put into the Overseer model to generate the NDA. The Overseer model will also be used in the preparation of a farm nitrogen management plan which will describe the way the farm will be managed to achieve the NDA.

RPV5 also provides a way that land owners will be able to trade nitrogen. Such trading will be done by one land owner increasing his/her consented NDA at the same time that another land owner decreases his/her NDA, by changing their respective consents. RPV5 also has policies and methods relating to the public fund. In particular, there is a requirement for the public fund to be used to permanently reduce nitrogen from rural land use activities by 20 percent. This is to ensure that the additional nitrogen yet to enter the lake from ground water will be offset by a nitrogen reduction, so that lake water quality reverts to 2001 levels by 2080.

Hearings, submissions and appeals

RPV5 was notified on 9th July 2005. In all, 136 submissions were received. The hearing began on 1 May 2006 and the hearing committee heard evidence and submissions from 123 witnesses representing 69 parties. The „Council Decisions Version‟ of RPV5 was released in February 2007. Nine appeals were lodged with the Environment Court with respect to the Environment Waikato decision and the appeal was heard from May 2008. The court decision, an interim ruling, was released on 12 November, 2008, and upheld Environment Waikato‟s proposed set of rules designed to effectively cap the amount of nitrogen entering the catchment at current levels. There is one outstanding matter to resolve before the policy is finally signed off by the environment court judge.

The last word….

From the *Waikato Times* 13 Nov, 2008

Farmers vow to help environment

By **Chris Gardner**
Business editor

Agricultural leaders have agreed to work with Environment Waikato to solve the problems caused to the environment by decades of over-intensive farming.

The move came at yesterday's Waikato Agriculture Summit in Hamilton, attended by about 80 people including farming leaders, agricultural industry officials, local and central government staff and environmental groups.

The summit supported a declaration that commits them to implement existing solutions such as nitrification inhibitors, and to work together to develop new solutions for managing agriculture's impact on the environment.

Fonterra said it was working on what the future of environmentally sustainable dairying in the region would look like.

Mr Buckley, a former Waikato Federated Farmers president, said he was impressed by the commitment to improve water and soil health following a council report in September that found around three-quarters of Waikato waterways were unsafe for stock to drink and people to swim in due to agricultural chemical leaching. The report said the trend was likely to continue unless something was done by the industry.

> ❛There was broad agreement that we all needed to do more to manage farming's environmental impact in the Waikato.❜
>
> – **Peter Buckley**
> **EW chairman**

"There was strong unity over the need to find solutions to the problems we face so we can maintain a healthy agriculture-based economy in the region while ensuring we do more to protect the environment," Mr Buckley said this morning.

"The report and summit have focused attention on the issues and promoted a common sense of ownership of the need to find solutions."

EW told those attending the summit, which was closed to the public and press, that the council had developed policies and rules that gave farmers freedom for most activities, provided they stuck to environmental protection rules.

That regime was backed by an extensive environmental monitoring network to ensure that the policies were working.

"There was broad agreement that we all needed to do more to manage farming's environmental impact in the Waikato," Mr Buckley said.

"There was also a general recognition that more hard, detailed thinking was required before we could arrive at the best solutions.

"I'm hoping that the summit will further develop linkages between EW and the farming sector so that our partnership approach to addressing the issues is strengthened. We are willing to work with anyone on getting things right for the Waikato."

Lake limits rile farmers

- Environment Waikato wants to clean up Lake Taupo by cutting nitrogen run-off from farms.
- But farmers say the new rules, backed by the Environment Court, threaten their livelihood.

By **Warwick Rasmussen**

Farmers have slammed an Environment Court decision backing efforts to clean up Lake Taupo, saying it strips them of rights and is “fundamentally flawed”.

The interim decision, released yesterday, upholds Environment Waikato's (EW) rules to protect water quality in and around the country's largest lake by restricting farming to cut back the amount of nitrogen, mainly from fertiliser use, entering waterways.

But Federated Farmers Ruapehu president Lyn Neeson said affected farmers would now need permits to go about their day-to-day work.

The news would come as “a big, big blow” to her affected members, mainly sheep and beef farmers on the western side of the lake, she said.

“The farmers down here care about the lake, they are all keen fishermen, they love the lake. They've put in a huge amount of effort to mitigate any problems, but this ruling is fundamentally flawed and fundamentally unfair.”

Ms Neeson said the extra level of compliance that would be heaped on farmers would deter people farming the area and hit property values.

Taumarunui-based farm consultant Geoff Burton has been working with farmers around the lake region for almost 30 years and said large tracts of Maori-owned land would be the hardest hit.

“The effect on the Maori land is significant because legally they aren't in a position where they can sell it or free up any capital. They are in a particularly difficult situation. They are stuck with what they have got.”

The Labour-led Government last year welcomed EW's measures to improve Lake Taupo's water quality by reducing harmful discharges by 20 per cent over 15 years.

LACHLAN MCKENZIE: Rights turned over.

PETER BUCKLEY: Decision a good outcome.

Federated Farmers environment spokesman Lachlan McKenzie said the rules were like needing a permit to dig a vegetable garden.

“This decision means all farmers in the Taupo area will need planning permission just to farm. This turns on its head the fundamental human right to grow food,” Mr McKenzie said.

However, EW chairman Peter Buckley, a former Waikato Federated Farmers head, said the court's interim decision was a good outcome after long, drawn out battle.

“I think it's struck a fair balance. They have gone through a due process and everybody's had a fair go. I think there's always going to be some apprehension of rule changes like this, that's to be expected.”

Mr Buckley said the new rules would also create opportunities for some farmers with a proposed nitrogen trading scheme.

Under the scheme, farmers in the catchment will be allocated a nitrogen discharge allowance based on their farm's past practices. If they want to increase their emissions, they can buy nitrogen credits from another Taupo land owner who doesn't need all their allocated nitrogen.

Nine parties, including farmers, appealed the council's plan change to the Environment Court. But in the interim decision, the court found that land use activities that result in nitrogen leaching, particularly farming, needed to be managed to restore Lake Taupo's water quality to 2001 levels.

EW evidence showed that farming contributed 92 per cent of nitrogen entering the lake, urban run-off and sewage contributed 6 per cent, and forestry, gorse and broom the remaining 2 per cent.

Day 2: Turangi –Palmerston North

Outline for Day 1 (Wednesday 28th July 2010)

8.00 am Depart, Parklands Motor Lodge , Turangi

9.00-9.45 am STOP 1. "Mangatoetoenui Quarry, Desert Road. Quarry exposure reveals good cover-bed succession of Holocene and Late Pleistocene Ruapehu- and Ngauruhoe-derived tephras resting on lahar deposits. Lapilli layers from here have proved useful in phosphate sorption experiments that may have use in industrial scale phosphate removal from waste water.

10.30 11.00 am Morning tea/coffee, **Taihape**, Toilet stop

11.30-12.00 noon STOP 2 Stormy Point lookout: A river aggradation terrace sequence on the western side of Rangitikei River, spanning the last 400 kyrs. Each terrace represents culmination of river aggradation during glacial conditions. Each aggradation surface was the source of a loess that blew on to older terraces. Independent dates are provided by interbedded volcanic ashes. During intervening interglacials the river cut down and soils formed. Each successive terrace is preserved because of uplift in the region. The terrace deposits overlie shallow marine and terrestrial sands and silts, containing pumice alluvium and air fall tephras. The sediments dip downstream gently at 2-4°, and in this area are from 0.8 – 1.5 Ma.

12.30 pm -1.30 pm LUNCH Cheltenham Hotel,

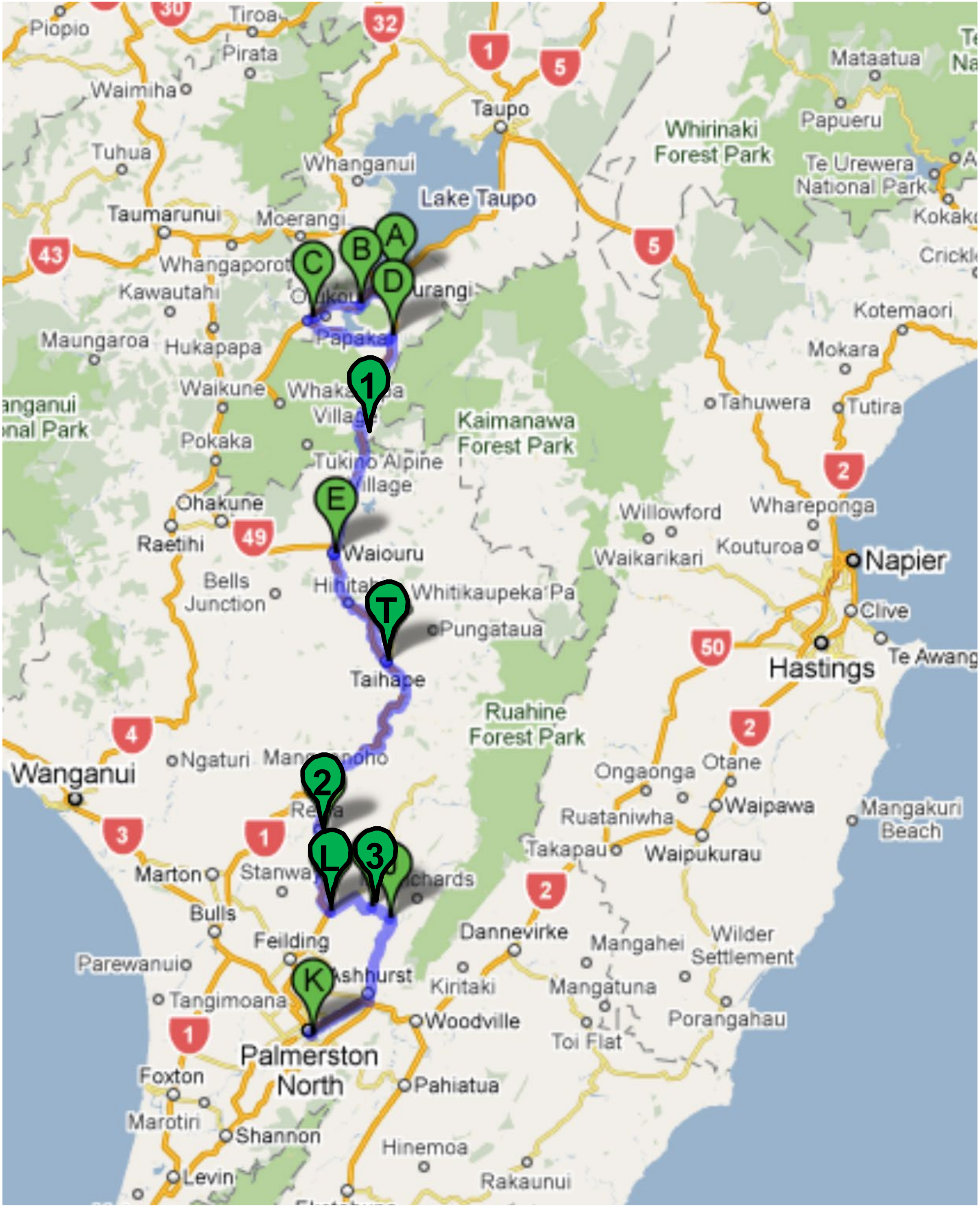
2.15-3.15 pm STOP 3 Branch Creek walkway, A view of steep-land formed in Early Pleistocene marine sands and muds. The land must be considered unsuitable for pastoral farming, having suffered a succession of slip erosion events, the latest being in February 2004. Some slopes lost 30% of their soil in this rainstorm, and follows earlier events that occur approximately every decade. The rate of formation of new soil is slower than the rate of soil loss. Exotic forestry or retirement to native shrubs and trees is desirable, but is politically and financially difficult to achieve.

3.15-3.40 pm Afternoon tea, Branch Creek walkway

4.45 pm Hotel Coachman, Palmerston North

6.30 pm BBQ at Wharerata, Massey University (includes food and beverage).

Day 2 – Route and scientific stops



A, Parkland Motor Lodge; B, Pihanga Saddle; T, toilet stop; L ,Lunch; 1,2,3, Scientific stops; K, Hotel Coachman and Massey University.

2.1 Transit Turangi , Te Kaanu to Stop 1 Dessert Road

On the morning of Day 2 we will climb the steep southern side of Lake Taupo and pass through the native podocarp forest on the Pihanga Saddle Road to view Mount Tongariro and the active volcanoes Ruapehu and Ngauruhoe. If the weather is clear we will make time for short photographic stops.

Our route then skirts around the western and southern shores of Lake Rotoaira, a popular trout-fishing locality, before we travel south along the Desert Road. Initially we traverse the strongly rolling terrain of the Tongariro ring plain, with its interbedded lahar and tephra deposits with occasional lava flows. The highly variable thickness of the Taupo Pumice pyroclastic-flow deposits in the uppermost part of the soil sequence is most noticeable. In deeper road cuttings the considerable depth of older andesitic tephras becomes apparent.

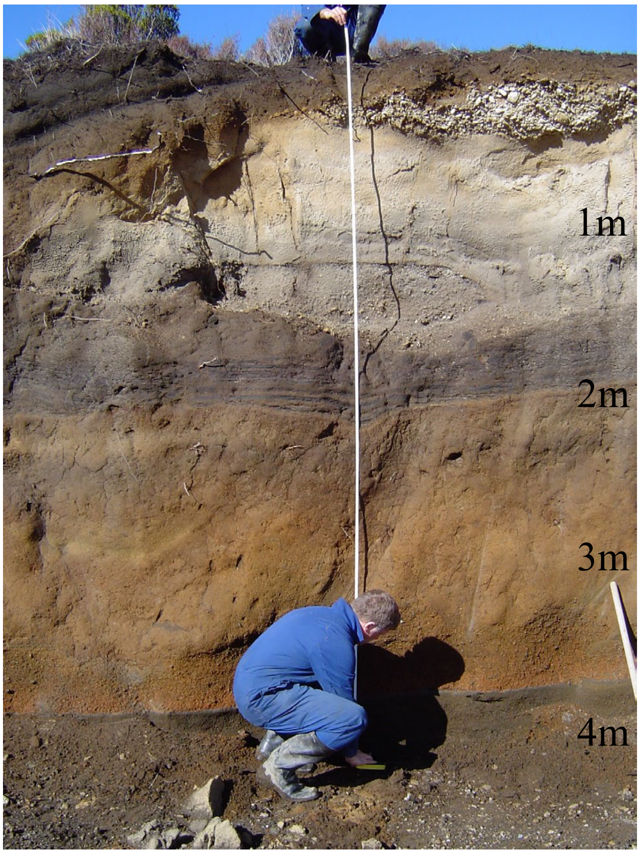
Mt. Ngauruhoe viewed from Mangatoetoenui Quarry, Desert Road

After crossing Waihohonu Stream, we begin to traverse the Ruapehu ring plain; much younger and thus more planar than its northern neighbour. Here it comprises largely lahar deposits with interbedded fluvial beds of mostly Last Glacial Maximum age, capped by predominantly Holocene andesitic tephra cover beds.

The vegetation at the northern end of the Deseret Road is dominated by manuka (*Leptospermum scoparium*) and introduced pines (*Pinus radiata*). The route passes through areas of mountain beech forest (*Nothofagus solandri* var. *cliffortioides*), principally in gullies, before emerging into red tussock (*Chionocloa rubra*) land on the Ruapehu ring plain.

2.2 Stop 1 – Mangatoetoenui Quarry, Desert Road

Mangatoetoenui Quarry exposes the cover-bed succession of Holocene and Late Pleistocene Ruapehu- and Ngauruhoe-derived tephras resting on lahar deposits. Here you will view one of the youngest soil parent materials in New Zealand – ash derived from the 1995 Ruapehu eruptions. Lapilli layers from here have proved useful in phosphate sorption experiments that may have use in industrial scale phosphate removal from waste water.



Mangatoetoenui Quarry Upper section, Ruapehu, Ngauruhoe and Taupo tephras

Depth	**Descrip**	**pH**	**P rtn %**
0.6 –1.0	**Pumice sand**	**5.8**	**32**
1.0 –1.4	**Pumice sand**	**5.9**	**23**
1.8 –2.3	**Leaf char. Andesite**	**6.1**	**48**
2.4 –2.6	**Weathered clay**	**5.9**	**98**
3.0 –3.2	**Weathered clay**	**6.0**	**99**
3.2 –3.4	**Fine lapilli**	**6.1**	**81**
3.4 –3.7	**Coarse lapilli**	**6.3**	**83**

A formal description of the stratigraphic units represented here, follows (from Donoghue et al. 1995).

Section name and map code: **Mangatoetoenui Quarry [MQ]**

Grid Reference: T20/459153

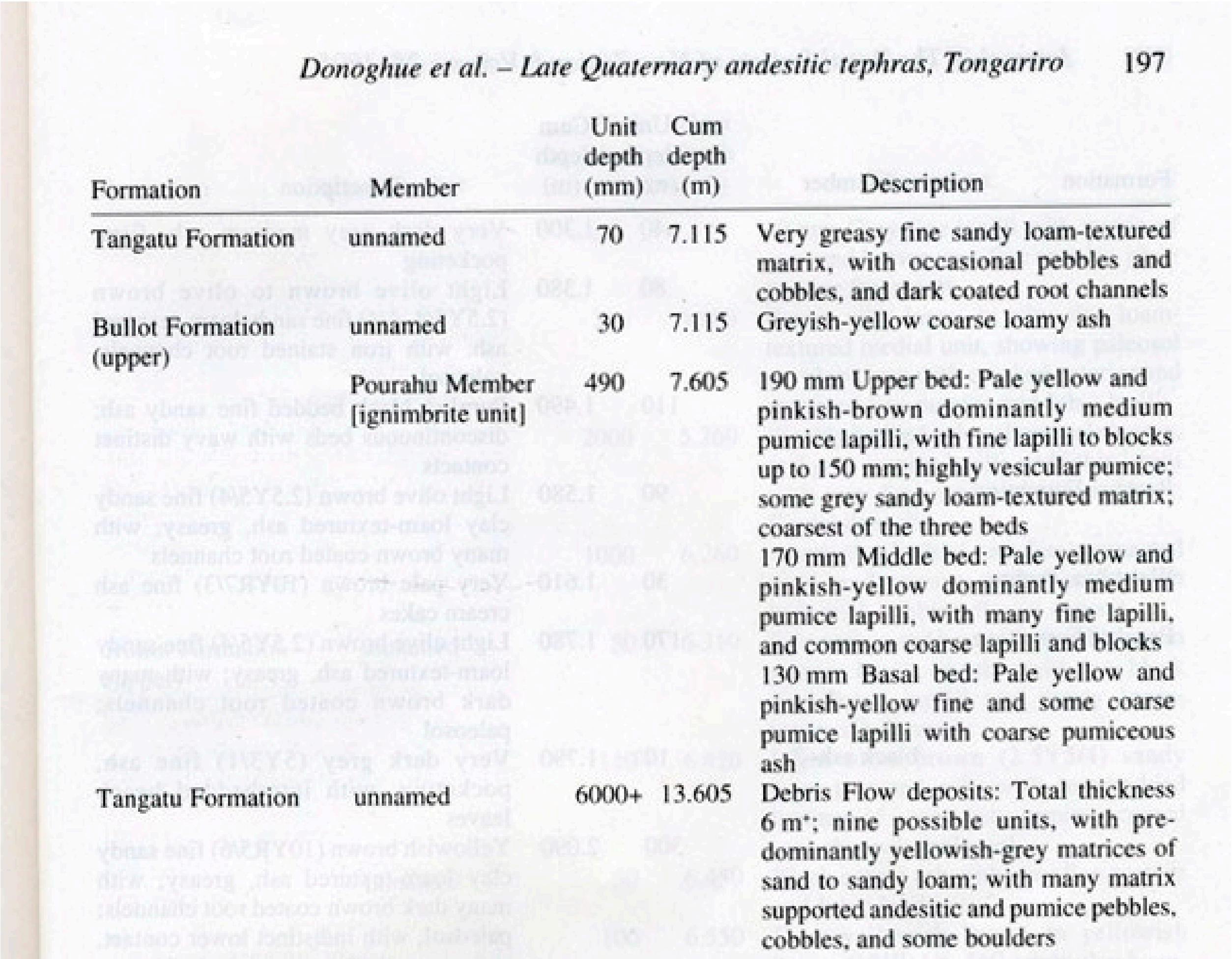
Locality: A large exposure within a quarry on the east side of the Desert Road, immediately south of the road bridge over Mangatoetoenui Stream

Formation	Member	Unit depth (mm)	Cum depth (m)	Description
Makahikatoa Sands + Tufa Trig Formation		200	0.200	Grey sand over brown fine sandy loam textured unit, and dark grey medium ash
Tufa Trig Formation	unnamed	25	0.225	Black coarse ash with fine grey ash base and top
Makahikatoa Sands		30	0.255	Grey coarse loamy sand-textured unit

Formation	Member	Unit depth (mm)	Cum depth (m)	Description
Tufa Trig Formation	Tf6	25	0.280	Reversely graded dark grey coarse ash, on 20 mm fine grey ash
Makahikatoa Sands		40	0.320	Brownish grey medium sandy loam-textured unit, slightly greasy
Tufa Trig Formation	Tf5	60	0.380	40 mm Bedded black coarse ash 20 mm Grey fine ash base
Makahikatoa Sands		40	0.420	Dark yellowish brown (10YR4/4) medium sandy loam-textured unit, slightly greasy
Tufa Trig Formation	Tf4	15	0.435	Very dark grey coarse ash with pale grey fine ash top
*		340	0.775	Dark yellowish brown (10YR4/4) sandy clay loam-textured ash; with dark coated root channels; paleosol developed in Taupo Ignimbrite
Taupo Tephra	Taupo Ignimbrite	750	1.525	White poorly sorted coarse ash and lapilli, with charcoalised branches.
Mangatawai Tephra		140	1.665	Dark brown fine sandy clay loam-textured ash, sticky; with interbeds of black coarse ash, pocketing; and many iron-stained root channels; sharp lower contact; paleosol
		510	2.175	Alternately bedded black and dark purplish-black coarse ash beds, with abundant yellowish-brown and orange beech leaves, and dark yellowish-brown (10YR4/4) fine sandy loam-textured ash beds; bed thicknesses <100 mm; upper beds discontinuous, lower beds continuous; wavy bed contacts
Papakai Formation		120	2.295	Dark yellowish brown (10YR4/4) coarse sandy clay loam-textured ash, very greasy; with many scattered fine lapilli and iron-stained root channels; sharp wavy contacts
Papakai Formation + Waimihia Tephra		100	2.395	Dark yellowish brown (10YR4/4) fine sandy clay loam-textured ash, with 40 mm thick interbedded pale olive (5Y6/3) fine ash cream cakes
Papakai Formation		280	2.675	Dark yellowish brown (10YR4/4) fine sandy clay loam-textured ash, sticky; with many dark coated root channels; indistinct contacts
Hinemaiaia Tephra		100	2.775	Yellow coarse pumiceous ash dispersed throughout dark yellowish brown sand clay loam-textured Papakai Formation; distinctive tephra
Papakai Formation		300	3.075	Yellowish brown (10YR5/6) and strong brown (7.5YR5/6) fine sandy clay loam-textured ash, strongly cracked exterior; with many bluish-grey fine lithic lapilli concentrated at base, and many dark brown coated root channels

Formation	Member	Unit depth (mm)	Cum depth (m)	Description
Motutere Tephra		10	3.085	Pale brown to pinkish brown coarse and fine ash cream cakes
Papakai Formation		310	3.395	Yellowish brown and strong brown fine sandy clay loam-textured ash, with many coated root channels, and interspersed fine lapilli; cracked exterior
reworked Mangamate Tephra		340	3.735	Brown and grey very fine angular, platy lithic fragments; normally graded deposit; weakly cemented; sharp smooth basal contact
Mangamate Tephra	Poutu Lapilli	240	3.975	Dark greyish brown (2.5Y4/2) fine and fewer medium lithic lapilli, and strong brown (7.5YR5/6) fine and medium pumice lapilli, with yellowish brown (10YR5/6) interiors; non- and poorly vesicular lapilli, moderately soft; slight normal grading; weakly cemented at surface of outcrop
		20	3.995	Black coarse sandy ash
	Wharepu Tephra	670	4.665	Bedded lapilli and ash: 110 mm Very fine lapilli and coarse ash; slight normal grading 160 mm Dark greyish brown (2.5Y4/2 and 5Y3/1) and common dark brown (7.5YR4/4) fine and very fine lapilli 100 mm Dark brown fine and very fine lapilli; sharp contacts
		40	4.705	Dark yellowish brown (10YR4/4) fine sandy loam-textured ash; prominent
	Waihohonu Lapilli	700	5.405	Bedded lapilli and ash: 330 mm Very dark grey (5Y3/1) dominantly medium angular lithic lapilli, and few yellowish brown (10YR5/8) pumice lapilli 50 mm Bright yellowish brown (10YR5/6) fine pumice lapilli and coarse pumiceous ash 190 mm Dark grey medium and fine angular lithic lapilli, and few strong brown pumice lapilli 20 mm Yellowish brown fine pumice lapilli and few black lithic lapilli, and coarse pumiceous and lithic ash 20 mm Coarse black ash
	unnamed tephra	90	5.495	80 mm Brown coarse loamy coarse ash; with many very fine lithic lapilli; sharp contacts 10 mm Coarse sandy clay loam-textured ash, very greasy
	Oturere Lapilli	480	5.975	470 mm Weakly bedded dominantly very fine and fine, very dark grey (5Y3/1) and fewer dark greyish brown (2.5Y4/2) lithic lapilli, and some yellowish brown (10YR5/6) pumice lapilli, poorly

Formation	Member	Unit depth (mm)	Cum depth (m)	Description
				vesicular, moderately soft; slight normal grading 10 mm Bluish-grey very fine and fine lithic lapilli, soft; in greasy sandy clay loam-textured ash
unnamed tephra		15	5.990	Grey (2.5Y6/0) to light brownish grey (2.5Y6/2) sandy clay-textured ash; greasy; with iron-stained upper contact
Karapiti Tephra		5	5.995	Pale grey fine ash cream cakes, few, indistinct
unnamed tephra		20	6.015	Grey (2.5Y6/0) to light brownish grey (2.5Y6/2) sandy clay-textured ash; greasy; with iron-stained lower contact
		100	6.115	20 mm Brown coarse sandy clay loam-textured ash, greasy 40 mm Yellowish brown (10YR5/6) dominantly fine and very fine pumice lapilli, soft, weathered; ungraded tephra 30 mm Black coarse ash and fine lithic lapilli 10 mm Greyish brown coarse loamy ash
Pahoka Tephra		240	6.355	Grey (2.5Y5/0–6/0), light olive-grey (5Y6/2), and olive (5Y6/3) colour-banded fine and medium, and few coarse pumiceous lapilli; light grey (2.5Y7/0), and olive (5Y6/3) non-banded pumiceous lapilli; and few olive and very dark grey lithic lapilli; blocky, angular, moderately hard pumiceous lapilli; slight normal grading with upper 50 mm comprising very fine angular, platy pumiceous lapilli; basal 20 mm comprises coarse pumiceous and lithic ash; distinctive tephra
Tangatu Formation	unnamed	340	7.115	Medium sand and granule matrix, moderately well sorted; with matrix supported very fine, and fine andesitic and pumice pebbles, and many grey aphanitic cobbles (150 mm) and boulders; ungraded deposit; debris flow deposit
Bullot Formation (upper)	unnamed	140	7.115	30 mm Coarse sandy loam 110 mm Yellowish brown (10YR5/6) fine pumice lapilli; discontinuous tephra
Tangatu Formation	unnamed	150	7.115	Coarse sand and granule matrix, moderately well sorted; with black and red dominantly medium andesitic pebbles, and brown and olive pumice pebbles; maximum clast 30 mm (coarse pebble); finer basal 30 mm without pebbles; debris flow deposit
Bullot Formation (upper)	unnamed	30	7.115	Coarse ash with some fine and few medium black lithic lapilli and yellowish brown pumice lapilli; normally graded



Donoghue et al. – Late Quaternary andesitic tephras, Tongariro 197

Formation	Member	Unit depth (mm)	Cum depth (m)	Description
Tangatu Formation	unnamed	70	7.115	Very greasy fine sandy loam-textured matrix, with occasional pebbles and cobbles, and dark coated root channels
Bullot Formation (upper)	unnamed	30	7.115	Greyish-yellow coarse loamy ash
	Pourahu Member [ignimbrite unit]	490	7.605	190 mm Upper bed: Pale yellow and pinkish-brown dominantly medium pumice lapilli, with fine lapilli to blocks up to 150 mm; highly vesicular pumice; some grey sandy loam-textured matrix; coarsest of the three beds 170 mm Middle bed: Pale yellow and pinkish-yellow dominantly medium pumice lapilli, with many fine lapilli, and common coarse lapilli and blocks 130 mm Basal bed: Pale yellow and pinkish-yellow fine and some coarse pumice lapilli with coarse pumiceous ash
Tangatu Formation	unnamed	6000+	13.605	Debris Flow deposits: Total thickness 6 m^{+}; nine possible units, with predominantly yellowish-grey matrices of sand to sandy loam; with many matrix supported andesitic and pumice pebbles, cobbles, and some boulders

2.3 Transit from Mangatoetoenui quarry to Stormy Point Look Out

Leaving Stop 1, we reach the summit of the Desert Road at about 1,100m, where glimpses of the Rangipo Desert on the eastern flank of Ruapehu become visible. This is the catchment from which the Crater Lake discharges. It is thus the major lahar route for the volcano in Holocene times. When the route crosses the Desert Road (Rangipo) Fault the main channel of the Whangaehu River becomes visible down which a major lahar traversed as recently as March 2007. Next town is Waiouru. About 9 km to the west is Tangiwai, site of the infamous disaster in 1953, when the Wellington-Auckland express train was crossing the railway bridge, a lahar swept it away, with the loss of 151 people. Beyond Waiouru, we descend off the Central North Island Volcanic Plateau for the southern half of our tour. Here we will view actively building mountain land (the western side of the Ruahine Ranges) adjacent to dissected steep-lands giving way to river terraces and terrace remnants and alluvial plains. Over the last 400,000 yrs, tectonic uplift, coastal marine processes and erosion by the Rangitikei River have produced one of the finest flights of river aggradation terraces in the world (D2:Stop 2). The hill country we will pass through is typical of moderately and deeply incised land, Class 6e and 7e, which describes steep hills susceptible to sheet and slip erosion. Erosion control is a major focus of contemporary farm planning. The last stop of the day (D2:Stop 3) will consider the problem of extensive hill country sheep farming on highly erodible steep-land formed in Early Pleistocene marine sandstones and mudstones.

Regional Geological Setting

***By A.S.Palmer, Soil and Earth Sciences, Massey University*.**

The Manawatu-Rangitikei area lies about 200km northwest of the Hikurangi Trough, the plate boundary between the Pacific and Australian Plates. The North Island landmass represents the leading edge of the Australian plate, crumpled and strained by its collision with the Pacific Plate. The top of the subducting Pacific Plate dips northwestward beneath the North Island, and is at approximately 30 km beneath the Manawatu coastline. Strain associated with the plate boundary and subducting plate is transferred up through the overriding Australian Plate to the ground surface in the form of uplift and active faults and folds (Begg et al 2005). This deformation has driven the evolution of the landscape.

Physiography

The physiography of the area can be conveniently divided into four broad divisions after Heerdegen (1982) and Begg et al (2005): the Ruahine and Tararua Ranges; dissected steep-land; terraces and terrace remnants and plains.

Ruahine and Tararua Ranges

The ranges are aligned north-east to southwest, roughly parallel to the subduction zone 150km farther east. The lowest point between the Ruahine Range in the north and the Tararua Range in the south is a few km north of the antecedent Manawatu Gorge. North and south of this point the ranges increase in elevation to over 1000m and 1500m in places. Both sides of the ranges are deeply dissected by streams, but the eastern side tends to be steeper and more rugged due to uplift along the Wellington-Mohaka Fault which runs along the foot of the Range. Despite this dissection, the crest of the ranges shows summit height accordance which represents the remnant of an ancient erosion surface.

The Manawatu Gorge cuts directly through the ranges, downcutting by the Manawatu River evidently having kept pace with the uplift. The Gorge walls are steep and immature. Instability along minor faults and sedimentary contacts is exacerbated by the placement of road and rail on the Gorge walls. The youth of the ranges is demonstrated by a drape of Late Tertiary and Early Pleistocene marine and non-marine rocks over the greywacke ranges near the northern side of the Gorge.

Dissected steep-lands

The steep-lands that form the eastern and northern parts of the Manawatu-Rangitikei area have dissected uplifted Late Tertiary marine sedimentary rocks. These rocks were deposited in the Wanganui Basin under the influence of global climatic cycles. The rocks dip gently to the south-southwest and the major rivers follow this trend. Many tributary streams, however, flow east-west, having picked out softer lithologies along strike. In general, elevation and dissection increases inland resulting in sharp narrow ridge tops, and deep narrow floored valleys. Mudstone lithologies cover the greatest area, now extensively scarred by landslide erosion. Sandstones and limestones locally form bluffs on the valley sides, and often form deep narrow gorges where tributary streams cut down to the major rivers.

Photo by Alan Palmer

View from Stormy Point looking west across the Rangitikei river aggradation terraces towards Mt Taranaki.

Terraces and terrace remnants

A broad arc of terrace lands extends from the foot of the northern Tararua Range, north and west towards Wanganui. At their inland edge, the terrace interfluves are uplifted, narrow and deeply dissected. The terrace interfluves become broader and lower towards the coast where uplift rates are lower. River terraces extend inland parallel to the major rivers and their tributaries, particularly those whose headwaters are in the greywacke-argillite ranges. Marine terrace strand-lines lie roughly parallel to the present coast-line.

The terraces are folded by northeast to southwest trending asymmetrical anticlines (Te Punga 1952, 1957). The eastern limbs of these anticlines are steep and underlain by thrust faults at depth (Melhuish et al 1996) and surface faults, while the dip on the western limbs is shallow. For example, on the eastern limb of the Pohangina Anticline, the 1Ma Potaka Pumice is tilted 70°, while the same unit on the western side dips at just 5°. Growth rates on the folds are such that drainage patterns are clearly affected (Jackson et al. 1998) and terraces as young as the Ohakean (late Last Glacial) are perceptibly tilted.

Photo by NZSSS

Rangitikei River and terraces near Ohingaiti, looking eastward to the Ruahine Range. The terrace in the lower left carrying the railway and State Highway 1 is the Last Glacial Ohakea Terrace. The white mudstone and brown sandstone exposed along the river are Lower Pleistocene, between 1.8 and 2.2 Ma. The Ruahine Range in the background is Mesozoic greywacke-argillite.

The marine terraces and older river terraces are mantled by up to 10m of loess, the loess mantle thickness generally increasing with terrace height (and age). The youngest river aggradation terrace, formed during the Last Glaciation, has little or no loess cover, and is often stony to the surface. In the north of the area, closer to sources volcanic ash, ash becomes a significant component of the loess.

Plains

The plains include low river terraces that extend up the major rivers and tributary streams, coastal low-lying land and coastal sand country. The lower reaches of the Manawatu River contrast strongly with the lower reaches of the Rangitikei River. The Manawatu River meanders towards an area of very slow uplift between Shannon and Foxton, an area that was a much extended Manawatu estuary following the post-glacial sea level rise. The lower reaches carry no gravel. In contrast, the Rangitikei River takes a direct route to the coast with a much steeper profile, and carries gravel to the coast. The Manawatu-Wanganui sand country covers a broad swathe of coastal land and extends up to 25 km inland. Dune morphology varies from shore parallel frontal dunes to barchans and longitudinal dunes farther inland. The sand overlies loamy, sandy or gravely alluvial deposits, and in some places loess or gravels from the terrace lands.

Geology

Mesozoic greywacke and argillite

The western side of the Ruahine and Tararua Ranges and foothills consist predominantly of greywacke with thin interbeds of argillite. Included within these rocks are spilitic basaltic lavas and associated cherts. Rare fossils within the assemblage of rocks show predominantly Triassic ages but there are also fauna and flora from the Permian to late Jurassic. The rocks are strongly deformed into tight folds, bedding plane shears and faults. Some zones have been sheared to the extent that melange has formed. These are commonly associated with the basalts and cherts.

The greywacke and associated rocks are generally deeply buried beneath the Manawatu-Rangitikei area, but are encountered in some water wells, particularly in Horowhenua, and in the Himitangi Anticline. There appears to be a very irregular topography to the top of the buried Mesozoic rocks, probably controlled by the growing anticlines, and thrust faults discussed above.

Pliocene to Early Pleistocene marine deposits

These rocks were deposited in the Wanganui Basin of which the Manawatu-Rangitikei area forms the central and eastern part. At the time the Wanganui Basin was a broad, relatively shallow continental shelf, where slow subsidence formed accommodation space for the accumulating sediment. The early rocks are almost entirely marine mudstones and silts with minor sandstones and limestones, and have been named Paparangi, Okiwa and Nukumaru Groups (Begg et al 2005). The Maxwell Group is largely of non-marine origin with common estuarine silts, fluvial over-bank silts and lignites, as well as shallow marine sands and silts. The Okehu, Kai-iwi and Shakespeare Groups consist of siltstones, marine and beach sands and deltaic to fluvial pumice sands.

All the sediments were laid down under the influence of global climatic cycles and have a sequence stratigraphic signature. By the Late Pliocene, global climatic cycles were well expressed; the sediments show clear and repeated cyclicity of sedimentation. Low stand systems tracts are represented by minor unconformities, shelly beach deposits and shallow marine sands; Trangressive Systems Tracts by shallow marine sands passing up into silts; Highstand Systems Tracts by mid to outer shelf silts; and Regressive Systems Tracts, where present, by a return to shallow marine sands. The Rangitikei (and Wanganui) sequences are some of the best in the world for demonstrating shallow marine deposition in global climatic cycles.

River systems that were feeding sediment in to the basin, from time to time carried large amounts of rhyolitic pumice. The part of the Taupo Volcanic Zone that was active at the time was a caldera at Mangakino, some 70 km northwest of Taupo. This centre erupted huge ignimbrites that engulphed the landscape over much of the Central North Island. Some ignimbrites reached as far as Auckland in the North and Napier in the east. The vast amounts of pumice deposited on the landscape from these ignimbrites and accompanying tephras were readily eroded by rivers with their headwaters in the area of deposition. At the time it appears that the headwaters of the ancestral Rangitikei River were eroding these pumice deposits. For example there are thick fluvial and shallow marine deposits of a one million year old pumice (Potaka Pumice), across the Rangitikei, all the way to near Palmerston North, where the ancestral river built a pumice rich delta into an embayment of the sea. The pumice deposits provide good time control for the sedimentary sequence because they can be dated by several different methods, and correlated using mineralogy and glass chemistry.

Through the Pliocene and Early Pleistocene, the Wanganui Basin was subsiding gently. Accommodation space created by this subsidence, allowed accumulation of the packages of sediment defined by the sequence stratigraphic model. However, the Basin depocentre migrated south to the Wanganui coast during this time, as uplift began in the north. By about 700 ka all the area north of Hunterville had emerged permanently from the sea, and areas to the south were only inundated at the higher highstands of sea level. As described above, pumice rich sands, particularly from about 1.5 Ma to 700 Ma rapidly prograded the coast-line.

By about 400 ka, rivers north of Palmerston North and Marton were largely confined to their present valleys between growing anticlinal ridges. These anticlines generally have shallow (2-5°) dipping west to northwest flanks and steeper (20-70°) east to south eastern flanks. This asymmetry is driven by either westward dipping reverse faults, or blind thrusts beneath the structures (Melhuish et al 1996).

Fluvial aggradation terraces

The rivers responded to global climatic change by aggrading in cool glacial conditions and down cutting in warm interglacials. Aggradation was driven by the tremendously increased supply of sediment eroded from the now deforested greywacke-argillite mountain ranges and the soft Tertiary to Early Pleistocene rocks to the north. During interglacials, returning forest and shrub-land, stabilised the ranges and dissecting Tertiary-Early Pleistocene sediments. The rivers were able to cut down through their recently deposited gravels, forming river terraces. The main aggradation terraces are normally paired on either side of the river valley, but minor and unpaired degradation terraces were left behind on valleys sides as the rivers cut down.

The sensitivity of the region to climatic fluctuations, coupled with the continual uplift and preservation of aggradation surfaces has resulted in a very clear and complete record of events (Te Punga 1952; Milne 1973a, 1973b; Palmer 1985; Pillans; 1994). The fluvial aggradation terraces formed by the Rangitikei River during the last 400,000 years may be one of the best developed and continuous sequences in the world (Plate above). A part of Milne's (1973) map of the terraces is reproduced for this booklet. In the southern North Island all fluvial aggradation surfaces older than the culminating surface of the last stadial (Ohakean), generally have loess cover.

Marine Terraces

Once the region began to uplift, accommodation space for marine sediment almost disappeared. Eustatic rises in sea level resulted in the sea eroding landward, producing a wave cut platform in the underlying sediment, and a former sea-cliff at its inland margin. The wave-cut surfaces are overlain by either beach or dune sands, or marine and fluvial gravels. Above these basal units, a variety of deposits are recorded, including estuarine sediments, sands, lignites, tephras and loess.

Broad flights of marine terraces occur along much of the southern North Island coastline. The terraces are nowhere better expressed than the coast-line northwest of Wanganui, where Pillans 1983, 1990) mapped twelve marine terraces spanning the last 700,000 years. The multiple terraces indicate a history of fluctuating eustatic sea level and uplift. Pillans did not map east of Wanganui River where terrace relationships to underlying deposits are not so clear. Recently, Palmer et al 2006 using tephras in overlying cover beds, and Begg et al 2005, mapping surfaces have correlated the marine terraces right across the basin to Palmerston North. The boundaries between marine terraces and fluvial aggradation terraces of similar age are often subtle, particularly in areas of lower uplift, and where the difference in age between sediments below the wave-cut surface, and those above, is minimal.

Loess source

There is little doubt that loess was derived from growing aggradation surfaces. Vella (1963), Milne (1973a, 1973b), Palmer (1985), and Lowe et al (2008), have shown that successive aggradational and degradational phases in southern North Island can be correlated with cooling and warming phases elsewhere in the world. Alluvial aggradation, described above, resulted from periglacial conditions lowering the forest line, increasing the rate of mechanical breakdown, thus increasing erosion rates and overloading the river headwaters with detritus. The tightly folded and extensively faulted greywacke-argillite s in the ranges was easily shattered by frost action to produce screes. Large low angle fans were produced by rivers with wide-braided channels. In their middle reaches the rivers passed through, and soft dispersible muds and sands in the Tertiary hill country adding huge volumes of sediment. Mechanical abrasion in the river beds readily produces mixtures of sand silt and clay. The finer products carried by the rivers were stranded on bars during floods and channel avulsion. There they dried and became an ideal loess source.

As the climate warmed following each glacial period, the landscape quickly revegetated with forest and was largely stabilised. The rivers, unencumbered by such a high sediment load, cut down through the just-laid aggradation gravels, substantially reducing channel width. The floodplains themselves became vegetated, limiting loess production. There is little loess on the last aggradation surface.

Loess and terrace chronology

Summary of the following stratigraphy is given in Table 1 at the end of this section.

The initial loess and terrace chronology was developed in a very influential thesis by Milne (1973a), followed by a scientific report including terrace maps and surveyed terrace heights (Milne 1973b). Some of the stratigraphy had already been introduced by Te Punga (1952). The terrace and accompanying loess names used by Milne, subsequently were adopted as chronostratigraphic units in the Pleistocene of the North Island. However, Milne designated no type sections. He, and anyone following has never formalised this chronostratigraphy.

The marine terraces have been dated indirectly by correlation to the marine oxygen isotope curve, supported by correlation of tephras in the terrace cover-beds, mostly dated elsewhere (Pillans 1990). It has become convenient to discuss the terrace ages in terms of the Marine Oxygen Isotope (MOI) Stages (Plate below).

In the southern North Island, there are three river aggradation terraces representing the Last Glacial, and these are matched by three loesses. They are named, from youngest to oldest, Ohakean (MOI 2), Ratan (MOI 3) and Porewan (MOI 4).

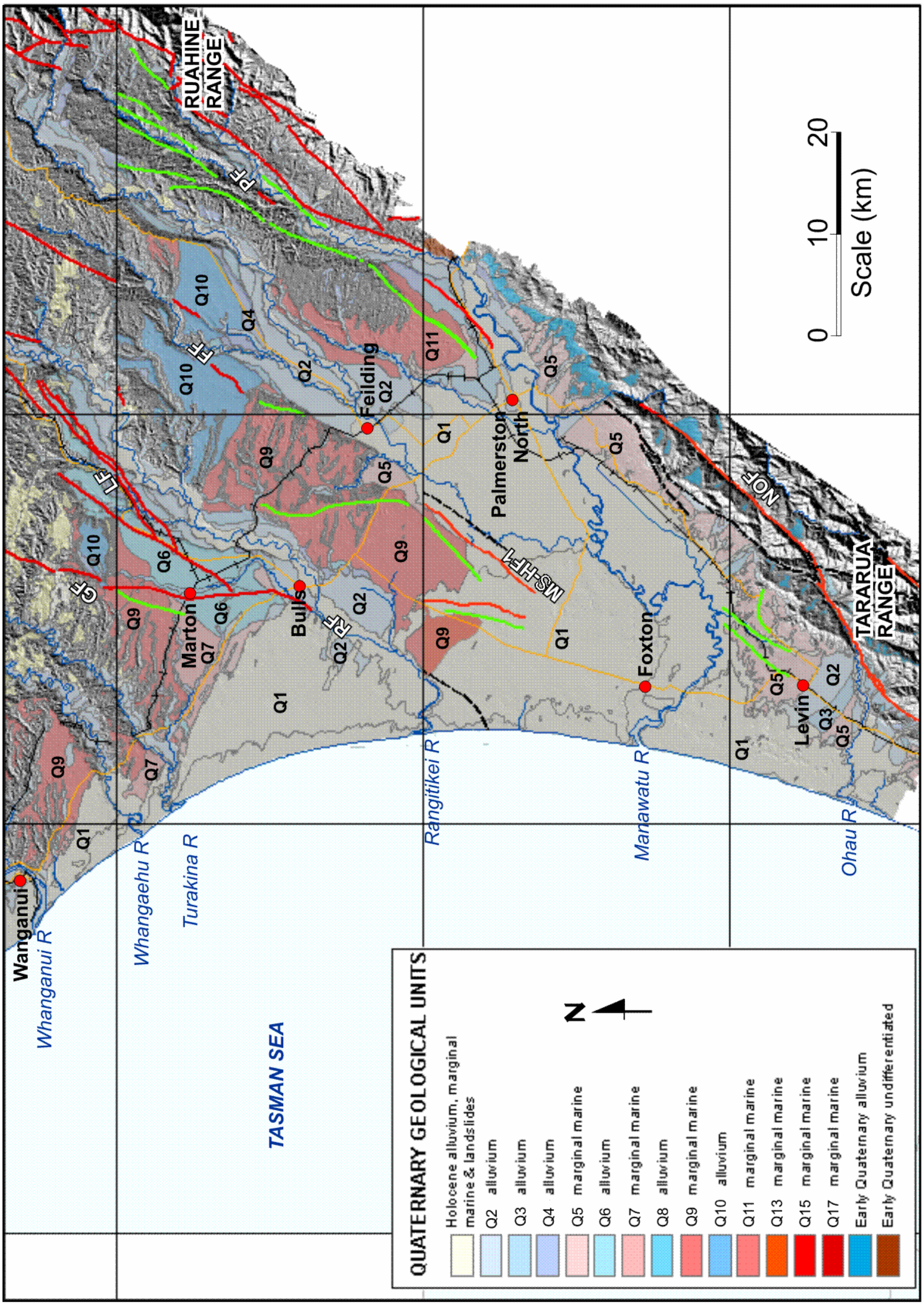
The loess contains little material datable by the radiocarbon method. Either oxidising conditions have been maintained throughout the deposition and weathering of the loess, or reducing conditions, conducive to preservation of datable material, developed after deposition and weathering. The uppermost (Ohakean) loess layer was deposited between 25,500 and 9,450 radiocarbon years B.P. based on dates in Rangitikei Valley (Milne and Smalley 1979).

Several studies elsewhere have attempted to pinpoint the timing of cessation of aggradation at the end of the last glacial cycle. Some of these (for example Hammond, 1997 in Hawkes Bay; Eden et al 2002 and Marden et al 2008 in Gisborne) have used the presence of the 14,700 yrs B.P 14C dated (ca 17,000 cal years) Rerewhakaaitu Tephra as the basal tephra overlying aggradation deposits, to postulate cessation of aggradation just prior to this time. Other studies have applied Optically Stimulated Light (OSL) to reach similar conclusions (e.g. Litchfield and Berryman 2005). There is considerable supporting evidence from elsewhere in New Zealand and in marine cores offshore for these dates (Alloway et al 2007).

The onset of the last stadial is more uncertain. The 22,500 yr BP 14 C date (ca 26,500 cal yrs) Kawakawa Tephra fell during near maximum cold conditions (Pillans et al 1993). Cold conditions were also established when the 26,000 yr old 14C date Omataroa Tephra was erupted (Alloway et al 2007).

Rata loess underlies Ohakea loess in most places. The loess is more weathered throughout, interpreted by Palmer (1985) to mean that it was deposited in less severe climatic conditions. A weak paleosol developed in Rata loess before deposition of Ohakea loess began. In Central North Island, loess deposition began shortly before the widespread Rotoehu Tephra erupted. There remains considerable dispute on the age of this tephra, ranging from finite and infinite radiocarbon dates of ca 42,000 years to a uranium series date on enclosing lava flows on Mayor Island of ca 60,000 years B.P. (Wilson et al 1992). A stratigraphic age of 50-55,000 years B.P. seems most reasonable since the tephra occurs in loess on 60,000 year old marine terraces on the East Coast of the North Island (Berryman, 1992). The 60,000 year old marine terrace near Wanganui has a cover of Ratan and Ohakean loesses (Pillans 1990), and Rotoehu Tephra occurs in the base of Ratan loess at a site nearby (Palmer and Pillans 1996).

Porewa loess is found on all Last Interglacial marine terraces; there are three or four terraces that span the interval 80,000 – 125,000 years depending on local uplift rates. After formation of the 80,000 yr B.P marine bench (Pillans 1990), sea levels fell markedly, and the Marine Oxygen Isotope (MOI) curve infers considerable ice volumes on land by 70,000 yrs B.P (MOI stage 4) (Shackleton et al 1990). By 60,000 yrs B.P considerable warming had taken place and a new marine terrace was formed (Pillans 1990). Therefore, Porewa loess was deposited between 80,000 and 60,000 years ago followed by a period of strong soil formation until ca 50,000 yrs B.P.



Quaternary geological units in the Manawatu-Wanganui Region. The even numbered units and Q3, represent river aggradation terraces. The odd numbered units excluding Q3 represent marine terraces. The Q numbers equate to Marine Oxygen Isotope Stages. The red lines are major faults (GF = Galpin Fault; RF = Rangitikei Fault; FF = Feilding Fault; MS-HF = Mt Stewart – Feilding Fault; PF = Pohangina Fault; NOF = Northern Ohariu Fault. Green lines are crests of active anticlines (source: Begg et al 2005).

The chronology of the older river aggradation terraces and loesses has undergone some revision since Milne's original work. There are two reasons for this:

1. Most of the loess bordering the Rangitikei River where Milne worked is in the "Pallic" facies; strongly mottled and poorly drained, where soil horizons are no longer clear. Pillans (1990) and Palmer and Pillans (1996) worked on "Allophanic" facies loess west of Wanganui. Particularly on the higher marine terraces, the loess stratigraphy is clear because pedogenic soil horizons are well preserved and expressed.

2. Milne's chronology at the base of his sequence was tied to a 230,000 yrs B.P fission track date on the "Mt Curl Tephra" (Milne 1973c). After considerable controversy, and some years later, this tephra was re-dated using an improved fission track technique at ca 340,000 yrs B.P (Kohn et al 1992) effectively a whole glacial cycle older. The tephra was also renamed Rangitawa Tephra for the location where it was first discovered by Te Punga (1952, 1962).

Milne (1973a, 1973b) originally described three loess units, the Greatford, Marton and Burnand representing the Penultimate Glacial (MOI stage 6) in Rangitikei Valley; each with a corresponding river aggradation terrace. However, he also mapped a minor terrace between the Greatford and the Porewa, he named Cliff, that apparently generated little loess. He recognized that considerable weathering took place between the deposition of Marton and Burnand loesses. It has now become clear that the only MOI stage 6 river aggradation terrace and loess is the Marton. Thus the Cliff terrace was formed in the Last Interglacial; probably the cool stadial MOI stage 5b. The Greatford terrace and loess formed in MOI stage 5d, the earlier and colder stadial during the Last Interglacial. The Burnand terrace thus formed in MOI stage 8 (Pillans 1994) and the weathering and time interval that Milne recognised between Burnand and Marton river terraces and loesses, actually represents weathering during an Interglacial (MOI stage 7). Recent mapping for Qmap by John Begg, Dougal Townsend and Alan Palmer (unpublished data) (hereafter Qmap) in the area west of the Rangitikei River, has borne this out. Ages assigned to these terraces by Pillans (1994) are as follows: Cliff 90-100 ka; Greatford 110-120 ka; Marton 140-170 ka; Burnand 240-280 ka. A weathered tephra, found at only two localities in the region, in the weathered zone between the Marton and Burnand loesses, could correlate, using glass chemistry, to the 230 ka Mamaku Ignimbrite eruption that formed Lake Rotorua (unpublished analyses by author).

The MOI stage 9 Brunswick marine terrace was mapped west of Marton by van der Neut (1996) and by Qmap (unpublished). In the area north of Marton it was apparently overwhelmed by the Burnand river aggradation gravels on the western side of Rangitikei River. However, the Brunswick sea cliff is prominent as an east-west oriented riser near Tutaenui (Pillans 1994).

Two river aggradation terraces, and loesses, formed in MOI stage 10, the Waituna, inferred to be 360-370 ka, and the Aldworth inferred to be 340-350ka by Pillans (1994). These terraces are seldom more than remnants west of Rangitikei River, but are extensive farther east. Near its upper contact, and in a weathered horizon, the Waituna loess contains the 340 ka fission track dated Rangitawa Tephra, mentioned above.

The terrace, loess and cover-bed stratigraphy of MOI stages 9 -11 is further elucidated by the presence of four other relatively widespread rhyolite tephras in the sequence above the

Rangitawa Tephra. The Lower Griffins Road Tephra was deposited at the cessation of river aggradation that formed the Aldworth terrace in MOI stage 10 (Plate below). It is also found in beach sand above the wave-cut surface of the Braemore (MOI stage 9c) marine terrace (Palmer et al 2006). Lower Griffins Road Tephra was correlated by Froggatt (1983) to a tephra near Te Piki, but it has not yet been correlated to a Central North Island source and ignimbrite.

The Middle Griffens Road Tephra is 5-10cm thick at sections in Turakina Valley, where it occurs within dune sand. At Griffins Road it lies within silty sediments that may be alluvium or loess. Near Feilding the tephra is enveloped in lignite that records a cooling from a full rimu-broadleaf forest to a *Nothofagus* dominated forest (Elliot & Palmer 1998) which is interpreted to represent the cooling from the OI 9c interglacial to the OI 9b stadial. Middle Griffins Road Tephra was correlated to the Matahina Ignimbrite by Froggatt (1983). This correlation is supported by glass chemistry in this study, and a fission track age on the ignimbrite of 0.34 ± 0.02 Ma by Black *et al* (1996). Its source is the Okataina caldera.

Photo by Alan Palmer

Griffins Road Quarry. The Upper Griffins Road Tephra is above Brad Pillan's head. The Middle Griffins Road Tephra is at his waist level, and Brent Alloway is sampling the Lower Griffins Road Tephra just above the Aldworth river gravels (OI 10).

Upper Griffins Road Tephra, 10-30cm thick throughout the area, is often partially cemented by silica. At the type section the tephra rests on a strongly developed paleosol in loess or alluvium, and is overlain by loess. At most other sites the tephra occurs at the top of a thick sequence of dune-sands, usually showing signs of soil formation directly below the tephra. At sites described by Bussell & Pillans (1992) near Fordell, Upper Griffins Road Tephra directly underlies Fordell Tephra. For these reasons, the tephra probably fell during OI 9a. Berger *et al.* (1992) reported a TL age (on loess) of 328± 43 ka directly below the tephra. The Upper Griffins Road Tephra was correlated to the Kaingaroa Ignimbrite by Froggatt (1983). The correlation is supported by glass chemistry here, and a fission track age on the ignimbrite of 0.31 ± 0.01 Ma by Black *et al* (1996). Its source is the Reporoa caldera.

Fordell Tephra directly overlies Upper Griffins Road Tephra and is found as a 5-10 cm thick ash between Wanganui and the Turakina River. At Fordell it occurs within lignites and silts that Bussell & Pillans (1992) interpret as early OI 9a. They estimate an age of 300 ka, but ages on OI stages would indicate a slightly older age of ca 310 ka. The source of the Fordell Tephra is unknown. It does not correlate to Mamaku Ignimbrite, which is too young (0.23 Ma) and has different glass chemistry.

MOI Stage	**Marine Terrace**	**River Terrace**	**Loess**	**Coastal Dunesand**	**Rhyolite Tephra**
1				Foxton	Taupo
2		Ohakea	Ohakea	Koputaroa	Kawakawa
3a		Rata	Rata		
3b	Rakaupiko			Huxley	Rotoehu
4		Porewa	Porewa		
5a	Hauriri			Rapanui	
5b		Cliff			
5c	Inaha			Rapanui	
5d		Greatford	Greatford		
5e	Rapanui			Mt Stewart	
6		Marton	Marton		
7	Ngarino			Brunswick	
8		Burnand	Burnand		Mamaku
9a	Brunswick				Fordell, UGR
9b			?	Mt Curl	MGR
9c	Braemore				LGR
10a		Aldworth	Aldworth		Rangitawa
10b		Waituna	Waituna		
11	Ararata				

Table 1 . Summary stratigraphy. For ages refer to the text. UGR = Upper Griffins Road; MGR = Middle Griffins Road; LGR = Lower Griffins Road. (Adapted from Pillans 1994).

Rangitikei River views

(see enclosed coloured map of Milne (1973).)

As we travel south of Utiki, , on the left side of the bus we will get views of the Rangitikei River Valley. Depending on the weather we will select a vantage point to view the Rangitikei River, and look across to the sedimentary sequence exposed in the cliffs which here is 1.8 – 2 Ma. We will point out the Last Glacial Ohakea Terrace, which has multiple treads separated by small risers. A.S.Palmer sampled glass within the thin loess cover on the highest Ohakea tread, in order to date the culmination of maximum aggradation. A small concentration of glass shards was recovered and analysed, but it was uncertain as to whether they belonged to the ca 17 ka cal Rerewhakaaitu Tephra or the ca 13 ka Waiohau Tephra of similar source and composition.

The lower treads of the Ohakea Terrace set have little or no cover over very stony aggradation gravels. Soils on the stony terrace tread of the Ohakea terrace are divided into three series in the Manawatu – Rangitikei District, based on colour of subsoil weathering and P retention. As rainfall increases from 900 mm to above 1500mm subsoil colours redden from 10YR with low P retention (Ashhurst soils) to 7.5YR with moderate P retention (Kawhatau soils) and 5YR with high P retention (Kopua soils). The P retention here is a reflection of leaching rather than increased volcanic input.

Selected soil properties for Kawhatau stony silt loam. The analyses are not from this site. (Landcare Research National Data Base. Lab No. SB 09943).

Selected soil properties for Kawhatau stony silt loam			
Soil Property	Topsoil	Subsoil	
		Upper	Lower
Bulk density (Mg m^{-3})	1.6	1.6 – 1.5	NA
Macroporosity (%)	NA	5 - 13	NA
Readily available water			
To 50 cm depth	-----------------------35 mm		
pH	6.0 – 5.2	5.4 – 5.3	5.1 - 5.2
Organic Carbon (g kg^{-1})	9.5 – 7.0	3.7 – 2.1	1.0 - 0.9
CEC (cmol kg^{-1})	41 - 28	17 - 12	11 - 8
TEB (cmol kg^{-1})	32 – 14.7	3.8 – 1.1	0.6 – 0.9
Base saturation	77 - 51	21 - 9	5 - 12
P retention (%)	54 - 55	80 - 90	85 - 62

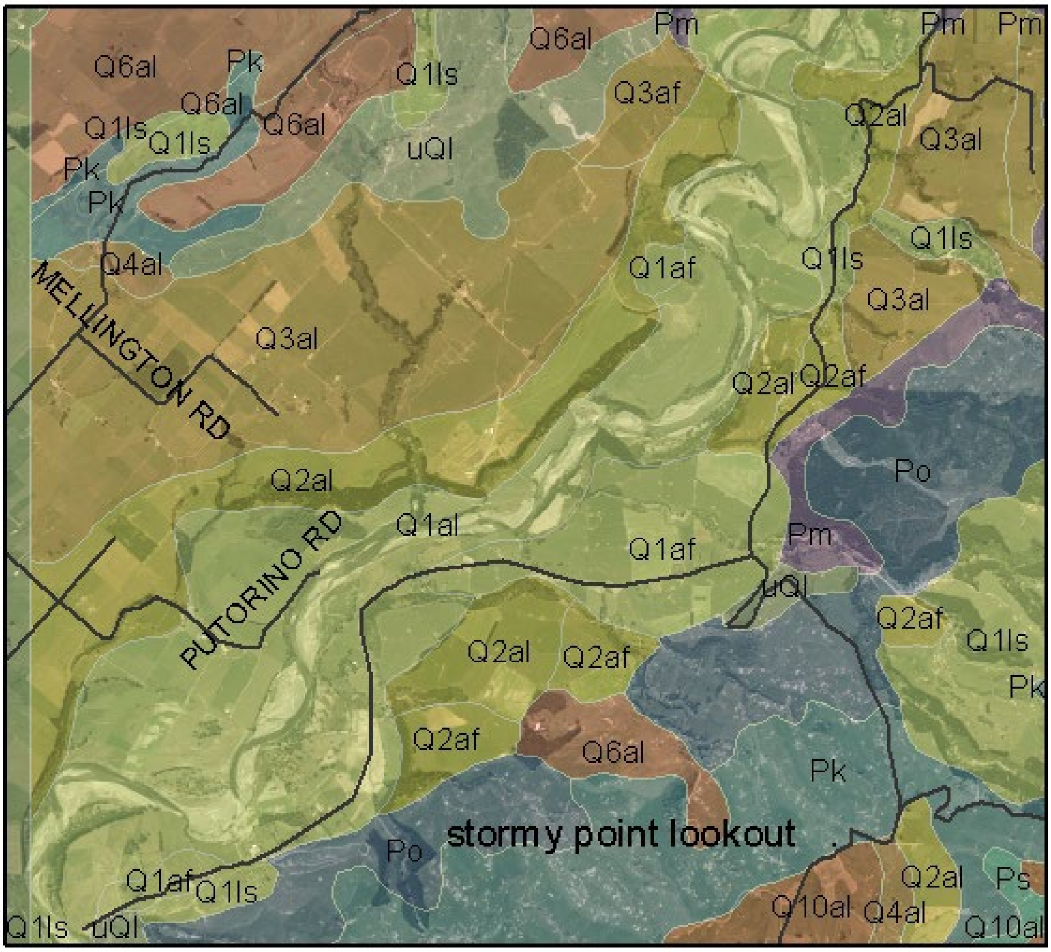
Because of their stony nature, the use of Kawhatau soils is limited mostly to grazing. They are excellent wintering soils for dairy cows but tend to dry off in summer, requiring supplementary feeds to be imported. Cropping is not an option due to stoniness. Perennial uses such as orchards are a possibility but these soils usually occur at rainfalls of 1100 mm and above, meaning that fungal diseases can be a problem. A few growers are trying grapes on these soils and meeting with success.

2.4 Stop 2. Stormy Point Lookout

Contributed by Grant Cooper,and Malcolm Todd, Horizons Regional Council

The terrace sequence and underlying geology will be explained from this vantage point. The lookout is on the Waituna river aggradation terrace, on the eastern bank of the Rangitikei River. A now vegetation covered roadside exposure has a complex loess stratigraphy, because of deposition then erosion of loesses and their soils. Near the base of the loess cover, are the Griffins Road Upper and Middle Tephras, and the Rangitawa Pumice. We cannot examine the section here because it is too dangerous with traffic passing by.

On a clear day Mt Taranaki can be seen on the horizon to the west, and Mt Ruapehu to the north. The terrace sequence on the western side of the river at this point is almost complete (refer to Table 1 and text above for terrace names and ages). The river aggradation terraces overlie shallow marine and terrestrial sands and silts, containing pumice alluvium and airfall tephras. The sediments dip downstream gently at 2-4o, and in this area are from 0.8 – 1.5 Ma.



Geological units visible from Stormy Point, Courtesy of Geological and Nuclear Sciences QMap Hawkes Bay legend.

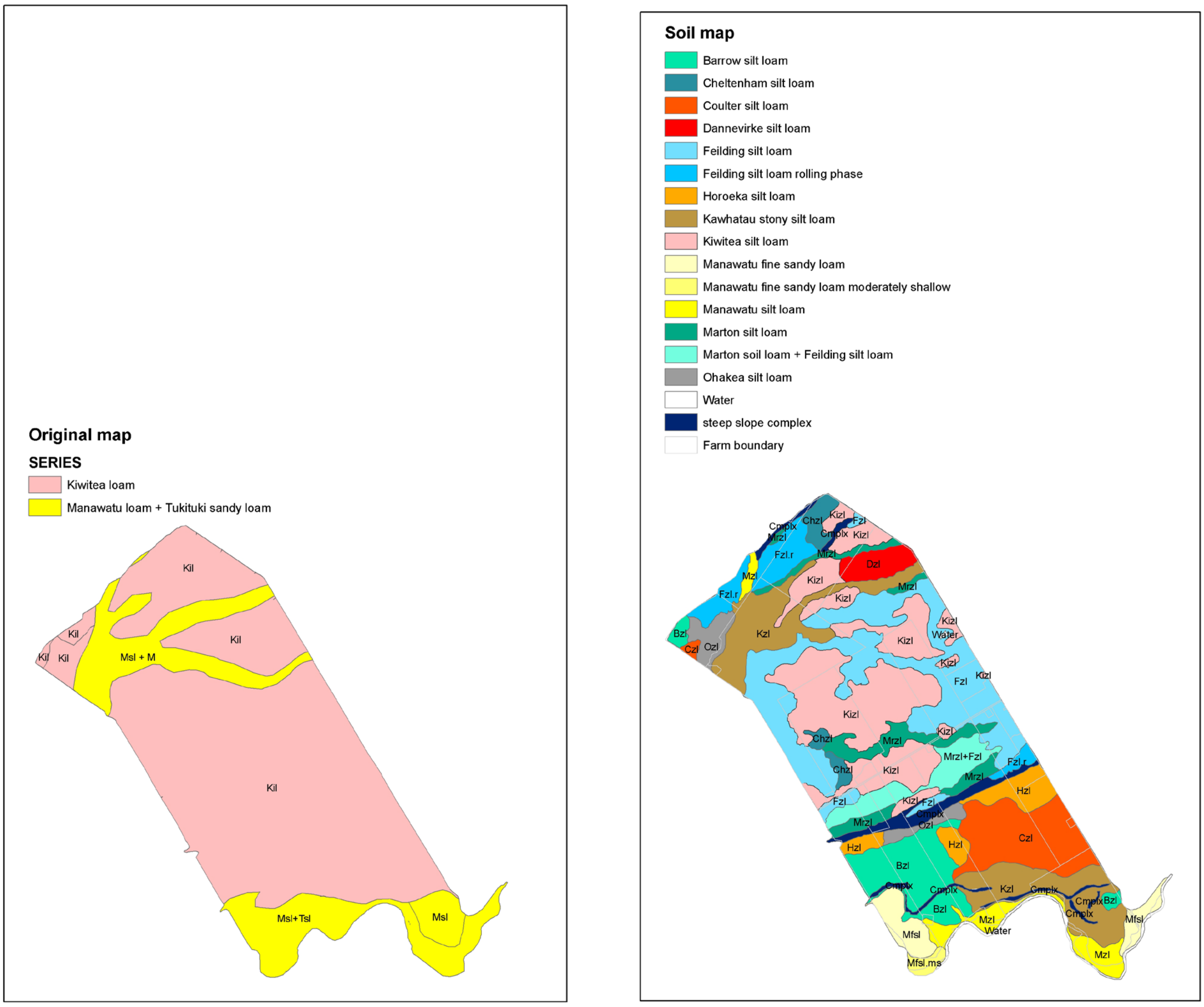
Geological units visible from Stormy Point

Draft Qmap Unit	Name	Age years before present
Q1	Quaternary sediments dated oxygen isotope 1	0 to 12k
Q2	Quaternary sediments dated oxygen isotope 2	12 to 24k
Q3	Quaternary sediments dated oxygen isotope 3	24 to 59k
Q4	Quaternary sediments dated oxygen isotope 4	59 to 71k
Q6	Quaternary sediments dated oxygen isotope 5	128 to 186k
Q10	Quaternary sediments dated oxygen isotope 10	339 to 362k
uQ	Undifferentiated Quaternary sediments	<300k
Ps	Shakespeare group	245 to 620k
Pk	Kai Iwi group	620k to 1m?
Po	Okehu group	<1.8m
Pm	Maxwell group	Around 1.8 m
Prn	Nukumaru group	
Pku	Upper Okiwa group	
Prm	Lower Okiwa group, including Mangrere formation	
Ppm	Paparangi group, including Mangaweka mudstone	<3.6m
Prt	Tangahoe mudstone	>3.6 m
Af	fan	
Al	alluvium	
l, ls	landslide	

2.5 Transit from Stormy Point Lookout to Branch Road Walkway

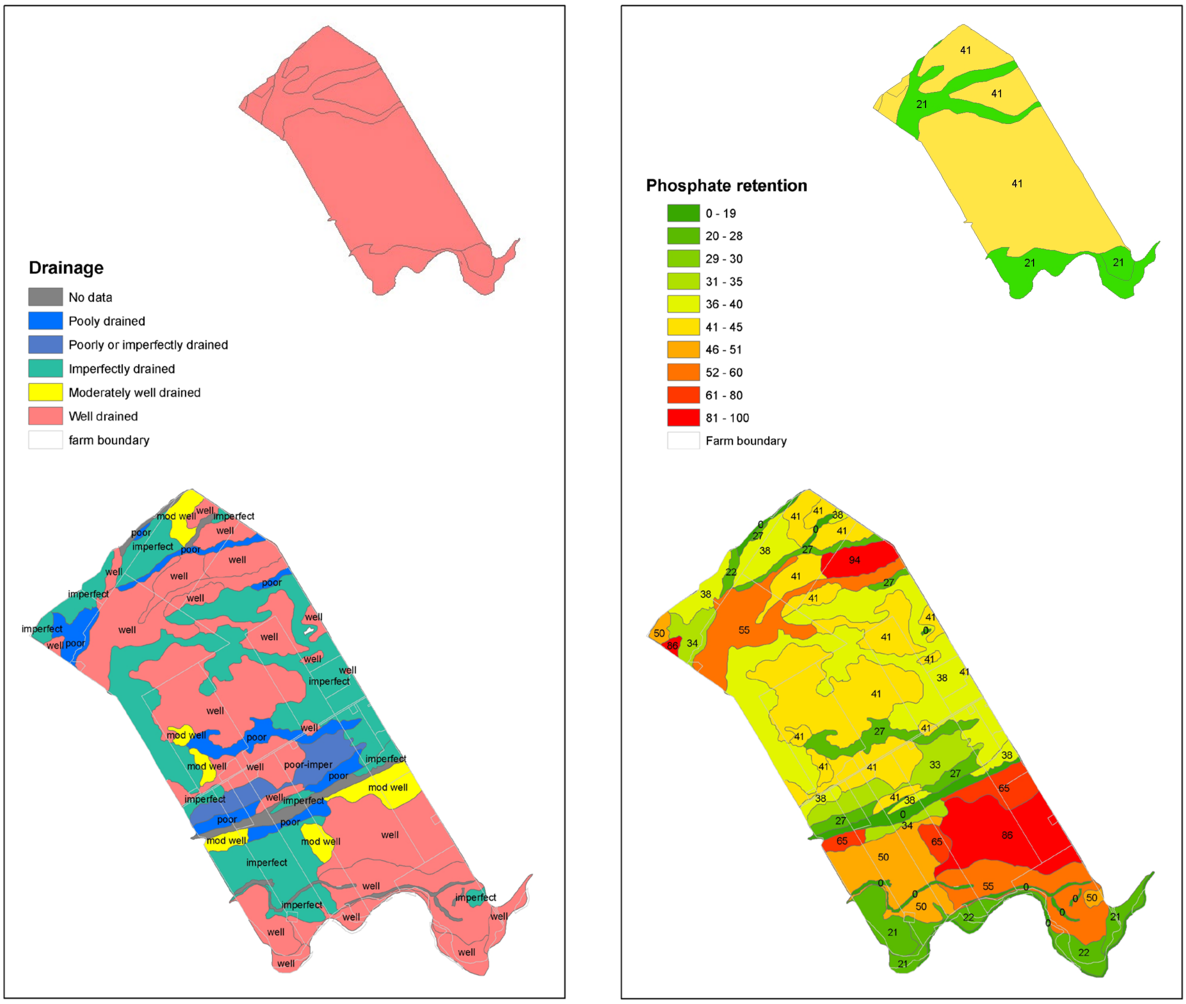
After lunch at Cheltenham we head north to “town” of Kiwitea, complete with 15 streets, none of which are formed, and a couple of hundred land parcels. A town was anticipated at this site if the main truck rail line arrived here. It never did!

The soils of Kiwitea town are LUC Class 1c elite soils formed in water-reworked volcanic loess, formerly mapped as Kiwitea series mafic brown soils. This area was mapped at 1:25,000 scale by Asoka Senarath for his PhD. The NZLRI had the area mapped as 24% Manawatu and Tukituki recent soil and 76% Kiwitea loam. Both map units were well drained, resilient to pugging and the recent soils had P retentions in the 20s while the Kiwitea loam was in the 40s.



Comparison of the results of mapping at 1:63,360 scale for the New Zealand Land Resource Inventory and at 1:25,000 scale by Asoka Senarath,

These soil properties were fundamentally changed after more detailed mapping, when the area of Kiwitea soil was down to 21% and the area of recent soils was 7%. That resulted in the area of well drained soil dropping to 50%, with 29% imperfectly drained and some 7% poorly drained. The P-retentions ranged from 94 to in the 20s and the vulnerability to pugging ranged from very resilient to vulnerable.



Comparisions of Asoka Senaraths mapping (main picture) with NZLRI (insert) showing the huge variability in drainage status and P retention present within the NZLRI map units.

Coulters Line

The Ohakean aggradation surface of the Oroua River is tilted gently away from the river, towards the southwest, on the southwestern flank of the Pohangina Anticline. The terrace is broad and flat, but is a terrace set rather than a single tread. The higher treads are covered in up to 2m of loamy alluvium and or loess and or tephra. At a relatively small scale, the soil pattern appears to show a progression from well drained Coulter; moderately well drained Horoeka; imperfectly drained Barrow and poorly drained Ohakea soils (Senarath and Palmer 2005). However, on more detailed survey at 1:10,000 and 1:5000 scale, parts of the surface are shown to be a soil complex, with an intricate and unpredictable soil pattern.

The Coulter soils are deep, silt loam to silty clay loam textured soils with moderately developed nut structures. They have medium bulk densities and high plant available water. P retention is high indicating the presence of allophane clay. They have slightly acid topsoil pH, but are more acid and with lower Base Saturation in the subsoil.

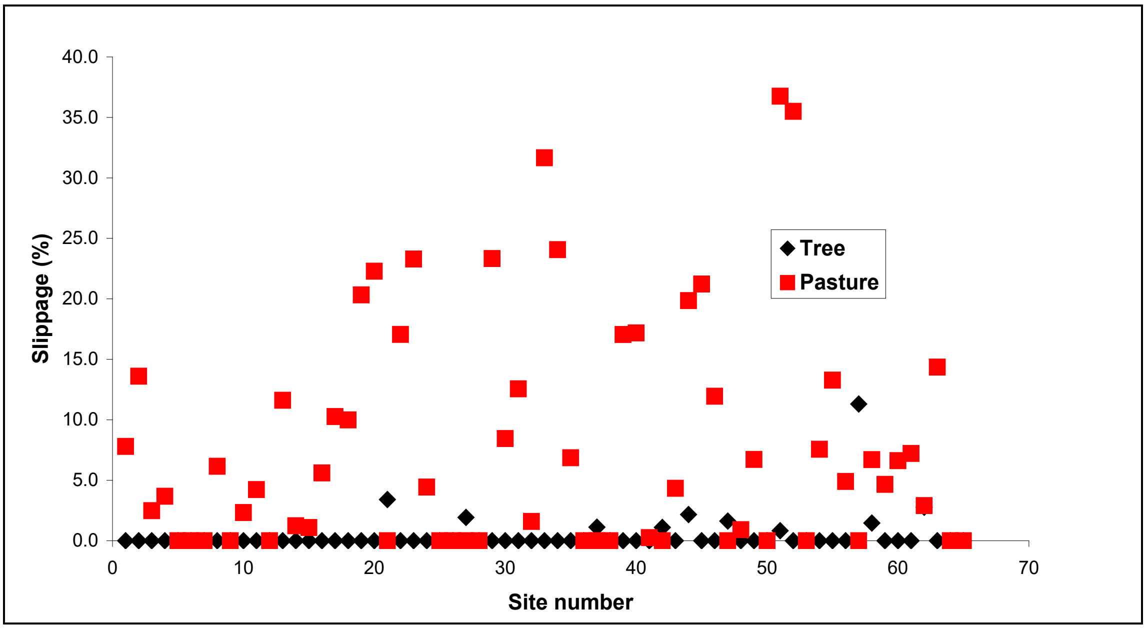
Dairying dominates the use of these soils. Until recently there were also cut flowers, some field vegetable crops, deer, sheep and beef, but the economics and logistics of these land uses has declined in comparison to dairying. These soils do have tremendous potential for a wide range of other uses, should economics permit, and if infrastructure to handle the product is available.

In the New Zealand Soil Classification the Coulter Soil keys out as both a Typic Orthic Allophanic Soil and a Pedal Allophanic Brown Soil.

Selected soil properties for Coulter silt loam. Data from Senarath and Palmer 2005

Selected soil properties for Coulter silt loam			
Soil Property	Topsoil	Subsoil	
		Upper	Lower
Bulk density (Mg m^{-3})	0.9	0.9	1.3
Macroporosity (%)	6-7	11	5-8
Readily available water			
To 50 cm depth	----------------------60mm		
To 100 cm depth	-------	-------------------------113mm	
pH	6.0 - 6.1	6.5	5.3 - 6.0
Organic Carbon (g kg^{-1})	6.6 - 5.5	1.5	0.9 – 0.3
CEC (cmol kg^{-1})	25 - 21	13	10 -12
TEB (cmol kg^{-1})	12.8 – 9.8	5.9	3.5 – 4.5
Base saturation	51 - 46	45	35 - 37
P retention (%)	86 - 87	90	87 - 33

On the right on the way down Coulters line we pass through some mature poplars planted on LUC Class 6e14 land for erosion control. Recent research by Agresearch and HortResearch found 8% slip scars under pasture and less than 1% under mature poplars planted at more than 30 stems per hectare.



Extent of slippage (%) on tree and pasture sites at 65 sites in Manawatu and Wairarapa in winter 2007 (from Douglas et al 2008).

At the lower end of Coulters Line lie the remains of trials done by Eddie Suckling in 1946 to 1949 on how to stabilise eroding gullies. A series of brush dams and drop structures, with willows in support, were constructed up the main gully. There were also plantings in neighbouring gullies, gabions, stream training and at least one large concrete flume was constructed, which is still working and visible below the road. As the photos below indicate, much of the work was overwhelmed, undercut or bypassed by the stream, but in this dynamic environment persistence pays off. The gully is now forested and stabilised, and you would not guess that it was once raw and severely eroding.

Fig. 34: No. 6 Dam shortly after flood waters reached the dam 7/1/49.
47

Fig. 11: Building No. 1 dam. A simple 2 row type.
20

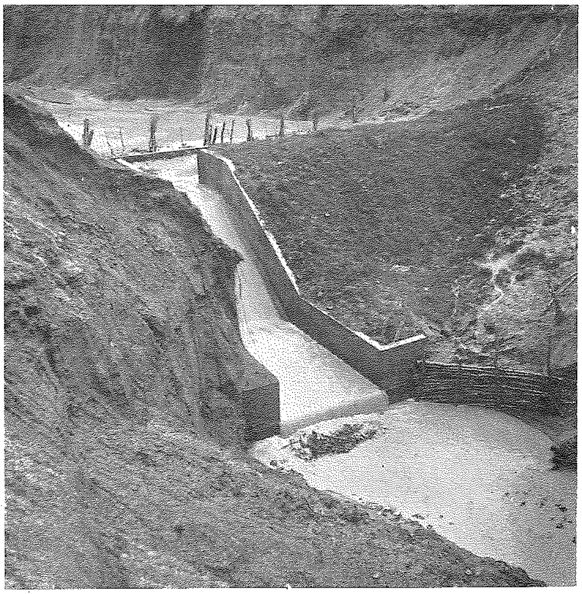


Fig. 22: Concrete dam and spillway in action shortly after construction.

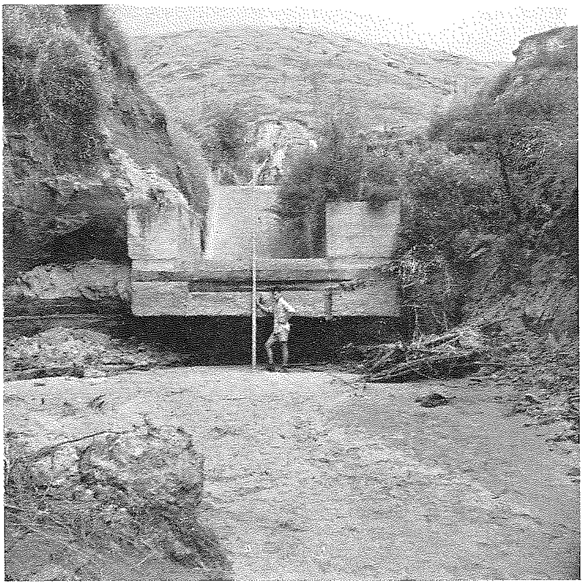
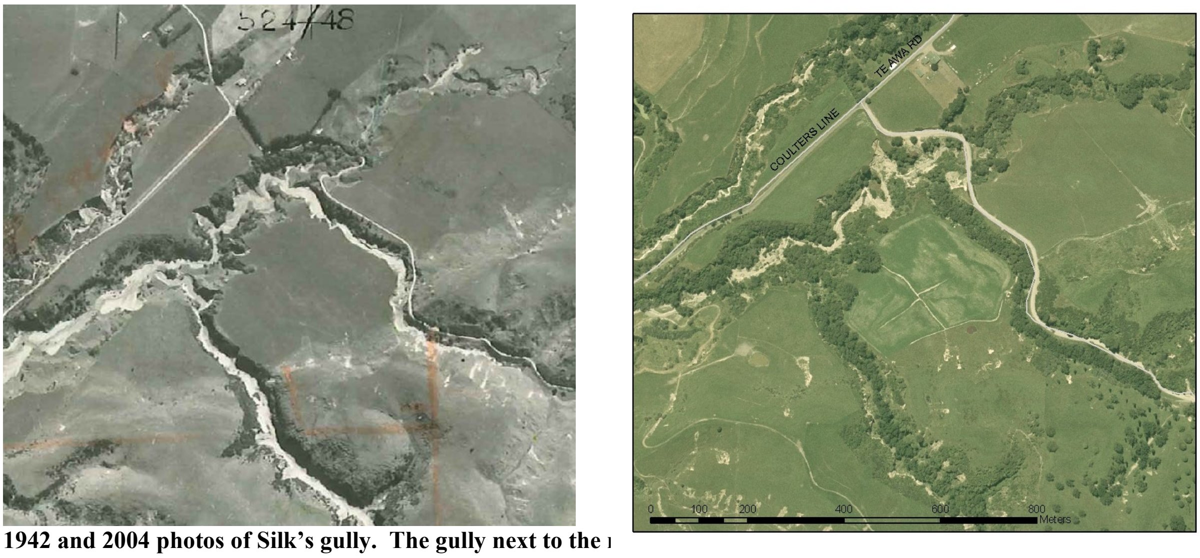


Fig. 24: Taking levels of gully floor after flood damage.
35

Before and after photos of concrete flume in Silk's gully, 1949, showing the ability of unconsolidated sand to scour.

We may have time to look over a gully head and the stream where Sucklings work was carried out.



1942 and 2004 photos of Silk's gully. The gully next to the
were constructed.

The soils on this flat are mapped as Kawhatau series, an allophanic brown soil developed in gravel.

2.6 Stop 3 Branch Road

The trip along the ridge road to this stop is basically the catchment boundary for the Pohangina (east) and Oroua (west) rivers, both of which drain into the Manawatu river. The exposed Castlecliffian sands are dipping to the west at 2-5 degrees. At Branch Road we will stop and discuss options for hill country land use and the influence of the rock type on the soils to the east (Pohangina steepland soil) and to the west (Raumai and Halcombe hill soils).

Properties of the main soils around Branch Road

Series and type	Halcombe hill soil	Raumai hill soil	Pohangina Steepland soil
Parent material	Loess colluvium over unconsolidated sandstone	Unconsolidated sandstone	Unconsolidated sandstone
Slope	Moderately steep	Moderately steep	Steep to very steep
Typical Profile	Silt loam topsoil over 20 to 40cm sandy clay loam subsoil over sandy loam over sand	Silt loam topsoil over sandy loam over sand	Sandy loam topsoil over sandy loam over sand
Drainage	Moderately well to poorly drained	Moderately well to very poorly drained	Moderately well to very poorly drained
P retention	Low to medium	Low	Low
Potential mean stocking rate	12.5	8.5	6
LUC Unit	6e2	6e8	7e16
NZSC (from Fundamental Soils layer)	Pallic Perch-Gley Argillic	Pallic Immature Typic	Pallic Immature Mottled

We will discuss SLUI Whole Farm Plans in the context of assisting land use charge.

2.7.Transit from Branch Road Walkway to Palmerston North

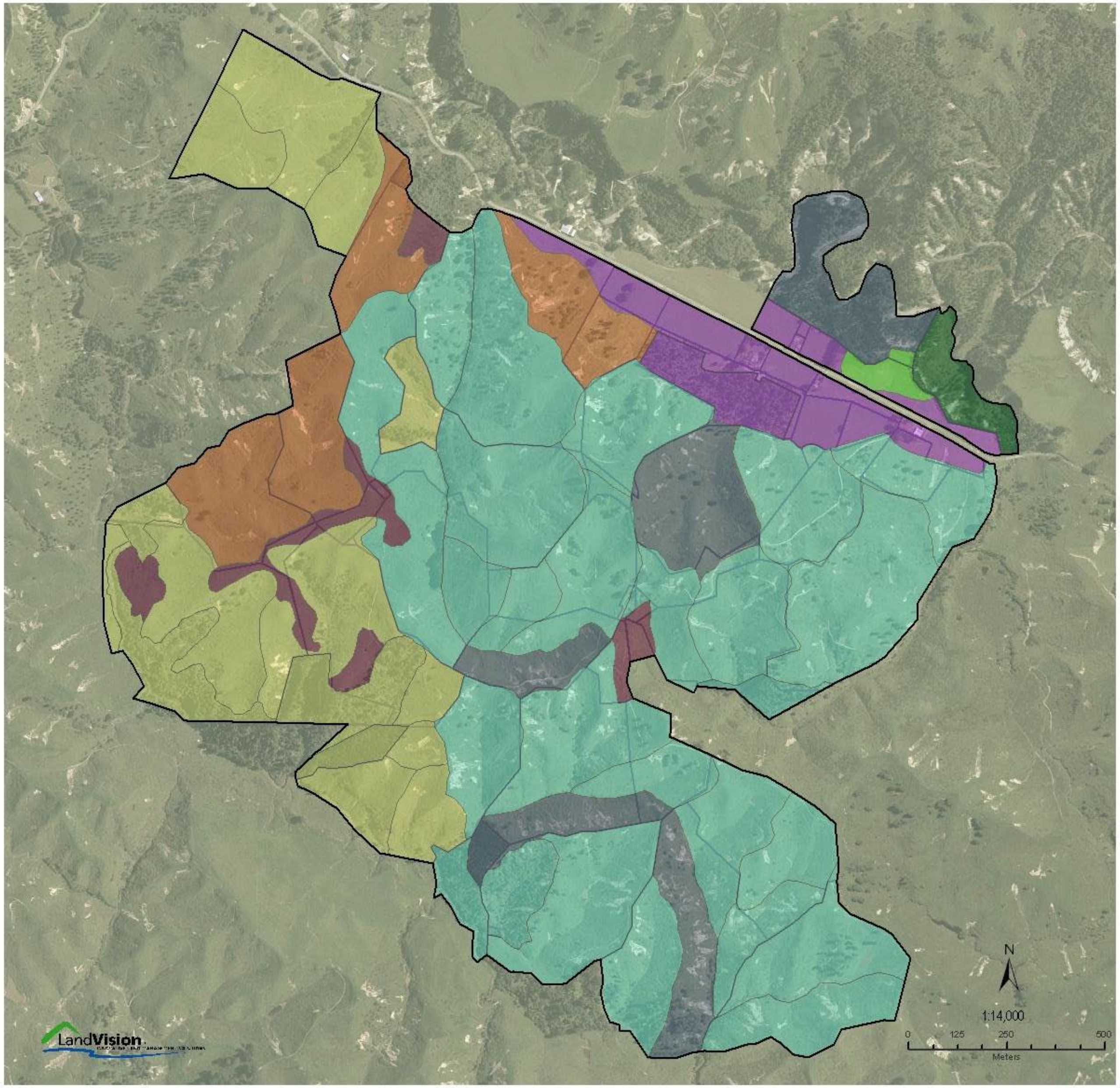
Finnis Road

(Notes adapted from Alan Palmer – Soil and Earth Sciences, Massy University)

The exposure here is of marine sands laid down over the last 1.3ma. The site shows the lack of consolidation of the sands making up hills in the area. The sand particles are very easily entrained by water. This, combined with uplift on the Pohangina anticline has produced extremely erodible hill country, now exhibiting severe soil slip erosion and extreme gully erosion, and supplying large quantities of sediment to the rivers. This catchment has been largely afforested in order to protect Pohangina township downstream.

There are a number of pumice markers: Rewa 1.29Ma, Potaka 1Ma, Kaukatea 0.87Ma and Kupe 0.64Ma. The pumices have all been water laid with the Rewa pumice at the base of the section deposited in the sea at a river delta? All pumices are derived from the Central North Island/Mangakino area (north of Taupo).

Fitzherbert Bridge, Palmerston North (February 2004).



LANDUSE CAPABILITY

Mt Huia

Ruahine Road, Mangaweka

🟩	IIs1		River levees with recent free draining, sandy textured soils.
🟪	IIIw2		Flat, narrow alluvial valley floors and areas of higher terraces mantled with colluvium from nearby valley slopes.
🟪	IVe3		Rolling to strongly rolling downlands with soils developed from loess or loess and volcanic tephra.
🟧	VIe2		Strongly rolling to moderately steep short hill slopes and terrace scarps. Unit has yellow grey earth soils and yellow brown earths derived from loess.
🟨	VIe4		Strongly rolling to moderately steep hills with yellow brown earth soils developed on mudstone.
🟦	VIe15		Moderately steep to steep hills of consolidated sandstone.
🟦	VIIe13		Steep to very steep slopes of consolidated massive sandstone.
🟩	VIIIe3		Very steep slopes formed from moderately consolidated sandstone and siltstone.

Date:	December 2007	Surveyors:	Landvision Ltd.
Property owner(s):	N & V Travers	Survey scale:	1:8,000
Property:	Mt Huia Farm Ruahine Road Mangaweka	Aerial photo:	Supplied by Horizons Regional Council (0.75m orthophoto from Terralink). Flown 2004/05.

2.31

2.8. Map and sections of river terraces in the Rangitikei Basin

Milne, J.D.G. 1973. Map and sections of river terraces in the Rangitikei Basin, North Island, New Zealand. *N.Z. Soil Survey Report 4*

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Day 3: –Palmerston North-Hawkes Bay- Taupo

Outline for Day 3 (Wednesday 29th July 2010)

8.00 am Depart, Hotel Coachman, Palmerston North.

8.30-9.00 am STOP 1. Ballantrae Research Station, Ballantrae is typical of much of the North Island's hill country, which covers 3.5 million ha (28% of the total farmland in New Zealand) and carries 35% of total sheep (17 million) and 20% of total beef cattle numbers.

9.40 10.40 am Barrow Dairy Farm, Dannevirke : Visit a 112 ha (94 ha effective) seasonal-supply and owner-operated dairy farm producing 14,750 kg pasture DM/ha/yr under irrigation (80.5 ha irrigated) and milking 250 Friesian x Jersey cows (2.65 cows/grazed hectare) at around ~1050 kg MS/ha/yr (performance above district average).

10.55-11.15 am Dannevirke : Morning tea , toilet stop

11.45 am -12.45 pm Takapau,, Sheep and Beef farm plus winery : 345 ha sheep/beef operation, as well as a viticultural and winemaking business on a mixture of Brown soils , Gley soils and Recent soils.

12.25 -1 .15 pm LUNCH (packed, Junction Winery, Takapau),

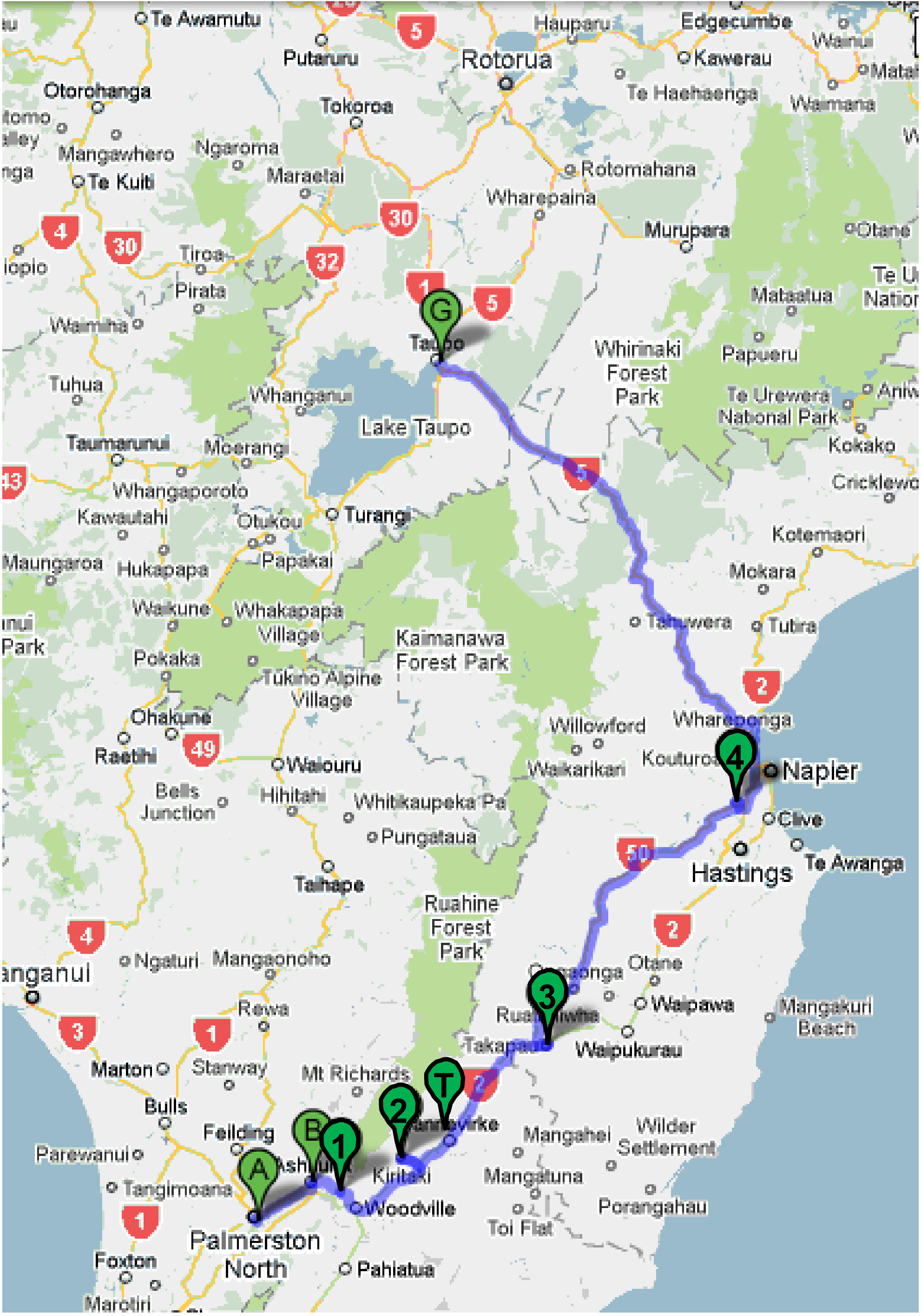
2.30-3.15 pm STOP 3 Springfield Road: A 35 hectare Apple orchard the owners describe as as being on 'early soil' which enables them to harvest ahead of others. This earliness is likely in part due to the free-draining nature of this terrace of alluvial soil close to the Tutaekuri River, plus the sheltered microclimate behind Taradale Hill (142m).

3.45-4.15 pm Afternoon tea, Marine Parade Napier.

6.00 pm Alpine Lake Motel

6.30 pm Maori Concert and Dinner.

Day 3 – Route and scientific stops



A, Hotel Coachman; B, Manawatu Gorge;T, toilet stop; 1,2,3, Scientific stops; G, Alpine Lake Motel, Taupo

3.1 Day 3 Theme

Intensification and Diversification of Land Uses: Economic and Environmental Trade-offs?

Day Tour Leader: Alec Mackay, AgResearch.

Authors: Brent Clothier, Grant Cooper, Alec Mackay, Hugh Wilde, Andrew Manderson, and Roger Parfitt

The Upper Manawatu catchment of Tararua District is experiencing land-use intensification as the profitability of dairying rises. The intensification of dairying brings with it increased loadings of nutrients which, if unchecked, could degrade river water quality. On this trip we explore the different types of land-use in the upper Manawatu, namely Sheep and Beef farming on steep hill country (Ballantrae, AgResearch Hill Country Research Station) and dairying (The Barrow's farm). We will outline their impacts on river water quality and discuss policy initiatives to improve water quality that are based on linking nutrient loss allowances to the natural capital value of the soils in the catchment.

Meanwhile, the Central Hawke's Bay District is undergoing diversification of land-uses, as viticulture and horticulture move southward across the Ruataniwha and Takapau Plains. We will visit an establishing vineyard, Junction Wines (John & Jo Ashworth), and discuss how the terroir value of the soil and climate are being productively exploited, and how they have developed and merged their viticultural business with their sheep and beef farming activities.

Pressures

Horizons Regional Council in their One Plan have identified 4 sustainability issues:

- Biodiversity
- Soil erosion
- Water quantity
- Water quality.

The quality of water in the Upper Manawatu is already not great (see below – the darker the colour, the poorer the water quality). Through intensification of land uses it will come under further pressure. Further, the catchment does have a significant fraction of its lands at risk of erosion.

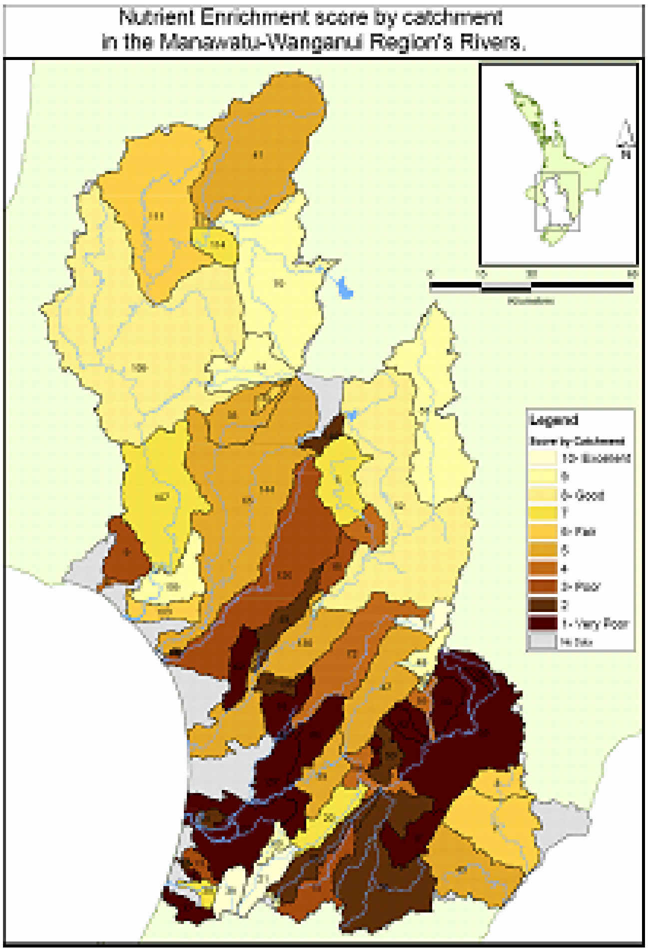
How does current land use affect the loading on nutrients in the river, and what kind of policy might be used to improve water quality? We have written a report to Horizons Regional Council on this. We present the nub of the proposition below.

Consider a catchment of area A comprising only the landuses of dairying and sheep/beef of areas A_{d} and A_{sb}

$$A = A_d + A_{sb} \qquad [1]$$

Then the annual loading of N in the river, Q, using mass balance will be

$$Q = q_d A_d + q_{sb} A_{sb} \qquad [2]$$



Here q_d and q_{sb} are losses of nutrients from dairy farms and sheep farms respectively. If there were a transmission attenuation of nutrients from the farm to the river of $\mathfrak{R}_d$ and $\mathfrak{R}_{sb}$, then we have a transfer-function scheme linking farm practices to river water quality,

$$Q = \mathfrak{R}_d \, q^*_d \, A_d + \mathfrak{R}_{sb} \, q^*_{sb} \, A_{sb} \quad . \qquad [3]$$

Here the fluxes q^* can be obtained from Overseer® (farm nutrient budgeting software) calculations, O^{-1}, and these would be dependent on farm practices L_d and L_{sb}

$$Q = \mathfrak{R}_d \, O^{-1}\left(L_d\right) A_d + \mathfrak{R}_{sb} \, O^{-1}\left(L_{sb}\right) A_{sb} \quad . \qquad [4]$$

	q (Eq 2) kg-N ha^{-1} yr^{-1}	q^* (Eq 3) kg-N ha^{-1} yr^{-1}	$\mathfrak{R}$
Dairying	15.4	31 (25-49)	≈ 0.5
Sheep/beef	3.9	7 (6-9)	≈ 0.5

The results from linking river loadings of N to farm discharges are given in the Table above. There is a loss of half of the N between the farm and river.

This scheme can be used to predict the impact of changing land use patterns, A_d *cf.* A_{sb}, and changing land-use practices of L_d and L_{sb} on river water quality.

Geological Overview

The geology of Southern and Central Hawke's Bay, the area of our field trip, is reasonably straightforward. In the west is the Ruahine Range, trending NNE–SSW and forming part of the axial divide of the North Island. East of the ranges lies a lowland plain about 10 km wide at its widest part and extending from Woodville in the south to Norsewood and Takapau in the north. East of the lowland plain lower Pleistocene and Tertiary age (< 10 M yr old) soft-rock hill country extends to the coast.

A series of NW–SE-trending anticlines and synclines extends eastwards from the Ruahine Ranges to the coast.

The Ruahine range is rugged and bush clad, with peaks exceeding 1500 m.a.s.l. It comprises alternating greywacke sandstone and argillite strata of Triassic and Jurassic age (Mesozoic = 140–230 M yr old). Intense physical weathering of the greywacke has provided a source of gravels and finer sediments to rivers and streams that flow east to the Pacific Ocean. This has occurred to such an extent that excessive aggradation of streambeds has occurred.

The lowland plain mainly comprises upper Pleistocene and Holocene sediments but is interrupted in places by older remnants of early Pleistocene and Pliocene (<10 M yr old) sediments forming low rolling hills. Soils of the lowland plain have formed within Holocene sandy and silty alluvium and late Pleistocene (Ohakean) outwash gravels and sands. Late Pleistocene loess mantles older pre-Ohakean terraces and fans as well as the low hilly remnants of the early Pleistocene and Pliocene sediments.

The eastern hills are typical of North Island 'soft rock hill country' that occurs along the drier east coast of both islands, from Gisborne to Palliser Bay in the North Island and from Marlborough to Otago in the South Island. The western part, where we make our first stop of the day, comprises a lower Pleistocene and Pliocene (<10 M yr old) sequence of mudstones, siltstones and sandstones with interbedded limestones. Interbedded pumice silts occur within the younger of these sediments, particularly to the north. This sequence of lower Pleistocene and Pliocene rocks is strongly faulted and abrupt changes in lithology and soil parent rocks are common. The area is also seismically active and a number of damaging earthquakes have occurred in this region since it was settled some 200 years ago. Further east, older uplifted Cretaceous sediments and Triassic greywacke outcrop occur to form the higher eastern ranges (Waiwaepa and Puketoi Ranges).

The lowland plain follows the Manawatu River and occupies an old synclinal or gently downfolded area. Near Dannevirke, there is a dissected plateau cut in lower Pleistocene rocks at about 300 m elevation, representing an old anticlinal structure. Dannevirke itself is situated on an uplifted pre-Ohakean terrace at c.200 m elevation. The dissected plateaus and high terraces rise gently to the north from Woodville (c. 100 m elevation) to Norsewood (c. 400 m elevation). North of the Manawatu River about 12 km north-east of Norsewood, the lower Pleistocene sediments no longer outcrop. Here the landforms comprise coalescing terraces and fans of late Pleistocene (Ohakean) and Holocene gravels, sands and silts and are informally named the Takapau Plains.

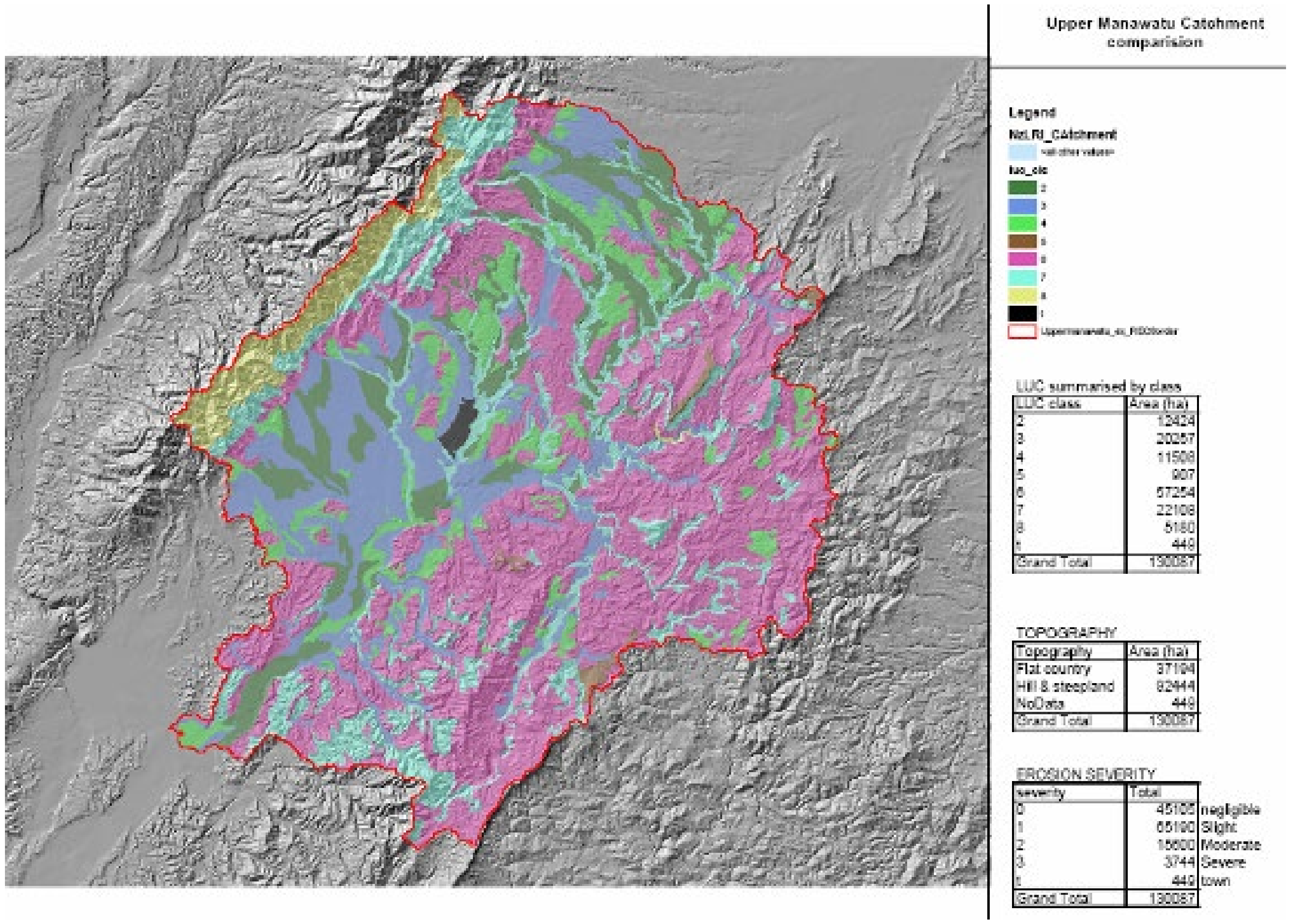
The Lands of the Upper Manawatu Catchment

The Upper Manawatu Catchment is some 130,000 ha in extent. Our stop at the Barrow dairy farm (Stop 2) is in the Upper Manawatu catchment. Stop 3 at the Ashworth's vineyard is just over the catchment boundary in the north and it is on the Takapau Plains. Horzons regional Council refer to the Upper Manawatu catchment as the Upper Manawatu Water Management Zone (UMWMZ).

As seen below, only some 37,000 ha of the UMWMZ is flat land, with the rest being hill country and steeplands. Only 45,000 ha have negligible erosion risk, with 20,000 ha being at moderate of severe erosion risk.

Under the New Zealand Land Use Capability (LUC) classification, some 60% of the catchment are in LUC classes greater than 6, whereas just 32,000 ha are better than 3. These better lands are in the west between the river and the foothills of the Ruahine Range. This is where the Barrow's farm is located.

Some 25% of the UMWMZ comprises Class 3 lands or better. Dairying currently only covers 16% of the catchment, so there is the capacity to enable further expansion of dairying. We have predicted that if dairying were to expand across all Class 2 and 3 land, there would be a further 18% increase in nitrogen loading in the Manawatu River at the point it leaves the UMWMZ (Eq 4).



LUC summarised by class

LUC class	Area (ha)
2	12424
3	20257
4	11508
5	907
6	57254
7	22108
8	5180
t	449
Grand Total	130087

TOPOGRAPHY

Topography	Area (ha)
Flat country	37194
Hill & steepland	92444
NoData	449
Grand Total	130087

EROSION SEVERITY

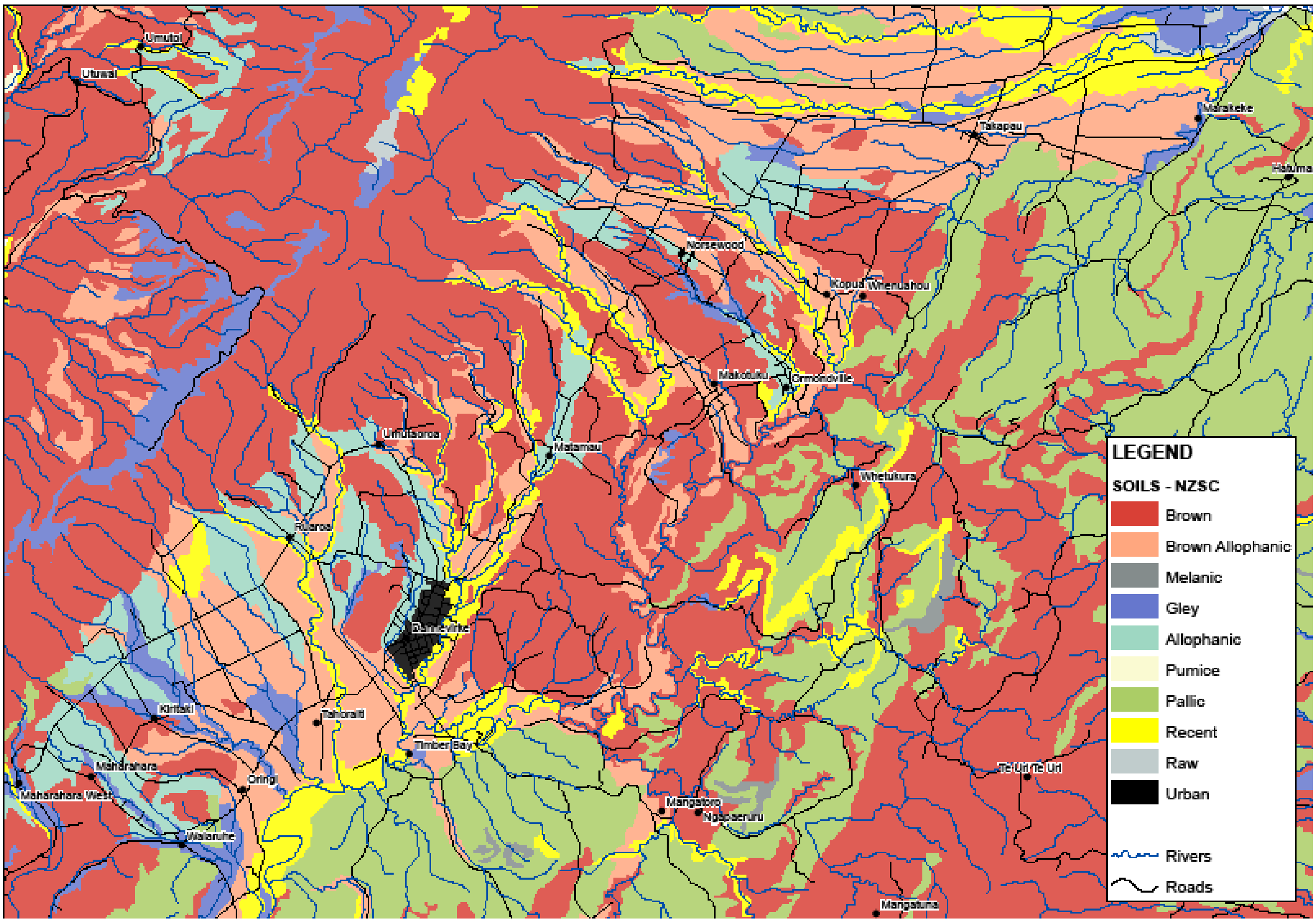
severity	Total	
0	45105	negligible
1	65190	Slight
2	15600	Moderate
3	3744	Severe
t	449	town
Grand Total	130087	

Land use classes of the Upper Manawatu Catchment

The proposed One Plan of Horizons has been notified and the Council's intention is that intensive land uses no longer be a permitted activity, rather they will be controlled through a resource consent process. Part of that consent will likely require that there be a limit of nutrient discharge from a farm. The nutrient loss right for an enterprise will, it is proposed, be calculated by considering the natural capital value of the land, and so a loss "right" (allowance) will be associated with an LUC class. Further, it will be expected that mitigation measures will be introduced so that the discharges from farms meet a sinking target that will in future improve water quality.

Soils of the Upper Manawatu

The following map shows the soils of the Upper Manawatu according to orders in the New Zealand Soils Classification (NZSC). The major orders and groups in this region are discussed below.



Soil Order Map New Zealand Soil Classification
Classification:

Brown Soils (US Taxonomy: Dystrudepts). These soils comprise New Zealand's most extensive soil order covering 43% of the country. They have a brown, or yellow-brown subsoil below a dark grey-brown topsoil. The brown colour is caused by thin coatings of orin oxides weathered from the parent material.

Brown allophanic (US Taxonomy: Andic Dystrudepts**).** In this soil group the soil has a horizon with soil properties dominated by allophanic material.

Gley (US Taxonomy: Aquepts). Gley soils are strongly affected by waterlogging and have been chemically reduced. They have light grey subsoils, usually with reddish brown or brown mottles.

Allophanic (US Taxonomy: Udands). These soils are dominated by allophane minerals. These nano-minerals (that have positive and negative charges) coat the sand and silt grains and maintain a porous, low-density structure with weak strength. These soils occur in the North Island resulting from volcanic ash, loessial deposition from ash deposits, and the weathering products of volcanic rocks under higher rainfall

Pallic (US Taxonomy: Fragiaquepts and Fragiaqualfs). Pallic soils have pale coloured subsoils due to low contents of iron oxides. They have weak structure and high density in subsurface horizons. Typically they are dry in summer and wet in winter.

Recent (US Taxonomy: Fluvents and Orthents**).** Recent soils are weakly developed showing limited signs of soil forming processes. A distinct topsoil is present, but a B horizon is either absent or only weakly developed. Typically these soils are on young surface such a alluvial floodplains. Most are less than 2000 years old.

Commentary

The Soil Order map shows the distribution of eight New Zealand Soil Classification soil Orders (see reference) throughout the Upper Manawatu River catchment and its immediate environs.

Brown soils (red on map) represents the largest area followed by Pallic soils (green on map), the latter occupying the drier eastern soft-rock hill country. Both Brown and Pallic soils contain 2:1 clay minerals with Brown soils containing secondary iron oxides dispersed throughout and with moderate to low base status, whereas Pallic soils are denser, contain fewer secondary iron oxides compared with Brown soils and have a moderate to high base status.

The Allophanic Brown soils (pale brown on map) with larger amounts of iron oxides than other Brown soils are closely associated with soils of the Allophanic soil Order (turquoise on map). Allophanic soils are strongly influenced by minerals with short-range order (allophane, imogolite and ferrihydrite) and have low bulk density and weak soil strength. Allophanic soils occur mostly on volcanic parent materials, particularly ash, and in the north of our area the soil parent materials do contain significant amounts of redeposited volcanic ash, but in the south this is debatable, with the increased amounts of amorphous constituents more likely a result of increased leaching of silica under high rainfall (see reference).

Recent soils (yellow on map), having generally formed within alluvium and showing only incipient effects of soil formation processes and lacking distinct topsoils, and poorly-drained Gley soils (blue on map) are next in abundance, followed by small areas of Raw soils (light grey on map) lacking topsoil development and formed within recent flood detritus. Pumice soils (pale yellow on map) from redeposited alluvial pumice in the north-east of the area are associated with Gley soils, and Melanic soils (dark grey on map) are well-structured high base status soils formed within calcareous parent materials.

References: Hewitt, AE 1998. New Zealand Soil Classification. Landcare Research Science Series No 1. 134 p.
Parfitt, RL 1990. Allophane in New Zealand – a Review. Aust. J. Soil Res. 28. 343–60.

3.2 Transit Palmerston North to Stop 1 Ballantrae AgResearch Hill Country Research Station

Departing Palmerston North on day 3, the route follows the Manawatu River northeastwards across alluvial terraces to the Manawatu Gorge (B, Day 3 Route and scientific stops). The headwaters of the River drain from hills and mountains on the eastern side of the Tararua and Ruahine Ranges, and since the River established its course the ranges have gradually been tectonically uplifted approximately 250m at this point (much more to the north and south), over the last 0.25-1 Ma. The first stop at AgResearch's Ballantrae Research Station (D3:Stop 1) also shows the scarp of the Wellington Fault responsible for the uplift on the eastern side.

3.3 Stop 1 – Ballantrae AgResearch Hill Country Research Station

Ballantrae is a summer-moist hill country research property . About 10% is flat to easy rolling country, 44% is strongly rolling to moderately steep hill country and 46% is steep to very steep hill country. Approximately 56 ha has suitable contour for cultivation.
The underlying geology is a combination of massive, silty mudstone and greywacke lithologies, with quartzo-feldspathic loess mantling some of the easier hill country and river flats formed from alluvium and gravels. The mudstone lithologies are the predominant rock type throughout the property. The greywacke is located mostly on the steeper north to north-western corners which form the lower end of the Ruahine Ranges. There are also some areas of colluvium on the lower footslopes and flats of the hill country. There are 10 dominant soil types on the property. The farm covers 477.1 ha with an estimated 319.9 ha in pasture, 52.2 ha in exotic forestry, 74.4 ha in indigenous bush, 28.1 ha in regenerating scrub and gorse, 1.5 ha in wetlands and 1.0 ha in farm buildings and houses.
The prevailing wind is from the west and the average annual rainfall is 1,150 mm/year.

Current Farming Practices

Livestock wintered to June 2009 totalled 2,407 stock units with a stocking rate of 7.5 su/ha from an effective area of 319.9 ha. This stocking rate on Ballantrae is not reflective of a typical hill country farm for this region. Due to the research nature of the farm, the stocking rate is considerably lower than the average farm in the Hawkes Bay/Wairarapa region which wintered 8.7* su/ha for the 2008-09 year. There was also the effect of three years of drought and consequently this average stocking rate was lower than they have been in previous years. Average stocking rates wintered in this region have been as high as 9.6-10.3 su/ha.

Fertiliser and Nutrient Management

Ballantrae historically has been split into multiple nutrient management blocks with various superphosphate and nitrogen fertiliser trials being conducted. Currently Ballantrae is being managed as four nutrient blocks - the Main Block and the 30-Year Block. The 30-Year Block is further split into three sub-blocks with different rates of superphosphate fertiliser. It is a long-running superphosphate trial block with an indefinite end-point and the fertiliser rates shown in the tables below have been running since 1965. Soil tests are taken annually and the latest soil test and herbage analysis were undertaken in March 2009. The results are shown in the tables below.

Sample sites	pH	Olsen P	Potassium	Organic Sulphur	Ca	Mg	Na
Transect 1	5.3	6	5	9	3	12	3
Transect 2	5.3	16	4	9	5	22	4
Transect 3	5.5	23	10	12	5	27	5

These average results indicate that the farm has good to low fertility levels, with some areas below an optimum range for pasture production (optimum Olsen P levels are 18-25 mgP/Lsoil and optimum pH is 5.8-6.0). Based on the current stocking rate of 7.5 su/ha, the property needs 12 kg P/ha applied to maintain current soil fertility levels.
The current fertiliser policy is shown in the table below.

Block	Fertiliser	Rate	Area
Main Block	Superphosphate (SSP)	233 kg/ha	300 ha
30-Year Block 1	Superphosphate	375 kg/ha	8 ha
30-Year Block 2	Superphosphate	125 kg/ha	8 ha
30-Year Block 3	No fertiliser	0 kg/ha	14 ha

Up until 2008, for the previous 12 years, the Main Block had been split into a 230 ha block receiving 233 kg SSP/ha and a 70 ha block receiving 370 kg RPR/ha. The RPR was supplying 46 kg P/ha/year and, as about a third of the phosphate in RPR is taken up each year, the RPR will continue to supply about 31 kg P/ha on this area in 2009 and 15 kg P/ha in 2010. Since finishing the RPR applications in 2008, these areas are now also receiving the 233 kg SSP/ha (an extra 21 kg P/ha) as part of the Main Block fertiliser policy.

The nutrient budget was calculated from current inputs and production levels using Overseer$^{®}$ (farm nutrient budgeting software) and the results are shown in the table below. In calculating the nutrient budget, the farm was considered in eleven blocks to capture the fertiliser management of the Main Block, the effects of the 30-Year superphosphate trial block, and the residual effect of RPR applied up to 2008. Results below are a summary nutrient budget for the whole farm system.

Kg/ha/yr	N	P	K	S	Ca	Mg	Na	H+
INPUTS								
Fertiliser	0	18	0	16	42	0	0	-0.3
Atmospheric/clover N	32	0	1	2	1	3	9	0.0
Slow release	0	3	22	8	3	4	5	0.0
OUTPUTS								
Product	7	1	0	1	2	0	0	0.0
Atmospheric	5	0	0	0	0	0	0	0.0
Leaching/runoff	5	0	9	25	2	1	12	-0.2
Immobilisation/absorption	16	11	0	0	0	0	0	0.0
Change in inorganic soil pool	0	8	14	0	42	6	2	-0.1

Based on the current stocking rate of 7.5 su/ha and the fertiliser applications in 2008-09:

- Olsen P levels are expected to marginally increase (< 1 unit per year) on the Main Block, increase about 6 units per year on the Main Block areas which received RPR, increase 3 units per year on the 30-Year Block 1, and decrease between 1 and 2 units on the other 30-Year Blocks.
- Potassium and magnesium units will remain the same or marginally increase.
- pH will slowly decrease. The areas that received RPR are expected to increase in soil pH over time until the residual effect ends.

3.4 Transit Ballantrae AgResearch Hill Country Research Station to Stop 2 Barrow Dairy farm

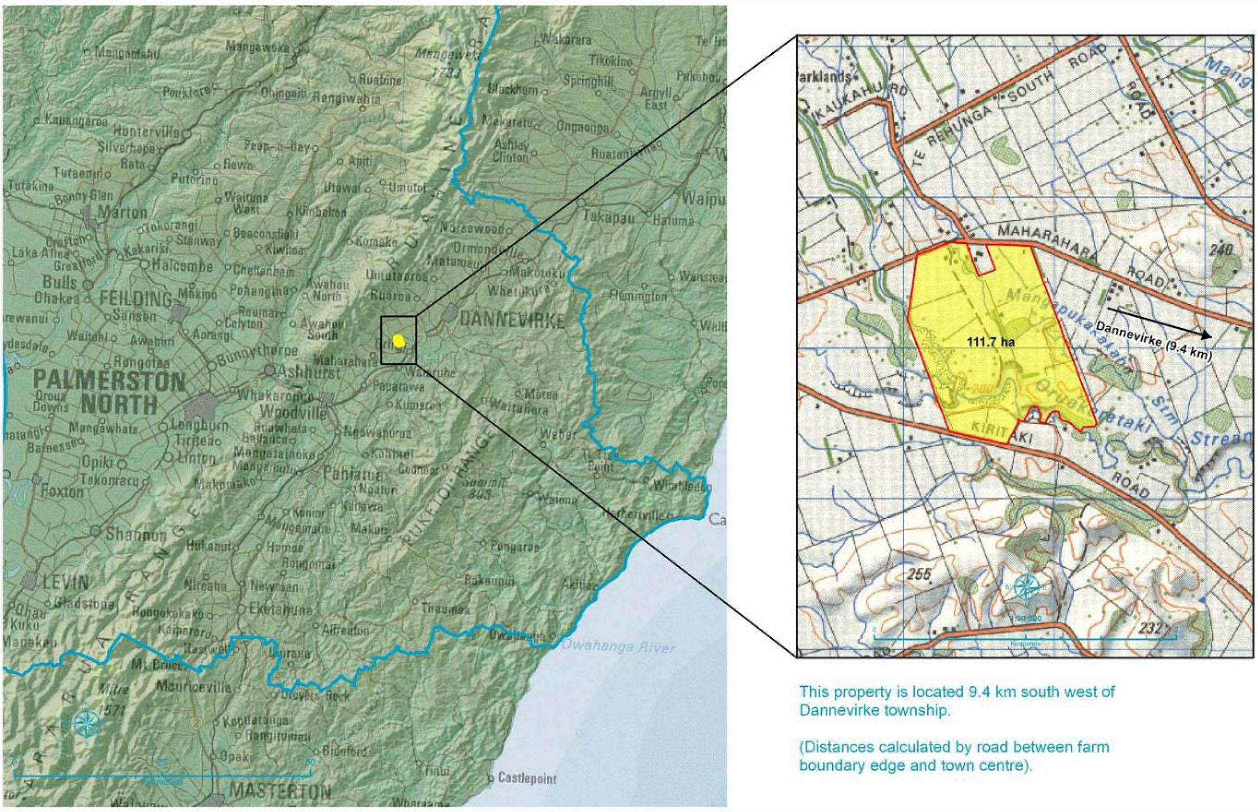
From Ballantrae northwards the route crosses mainly rolling country which was being uplifted from the sea as recently as 1 Ma. Subsequent tectonic uplift to both the east and west has formed the Woodville and Dannevirke Synclines, in which young marine and coastal lignite deposits with pumice beds are preserved. This country has some massive and deep-seated slumps leading to much localised land sliding. Soils are either derived directly from these parent materials (mainly in the hill country) or from cover beds of both quartzofeldspathic (Mesozoic-greywacke derived) or volcanic loess. In the area south of Dannevirke and to the north of Norsewood the route traverses extensive areas of gravel terrace (the Ohakean terrace) deposited during the Last Glacial Maximum (circa. 20,000 years ago). As one travels northwards the topsoils on these terraces show increasing volcanic provenance (mostly andesitic) in the fine-grained accumulations above the gravels.

3.5 Stop 2 – Barrow Dairy farm Maharahara Road (John & Debbie Barrow)

At the Barrow Dairy farm (D3:Stop 2) we will stop to discuss farm-scale soil mapping and the development of farm management plans.

John and Debbie Barrow run a 112 ha (94 ha effective) seasonal-supply and owner-operated dairy farm producing 14,750 kg pasture DM/ha/yr under irrigation (80.5 ha irrigated) and milking 250 Friesian x Jersey cows (2.65 cows/grazed hectare) at around ~1050 kg MS/ha/yr (performance above district average).

Topography is mostly flat, with the farm situated on the lowest glacial terrace found in the district (Ohakean Terrace), characterised by deep gravels (+2m) over a mudstone base, and a thin mantling of either loess (wind-blown sediment from the river below), very old river sediments, or a mix of both. Depth to gravels is highly variable (range = 0m – 1.2m), and the gravels may be inter-bedded with thick bands of silty sands. The upper terrace graduates down to the Oruakeretaki Stream in a series of small sub-terraces with short scarp slopes, and a slightly undulating topography. A steep high cliff (2-3 m) marks the transition from the glacial terrace down to the Oruakeretaki Stream flood plain.
Soils are dominated by Ashhurst silt loam and stoney silt loams on the drier parts of the upper terrace (Typic Orthic Brown Soils); Ohakea silt loam for the wetter parts (Typic Orthic Gley Soils); and recent alluvial soils around the Oruakeretaki Stream.



This property is located 9.4 km south west of Dannevirke township.

(Distances calculated by road between farm boundary edge and town centre).

The Famer Applied Resource Management Strategy (**FARMS**) is part of an initiative aiming to improve freshwater quality. A **FARM Strategy** is a document to help farmers work out a nutrient management plan for their farm and apply for all the resource consents they need in one go.

FARM LOCATION & ACCESS

John & Debbie Barrow, Maharahara Road, Dannevirke

Prepared for Horizons Regional Council by AgResearch Ltd, as part of the FARMS initiative.
July 2007.

FARM Strategy (Farmer Applied Resource Management Strategy)

At present eleven important catchments in the Manawatu-Wanganui Region have nutrient levels far in excess of what is desirable. To help address this issue Horizons have proposed a Rule in the One Plan that aims to lessen the nutrient-impact from activities associated with intensive farming. Resource consents concerning irrigation takes, fertiliser, stock feed, biosolids, soil conditioners, dumps, offal holes, and effluent, will be necessary for dairy farming, cropping, market gardening, and intensive sheep and beef farming. Nutrient budgets will be required for operations that apply nitrogen fertiliser to land. The Rule will come into effect at different times for each of the eleven catchments.

A new consent process will be available under the One Plan. The traditional approach of having several separate consents for a farm is replaced with a single whole-farm consent. This means only one consent – not many – is needed for the entire farm. This promises to make the process simpler, quicker and considerably less expensive. A FARM Strategy is a necessary prerequisite for a whole-farm consent.

A FARM Strategy (Farmer Applied Resource Management Strategy) represents an assessment of permitted and controlled activities for a farm, and a strategic plan to ensure those activities comply with One Plan specifications and water quality targets. It combines a nutrient budget, a comparision of farm nutrient-loss against catchment water-quality targets, an evaluation and recommendation of mitigation options (if the farm is operating outside of

catchment water-quality targets) including cost and effectiveness, an assessment of eligibility for relevant consents, and a farm plan of works that spells out the where, when and how much of achieving sustainable land use within the given catchment of interest.
The Barrow's farm represents the first application of the FARM Strategy framework.

3.6 Stop 3 – Takapau Sheep and Beef farm and Winery

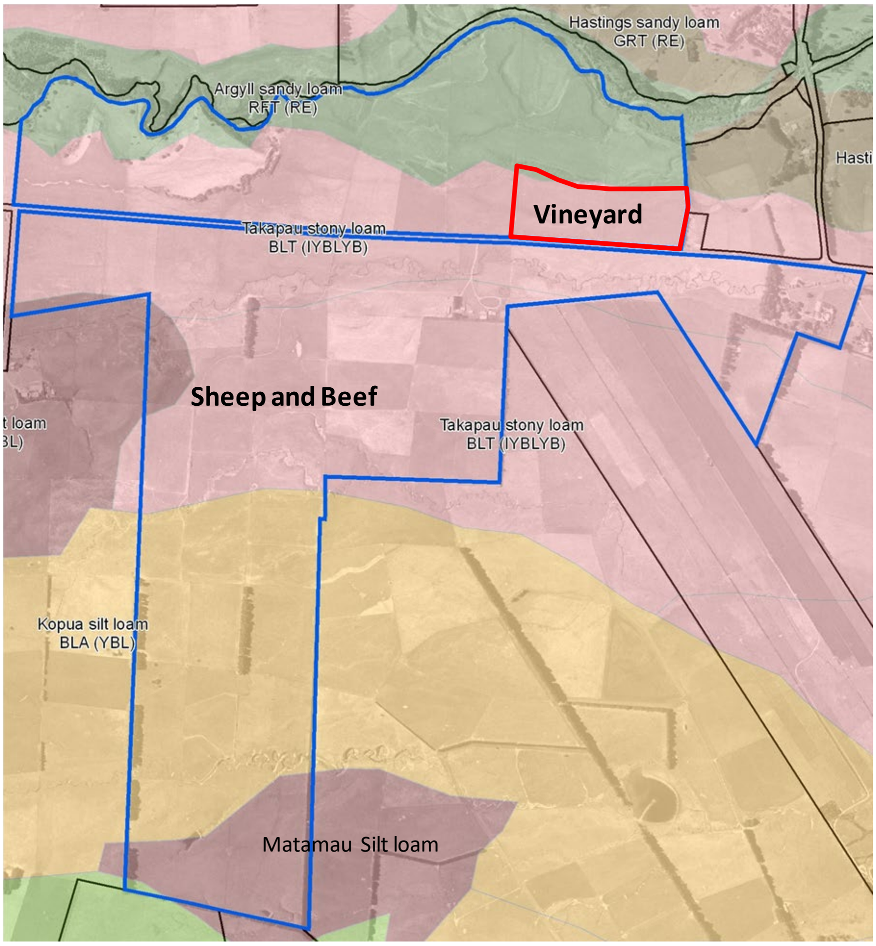
Junction Wines (John & Jo Ashworth).

John and Jo Ashworth's farm is about 345 ha, along with about 16 ha of Maori-lease land. The Ashworths have a sheep/beef operation, as well as a viticultural and winemaking business. The sheep farm permanent pastures are established on Takapau Stony loam and Kopua silt loam (see Map and soil descriptions below).

Sheep/Beef Operation

The Ashworths have 2,000 breeding ewes, and 600 replacement Romney hoggets. Every year, some 600 cull ewes are mated to a South Suffolk ram for lambing in early August. These ewes are sold for mutton once the lambs are weaned. The balance of the ewes are mated to a Romney ram. All lambs are finished on the property, with a target weight of 18-20 kg for the lambs to be sold for export.
Every year, the Ashworths buy approximately 150 weaner calves at weaner fairs, and these are taken through to a killing weight of about 270 kg as rising 2 year old cattle.

Soil Map of Ashworth's Farm and Location of Junction Wines



Boutique Vineyard

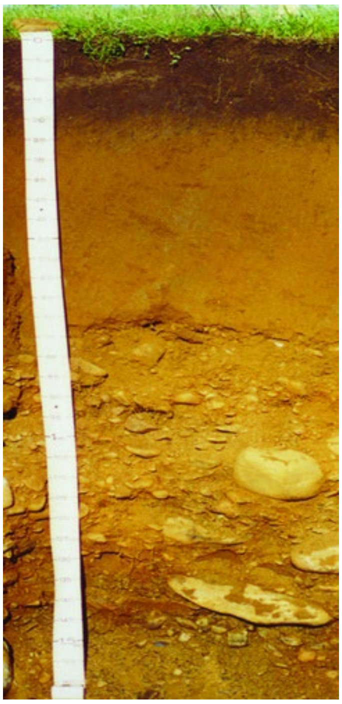
The Ashworths also have some 10 ha of grapes, which they have developed in stages over the last six years using funds from their sheep/beef operation. The vineyard has been established on the Takapau stony loam on the River Block (shown above). John and Jo's son, Leith, is the winemaker for their wines, appropriately named Junction Wines, for the vineyard is at the junction of State Highways 50 and 2.

The grape varieties include Pinot noir, Sauvignon blanc, Riesling, Pinot gris, Gewürztraminer and Chardonnay. We will have lunch at Junction Wines, and there will wine tasting and it will be possible to purchase the wines. You will even be able to talk to John about his 52 games for the All Blacks, as a prop, between 1977 and 1985. He played in 24 Tests.

Soil type: Takapau sandy (stony) loam (39,39g, US Taxonomy: Andic Dystrudept***)***

Parent material	Tongariro alluvium from volcanic ash and greywacke over red metal stones	 ***Photo. K. Vincent***
Characteristics of site	Intermediate terraces	
Soil features	Sandy loam with some ash over ashy sandy loam over stones	
Natural drainage Depth to water table after wet periods	Good >10 m	
Potential rooting depth, texture, and limiting layer	39 - 30-45 cm sandy loam on ashy sandy loam on stones 39g – about 30 cm ashy sandy loam on stones	
Available water capacity	39 - 25-50 mm 39g – <25 mm	
Infiltration rate	39 – moderate 39g - rapid	
Permeability rate	Very rapid	
Susceptibility to pugging and compaction when wet	Low	
Susceptibility to wind erosion when dry	Extremely high	
Unfavourable soil characteristics	39 - Low AWC 39g – very low AWC 39g - rapid infiltration 39, 39g - very rapid permeability Topsoil easily eroded by wind Low fertility – moderate to high phosphate retention (moderate allophane)	

Soil Type Kopua silt loam (40, US Taxonomy: Andic Dystrudepts)

Parent material	Tongariro alluvium from volcanic ash mixed with a little greywacke	 ***Photo. K. Vincent***
Characteristics of site	Gently sloping intermediate terrace	
Soil features	Ash on red metal	
Natural drainage Depth to water table after wet periods	Good >10 m	
Potential rooting depth, texture, and limiting layer	30-45 cm ash on stones	
Available water capacity	25-50 mm	
Infiltration rate	Very rapid	
Permeability rate	Very rapid	
Susceptibility to pugging and compaction when wet	Very low	
Susceptibility to wind erosion when dry	Extremely high	
Unfavourable soil characteristics	Low AWC Very rapid infiltration Very rapid permeability Topsoil easily eroded by wind Low fertility - high phosphate retention (high allophane)	

3.7 Transit Takapau to Stop 4 Springfield Road Orchard.

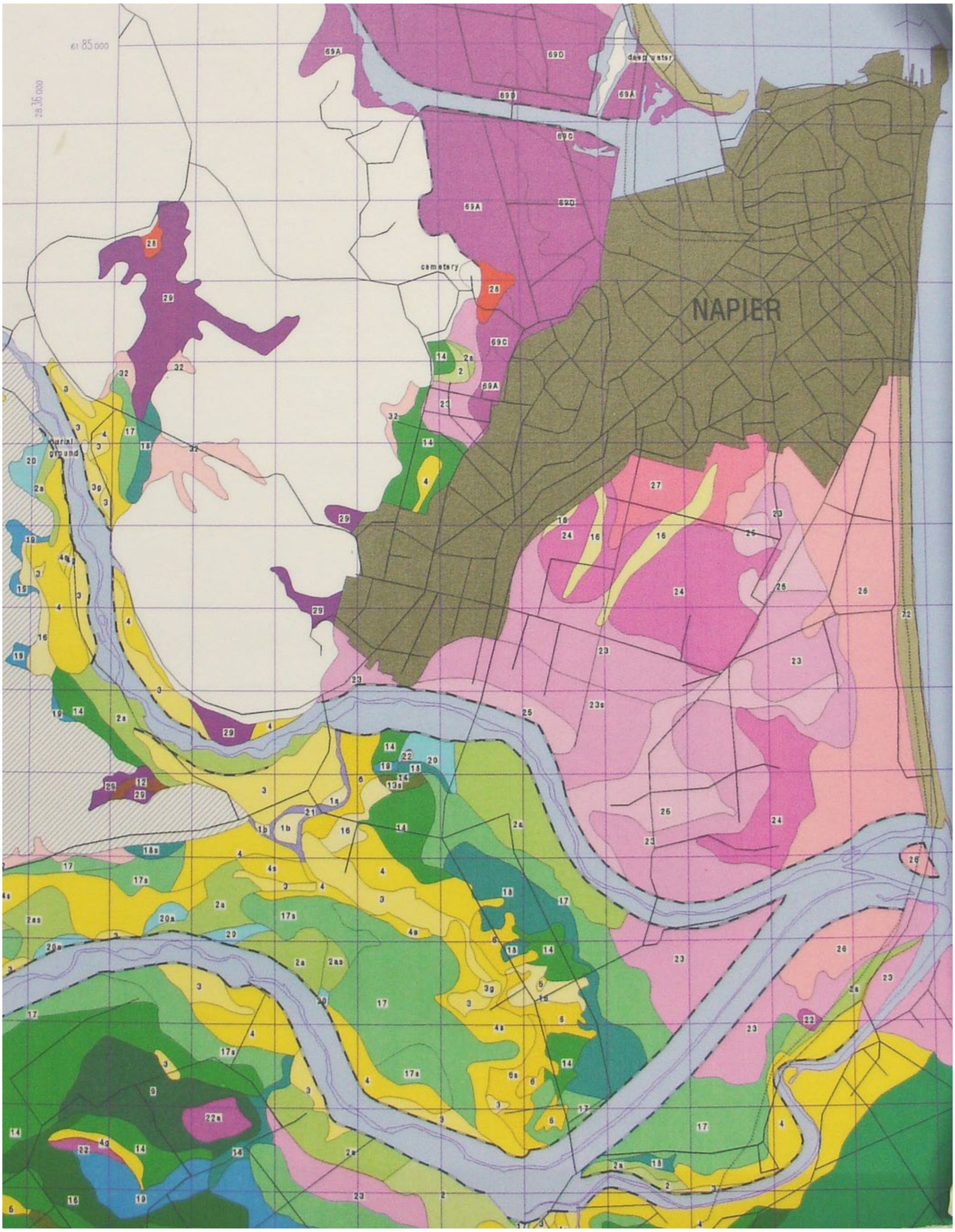
After visiting a sheep and beef farm plus winery at Takapau (D3:Stop 3), we take Highway 50 northwards to the Heretaunga Plains of Hawkes Bay. The pattern continues until approaching the Plains where a marked decrease in rainfall and increase in sunshine hours combines with the Holocene alluvial soils to produce the "Fruitbowl of New Zealand" (D3:Stop 4). Most of the soils on the Plains have been deposited by the combined aggradation of 3 rivers - the Tutaekuri (north), Ngaururoro (west) and Tukituki (south), discharging fine-grained sediments that have prograded the coastline in late Holocene times. Most of the soil parent materials are less than 2,000 years old, shown by extensive areas of alluvial pumice which were transported down the Ngaururoro River to inundate the lowlands of the river mouth just 1800 years ago. As the Ngaururoro River flows across the western margin of the Plains it loses half its flow into the underlying gravels which dip under the Plains providing one of New Zealand's premier artesian water systems. The buried aquiclude confining the aquifer in the lower half of the Plains is marine mud deposited by the Holocene high sea level about 6,500 years ago. Flow rates of up to 180,000 litres/hour of high quality water from a 10 cm diameter pipe are recorded. It is no wonder that the climate and soils combined with this underground water resource proved to be the successful recipe for the establishment of the food canning industry which Watties began.

3.8 Stop 4 – Springfield Road Orchard Steve & Di Gillum, Springfield Road, Taradale.

The Gillums have been growing apples on Springfield Road since 1984, and their orchard covers 35 hectares of Omarunui sandy loam (see Soil Map of the Heretaunga Plains). The Gillums describe their orchard as being on 'early soil' which enables them to harvest ahead of others. This earliness is likely in part due to the free-draining nature of this terrace of alluvial soil close to the Tutaekuri River, plus the sheltered microclimate behind Taradale Hill (142m). There are 9 apples varieties grown, with the major cultivars being Royal Gala, Bareburn, Jazz, Fuji and Pacific Rose. The orchard is Global GAP compliant, and has certification through Nature's Choice. A Pacific Region Employment Scheme (PRSE) is utilised to obtain sufficient seasonal workers for picking and packing. The owners have developed a direct relationship with a village in Samoa. The village elders select the PRSE workers, and the owners as registered as exporters can return goods, such as a mini-bus and building tools back to the village as part of the remuneration package for orchard labour.

Image Google Earth

Extract from Soil Map of Heretaunga Plains



Soil Map of the Heretaunga Plains North Island New Zealand
Soil map and ledgend compiled by E. Griffiths, 1996, from the Soil Map of Heretaunga Plains, Hawkes Bay (DSIR 1938), with additional soil surveys by E.Griffiths, G.Smith, B Purdie and B. McLauchlin, of New Zealand Soil Bureau, DSIR, 1971 to 1991, and by E. Griffiths 1991 to 1995.
Copy right. Hawkes Bay regional Council.

Soil type: (4) Omarunui sandy loam

Parent material	Water deposit (alluvium) from greywacke and/or sandstone	 **Omarunui sandy loam** **(4, 4g, 4s)** ***(photo E. Griffiths)***
Characteristic site and soil features	Low terrace adjacent to recent channels; protected from flooding by stop banks: sandy loams overlying permeable older deposits, often stones but maybe heavier textures. If the sandy loams bury impermeable old topsoils, to be included in this mapping unit, they must be deep enough (probably at least 75cm) so that the perched gley is >60cm from the surface.	
Natural drainage and depth to gley and hence to water table after wet periods	Good >60cm	
Potential rooting depth, texture, and limiting layer	4>45cm sandy loam on permeable sediments (maybe stones or heavier textures): >75cm sandy loam if on slowly permeable old buried topsoil 4g,30-45cm sandy loam/loamy fine n stones 4s, 30-45cm sandy loam/loamy fine sand on sand	
Available water capacity (AWC)	4, 50-750mm 4g, 30-50mm 4s, 30-50mm	
Infiltration rate	Moderate	
Permeability rate	Moderate, but slow if old buried topsoil	
Susceptibility to pugging and compaction when wet	4 moderate	
Susceptibility to wind erosion when dry	4g,high where sand topsoil	
Unfavourable soil characteristics	4g, <45cm to stones low AWC rapid permeability 4s, <45cm to sand low AWC	

3.9 Transit Springfield Road Orchard to Taupo via Napier.

The Hawke's Bay Earthquake – 1931

One of the worst disasters in New Zealand's history was the Hawke's Bay earthquake of 1931, intensity 10 on the Ross-Ferrel scale (Henderson et al., 1934). Without any warning, at 10.47a.m. on the morning of 3rd February, the main shock occurred, being most severely felt in the area surrounding Napier and Hastings. The first shock developed rapidly in intensity, had a distinctly uplifting motion associated with violent and confused swaying. Then following a pause of about half-a- minute, a second shock occurred, with a motion resembling a sharp bump downwards. The tremors continued for two-and-a-half minutes. At Napier, it was followed by a period of quiet, but before long further tremors commenced and continued for 10 days, some of them equalling the intensity of the first disastrous upheaval. The earthquake was felt throughout New Zealand, with the exception of the northern portion of the Auckland Peninsula and Otago.

In it's wake the earthquake left a trail of destruction from Waipukurau north to Gisborne. In the centre of most damage were Napier and Hastings. Many of Napier's largest structures – the Nurses' Home and Cathedral, collapsed with heavy loss of life followed by fires which raged through 10 acres of buildings in the city centre. 256 people were killed and an estimated NZ$14million worth of damage was caused in Napier and Hastings.

Geology:

The region immediately to the north of Napier was uplifted a maximum of 2.5m (8ft) whilst a region to the south was depressed about 1m. The zero isobase or line of no change ran obliquely across the Heretaunga Plains from north-east to south-west. The result of the earthquake was most striking in the uplift of Ahuriri Lagoon to the north of Napier, producing 3,600 hectares (9,000 acres) of dry land. North of Napier great stretches of the coastline slipped into the sea, hillsides collapsed, rivers became blocked or changed their courses and huge cracks and fissures opened all over the countryside.

One set of ridges, rents and cracks to the south of Hastings, at Poukawa, were considered to be associated with a deep-seated fracture. Low-angle over-thrusting extending along the fracture for 5km (3 miles) indicated an overall crustal shortening in excess of 0.6 m (2 feet), but a road which paralleled the fracture was displaced by a 2m horizontal movement at right angles to the fracture. Re-levelling surfaces and extensive geological reconnaissance established that and earth block 100km (60 miles) long in a north-east direction and at least 16 km (10miles) wide was uplifted.

As we travel from Taradale to Napier one begins to cross land that was swampy prior to the 1931 Napier Earthquake. North of Napier the current land had been a large embayment of the sea. After the Earthquake the soils remained salty for most of 50 years before the salts were leached from the profile (Ahuriri Clay Loam, soil description below)

Soil Type: (69) - Ahuriri (clay loam, sandy loam, silt loam, sand on - shelly sand or - shelly gravels)

Parent material	Saline lagoon deposits	 **Ahuriri (69)** **(photo D. Bloomer)**
Characteristic site and soil features	in old lagoon raised in 1931; variable soils from clay loams in hollows to shells on ridges	
Natural drainage and depth to gley and hence to water table after wet periods	Very poor 0cm	
Potential rooting depth, texture, and limiting layer	69A 30-45cm clay loam on shelly sand 69B 45-60cm sandy loam on shelly sandy loam 69C 30-45cm silt loam on shelly sand 69D 30-45cm sand on shelly sand 69E <30cm sand on shelly gravels	
Available water capacity (AWC)	69A 30-50mm; 69B 50-75mm; 69C 50-75mm; 69D 20-30mm; 69E 15mm	
Infiltration rate	69A slow; 69B moderate; 69C moderate 69D rapid; 69E very rapid	
Permeability rate	69A slow; 69B slow; 69C slow; 69D very rapid; 69Every rapid	
Susceptibility of topsoil to pugging and compaction when wet	69A extremely high; 69B moderate; 69C very high; 69Dlow; 69E very low	
Susceptibility to wind erosion when dry	69Dhigh;69Ehigh	
Unfavourable soil characteristics	all saline 69Aheavy topsoil easily compacted and difficult to manage in wet conditions, slow infiltration and permeability 69B slow permeability 69C silty topsoil difficult to manage in wet conditions, slow permeability 69D topsoil susceptible to wind erosion, low AWC, rapid infiltration, very rapid permeability 69E topsoil susceptible to wind erosion, shells at, surface, very low AWC, very rapid infiltration	

AHURIRI CLAY LOAM

PEDOLOGY

Location: Ahuriri Lagoon, part of sea bed raised above sea level during 1931 Napier earthquake. N124/267425. **Slope**: Flat. **Altitude**: 5 ft.

Vegetation of Site: Ryegrass, white clover.

Profile:

A_{1g}	0–½ in.	dark brown to greyish brown (10YR 3/3–5/2) clay loam; friable; moderately developed fine granular structure; many roots; distinct boundary,
A_{3g}	½–3 in.	olive grey (5Y 5/2) clay loam; firm; weakly developed medium nutty structure with few cast granules; few roots,
GC_{11}	3–11 in.	olive grey silty clay loam; firm but friable when dug; weakly developed fine blocky structure with weak tendency to columnar; few roots and shells,
GC_{12}	11–20 in.	grey (5Y 5/1) sandy clay; very firm; moderately developed coarse prismatic structure; few roots and shells,
GC_{13}	20–30 in.	grey clay loam; very firm; moderately developed coarse prismatic structure with large spaces between prisms when dry; few roots and shells,
D_n	30–32 in.	shelly sand,
D_n	on	grey sand with shells; wet.

Parent Material: Estuarine mud and sand.

Native Vegetation: *Salicornia* and salt plants. **Rainfall**: 35 in. unevenly distributed.

Classification: (a) Central saline gley recent soil (in process of reclamation).
(b) Very weakly enleached upon saline regi-madentic soil.

Main Use of Soil: Pastoral land for fattening sheep and cattle but with some market gardening. Some salt damage to pastures occurs in places.

Monolith: See Plate 52.

The Samples for the analysis of Ahuriri clay loam are registered in Soil Bureau records as follows:
SB 7605 A 0–3 in. 7605 B 3–11 in. 7605 C 12–20 in. 7605 D 30–40 in.
No numbers have been given to undisturbed cores.

SOIL PHYSICS

Depth (in.) ..	0 3	3 11	12 20		30 40			
Horizon	A_g	GC_{11}	GC_{12}		Dn			
Mechanical analysis								
% Sand (2–·02 mm)	20	2	8					
% Silt (·02–·002 mm)	45	57	51					
% Clay (<·002 mm)	35	41	41					
Texture	sicyl	sicyl	sicyl					
Moisture								
Est. field cap. % w/w <2 mm	39.8	34.7	39.2		6.2			
Wilting point % w/w..	18.5	16.6	20.3		3.1			
Avail. moisture % v/v ..	24.9	21.5	21.5		4.6			
Undisturbed cores								
Depth (in.)	0 3	5 8	12 15	17 20	32 35			
Dry bulk density g/cc	1.17	1.19	1.23	1.05	1.47			
Total porosity %	55.2	55.2	53.6	60.3	42.0			
Macroporosity % ..	13.5	12.3	9.6	15.2	11.2			
Stones(>2mm)%v/v								
Density								
Stones g/cc ..								
Particles (<2mm) g/cc	2.62	2.65	2.64	2.64	2.65			

SOIL ENGINEERING

Depth (in.) ..	0 3	3 11	12 20	30 40				
Horizon	A_g	GC_{11}	GC_{12}	Dn				
On site 12/ 4 / 60 ..			(76.6					
Dry bulk dens. lb/ft³	72.9	74.1	(65.4	91.6				
Water content %	31.6	26	32.3	11				
Penetr. resist. lb/in²	190	(355	225	265				
Compaction		(265						
Max. dry bulk density lb/ft³		90	88	100				
Opt. water content %		28	31.5	17				
Penetr. resist. lb/in²		450	300	160				
Size analysis								
<0·076 mm ..	97	99	99	27				
<0·422 mm ..	100	100	100	100				
<2 mm								
<60 mm								
Effective size d10 mm..				0.06				
Unif. coeff. d60/d10 ..				2				
Plasticity								
Liquid limit ..	66	58	68					
Plastic limit ..	35	29	29					
Activity	0.87	0.71	0.92					
Class. symbol ..	MH	CH-MH	CH	SU				

SAND MINERALOGY

Frequency of mineral species in sand (2 to 0·02 mm)

Depth (in.)	0 3	3 11	12 20	30 40
Horizon	A_g	GC_{11}	GC_{12}	D_n
Sand % of soil	25	27	20	92
Quartz	A	A	A	C
Feldspars				
Acid	A	A	A	S
Andesine				C
Glass	C	a	a	a
Micas				
Muscovite	R	S	S	R
Biotite				
Chlorite	R	S	S	R
Amphiboles				
Hornblende A	R	S	S	
Hornblende B			R	
Glaucophane Actinolite				
Pyroxenes				
Augite				
Diopside	R	R		R
Hypersthene	R	R	R	S
Enstatite				
Epidotes				
Epidote	R		R	
Zoisite, clinozoisite	c	C	a	
Saussurite				
Pumpellyite				
Sericitic aggregates	S	S	S	A
Quartz aggregates				S
Chert				
Plant opal	R	R	R	
Lignite				
Calcite				
Apatite				
Accessory oxides				
Cristobalite				
Tridymite				
Rutile				
Brookite				
Ilmenite				
Magnetite				
Accessory silicates				
Zircon		R		
Tourmaline	R			
Sphene				
Kyanite				
Garnet		R		
Kaolinite				

SOIL CHEMISTRY

Depth (in.)	0 3	3 11	12 20	30 40
Horizon	A_g	GC_{11}	GC_{12}	D_n
pH (moist soil, H_2O)	7.5	8.1	7.8	8.3
(dried soil, H_2O)	7.0	7.7	7.7	8.0
(dried soil, N KCl)	7.2	7.5	7.4	7.6
$CaCO_3$ %	0.8	1.7	2.0	4.4
Cation exchange				
CEC me.%	22.3	17.9	19.3	3.6
TEB me.%				
BS %				
Ca me.%				
Mg me.%	5.6	6.2	6.6	2.2
K me.%	1.19	1.01	1.60	0.43
Na me.%	1.0	1.2	2.0	0.7
Organic matter				
C %	3.0	1.1	0.9	0.3
N %	0.26	0.10	0.08	0.02
C/N	12	11	11	15
Phosphorus (P)				
Total mg%	86	65	64	32
Organic mg%	19	10	7	0
Inorganic mg%	67	55	57	32
N H_2SO_4 mg%	57	50	50	28
Truog mg%	17	9	8	3
Citric mg%	22	11	12	3
P retention %				
N/Organic P	14	10	11	
Potassium (K)				
Total me.%	53	54	58	42
Exch. (moist) me.%	1.75	1.51	0.70	
K_e	0.82	0.81		
Magnesium (Mg)				
Acid-sol. me.%	42.9	43.8		
Sulphur (S)				
Total mg%				
Adsorbed mg%				
Tamm oxalate				
Al %	0.31	0.32	0.29	0.07
Fe %	0.53	0.53	0.51	0.19
Horizon weights				
Thickness (in.)	3	8	8	
Weight, lb/ac × 10^6	0.5	2.2	2.1	
* Soluble Salts(Total, %)	0.10	0.12	0.47	0.31

* For individual ions see Table 7.1.2 (Part 2)

CLAY MINERALOGY

Constituents as % of minerals (<2μ) identified

Clay % of soil	30	27	30	4
Free Fe_2O_3 % of soil	1.5	1.4	1.5	0.4
Chlorite	6	8	3	10
Interlayered chlorite	9	10	1	19
Mica				
Illite	30	35	37	19
Interlayered hydrous mica	12	10	10	19
Clay-vermiculite 1	3		5	
Clay-vermiculite 2	23	27	33	8
Montmorillonite	4	3	3	15
Kaolin				
Quartz	5	4	4	
Feldspar	8	6	4	10
Hydrous feldspar				
Allophane				
Halloysite				
Gibbsite				
Cristobalite				

SPECTROGRAPHIC ANALYSIS (APPROX.)

Macroelements %				
Al	11	10	12	12
Fe	3.5	3	4	2.5
Ca	2.5	2	3	4.5
Mg	0.9	0.7	1	0.8
Na	1.3	1.2	1.7	1.6
K	2.3	2	2.7	1.9
Microelements p.p.m.				
Zr	200	200	200	200
Cr	25	20	25	15
Ni	3	3	3	1
Co	<1	<1	<1	<1
Mn	250	200	200	200
Mo	<1	<1	<1	<1
Ga	8	10	10	8
V	50	30	50	30
Cu	15	10	10	3
Ba	800	600	800	900
Sr	300	250	400	1500
Ti	2500	2000	2500	2000
Loss on ign. %	5	3	1	0.1

Return to the Volcanoes

At the Esk Valley the route turns inland and begins to traverse typical North Island hill country. Most of the strata from the Esk to the Mohaka Rivers was under the ocean until 1 -2 Ma. Subsequent tectonic uplift has led to a general dip slope towards the east, so as we traverse westwards we pass increasingly older strata from 2 to circa 15 Ma (Miocene) years old.

The Esk Valley Flood – 1938

After three days of heavy rain between 23 - 25th April 1938, there was very severe flooding in the principal catchments of Hawke's Bay resulting in unprecedented damage to roads, bridges, livestock and other property. The meteorological system, which gave cause to this exceptional rainfall, was a warm moist air front from the north-east meeting a cooler air front from the south-east, the ascent of the warm air being accentuated by the continuous range of the mountains in Hawke's Bay. The distribution of rainfall was similar on each day despite the movement of the storm, thus pointing to the dominant influence of the topography. The area of very heavy rainfall was a well-defined area about 15km wide, parallel with the coast of Hawke's Bay, extending over a length of about 60km. The fall inside this area was everywhere over 90 mm (3.5 inches) on the first day, over 280 mm (11 inches) on the second day, and 225mm (9 inches) on the third, a total of over 600 mm (24 inches).

The topography of the country which experienced the heavy rainfall encourages high runoff. It is mainly table land at an elevation of about 450m (1,500 ft.) and deeply carved by many gorges. The Mohaka River discharge was held near a peak of 225,000 cusecs for about six hours, the rise at the Mohaka viaduct being 13.5m (45ft). In the lower Esk Valley an area of 700 hectares (1,750 acres) was silted to an average of at least 1m and the river rose 10m (30 ft.) in places. Both Napier and Hastings were inundated to depths of up to 1m. The total flood damage to roads and bridges in the district amounted to NZ $400,000.

Mohaka River

At the Mohaka River the route descends to the younger river terraces before climbing once more into Tertiary hill country. Soon Mesozoic greywackes appear and the land is less productive, steeper and often left in native forest or planted in pines. In the vicinity of the Tarawera Tavern, the terminus of pumiceous pyroclastic flows from the 232 AD eruption of Taupo are encountered, forming a distinct pumice terrace on the lower hillsides. As we begin to emerge from the hill country onto the Central Volcanic Plateau once more, we encounter Te Whaiti Ignimbrite from the c. 360,000 year Whakamaru eruption of the Taupo-Mangakino region which formed most of the planar landscape to Taupo. Here the soils are totally pumice dominated (Vitrudands). Nearing Taupo we pass the dacitic Tauhara dome complex.

Day 4: Taupo–Rotorua–Tirau–Auckland

Outline for Day 4 (Friday 30th July)

8.00 am Depart Alpine Lodge, Taupo

8.15-9.50 am STOP 1 Craters of the Moon and Huka Falls
The Craters of the Moon geothermal area in Wairākei is a typical acid sulfate geothermal system, with abundant fumaroles, steaming ground, mud pools, explosion craters and colourful soils. Huka Falls, the largest on the Waikato River, lie 4.8 km below Lake Taupo.

9.50 - 10.10 am Morning tea and toilet stop at Huka falls.

10.30 -11.30 am STOP 2 View Road tephra section and Taupo soil near Aratiatia Rapids

- Taupo sand, a rhyolitic pumice soil profile (Typic Udivitrand) overlying Holocene tephras and buried soil horizons on tephric loess
- view landscapes of plantation pine-to-pasture dairy conversions.

12.10-12.40 pm LUNCH Options: Rerewhakaaitu lakeside reserve, Brett Rd [toilet available] (near Stop 3), or Rerewhakaaitu village hall if wet.

12.40-1.30 pm STOP 3 Brett Rd, Rerewhakaaitu: Holocene tephras and buried soils, Rotomahana soil

- Volcanic landscape, historical importance of area for NZ soil survey
- Stratigraphy of sequence (~9.5 cal ka to 10 June 1886 Tarawera eruption)
- Rotomahana sandy loam (Typic Udivitrand)
- "Project Rerewhakaaitu": Chris Sutton (local farmer)

2.10-2.30 pm STOP 4 Kuirau Park, Ranolf St, Rotorua: explosion crater

- View results of 5-min steam eruption of 26 January, 2001

3.10–4.10 pm STOP 5 plus afternoon tea. Goodwin farm, Tapapa Rd, Tapapa: welded ignimbrite, tephras, loess, buried soils, Tirau soil

- Stratigraphy of sequence (~230 ka and younger)
- Tirau silt loam (Typic Hapludand)
- farming the Tirau soil: Barry Goodwin (local farmer)

4.40 – 5.00 pm Matamata toilet stop (T)
SH 27 Tirau to Auckland. To complete the tour, we travel SH 27 from Tirau through Matamata and on to Auckland via the Hauraki Basin/Plains. Prior to its switch c. 22,000 cal years ago to the Hamilton Basin, the ancestral Waikato River flowed northward through the Hauraki Basin into the Firth of Thames. The soils generally mimick the alluvial pattern in the Hamilton Basin but the distal tephra cover in Hauraki is thicker (~60-80 cm thick). The northern part of the Hauraki Plains are dominated by a large raised bog, Kopouatai, the world's last remaining restiad bog (formed mainly by jointed rushes). It supports Histosols. Kopouatai bog, ~14 m deep in places (its base is well below sea level), is a designated wetland conservation site under the Ramsar Convention. To the east are the volcanic Kaimai Ranges, bounded by the Hauraki Fault (>400 m throw) that was active between c. 2.1 and 1.2 Ma (Briggs et al., 2005). To the west are the Kiwitahi volcanics (5.5-15 Ma) (Booden et al., 2010).

7.00 pm Auckland, Airport Gateway Motel, 296 Kirkbride Rd. Mangere, Auckland
8pm Dinner

Day 4 – Route and scientific stops

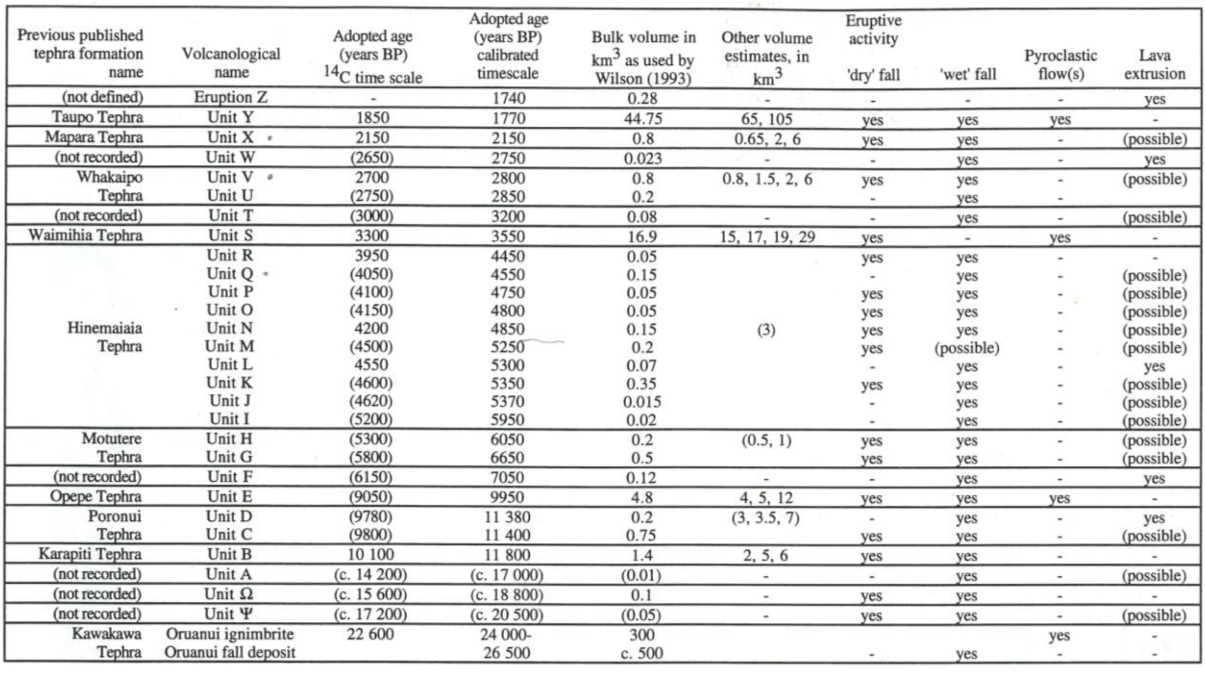
4.1 Introduction to Taupo volcano

David J. Lowe
Department of Earth and Ocean Sciences, University of Waikato, Hamilton

Taupo volcano is the most frequently active and productive rhyolite volcano on Earth. Activity began after the eruption of the widespread and voluminous c. 340 ka Whakamaru group ignimbrites, including a correlative Rangitawa Tephra (noted earlier on the tour), from Whakamaru caldera. Several groupings of silicic eruptives including domes making up the Whakaroa ridge immediately north of Taupo have ages estimated between c. 150 and 60 ka (Wilson et al., 2006). Modern activity began c. 60 ka and has been overwhelmingly pyroclastic (>95%) from vents mostly now concealed beneath Lake Taupo (Wilson et al., 2006). Pyroclastic deposits exposed in the Taupo-Maroa area represent 11 eruptions from c. 60 ka to c. 28 cal ka, and then the phreatomagmatic Kawakawa/Oruanui eruption occurred at c. 27 cal ka. This eruption was extremely voluminous with a total dense-rock equivalent (DRE) volume of ~530 km^3 (equivalent to nearly 1200 km^3 as bulk pyroclastic material) (Wilson et al., 2006), and it generated one of the most widespread and stratigraphically useful tephra-fall deposits in the New Zealand region (Wilson, 2001; Wilson et al., 2006; Lowe et al., 2008, 2010; Holt et al., 2010). Caldera collapse associated with this eruption generated most of the modern outline of the basin now partly filled by Lake Taupo, and much of the central North Island landscape was changed as a consequence of the eruption as noted on Day 1 (Manville and Wilson, 2004; see also Rosenberg & Kilgour, 2004, and Wilson et al., 2009).

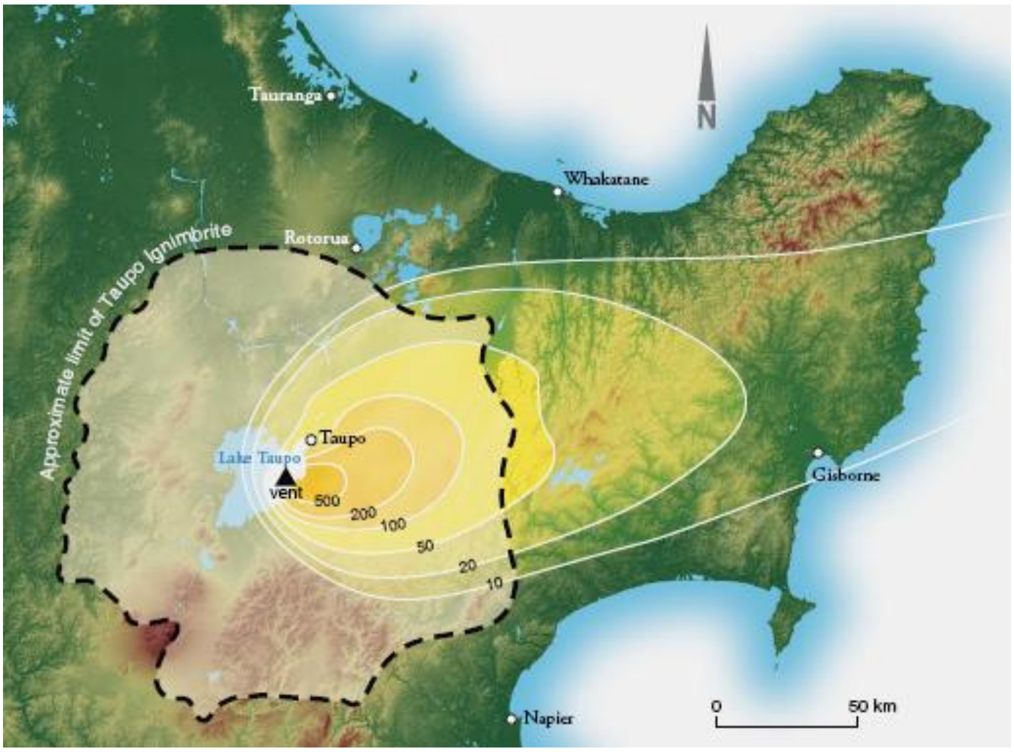
Since the Kawakawa/Oruanui event, there have been a further 28 eruptions, all but three taking place in the last 12,000 cal. years. The most recent (apart from lava extrusion of eruption Z) was the extremely powerful „ultraplinian‟ caldera-forming Taupo eruption event (Wilson and Walker, 1985; Wilson, 1993). Wilson (1993) erected a volcanological nomenclature for these 28 events beginning with ψ (the oldest) followed by Ω, A, …, and Z. Other names are also used for some of them (Froggatt and Lowe, 1990).

Summary of tephra names and ages and other information for 28 Taupo eruptives post-dating the Kawakawa/Oruanui eruption c. 27 cal ka (from Wilson, 1993, 1994). Note that ages for some eruptives have been modified since this table was published (see Lowe et al., 2008)



Previous published tephra formation name	Volcanological name	Adopted age (years BP) ^{14}C time scale	Adopted age (years BP) calibrated timescale	Bulk volume in km^3 as used by Wilson (1993)	Other volume estimates, in km^3	Eruptive activity		Pyroclastic flow(s)	Lava extrusion
						'dry' fall	'wet' fall		
(not defined)	Eruption Z	-	1740	0.28	-	-	-	-	yes
Taupo Tephra	Unit Y	1850	1770	44.75	65, 105	yes	yes	yes	-
Mapara Tephra	Unit X	2150	2150	0.8	0.65, 2, 6	yes	yes	-	(possible)
(not recorded)	Unit W	(2650)	2750	0.023	-	-	yes	-	yes
Whakaipo Tephra	Unit V	2700	2800	0.8	0.8, 1.5, 2, 6	yes	yes	-	(possible)
	Unit U	(2750)	2850	0.2		-	yes	-	
(not recorded)	Unit T	(3000)	3200	0.08	-	-	yes	-	(possible)
Waimihia Tephra	Unit S	3300	3550	16.9	15, 17, 19, 29	yes	-	yes	-
Hinemaiaia Tephra	Unit R	3950	4450	0.05	(3)	yes	yes	-	-
	Unit Q	(4050)	4550	0.15		-	yes	-	(possible)
	Unit P	(4100)	4750	0.05		yes	yes	-	(possible)
	Unit O	(4150)	4800	0.05		yes	yes	-	(possible)
	Unit N	4200	4850	0.15		yes	yes	-	(possible)
	Unit M	(4500)	5250	0.2		yes	(possible)	-	(possible)
	Unit L	4550	5300	0.07		-	yes	-	yes
	Unit K	(4600)	5350	0.35		yes	yes	-	(possible)
	Unit J	(4620)	5370	0.015		-	yes	-	(possible)
	Unit I	(5200)	5950	0.02		-	yes	-	(possible)
Motutere Tephra	Unit H	(5300)	6050	0.2	(0.5, 1)	yes	yes	-	(possible)
	Unit G	(5800)	6650	0.5		yes	yes	-	(possible)
(not recorded)	Unit F	(6150)	7050	0.12	-	-	yes	-	yes
Opepe Tephra	Unit E	(9050)	9950	4.8	4, 5, 12	yes	yes	yes	-
Poronui Tephra	Unit D	(9780)	11 380	0.2	(3, 3.5, 7)	-	yes	-	yes
	Unit C	(9800)	11 400	0.75		yes	yes	-	(possible)
Karapiti Tephra	Unit B	10 100	11 800	1.4	2, 5, 6	yes	yes	-	-
(not recorded)	Unit A	(c. 14 200)	(c. 17 000)	(0.01)	-	-	yes	-	(possible)
(not recorded)	Unit Ω	(c. 15 600)	(c. 18 800)	0.1	-	yes	yes	-	-
(not recorded)	Unit Ψ	(c. 17 200)	(c. 20 500)	(0.05)	-	yes	yes	-	(possible)
Kawakawa Tephra	Oruanui ignimbrite	22 600	24 000-26 500	300				yes	-
	Oruanui fall deposit			c. 500		-	yes	-	-

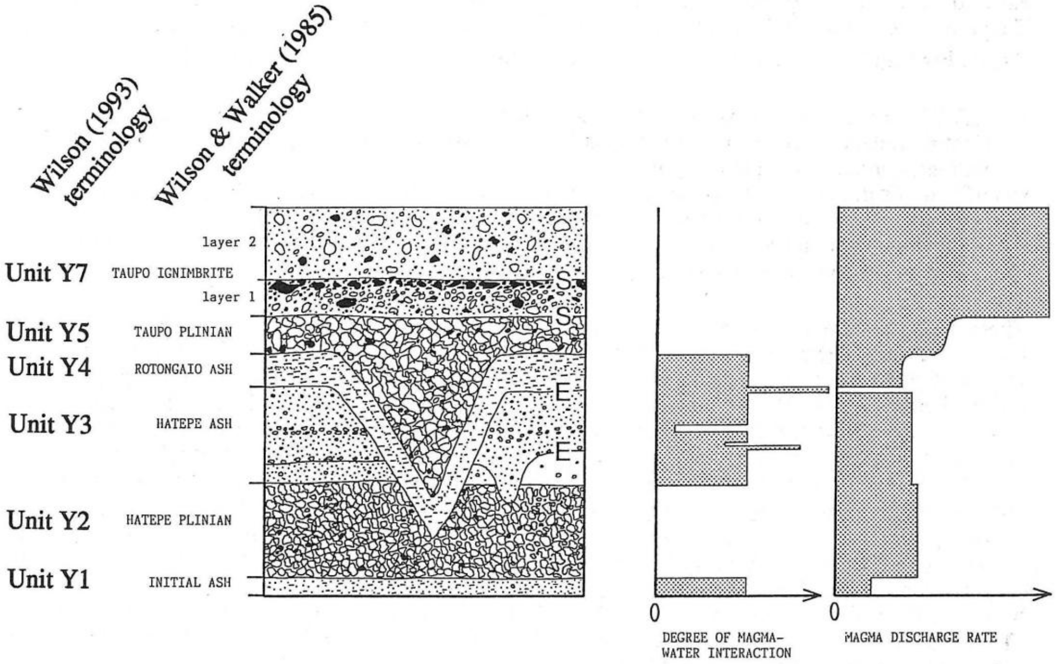
The so-called Taupo eruption (eruption Y) took place in late summer to early autumn (typically late March to early April) on the basis of fruit and seeds preserved in a buried forest at Puroera and the lack of an outer latewood ring (Clarkson et al., 1988; Palmer et al., 1988). The eruption year was 232 ± 5 AD according to new dendrochronology and wiggle matching by Hogg et al. (2009) (see also Sparks et al., 1995, 2008). Lowe and de Lange (2000) reviewed age estimates derived from radiocarbon dating, putative historical observations in Rome and China of disputed veracity, Greenland ice-core records, and dendrochronology. A total eruptive bulk volume was estimated at ~105 km^3 (~30 km^3 DRE).



Distribution of Taupo ignimbrite radially around Lake Taupo and tephra fallout isopachs (in cm) derived from the Taupo eruption (from Wilson and Leonard, 2008)

The eruption was complex, generating three phreatomagmatic („wet‟) and two plinian („dry‟) fall units, a multi-flow intraplinian ignimbrite, and at the eruption climax, the extremely violently emplaced Taupo ignimbrite (Unit Y7). The height of the main ultra-plinian phase (Unit Y5) eruption column has been estimated at 50-55 km; this phase lasted for ~6-17 hours (Walker, 1980). The ignimbritic material was emplaced cataclysmically over about 400 seconds (~7 mins) by an extremely energetic pyroclastic flow (also called a pyroclastic density current or PDC) moving at 200-300 m/s over a near-circular area (~80 km radius) of c. 20,000 km^2 around the vents (Wilson, 1985, 1993; Wilson and Walker, 1985; Smith and Houghton, 1995). Its temperature was about 400-500° C at ~ 50 km from vent (within ~30-40 km of the vent it was 150-300° C) (McClelland et al., 2004; Hudspith et al., 2009). The non-welded ignimbrite was spread thinly over the landscape to generate an archetypal „low aspect ratio‟ ignimbrite (Walker and Wilson, 1985). Ignimbrite-veneer deposits (IVD) are generally 0.5 to 1 m-thick and drape topographic highs; valley-pond ignimbrites (VPI) infil valleys and depressions to depths of 5 to 60 m (Manville, 2001).

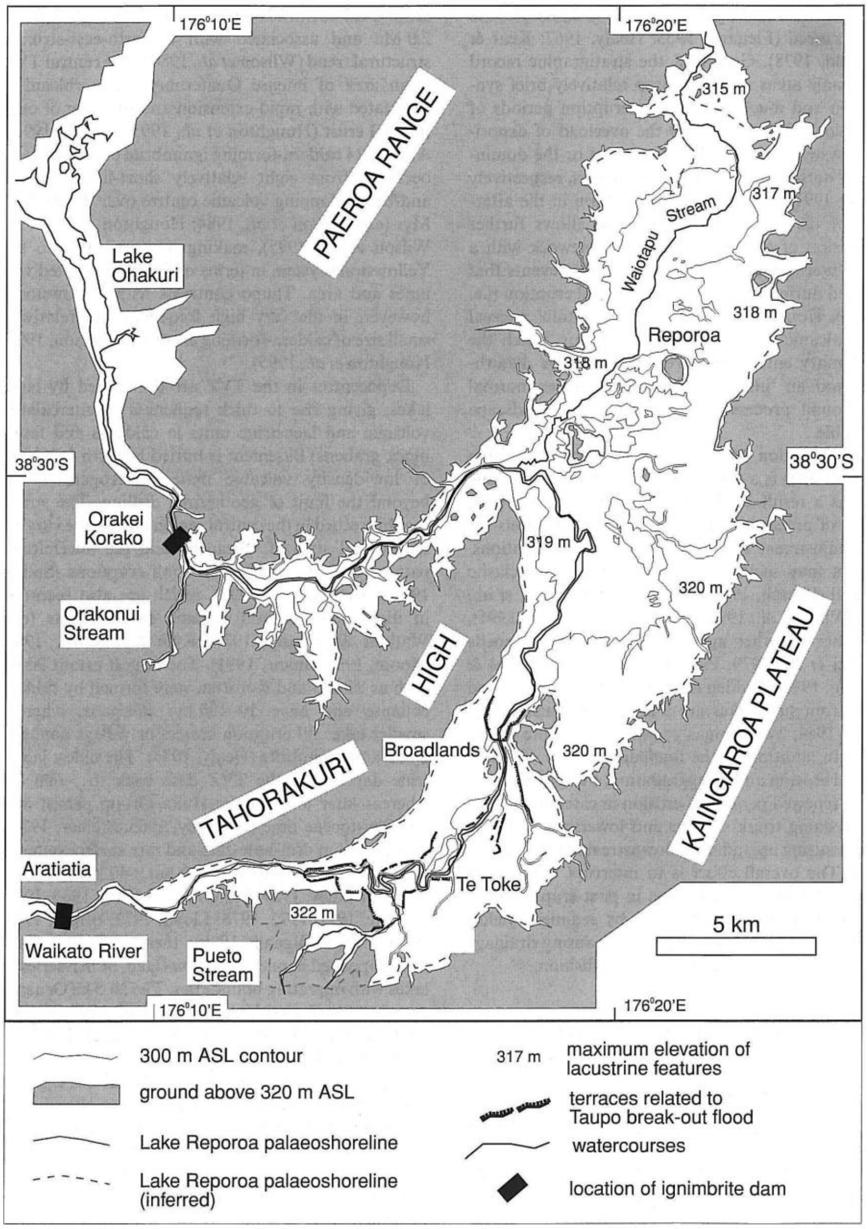
Because of its extreme violence and energy release (≥150 ± 50 megatons explosive yield), and by analogy with the 1883 Krakatau event, it is likely that the ignimbrite-emplacement phase generated a volcano-meteorological tsunami that may have reached coastal areas worldwide (Lowe and de Lange, 2000). The emplacement of the ignimbrite destroyed all forests in its path, and then ignimbrite contains numerous charred logs and charcoal, many of the logs notably being orientated radially around the vents (Froggatt et al., 1981). Yet the forests recovered within 100-200 years (Clarkson et al., 1992; Wilmshurst and McGlone, 1996).



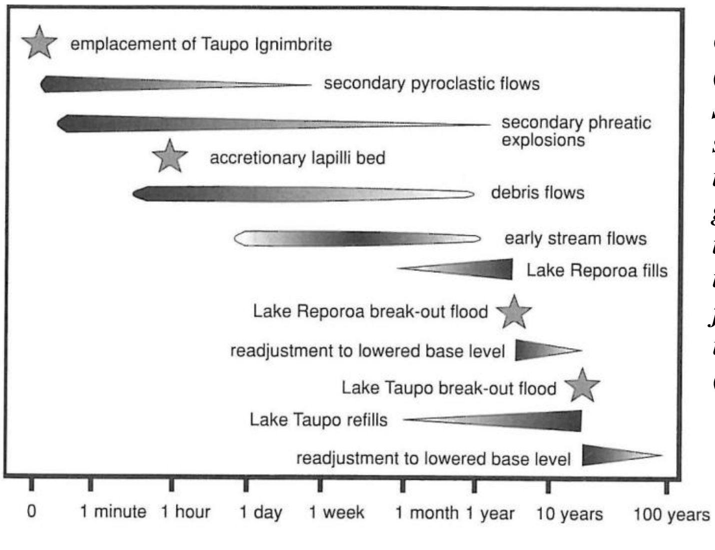
Summary of the stratigraphy of pyroclastic deposits of the Taupo eruption (eruption Y of Wilson, 1993). Graphs at right indicate qualitative changes in the inferred degree of magma-water interaction and the magma discharge rate during the eruption. E = erosion horizons formed by running water; S = erosion horizons from shearing beneath the fast-moving pyroclastic flow that deposited the Taupo ignimbrite (from Wilson, 1994).

The wide variation in eruption styles and dynamics relate to variations in discharge rate and the degree of interaction between the magma and water in the proto-Lake Taupo (Wilson and Walker, 1985; Wilson, 1993, 1994; Houghton et al., 2010). Much of Lake Taupo was expelled, evaporated, or drained into a caldera-collapse structure beneath the current lake floor during the eruption. Afterwards it refilled over approximately 15 to 40 years, reaching a height of ~400 m, about 30-40 m above its present level (357 m) to form a semi-continuous, wave-cut bench and highstand shoreline deposits (Manville et al., 1999, 2007). Catastrophic failure of a pumiceous pyroclastic dam led to the restablishment of the Waikato River and the release of ~20 km^3 of water in a single phase, the peak discharge being 20,000–40,000 m^3/sec, equivalent to the Mississippi River in flood (Manville et al., 1999). The break-out flood deposits can be traced 220 km downstream of Lake Taupo (Manville et al., 2007).

The Reporoa Basin, to the north of Taupo (see map below), was temporarily infilled by a supra-ignimbrite lake, „Lake Reporoa‟, because of blockage by Taupo ignimbrite of the basin near Orakei Korako. Lake Reporoa would have formed in about three years and had a maximum area of ~190 km^2 and a volume of ~2.5 km^3 (Manville, 2001). The lake highstand shoreline is marked approximately by the 320-m contour (perhaps up to 360 m: Manville and Wilson, 2004) where a prominent bench and associated beach and lake sediments occur (Manville, 2001). The lake would have emptied quickly after overtopping the barrier at its lowest point, near Orakei Korako, generating a peak flood discharge of about 17,000 m^3/sec which contrasts with the Waikato River flow rate through the area today of ~130 km^3/sec (Manville, 2001). Several decades after the formation and destruction of Lake Reporoa, the basin was again partially inundated by the the break-out flood triggered by the failure of the ignimbrite dam at the outlet of intracaldera Lake Taupo as described above.



Outline topography of Reporoa Basin, the area covered by temporary 'Lake Reporoa' and the location of ignimbrite dams that blocked the Waikato River after the Taupo eruption (from Manville, 20001)



Chronology of post-Taupo eruption (after c. 232 AD) responses and events. Scale approx. logarithmic. Tapering shaded bars indicate duration and intensity of each process; stars indicate geologically instantaneous events including emplacement of Taupo ignimbrite and break-out flood event from Lake Taupo (hence these can be used as chronostratigraphhic markers) (from Manville, 2001)

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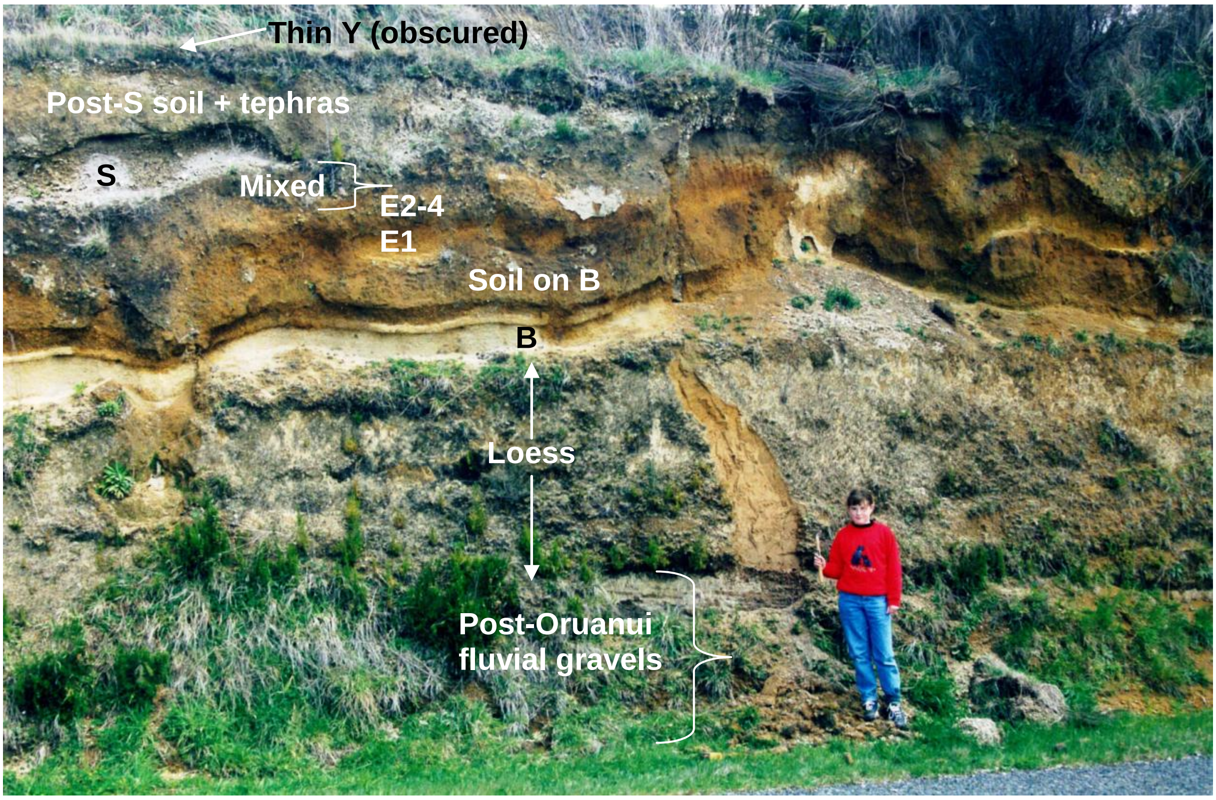
4.2 Stop 1 – Craters of the Moon and Huka Falls

The Craters of the Moon thermal area in Wairākei is a typical acid sulfate geothermal system, with abundant fumaroles, steaming ground, mud pools, explosion craters and colourful soils . Huka Falls are the largest on the Waikato River and lie 4.8 km below Taupo and 3.2 km above Wairakei. The falls occur when the Waikato River, after flowing over a comparatively wide bed, is abruptly confined for about 220 metres to a narrow rock-bound chasm less than 15 m wide. (http://www.teara.govt.nz/1966/H/HukaFallsAndAratiatiaRapids/HukaFallsAndAratiatiaRapids/en)

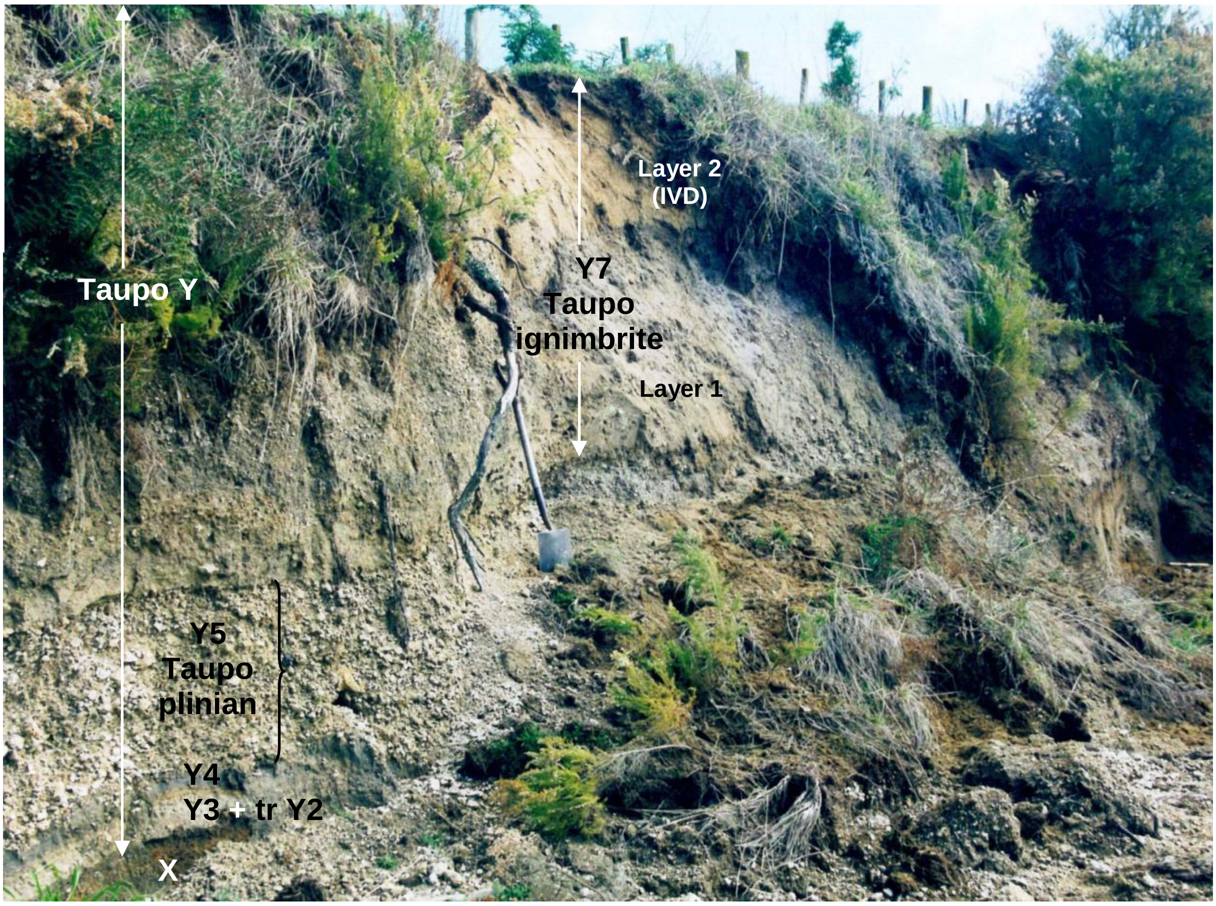
4.3 Stop 2 – Tephras, Loess and Buried Soil Sequence, Taupo sand, View Rd, Aratiatia

Location U17 845814, elevation 380 m asl, rainfall ~1100 mm pa

Photo of View Rd section taken in 2000 showing lower and upper parts



Stratigraphy of lower part of View Rd section. Tephra names and ages: Unit B, Karapiti (11,410 ± 190 cal yr BP); E, Opepe (10,075 ± 155 cal yr BP); mixed c. 6000-4000 cal yr BP; S, Waimihia (3410 ± 40 cal yr BP); Y, Taupo (1718 ± 5 cal yr BP or 232 ± 5 AD: Hogg et al., 2009). Lydia Lowe provides the scale (2000).



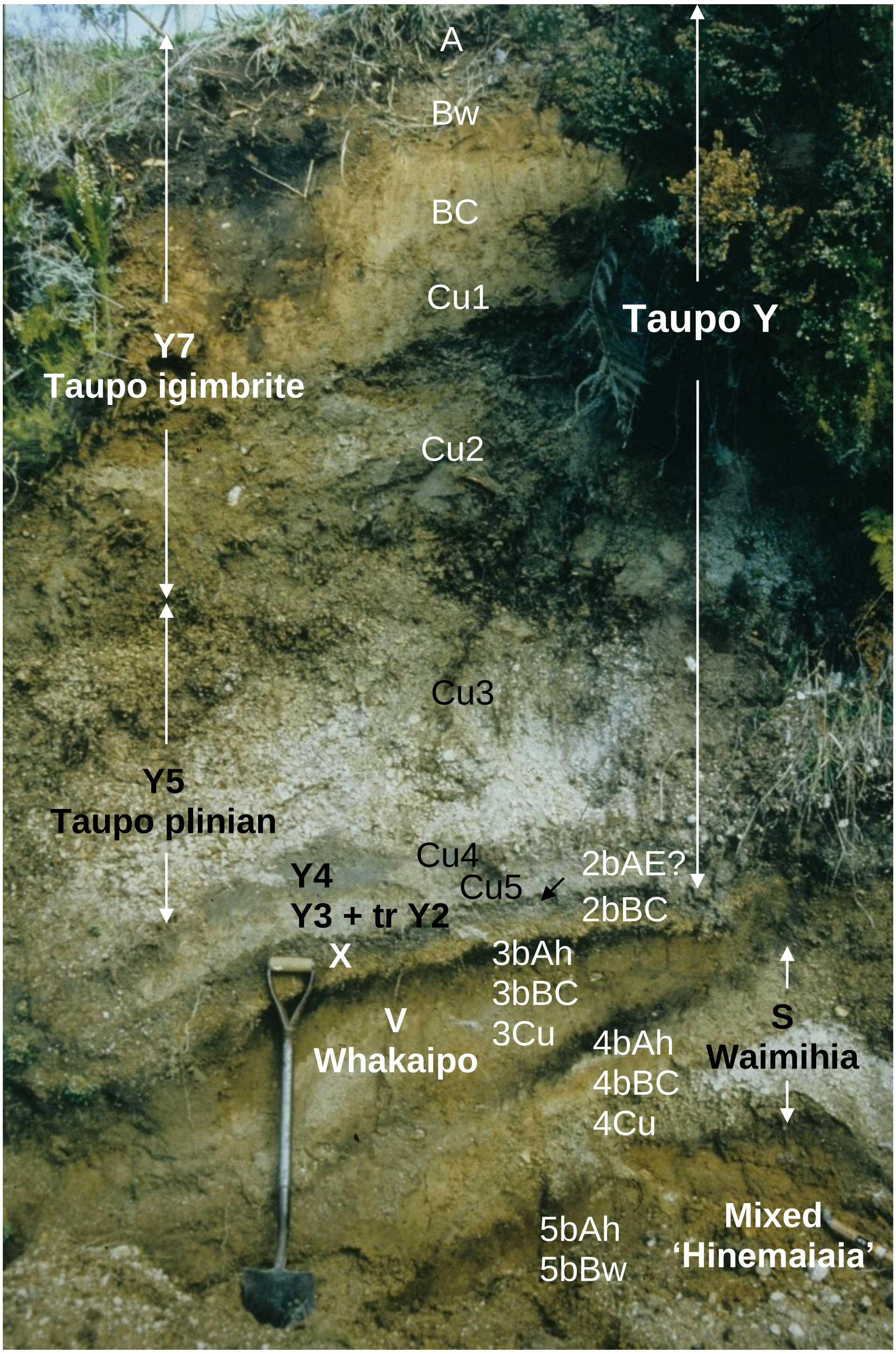
Stratigraphy of upper part of View Rd section. Tephra names and ages: Unit X, Mapara (2075 ± 85 cal yr BP); Y, Taupo (1718 ± 5 cal yr BP or 232 ± 5 AD): Y2, Hatepe plinian; Y3, Hatepe ash; Y4, Rotongaio ash; Y5, Taupo plinian, Y7, Taupo ignimbrite. Spade ~1.1 m long

Selected analyses on buried soil horizons on Whakaipo (Unit V) and Mapara (Unit X) tephras at De Brett section on SH 5, Taupo (from Lowe and Percival, 1993, after Green, 1987).

	Sand %	Silt %	Clay† %	Org. C %	Al_o %	Al_p %	Al/Si ratio	Si_o %	Fe_o %	Fe_p %	Alloph. %	Ferrihyd. %
Mp	65	32	3	0.1	0.06	neg	2.0	0.03	0.04	neg	0.2*	0.1
Wo	66	29	5	0.6	0.27	neg	2.1	0.13	0.21	neg	1.0*	0.4

neg = negligible † clay <2 µm, silt 2-63 µm, sand >63 µm

* Allophane wt% in the clay, silt, and sand fractions in Mp are 0.15, 0.06, 0.00, respectively (total 0.2); in Wo, they are 0.97, 0.63, 0.00, respectively (total 1.6).



Stratigraphy and provisional horizonation of upper part of View Rd section. Tephra names and ages: Mixed 'Hinemaiaia', undifferentiated tephras c. 4000-6000 cal yr BP; Unit S, Waimihia (3410 ± 40 cal yr BP); V, Whakaipo (2865 ± 145 cal yr BP); X, Mapara (2075 ± 85 cal yr BP); Y, Taupo (1718 ± 5 cal yr BP or 232 ± 5 AD): Y2, Hatepe plinian; Y3, Hatepe ash; Y4, Rotongaio ash; Y5, Taupo plinian, Y7, Taupo ignimbrite. Spade ~1.1 m long. Colin Wilson (Victoria Univ. of Wellington) provided expert assistance here with the stratigraphy.

Soil profile description and analyses of Taupo sand, Wairakei

Landform and site location: summit of hill on (former) Wairakei Research Station ~500 m north of Wairakei Village (see Rijske and Vucetich, 1980)

Parent material: Pumiceous tephra – Taupo Tephra 232 ± 5 AD (stratigraphy indicated)

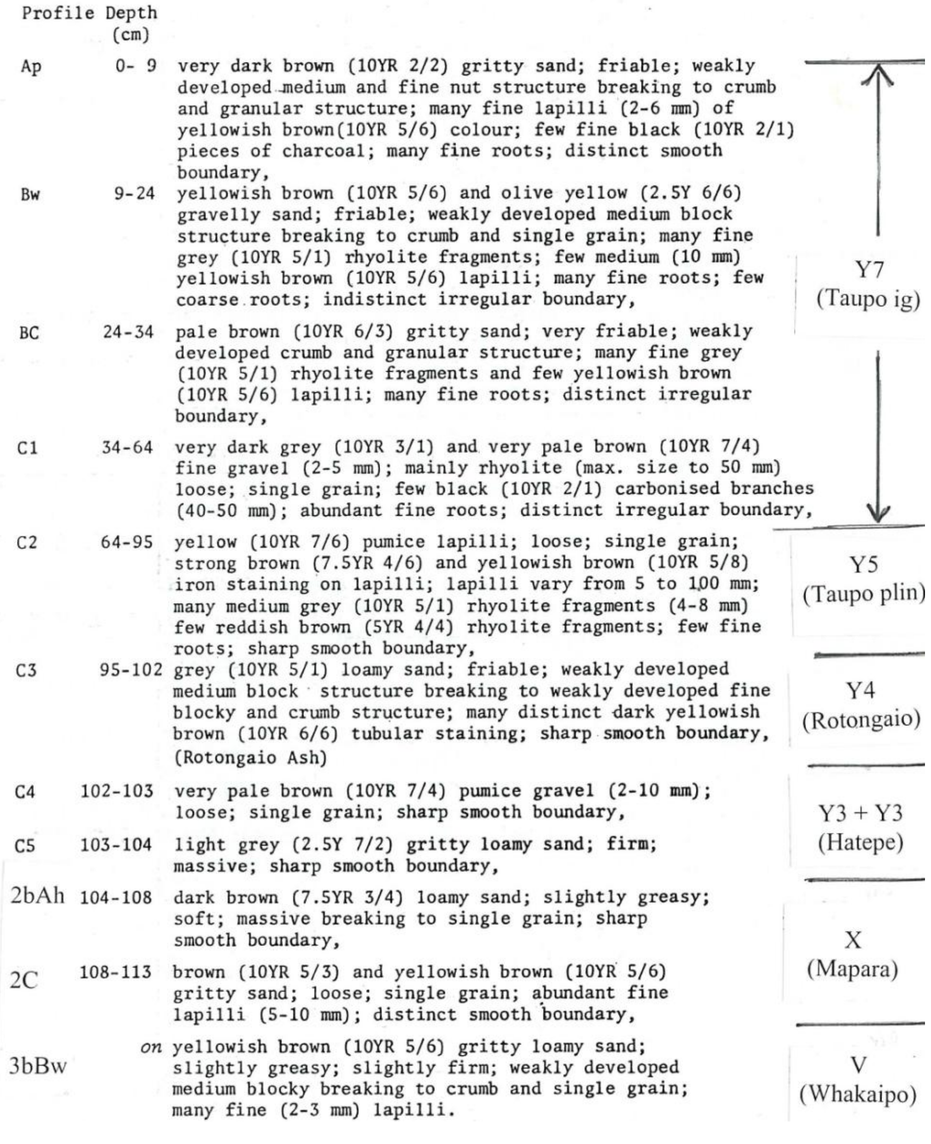
Location U17 799834, elevation 450 m asl, rainfall ~1280 mm. Well drained

NZSC: Immature Orthic Pumice Soils; tephric, rhyolitic; loamy/sandy; rapid

Soi Taxonomy: Ashy/pumceous, mesic Typic Udivitrands

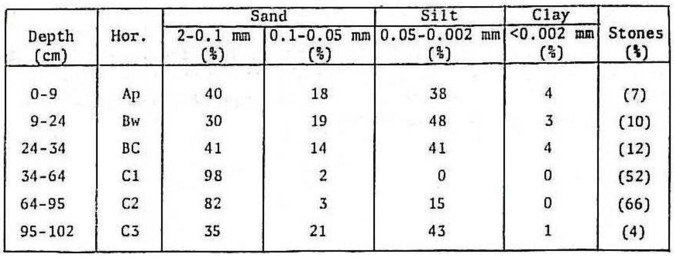
Analytical data from Parfitt et al. (1981) (see also NZ Soil Bureau, 1968; Lowe and Percival, 1993) (*Note*: in description below, **Y3 +Y3** should read **Y3 + Y2**)

Profile description and stratigraphy

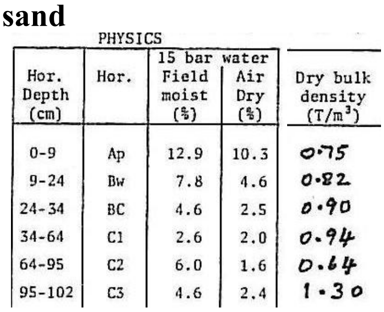


Profile	Depth (cm)		
Ap	0- 9	very dark brown (10YR 2/2) gritty sand; friable; weakly developed medium and fine nut structure breaking to crumb and granular structure; many fine lapilli (2-6 mm) of yellowish brown(10YR 5/6) colour; few fine black (10YR 2/1) pieces of charcoal; many fine roots; distinct smooth boundary,	Y7 (Taupo ig)
Bw	9-24	yellowish brown (10YR 5/6) and olive yellow (2.5Y 6/6) gravelly sand; friable; weakly developed medium block structure breaking to crumb and single grain; many fine grey (10YR 5/1) rhyolite fragments; few medium (10 mm) yellowish brown (10YR 5/6) lapilli; many fine roots; few coarse roots; indistinct irregular boundary,	
BC	24-34	pale brown (10YR 6/3) gritty sand; very friable; weakly developed crumb and granular structure; many fine grey (10YR 5/1) rhyolite fragments and few yellowish brown (10YR 5/6) lapilli; many fine roots; distinct irregular boundary,	
C1	34-64	very dark grey (10YR 3/1) and very pale brown (10YR 7/4) fine gravel (2-5 mm); mainly rhyolite (max. size to 50 mm) loose; single grain; few black (10YR 2/1) carbonised branches (40-50 mm); abundant fine roots; distinct irregular boundary,	
C2	64-95	yellow (10YR 7/6) pumice lapilli; loose; single grain; strong brown (7.5YR 4/6) and yellowish brown (10YR 5/8) iron staining on lapilli; lapilli vary from 5 to 100 mm; many medium grey (10YR 5/1) rhyolite fragments (4-8 mm) few reddish brown (5YR 4/4) rhyolite fragments; few fine roots; sharp smooth boundary,	Y5 (Taupo plin)
C3	95-102	grey (10YR 5/1) loamy sand; friable; weakly developed medium block structure breaking to weakly developed fine blocky and crumb structure; many distinct dark yellowish brown (10YR 6/6) tubular staining; sharp smooth boundary, (Rotongaio Ash)	Y4 (Rotongaio)
C4	102-103	very pale brown (10YR 7/4) pumice gravel (2-10 mm); loose; single grain; sharp smooth boundary,	Y3 + Y3 (Hatepe)
C5	103-104	light grey (2.5Y 7/2) gritty loamy sand; firm; massive; sharp smooth boundary,	
2bAh	104-108	dark brown (7.5YR 3/4) loamy sand; slightly greasy; soft; massive breaking to single grain; sharp smooth boundary,	X (Mapara)
2C	108-113	brown (10YR 5/3) and yellowish brown (10YR 5/6) gritty sand; loose; single grain; abundant fine lapilli (5-10 mm); distinct smooth boundary,	
3bBw	*on*	yellowish brown (10YR 5/6) gritty loamy sand; slightly greasy; slightly firm; weakly developed medium blocky breaking to crumb and single grain; many fine (2-3 mm) lapilli.	V (Whakaipo)

Physical data for Taupo sand



Depth (cm)	Hor.	Sand		Silt	Clay	Stones (%)
		2-0.1 mm (%)	0.1-0.05 mm (%)	0.05-0.002 mm (%)	<0.002 mm (%)	
0-9	Ap	40	18	38	4	(7)
9-24	Bw	30	19	48	3	(10)
24-34	BC	41	14	41	4	(12)
34-64	C1	98	2	0	0	(52)
64-95	C2	82	3	15	0	(66)
95-102	C3	35	21	43	1	(4)



PHYSICS

Hor. Depth (cm)	Hor.	15 bar water		Dry bulk density (T/m³)
		Field moist (%)	Air Dry (%)	
0-9	Ap	12.9	10.3	0·75
9-24	Bw	7.8	4.6	0·82
24-34	BC	4.6	2.5	0·90
34-64	C1	2.6	2.0	0·94
64-95	C2	6.0	1.6	0·64
95-102	C3	4.6	2.4	1·30

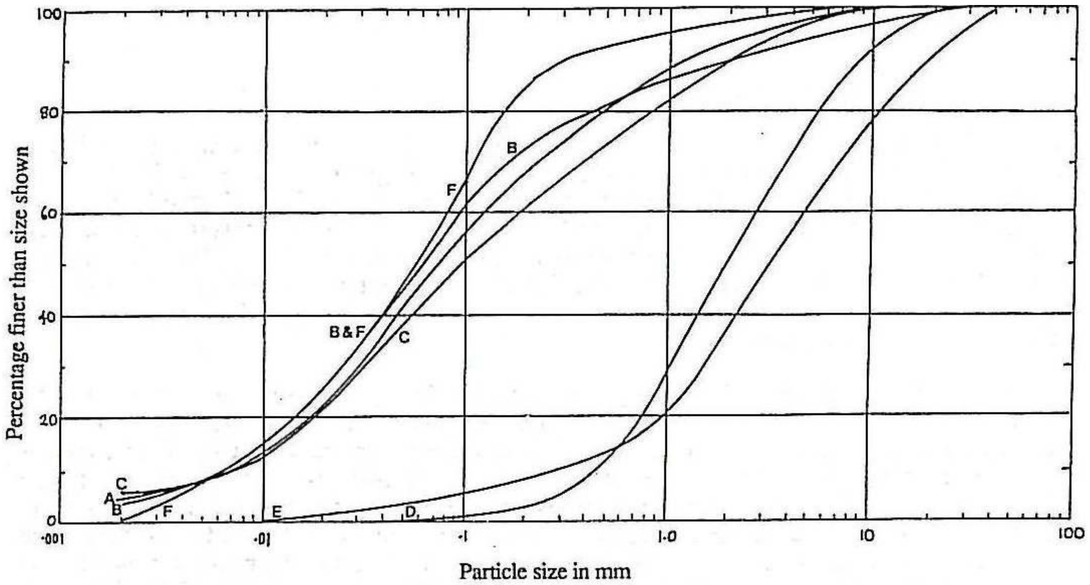


Fig. 6.12 Size grading curves for Taupo sand, Wairakei. A, 0-9 cm; B, 9-24 cm; C, 24-34 cm; D, 34-64 cm; E, 64-95 cm; F, 95-102 cm (from Parfitt et al. 1981).

Chemistry and mineralogy of Taupo sand

Depth (cm)	Hor.	pH				Exchangeable cations (meq/100 g)						Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g)		Base saturation (%)	
		H_2O	KCl	ΔpH	NaF	Ca	Mg	K	Na	H (KCl)	Al (KCl)				NH_4OAc (pH 7)	Σ Cations (pH 8.2)	Σ bases / CEC NH_4OAc	Σ bases / Σ Cations
0-9	Ap	5.0	4.2	-0.8	10.0	3.2	0.29	0.65	0.05		1.9	31.1	29.2	6.1	17.3	35.3	24	12
9-24	Bw	5.5	4.6	-0.9	10.7	1.1	0.03	0.57	0.06		0.60	14.5	13.9	2.4	6.3	16.3	29	11
24-34	BC	5.9	5.0	-0.9	10.3	0.7	0.03	0.90	0.07		0.08	6.3	6.2	1.8	3.5	8.0	49	21
34-64	C1	6.4	5.1	-1.3	8.1	2.3	0.21	0.97	0.63		0.00	3.0	3.0	4.1	4.6	7.1	89	58
64-95	C2	6.7	5.8	-0.9	9.3	1.0	0.06	1.18	0.24		0.03	1.6	1.6	2.5	2.9	4.1	86	61
95-102	C3	6.3	4.9	-1.4	9.4	0.9	0.07	1.58	0.50		0.03	1.5	1.5	3.1	3.7	4.6	84	67

Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g)			P Retention (%)	Dithion. cit. (%)		Tamm ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)
				H_2SO_4 (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K_c	Mg_r	
0-9	Ap	5.3	0.35	73	84	49	44	0.37	0.43	0.29	0.66	0.11	0.19	0.43	0.09	1.2	10
9-24	Bw	1.4	0.08	52	62	22	44	0.26	0.31	0.20	0.75	0.25	0.08	0.22	0.11	1.4	3
24-34	BC	0.4	0.03	24	32	11	29	0.20	0.14	0.13	0.42	0.15	0.03	0.10	0.13	1.7	3
34-64	C1	0.3	0.01	33	36	4	5	0.23	0.06	0.18	0.04	0.01	0.03	0.03	0.13	2.8	0
64-95	C2	0.2	0.01	24	32	3	11	0.22	0.11	0.14	0.13	0.07	0.03	0.04	0.16	2.2	4
95-102	C3	0.1	0.01	9	17	1	11	0.21	0.06	0.18	0.12	0.06	0.03	0.04	0.34	1.7	3

Depth (cm)	Hor.	Clay Fraction (%)															Sand Fraction (%)													
		Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Glass	Hematite	Quartz	Feldspar (acid)	Andesine	Glass	Muscovite	Biotite	Horneblende	Augite	Hypersthene	Epidote	Quartz Ag	Apatite	Magnetite	Plant opal
0-9	Ap							23					2		75		S		c	A		tr	tr	tr	S			tr	R	
9-24	Bw							7					14		79				S	A					S				R	
24-34	BC							3					9		88				S	A				tr	S				R	
34-64	C1							3					5		92		S		C	A			R	tr	c		R		R	
64-95	C2												6		94		R		c	A				R	R				tr	
95-102	C3											5	3	5	87				S	A					S				S	

Green, B.E. 1987. Weathering of buried paleosols on late Quaternary rhyolitic tephras, Rotorua region, New Zealand. Unpublished MSc thesis, University of Waikato.

Lowe, D.J., Percival, H.J. 1993. Clay mineralogy of tephras and associated paleosols and soils, and hydrothermal deposits, North Island [New Zealand]. *Review and Guide Field Tour F1 – New Zealand.* Tenth International Clay Conference, Adelaide, Australia, 1-110.

NZ Soil Bureau 1968. Soils of New Zealand Part 3. *New Zealand Soil Bureau Bulletin* 26 (3), 74-75.

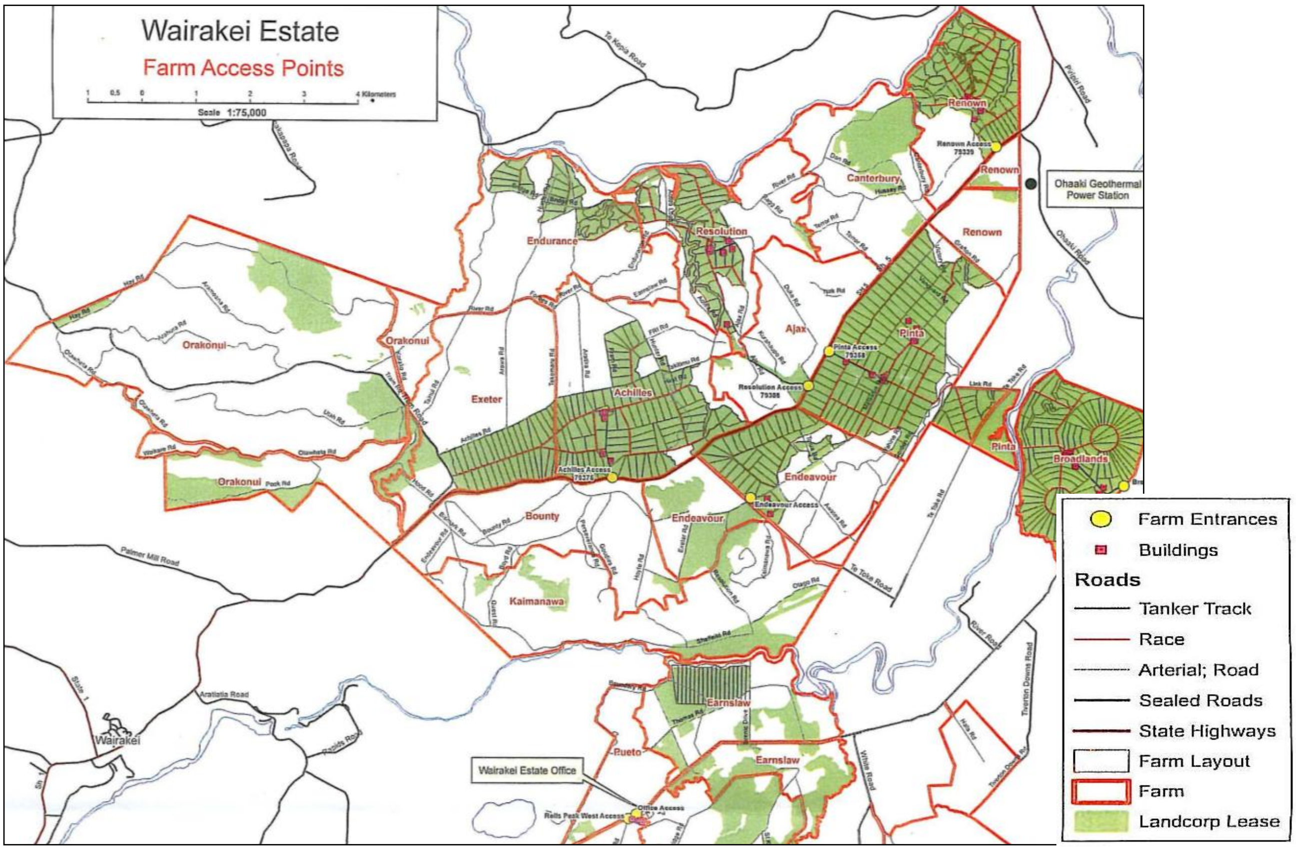
Parfitt, R.L., Pollok, J.A., Furkert, R.J. (compilers) 1981. Guide book for Tour 1 Pre-conference North Island New Zealand. *Soils With Variable Charge Conference*, Palmerston North, New Zealand. 153 p.

Rijske, W.C., Vucetich, C.G. 1980. Soils of Wairakei Research Station, North Island, New Zealand. *New Zealand Soil Survey Report* 57. 26p.

4.4 Transit from Aratiatia (Stop 2) to Rerewhakaaitu (Stop 3)

Forest to dairy farm conversions e.g. Achilles Farm, Wairakei Estate, SH 5

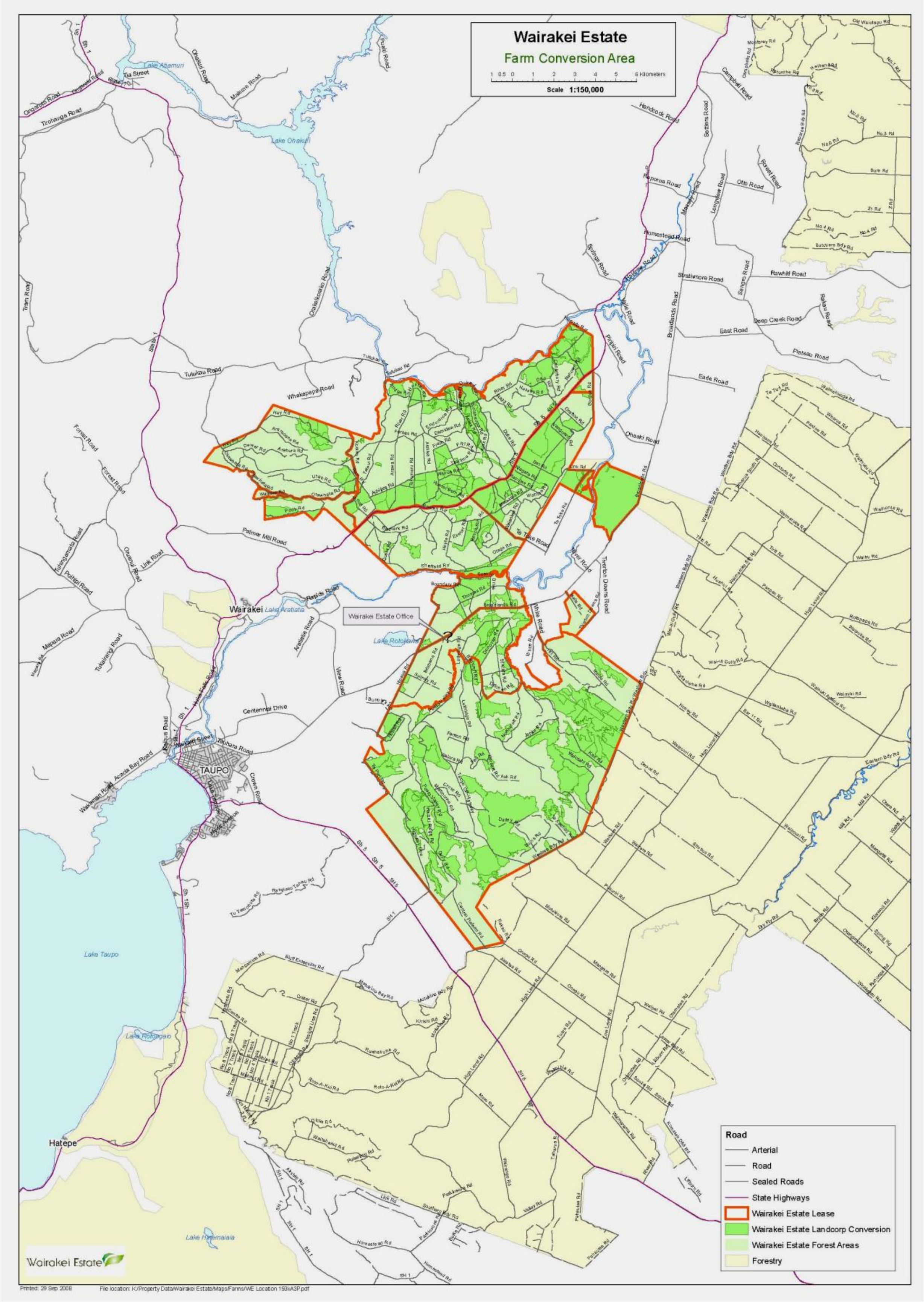
Newly operational dairy farm, fomerly a pine plantation, on Achilles Farm ~12 km NE of Wairakei. Flattish landscape is dominated by Taupo soils on ~2m-deep Taupo eruptives (c. 232 AD) very similar to those at View Rd (Stop 2). Welded ignimbrites and rhyolite domes form skyline beyond. Photo Oct 2008: David Lowe.



Map of Wairakei estate showing dairy farms in operation as at October 2008. Note radial paddocks at Broadlands farm bottom right. Map provided courtesy of Alan Bullick, Landcorp Pastoral.

Pine plantations in the process of being converted to pasture for dairying near Reporoa, 30 September 2008. Native forest clings to rhyolite dome in background. Photo: David Lowe

New dairy pastures on Achilles Farm near Wairakei. The pine trees formerly on this site were ripped out roots and all (like extracting teeth). The fastest conversion took just 6 weeks (Alan Bullick).



Wairakei Estate showing land conversions from plantation forestry to pastoral farming as at October 2008 (map provided courtesy of Alan Bullick, Landcorp Pastoral)

4.5 Agriculture and the environment

Chris McLay

Environment Waikato, Hamilton

Background

The impacts of agriculture are the most pervasive environmental management issue facing Environment Waikato (Waikato Regional Council). The effects of agriculture are obvious, widespread and well understood. Agriculture is the economic mainstay of the Waikato, and the present rate at which agriculture is both expanding and intensifying places Environment Waikato in an increasingly difficult position as it seeks to resolve issues of community, economic, environmental and cultural imperatives. Environment Waikato has a long history of innovative work managing the impacts of agriculture. As well as undertaking many small catchment schemes, larger projects include the following:

- Lake Taupo Catchment Control Scheme
- Waihou Valley Scheme
- Clean Streams
- Protecting Lake Taupo Project
- Project Watershed
- Peninsula Project
- Fonterra Accord

Agricultural intensification

Dairy cow numbers increased by 10 per cent in the Waikato region during the decade ending 2004. The Ministry of Agriculture and Fisheries expects a further 3.5 per cent increase in the national dairy herd between 2005 and 2009. Average stocking rates for the Waikato region rose from 2.8 cows per hectare in 1998 to just over 3 cows per hectare currently – resulting in an additional 16 cows per 100 hectare farmed and another 1.6 tonnes of nitrogen leached for an average farm. Another process of agricultural intensification is land-use change from plantation forests to pastoral agriculture, particularly in the upper Waikato river catchment, between Taupo and Lake Karapiro (see below). That legislation has prevented forested areas being converted to pasture but has not put any hindrance for further intensification of farmed land.

Summary of land-use change in the central North Island

Land use change in the central North Island has occurred through intensification of current pastoral systems (e.g. drystock to dairying) and the conversion of established plantation forests to pasture, most commonly for dairying. Conversion is driven by the perceived better long term economic returns from farming compared with forestry. Up until 31 December 2007, when potential impacts of the Emission Trading System (ETS) were signalled by central Government (the ETS is part of the Government"s response to climate change obligations under the Kyoto Protocol), significant forestry clearance was occurring for agriculture.

Scale of conversion

Large-scale conversion of established plantation forest to pasture occurred, and potentially will continue, primarily in the Waikato River catchment, between Taupo Gates and Lake Karapiro. There are some smaller private developments (one of which is >600 hectares), but the main areas are:

- Land previously sold from the Kinleith Forest to private landowners by Carter Holt Harvey (CHH). The area of land is in the order of 5,000 to 8,000 hectares. We understand that no more sales will be made, but there are areas of land that have been sold but not yet converted.

- CHH advised us that approximately 32,000 hectares of the Kinleith Forest were identified for pastoral or lifestyle use, and were withheld from the sale of the CHH forest estate. To date, it is estimated up to 10,000 ha may have already been converted for dairying, and 27 dairy farms from this conversion are currently for sale on the market.
- Wairakei Pastoral Ltd (WPL) is converting the whole of the ex-Tenon Tahorakuri and Tauhara forests. Approximately 22,500 ha of the 26,000 ha property will be converted to dairying and to drystock. To date, it is estimated 9500 ha have been converted, with more than half for dairying and the rest for drystock.

Positive effects arising from land use change

Economic activity will be directly generated by the work needed to convert the forest land to established farmland. The development of farms will result in an increase in population in both Taupo and South Waikato districts. This increase will be of particular significance in the somewhat economically stressed South Waikato District. In the long term there will be on-going returns from agricultural production accruing nationally and regionally.

Negative effects arising from land use change

In addition to the long term loss of forestry production, there will be a range of potential negative environmental effects. Many of these will occur over long time frames and many will be mainly experienced outside the area where the activity is occurring. Brief comments on each of the main potential adverse effects are given below.

Water quality

There will be short–medium term impacts on water quality from soil and debris loss during land conversion. These are relatively easy to manage, although our ability to do so depends on prior knowledge of the activity and the availability of resources to advise and monitor individual properties. In the longer term, the main impact is from the increased losses of nitrogen into ground and surface waters. For the main stem of the Waikato River, including the hydro lakes, this N loading will mean the river water will be able to support more algae. The clarity of the water will decline, and it will appear a slightly greener colour. There will also be an increased risk that blooms of potentially toxic blue-green algae will occur. Environment Waikato scientists believe that existing land use intensification will cause more algal blooms in the future. This potential will be enhanced by, but not solely caused by, the forest-pasture land use changes.

In a free running river, the effects of increased nutrients are not often seen because the conditions required for algal growth may not be present. The Waikato hydro system provides still water and an extended residence time, two factors that create ideal circumstances for algal and weed growth. Thus the current and future water quality of the Waikato River depends on both the level of nutrients entering the water and the degree of impoundment caused by the dams. There are very few options for minimisng this effect while still maintaining an effective hydro system. This conundrum is one of the major management decisions facing Environment Waikato at present and in the immediate future.

Water allocation

Urban, industrial and agricultural development will all lead to greater demands for water in future. To manage the allocation of water, a variation to the Waikato Region Plan has been proposed (Variation 6) and challenges to the policy are being taken to the environment court. Effectively, the policy defines levels of allocation for use in catchments and prioritises use in fully allocated catchments. The water in the Waikato river catchment is vital for ecological and recreation purposes as well as domestic, municipal and agricultural needs in addition to the generation of electricity and industrial use.

Flood management

Large scale changes in land use will alter the flood hydrology of the Waikato River system. A working group is currently assessed the impacts of land use conversions on flood hydrology and found that land use can have considerable impact on local flooding, with impacts below the dammed part of the Waikato river only of importance in extreme weather events.. Meanwhile, Taylor et al. (2008) showed that infiltration rates under grazed pasture were an order of magnitude less than those under pine forest for a range of soils in the upper Waikato catchment (mainly as a result of low macroporosity).

Carbon management

There will be major loss of carbon sequestration following deforestation. The forests in question are all well established plantation forests. Their conversion to permanent pastoral use represents a major reduction in New Zealand"s forest area. There will also be a consequent increase in pastoral related green-house gas emissions.

The cost of New Zealand"s projected excess agricultural emissions (above 1990 levels) for the first commitment period (2008–2012) is ~$600 million and the cost of deforestation emissions is estimated at a further ~$600 million over the same period. The productivity of the Waikato agriculture sector has increased dramatically since 1990. The proposed deforestation in the Waikato described here will be significantly implicated in Government"s climate change policies.

Renewable energy

As noted above, the technical assessment of the effects on flood management is incomplete. However, it is possible that the land conversions may force changes to the management of the Waikato hydro system during high flows. In addition, demands for water for irrigation and stock watering will reduce the amount of water available for hydro generation. This is of particular significance in the Waikato hydro system because the loss of water from the head of the catchment results in reduced generation at each of the eight sites in the hydro cascade in turn. These factors may consequently cause a reduction in summer generation at the (large) Huntly Power Station.

Biodiversity

Plantation forests can contribute to the maintenance of indigenous flora and fauna, particularly in comparison with intensively farmed pasture. Several large wetlands are located in the forests. Land clearance near these wetlands is removing habitat for some rare native wetland birds such as the bittern.

Soil erosion arising from land clearing activity

This should be mainly a localised issue in this catchment if the conversion is undertaken to a high standard. To date, our view is that the WPL work is undertaken to best practice but this has not been the case on all other developments.

Iwi issues

The government has passed legislation that allows for settlement of past grievances with respect to the Waikato River and its degradation with the Waikato-Tainui iwi. This legislation allows for new co-management arrangements between iwi and local/regional/central government. Deeds of settlement have also been signed for settling grievances with three other iwi in the catchment with a fourth yet to be finalised. In addition to a new era of management of resource issues in the catchment, the settlement provides for considerable new funding ($210 over 30 years) for restoration and protection purposes.

Mandate for action

Environmental impacts of agriculture are obvious and well documented in the Waikato (e.g. Environment Waikato, 2008). More rural streams are deteriorating than improving. Nitrogen loads are increasing in rural streams on average by 2 per cent per year and for phosphorus by 4 per cent per year. Microbial levels in streams are high. Sixteen of sixty-nine sites meet the microbial standards for stock water.

The size and mana (cultural status) of the Waikato River ensures it is a significant water body in the region. The Waikato River has shown an improvement in water quality in response to careful management of point source discharges, but deterioration as a result of agricultural sourced pollutants and nutrients is now indicated at several sites in the Waikato River since 2002. Increased nutrients will result in loss of clarity and more risk of toxic algae blooms.

Modelling of the impact on the Waikato River suggest that nitrogen flows to the river will increase by 22 per cent as a consequence of deforestation. This estimate assumes that nitrogen loss rates from dairy and sheep systems continue with no further intensification. To maintain current water quality, it is estimated that the impact of these developments will require all dairy farms in the catchment to reduce the nitrogen leaching rates by 30 per cent to an average of 25 kg/hectare. This reduction in on-farm nitrogen losses is potentially possible, but expensive infrastructure and education will be required (for example, feed pads, use of nitrogen inhibitors, advanced fertiliser management, and wintering off).

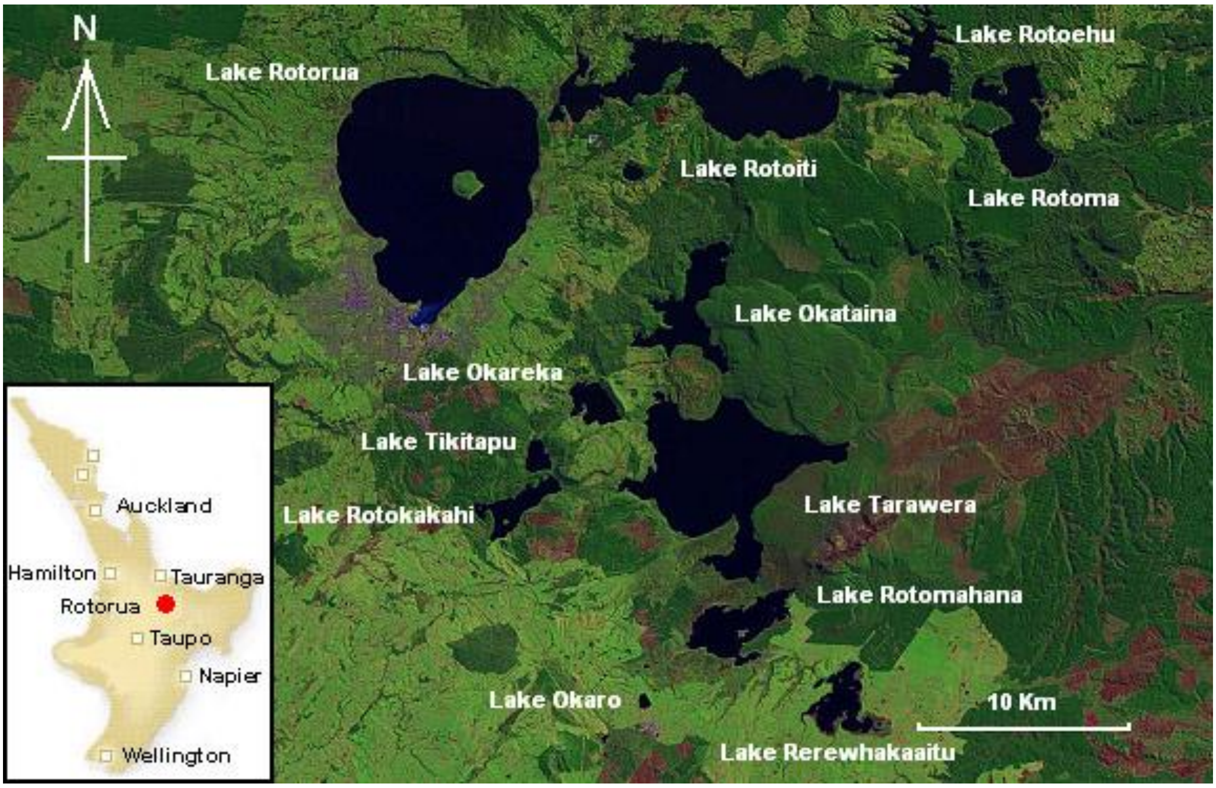
Societal expectations for action are clear. The Waikato community has identified water quality as the highest priority of environmental management issues. The Waikato Regional Policy Statement outlines the community‟s aspirations for maintaining and enhancing water quality, using water efficiently, protecting the productive capacity of soils, maintaining biodiversity and protecting communities and productive land from flooding.

Cultural imperatives are clear from the settlement reached between the Crown and iwi. Iwi have indicated a desire to see the river restored and protected.

Agriculture contributes ~30 per cent of the Waikato gross domestic product (GDP) when direct, indirect, and flow-on effects are included. More than 33,000 people are employed in farming or supporting industries, nearly 25 per cent of the region‟s workforce. The dairy sector is the second biggest employer in the region (~16,000 employees) followed by sheep, beef and mixed livestock farming (~6,000 employees). Less well understood are the costs of externalities to other sectors of the community as agriculture intensifies – in regard to the potential for increased flooding, increased need for water treatment, reduced amenity values, increased weed growth, reduced storage capacity in the Waikato hydro-electric system and loss of carbon sequestration. These factors will be considered carefully during development of policies to manage water quality in the upper Waikato catchment.

Environment Waikato 2008. The condition of rural water and soil in the Waikato region – risks and opportunities. Waikato Regional Council (Environment Waikato), Hamilton, 60 pp. URL: http://www.ew.govt.nz/PageFiles/10480/The%20condition%20of%20rural%20water%20and%20soil%20in%20the%20Waikato%20region%20-%20risks%20and%20opportunitiesSMALL.pdf

Taylor, M., Mulholland, M., Thornburrow, D. 2008. Infiltration of water into soil under forestry and agriculture in the upper Waikato catchment. *New Zealand Soil News* 56, 6-8.



The Rotorua lakes (EBOP image)

4.6 An introduction to the Rotorua Basin and Okataina Volcanic Centre: an iconoclastic view

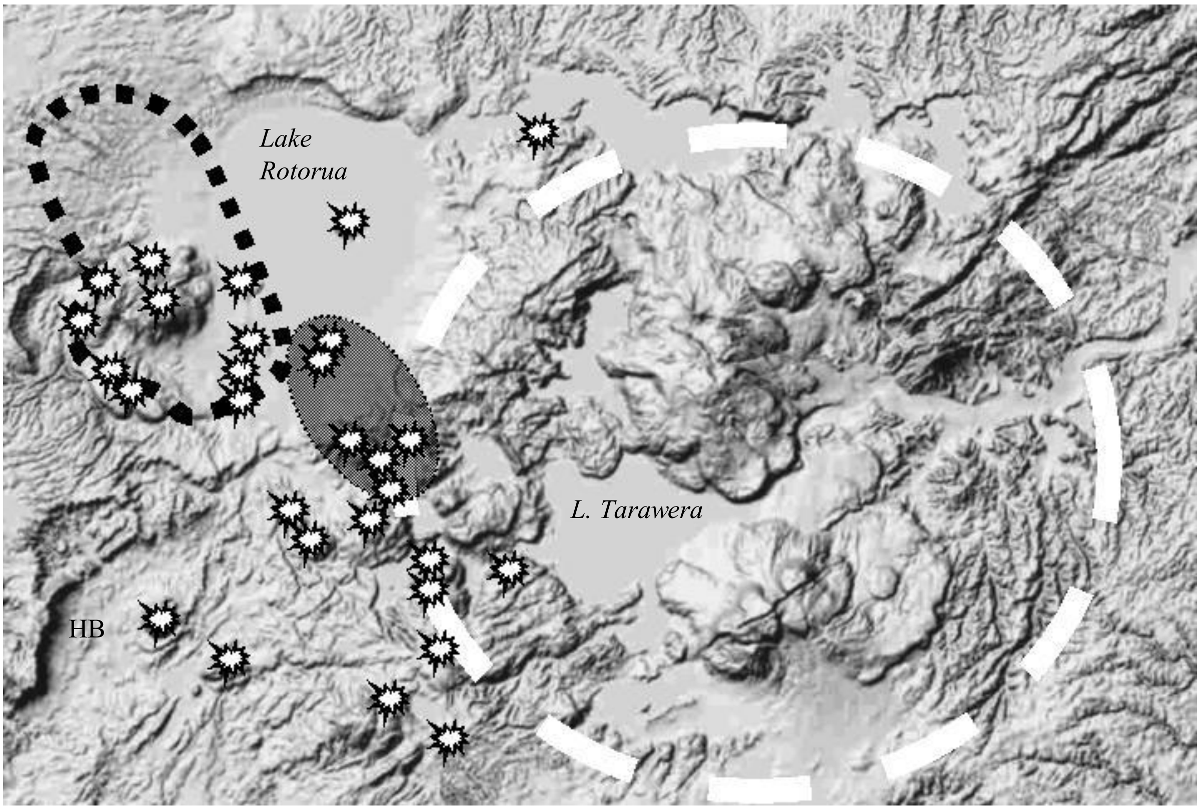
Will Esler
Former PhD student, Department of Earth and Ocean Sciences, University of Waikato

Basin formation

For over 40 years the Rotorua Basin has been regarded by volcanologists as a nicely circular, single-event caldera formed by the eruption of the Mamaku Ignimbrite dated, most recently, at c. 230 ka. However, it has become clear in recent times that the Basin has a rather more complex and interesting history. There is a small caldera within the western Rotorua Basin probably associated with the Pokai and/or the Waimakariri Ignimbrite eruptions between c. 320 ka and c. 250 ka. Part of the old caldera wall is exposed in Paradise Valley. Outcrop, borehole, gravity, and magnetic evidence suggest this caldera and other structures extending both north-west and south-eastward from the city have a merely geographic affinity with the Taupo Volcanic Zone (TVZ). It is refreshing to think they form the modern part of the Coromandel Volcanic Zone (CVZ).

The eastern half of the Rotorua Basin has normal gravity and is not a caldera. Mamaku Ignimbrite is a thin veneer (mostly <120 m) draped over previous topography in the west. New data suggest the volume of moderately crystalline magma involved in the Mamaku Ignimbrite eruption was nearly 200 km^3. Less than a quarter of this can be credibly retrofitted into the Rotorua Basin. Much of the Rotorua Basin gravity anomaly is demonstrably older than the Mamaku Ignimbrite. The source of the Mamaku Ignimbrite caldera is probably Kapenga Caldera next to the Horohoro Bluffs south of Rotorua. This eruption overlapped with that of the Ohakuri Ignimbrite a little farther south, and probably tapped the same big magma chamber. Extreme regional extension of the Taupo Fault Belt accompanied the double eruption. This extension temporarily re-defined the structural boundaries of the TVZ and caused severe caldera-like block faulting in the eastern Rotorua Basin, as in many other parts of the region. The energetic collapse of the Kapenga caldera would have strongly compacted the thick sediments and pyroclastics that partly filled the small Rotorua Caldera. This subsidence disrupted the veneer of Mamaku Ignimbrite, imitating local structural collapse.

Residual Mamaku Ignimbrite magma was probably responsible for the hydrothermal conversion of voluminous glassy lake sediments to zeolite in the Ngakuru area. The „type" TVZ rhyolite dome, Haparangi, probably erupted from this magma after a period of further crystallization. The soft top of the Mamaku Ignimbrite was severely eroded by frost, rain and wind during the Last Glacial Maximum, and in earlier cold periods. The famous tors of the Mamaku Plateau and the lesser known „great walls" near Kaharoa were etched from their softer matrix at this time. The suggestion that the tors represent fumarolic hardening immediately after the ignimbrite eruption has minimal evidence to support it. These landforms probably owe more to „topographic inversion". This happens when former gorges are infilled with thick, welded, erosion-resistant ignimbrite. Many of the "isolated" tors are part of distinct chains, probably defining ancient watercourses.



Vents active from c. 230 ka to c. 60 cal. ka and the Rotorua gravity anomaly (black dashes), the Lynmore magnetic anomaly (stippled), and the so-called Okataina Ring Structure (white dashes). HB, Horohoro Bluffs.

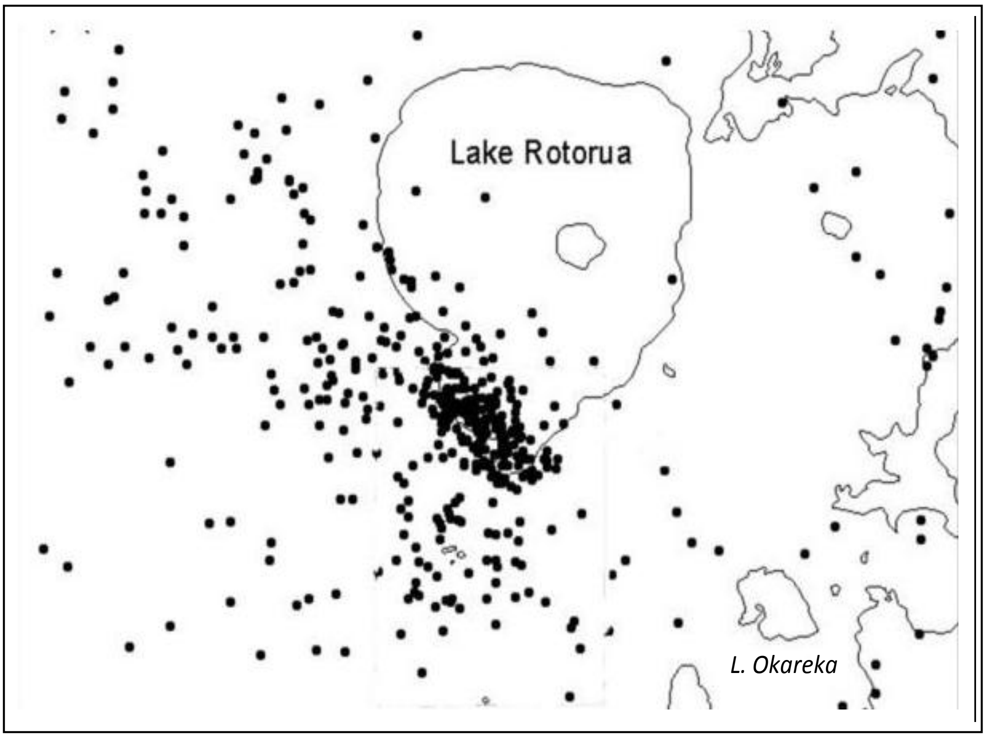
The Ngongotaha and Pukehangi hyolite massifs, and small domes in the city area erupted after the Mamaku Ignimbrite from an unrelated chamber of volatile-poor glassy magma. Much of the „caldera" collapse in the city area and Paradise Valley followed, not preceded, this unusually voluminous rhyolite extrusion. Slightly later, extensional faulting perpendicular to the TVZ sheared lake sediments and further depressed the Rotorua city area. Judging by the pattern of microseismicity (see map below), it is still doing so. Most of the known volcanism aged c. 230 to c. 60 ka in what has been misleadingly called „the northern TVZ" lies along this line of strike. An „Okataina Ring Structure" (ORS) has been invoked to explain away this alignment. The mythical ORS was of course inert everywhere else during this long interval. Most of these middle-aged rhyolites were notably volatile-poor in contrast to the young volcanics of the Okataina Caldera. The latter produced voluminous tephras. Mokoia Island and two small, highly crystalline lava domes south of the airport are older than previously thought. All pre-date the Rotoiti Ignimbrite eruption of c. 50-60 cal. ka. The two domes south of the airport are linked to the major positive magnetic anomaly underlying the suburb of Lynmore. This very prominent geophysical feature is also aligned NNW/SSE. The anomaly does not fit the „TVZ caldera" model and is omitted from most accounts of local geology. It probably defines the young water-cooled magma body that powers the Rotorua Geothermal Field. The seductive curve of the Rotorua Basin was completed by subsidence of the southern and western extremities of the „Tikitere Graben" beginning some tens of thousands of years before the Rotoiti Ignimbrite eruption from the northern Okataina Caldera. This quite recent deformation formed the classic „caldera" fault in the northern Rotorua Basin, the Hamurana Bluffs. This fault moved again about 35 ka, dislodging huge rhyolite blocks, and vast packets of lake sediment.

Local geological history

The Rotorua Basin on the upwind margin of the TVZ has proved the best place to find evidence of the history of the past c. 250,000 years in the central North Island. Rotorua City has the most detailed local history in the country. Lake Rotorua is the oldest lake in the North Island, and perhaps New Zealand. Its default condition is diatomite accumulation.

Within the sediments are more than 40 recognised tephras preserved in exquisite detail. Many more await study. Electron microprobe analysis of glass to obtain major element chemistry is the most useful tephra identification technique, along with mineral assemblages. Tephras from Okataina, Taupo, Taranaki, Tongariro, and Mayor Island volcanic centres have been identified.

Ernst Dieffenbach (the first trained scientist to work in New Zealand) made a flying start on local history with the 1841 observation that the same tephra sequence was recognizable in different parts of Rotorua Basin (Dieffenbach, 1843). Les Grange put local stratigraphy on a rational, objective basis with chemical and mineralogical description of tephras in the 1920s-1930s (e.g. Grange, 1933, 1937). Unfortunately, Grange also spawned the enduring myths of „downwarping" in the north-western basin, and of ancient „southern drainage". A great milestone was the classic, if geologically naïve, paper by Kennedy et al. (1978). Tephra studies, with attention to fine detail, were at that time firmly in the „soils" camp, and thus barely respectable. To that date, the geologists had made little progress on Rotorua Basin history using traditional broad-scale methods. From the late 1970s, Ian Nairn successfully united both approaches in the Okataina Caldera Complex (e.g. Nairn, 2002).



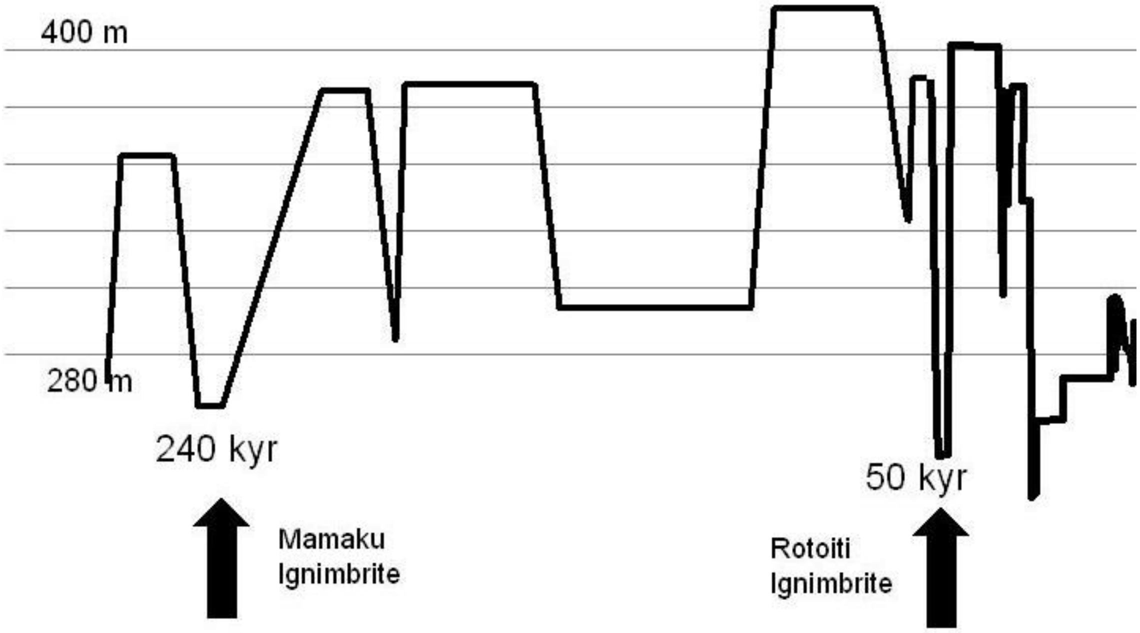
Seismicity in Rotorua region since 1992 (all earthquakes < 40 km depth and < 3.9 magnitude) (from Geonet http://www.geonet.org.nz/earthquake/, courtesy of Brad Scott, GNS Science)

Lake level

Lake level history has proved to be far more complex than Kennedy et al. (1978) suggested. There have been at least seven periods of very high lake level, to 120 m and more above present level (Lake Rotorua is currently at ~280 m asl). The lake has drained completely at least twice. One of these highstands *preceded* the Mamaku Ignimbrite eruption, leaving highly silicified sediments now exposed in the Hemo Gorge. Before about 70 ka, Lake Rotorua had several times been part of a huge lake extending to Atiamuri or beyond. Lake level responded to whatever geological events were on offer. The usual situation has been seepage of lake water into the thick pumice aquifer beneath the Mamaku Ignimbrite rather than surface discharge. The upper part of this aquifer supplies most of Rotorua‟s drinking water. In places it is enriched with agricultural nutrients moving steadily towards the lake. The north-eastern rim of the Rotorua Basin was first breached between about 100 and 60 ka during Tikitere Graben formation. The eruption of Rotoiti Ignimbrite re-impounded the lake, jointly with Earthquake Flat Ignimbrite erupted from vents perpendicular to the TVZ southeast of Rotorua. Water level rose to c. 400 m for about 20,000 years, but with two internal drainage episodes. The lake then extended well beyond the Rotorua Basin. The shallow lake arm south of Hemo Gorge was larger than the present Lake Rotoiti. The last major highstand, from 33 to 30 cal. ka, was at c. 380 m asl. The prominent high terrace around the Rotorua Basin dates from this time.

The present surface discharge from the Rotorua Basin is abnormal. From 30 cal. ka, collapsing groundwater seepage tunnels in the Okere Falls area caused the lake to fall to about 330 m asl, draining to the Kaituna River. A few thousand years later, the remnants of the Rotoiti Ignimbrite dam within the Tikitere Graben gave way, allowing a period of profound erosion and the switch of surface drainage eastward into the Tarawera catchment. Lava flows of the Te Rere eruptive episode (c. 25,270 cal. yr BP) partially impounded the new Rotoiti

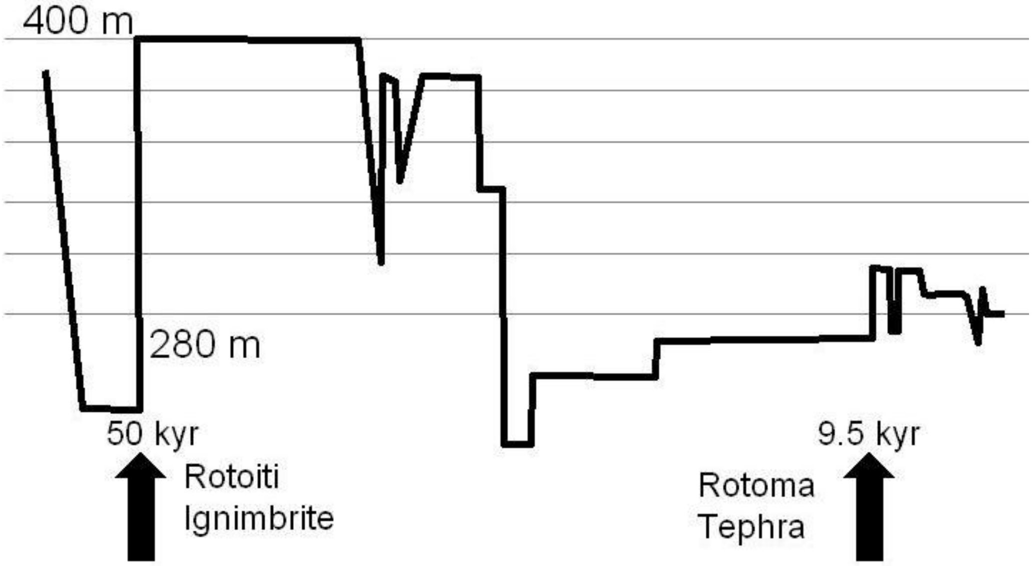
River and formed a united Late Rotoiti/Rotorua somewhat below present level. The Rotorua Tephra eruption c. 15,425 cal. yr BP deposited pumice from vents perpendicular to the TVZ that gathered as a giant raft on the lake. The raft lodged in the narrows at the present isthmus between the present lakes, saturated, and sank. These shoals were rejuvenated a few decades by the Kaharoa Tephra before Maori occupation of the area.



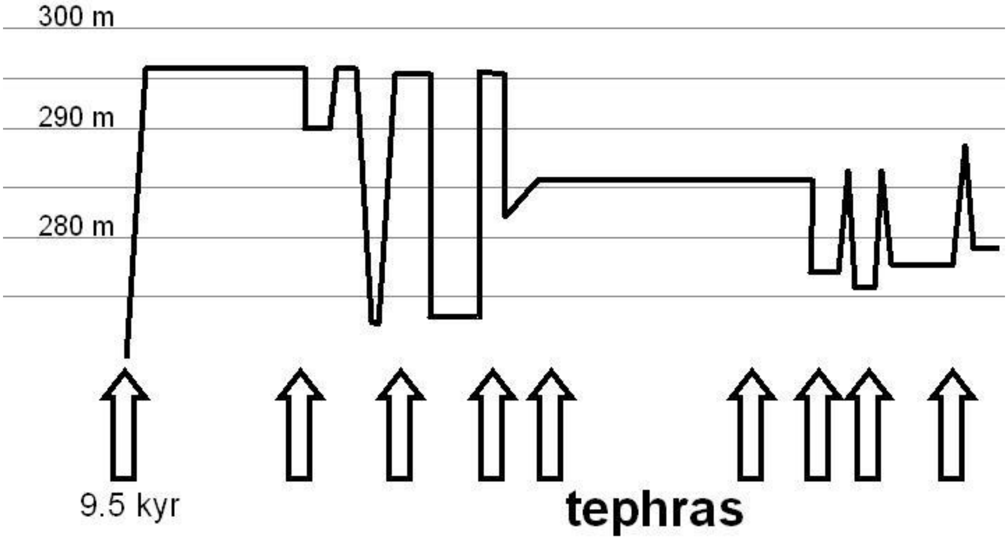
Pattern of changing levels of Lake Rotorua since c. 250,000 years ago. Present lake level is c. 280 m asl. The Rotoiti eruption episode is variously dated between c. 50 and 60 cal. ka (Wilson et al., 2007) (W.R. Esler, unpubl. data)

Lava dams of the Rotoma eruptive period c. 9505 cal. yr BP raised Lake Rotorua 17 m above the present level. Surface drainage into the Kaituna River resumed at this time. Periodic down-faulting averaging almost 2 mm/year in the Okere Falls area now exerts gross control over lake level, although episodes of seepage to groundwater have partially drained the lake at least three times in the past 8000 cal. years. Erosion of the rock ledge at the top of the Okere Falls seems to have been minimal during this period. Lake level fell about 9 metres at the time of the the Whakatane Tephra eruption, 5530 ± 60 yrs BP due in part to movement on the newly identified „Waiohewa Fault" that runs west from Lake Rotokawau. The Lake Rotokawau basin was probably formed by subsidence at this time, and clearly predates the Rotokawau Basalt eruption. The basin lacks a tuff ring and is not a maar, as previously thought.Lake Rotorua waters spiked to more than 6 m above their previous level for a few decades after the last significant tephra fall in the Rotorua Basin: Kaharoa Tephra pumice (c. 1314 AD).

On present trends, Lake Rotorua will have again drained completely in less than 6000 cal. years. Te Arawa iwi has recently resumed ownership of the lake bed and can expect a real-estate bonanza a few seconds after the next earthquake in the Tikitere Graben.



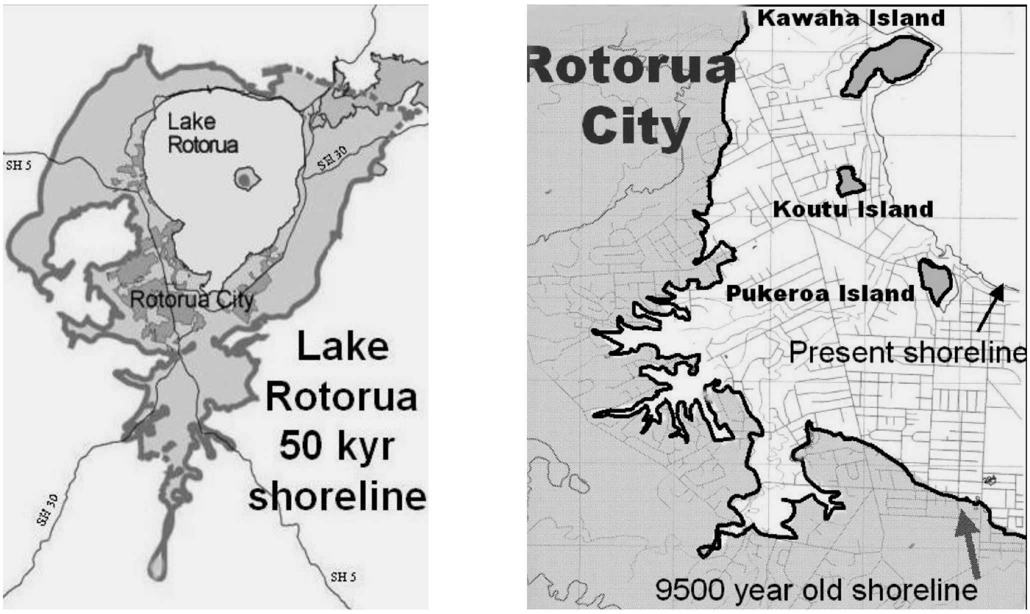
Changing levels of Lake Rotorua since c. 60,000 years ago. Present level is c. 280 m asl (W.R. Esler, unpubl. data)



Changing levels of Lake Rotorua since c. 9,500 cal. years ago. Arrows record deposition of marker tephras from Okataina, Taupo, and Tuhua sources used to help constrain the lake level model for this time period. Present lake level is c. 280 m asl (W.R. Esler, unpubl. data)

Other hazards

Much of Rotorua city has been built on a sandy tephra pad <1 m thick over soft lake silts that will inevitably liquefy in some places during a moderate earthquake. Building has recently accelerated on land identified as unsuitable for housing by DSIR Soil Bureau a generation ago. The paths of several 1886 lahars towards the airport have been overlooked as a menace. Highly toxic hydrogen sulphide adds a distinctive flavour to geothermal hazards in the city. More deaths have been caused by various geothermal mishaps in the Rotorua area than by the 1886 Tarawera eruption that claimed about 108 lives. Many of the geothermal casualties were Maori in pre- and early European times. The dramatic lake level changes in the past c. 60,000 cal. years have caused some massive hydrothermal explosions. Some abandoned geothermal bore casings are now in a brittle condition; awaiting a good shake. Clearly, citizens in some parts of Rotorua are exposed to multiple hazards.



Reconstructed shorelines, constrained by tephrochronology, of Rotorua Basin (left) and the area adjacent to Rotorua City (right) at two different times in the past (W.R. Esler, unpubl. data)

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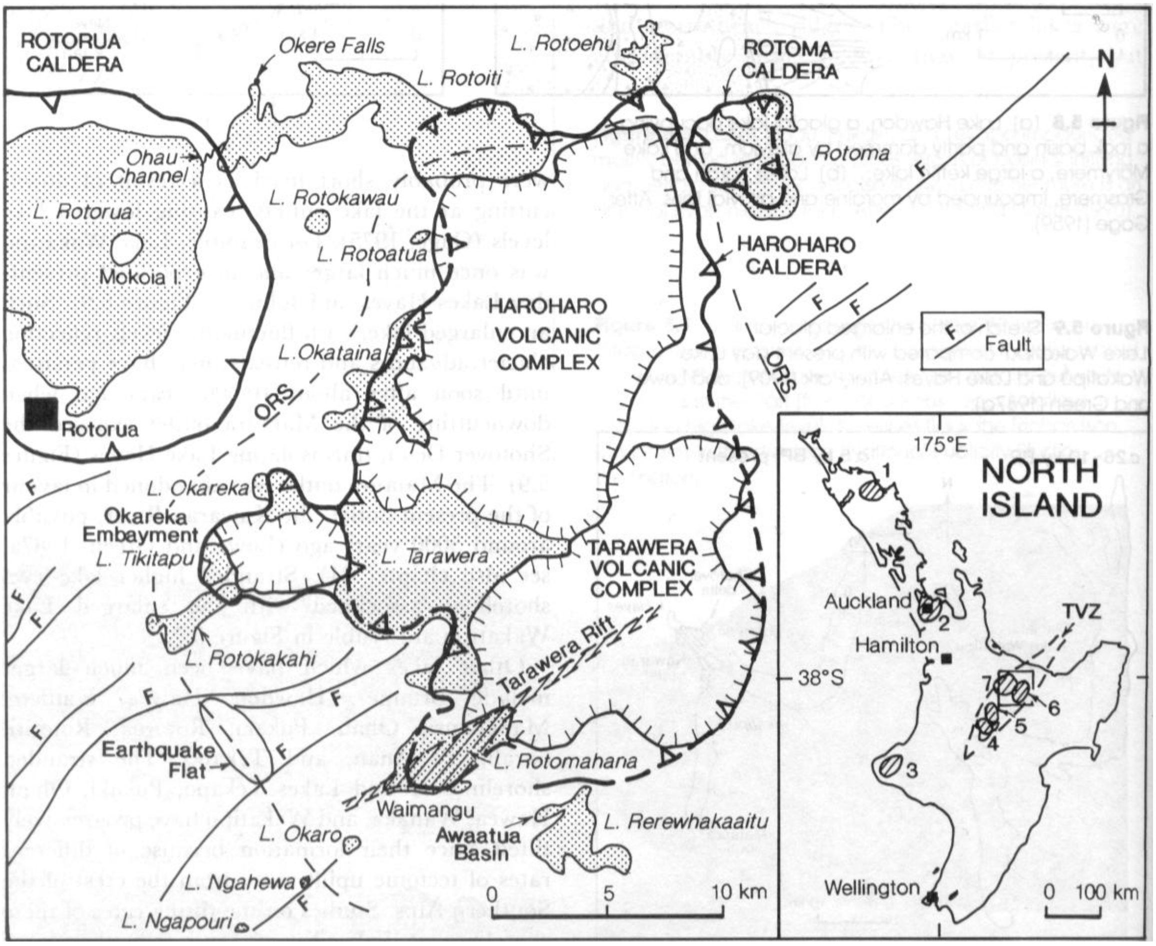
Summary of main rhyolitic tephras deposited in the Rotorua-Rerewhakaaitu region during the last c. 27,000 cal years (D.J. Lowe)

Descriptions are generalised because character may differ from proximal to distal locations and from site to site. The region has additionally received distal tephras from Taupo and Tuhua (Mayor Island) volcanic centres, and has been dusted regularly with andesitic tephra fallout from numerous eruptions at Tongariro Volcanic Centre and Egmont Volcano, most recently in the 1995-96 Ruapehu eruptions.

Name (source)*	**Date or age** (cal yr BP)[¶]	**Description**
Tarawera Tephra (Tarawera)	10 June 1886	Comprises basaltic scoria (Tarawera Scoria) with occasional rhyolite clasts and/or fine greyish brown „muddy‟ ash (Rotomahana Mud). Mud was dispersed more widely.
Kaharoa Tephra (Tarawera)	1314 ± 12 AD (636 ± 12 cal BP)	Fine to coarse white to grey ash, with occasional dense pumice, rhyolite, obsidian and basalt lapilli. Contains abundant biotite.
Taupo Tephra (also known as Unit Y) (Taupo)	232 ± 5 AD (1718 ± 5 cal BP)	Creamy coloured coarse ash with plentiful shower-bedded pumice lapilli (crushable). Ignimbrite unit always associated with charcoal fragments.
Whakatane Tephra (Haroharo)	5530 ± 60 cal BP	Shower-bedded pale yellow coarse ash, overlying a fine to coarse rhyolitic (pale grey) ash. Rich in cummingtonite. Has reddish-brown uppermost horizon (sometimes contains weathered basaltic Rotokawau Tephra).
Mamaku Tephra (Haroharo)	8005 ± 45 cal BP	Loose, coarse yellowish-brown pumice ash grading into a weakly shower-bedded coarse ash/lapilli.
Rotoma Tephra (Haraharo)	9505 ± 25 cal BP	Shower-bedded fine grey to yellowish brown ash with coarse ash layers, rich in cummingtonite. Marked typically by a dark Ah horizon at top, sometimes podzolised.
Waiohau Tephra (Tarawera)	13,635 ± 165 cal BP	Grey fine and coarse shower-bedded ash. Distinctive v. fine ash layer at the base. Usually has a well developed yellowish-brown upper soil horizon reflecting pedogenesis before burial.
Rotorua Tephra (Okareka embayment)	15,425 ± 325 cal BP	Shower-bedded pumiceous yellowish lapilli or blocks (gravel). Occasional rhyolitic lithics.
Rerewhakaaitu Tephra (Tarawera)	17,625 ± 425 cal BP	Yellowish-brown ash grading down into tephric loess. Contains abundant biotite. Marks transition from Last Glacial to Post Glacial conditions; reafforestation occurred soon after deposition.
Okareka Tephra (Tarawera)	21,800 ± 500 cal BP	Yellowish brown ash contains abundant biotite. Marks coldest part of Last Glacial (typically encased in yellowish to olive brown tephric loess).
Te Rere Tephra (Haroharo/Okareka)	25,271 ± 779 cal BP	Yellowish-brown ash (typically encased in yellowish to olive brown tephric loess).
Kawakawa Tephra (also known as Oruanui) (Taupo)	27,097 ± 957 cal BP	Olive brown to pale yellowish brown ash (typically encased in yellowish to olive brown tephric loess). Marks early phase of Last Glacial Maximum that began c. 29 cal ka (referred to as the „extended LGM‟ in New Zealand)

*Terminology is based mainly on Froggatt and Lowe (1990). Descriptions partly after Rijkse (1979, 1992).

[¶] Most ages are given in calibrated or calendar (cal) years (95% probability range) before present (BP), „present‟ being 1950 in the ^{14}C timescale (based on Bayesian probablity age modelling: Lowe et al., 2008). Calendar dates for the Kaharoa and Taupo eruptions have been determined by dendrochronology and wiggle-match dating (Sparks et al., 1995, 2008; Lowe and de Lange, 2000; Hogg et al., 2003, 2009).



Volcanic lakes in the Rotorua area and simplified structural and volcanic features associated with the Rotorua and Haroharo calderas. Haroharo caldera comprises two main volcanic complexes, Haroharo and Tarawera, and lies within the Okataina Volcanic Centre (dashed line marked ORS) (from Lowe and Green, 1992). More faults (F) are present than shown (e.g. see Nairn, 2002; Berryman et al., 2008). Origin of Rotorua caldera as shown, and some other features, are disputed (see article above by W.R. Esler, this volume). Stop 3 is near the southwestern shore of Lake Rerewhakaaitu.

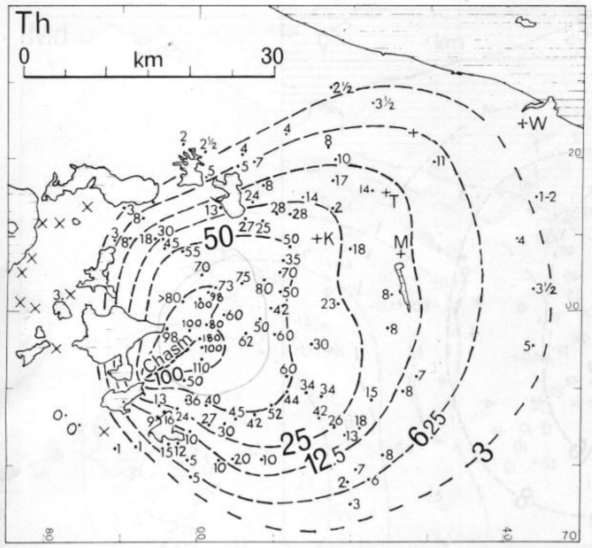


Fig. 3. Isopach map of the Tarawera 1886 basaltic scoria-fall deposit. Thickness values are in centimetres. K = Kawerau; M = Te Mahoe; T = Te Teko; W = Whakatane. Bars along margins relate to the New Zealand Survey 1000-yard grid. × = locations where basaltic scoria occurs admixed with Rotomahana Mud, but does not form a discrete layer.

Isopach map of 1886 Tarawera scoria fallout (in cm) from Walker, G.P.L., Self, S., Wilson, L. 1984. Tarawera 1886, New Zealand – a basaltic plinian fissure eruption. *Journal of Volcanology and Geothermal Research* 21, 61-78.

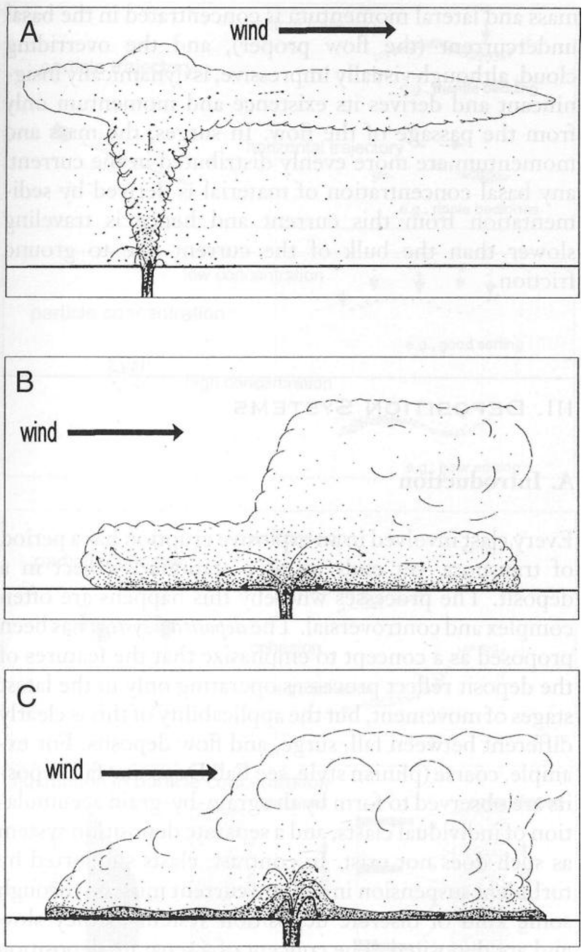


FIGURE 1 Schematic diagram to illustrate the three main end-member transport systems for the emplacement of pyroclastic deposits. (A) Fall: high buoyant plume carrying all except coarsest particles to heights of kilometers to tens of kilometers above the surface; particles sedimented from plume to form deposit; plume dispersal controlled by wind direction and strength. Coarsest clasts (arrows) follow ballistic trajectories and fall within 3–5 km of vent regardless of wind. (B) Surge: ground-hugging relatively dilute density current with gradual (exponential?) downward increase in density; not influenced by wind, but generating a secondary buoyant plume that is wind affected. (C) Flow: ground-hugging, clearly defined, concentrated density current with accompanying dilute overriding cloud; not influenced by wind, but generating a secondary buoyant plume that is wind affected.

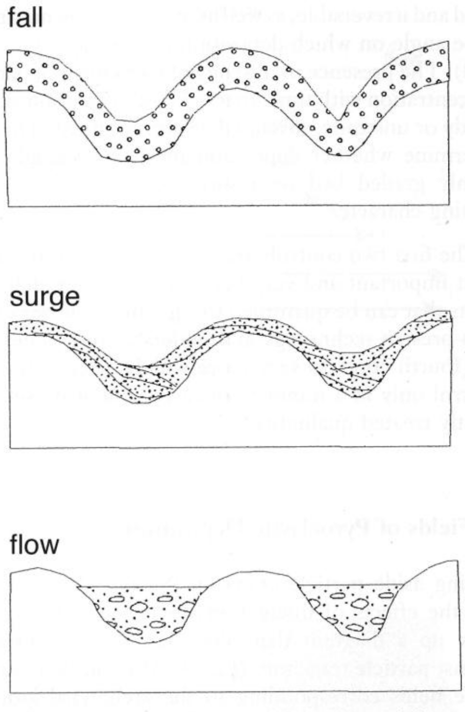


FIGURE 5 Schematic diagram of the archetypal characteristics of the three main pyroclastic deposit types. Fall—mantle bedding, with plane parallel beds and no internal erosion, good sorting (except where water is present; see Section III,E), juvenile clasts with angular to ragged shapes. Surge—nonmantling beds, thickening into low-lying areas, with cross-stratification, pinch-and-swell bedding and scoured contacts, moderate sorting, juvenile clasts with some degree of rounding. Flow—landscape-filling units, generally poorly bedded to nonbedded, poor sorting, rounded juvenile clasts.

Volumes (minimums) and discharge rates calculated for some Kaharoa eruption units. Data for plinian eruptives A–L from Sahetapy-Engel (2002). Plinian discharge rates are based on eruption column heights derived from the tephra fall distributions, using the method of Carey and Sparks (1986). Lava (N) extrusion rates from Nairn et al. (2001)

Eruption unit	Magma type	Volume (10^6 m^3 DRE)	VDR* (10^3 m^3/s)	Duration (h)
A	T1	75	4.31	4.8
B	T1	225	11.5	5.4
D	T1	112	10.1	3.1
E	T1	89	10.5	2.3
F	T1	492	45.6	3.0
G	T1	80	4.1	5.4
H	T1	173	15.0	3.2
I	T1+2	155	15.0	2.9
J	T1+2	295	33.9	2.4
K	T1+2	370	5.4	19.1
L	T1+2	112	5.4	5.8
N (dome lavas)	T2	1000	0.03	10^4

*VDR is DRE volumetric discharge rate.

(Upper) from Wilson and Houghton (2000) and (lower) Nairn et al. (2004)

4.7 Stop 3 – Rotomahana silt loam, Brett Rd, Rerewhakaaitu

Location V16 146168, elevation 450 m asl, rainfall ~1500 mm pa

Note: Lake Rerewhakaaitu lies in a shallow basin impounded initially by pyroclastic deposits of the Waiohau eruption ca. 13,700 cal. yr BP, with further damming to present levels by Kaharoa pyroclastic deposits in 1314 ± 12 AD. It has an area of 7.4 km^2 and a maximum depth of 15 m. Awaatua basin is a small explosion crater ca. 10,000 years old (Nairn, 2002).

Stratigraphy of Brett Rd section and Rotomahana soil. Note black buried A horizon on Rotoma Tephra in places (contains charcoal?). Unit-Q (Stent tephra, 4405 ± 175 cal yr BP, Alloway et al., 1994) may also be present in places (in buried soil on Whakatane Tephra). Photo: David Lowe

Notes from Mac Pacey, farmer on 'The Mud', Tulachard Farm, Brett Rd

Advantages

Naturally good fertility. High in Ca, Mg and K. Mainly fertilise with P and S. Good pH. Holds on better than surrounding country in dry periods. We stay green and do not have plant deaths in dry periods and therefore when it rains we recover quite quickly. When conditions are good we certainly grow grass.

Disadvantages

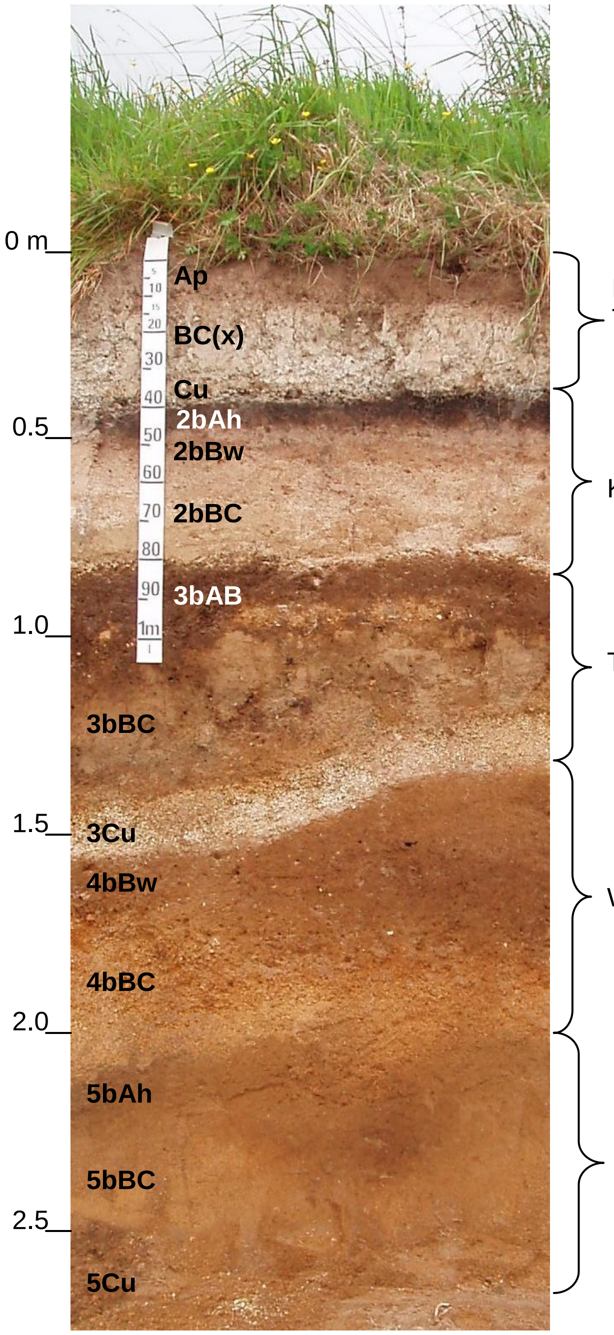
When it rains and the soil is sodden the pasture can turn to mud very quickly. To overcome this we have built a feed pad to feed cows and stand them on in particularly wet conditions. But we do drain very well and once it stops raining we can go back on the pasture within 24 hours with care. „Mud‟ is high in Mb which causes Cu deficiency in the cattle so we have to supplement with Cu.

P.S. I feel very fortunate to have a farm on Rotomahana Mud

Rotomahana silt loam

NZSC: Buried-pumice Tephric Recent Soils; tephric, rhyolitic; silty/sandy; moderate/rapid

Soil Taxonomy: Fine-loamy/medial, mixed/glassy, active, mesic Typic Udivitrands



Rotomahana Mud with thin layer Tarawera Scoria at base (10th June 1886)

Kaharoa Tephra (1314 ± 12 AD)

Taupo Tephra (232 ± 5 AD)

Whakatane Tephra (5530 ± 60 cal BP)

Rotoma Tephra (9505 ± 25 cal BP)

Modern soil, buried soil horizons and tephra layers at Brett Rd section. *Photo, stratigraphy and horizonation*: Haydon Jones, Loretta Garrett, David Lowe, and Wim Rijkse. Ages from Lowe et al. (2008).

Data on the Rotomahana soil at the Waimangu Tearooms site (see pages following description) are from Parfitt et al. (1981). At that site,the soil is classed as a Typic Udorthent.

Soil profile description by Haydon Jones

Scion, Rotorua

Rotomahana reference data

- Soil name:
    - Series: Rotomahana; Type: silt loam.
- Soil classification:
    - NZSC: Buried-pumice Tephric Recent Soils; tephric, rhyolitic; silty/sandy; moderate/rapid
    - Soil Taxonomy: Fine-loamy/medial, mixed/glassy, active, mesic Typic Udivitrands

Site data

- Location:
    - Map reference: NZMS 260 V16 2814530 6316815
    - Word description: road cutting on Brett Road (western side of Lake Rerewhakaaitu) about 215 m north of reserve/boat ramp
- Elevation: 450 m
- Geomorphic position: Profile on a 6° convex/linear slope with 125° aspect contained within a gentle slope in easy rolling country
- Erosion/deposition: Nil
- Vegetation: Pasture, grasses
- Parent material: Rotomahana Mud over a thin layer of Tarawera Scoria with underlying buried soil horizons formed in various tephra deposits (Kaharoa, Taupo, Whakatane, and Rotoma tephras) (see photos for tephra ages)
- Drainage class: Well drained

Soil data

Ap	
0-11 cm	Very dark greyish brown to dark brown (10YR 3/2.5) silt loam; slightly sticky; moderately plastic; peds weak and friable; weakly pedal; common fine polyhedral peds; non allophanic; abrupt smooth boundary. [Rotomahana]
11-36 cm	Greyish brown (2.5Y 5/2) silt loam; very few extremely fine faint brown (7.5YR 5/4) mottles; slightly to moderately sticky; very plastic; peds slightly firm and brittle; very high penetration resistance; weakly pedal; common fine to coarse blocky peds; non allophanic; abrupt smooth boundary. [Rotomahana]
Cu	
36-39 cm	Greyish brown (2.5Y 5/2) extremely gravelly sand with fine to medium sub-rounded slightly weathered scoria gravels; non sticky; non plastic; apedal single grain; non allophanic; abrupt smooth boundary. [Tarawera]
2bAh	
39-46 cm	Black (2.5Y 2.5/1) sandy loam; slightly sticky; non plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; weakly allophanic; distinct smooth boundary. [Kaharoa]
2bBw	
46-68 cm	Dark greyish brown to brown (10YR 4/2.5) very slightly gravelly loamy sand with fine sub-rounded slightly weathered pumice gravels; slightly sticky; non plastic; soil very weak and very friable; apedal single grain; moderately allophanic; indistinct wavy boundary. [Kaharoa]

2bBC 68-79 cm	Light olive brown to light yellowish brown (2.5Y 5.5/3) very slightly gravelly loamy sand with fine sub-rounded slightly weathered pumice gravels; very few extremely fine distinct brown (7.5YR 4/4) mottles; slightly sticky; non plastic; soil weak and friable; apedal massive; strongly allophanic; distinct wavy (occluded) boundary. [Kaharoa]
3bAB 79-101 cm	Very dark grey (2.5Y 3/1) very slightly gravelly sandy loam with fine sub-rounded slightly weathered pumice gravels; slightly sticky; slightly plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; strongly allophanic; distinct irregular (occluded) boundary. [Taupo]
3bBC 101-138 cm	Olive brown to light olive brown (2.5Y 4.5/3) very slightly gravelly loamy sand with fine sub-rounded slightly weathered pumice gravels; slightly sticky; non plastic; soil very weak and friable; apedal massive; strongly allophanic; distinct wavy boundary. [Taupo]
3Cu 138-151 cm	Pale yellow (2.5Y 7/3) extremely gravelly sand with fine to medium sub-angular slightly weathered pumice gravels; non sticky; non plastic; apedal single grain; very weakly allophanic; distinct wavy boundary. [Taupo]
4bBw 151-173 cm	Very dark greyish brown to dark brown (10YR 3/2.5) slightly gravelly sandy clay loam with fine sub-rounded slightly weathered pumice gravels; moderately sticky; slightly plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; strongly allophanic; indistinct irregular (occluded) boundary. [Whakatane]
4bBC 173-199 cm	Yellowish brown (10YR 5/6) very gravelly sand with medium sub-rounded slightly weathered pumice gravels; non sticky; non plastic; apedal single grain; strongly allophanic; distinct irregular boundary. [Whakatane]
5bAh 199-225 cm	Dark greyish brown to brown (10YR 4/2.5) very slightly gravelly sandy loam with fine sub-rounded slightly weathered pumice gravels; slightly sticky; non plastic; peds very weak and friable; apedal earthy; profuse very fine polyhedral peds; moderately allophanic; indistinct wavy boundary. [Rotoma]
5bBC 225-255 cm	No data.
5Cu 255 cm –on	No data.

Soils and land use in the Waiotapu region (covering five districts including Rerewhakaatiu) were described by Vucetich and Wells (1978). The Rerewhakaaitu area was surveyed by Derek Cross (scale 1: 31,680). Analytical data for the Rotomahana soil are available in Parfitt et al. (1981; data below) and in Part 3 of „Soils of New Zealand‟ (1968) (pp.122-123) from a site ~400 m west of the Waimangu Tearooms. Phytolith and humus analyses were undertaken at that site by Hosono et al. (1991); the clay minerals were examined by Kirkman (1976), who identified allophane, interstratified montmorillonite/mica, montmorillonite, mica, kaolinite, and a zeolite mineral: mordenite.

Note from Wim Rijkse

Rotomahana coarse sandy loam (near Waimangu Tearooms) is moderately to slightly acid and weakly leached (base saturations 71%, 65%, 94%). Exchangeable cations (Ca, Mg, K and Na) are of medium to high levels. Reserve potassium and magnesium of the Rotomahana Mud are of medium to high value. Extractable phosphorus is low.

ROTOMAHANA LOAM

Location: Waimangu Road, 400 m west along from tearoom, east side of road reserve
Grid ref: N85/845863
Aspect: West near top of ridge
Altitude (m): 400
Rainfall (mm): 125
Slope: 2°
Landform: Ridge
Vegetation: Bracken fern with mahoe, coprosma, kamahi, lupin
Drainage class: Moderately well drained
Land use: Dairying and semi-intensive sheep farming
Parent material: Rotomahana Mud, hydrothermally altered rhyolitic ejecta from Lake Rotomahana (erupted in 1886)

PROFILE DESCRIPTION

Profile	Depth (cm)	
Ah	0- 7	very dark brown (10YR 2/2) loam; slightly sticky non plastic; slightly greasy; friable; moderately developed fine nut structure; many fine and medium roots; distinct smooth boundary,
C1	7-50	light olive grey (5Y 6/2) silt loam; friable; sticky slightly plastic; weakly developed medium block structure breaking to crumb structure; few fine roots; indistinct irregular boundary,
C2	50-67	light olive grey (5Y 6/2) silt loam; slightly firm; slightly sticky non plastic; weakly developed medium block structure breaking to crumb structure; few fine grey (10YR 6/1) basaltic lapilli; few dark brown root channels; distinct regular boundary,
Cg	67-78	pale olive (5Y 6/3) sandy loam; slightly firm; weakly developed medium block breaking to crumb structure; many indistinct yellowish brown and dark yellowish brown (10YR 5/6 & 4/6) fine and medium mottles; few medium dark brown (7.5YR 3/2) root channels; sharp smooth boundary,
2Ah	78-87	black (7.5YR 2/0) sandy loam; friable; weakly developed medium nut structure; few roots; distinct smooth boundary,
2Bw	87-96	dark brown (10YR 3/3) sandy loam; friable; weakly developed fine nut and crumb structure; few medium (2-6 mm) lapilli; locally a 4 cm pale brown (10YR 6/3) gritty sandy loam layer (E hor.) overlies this horizon; distinct irregular boundary,
2Bs	96-105	strong brown (7.5YR 4/6) pumice gravel; loose; single grain; lapilli 2-10 cm; sharp smooth boundary,
3Ah	105+	*on* yellowish brown (10YR 5/4) sandy loam; friable; weakly developed nut and crumb structure; many fine (2-4 mm) lapilli; few fine roots.

CLASSIFICATION - N.Z. Genetic: Recent soil (ash)   Taxonomy: Typic Udorthent, fine loamy, mixed, mesic

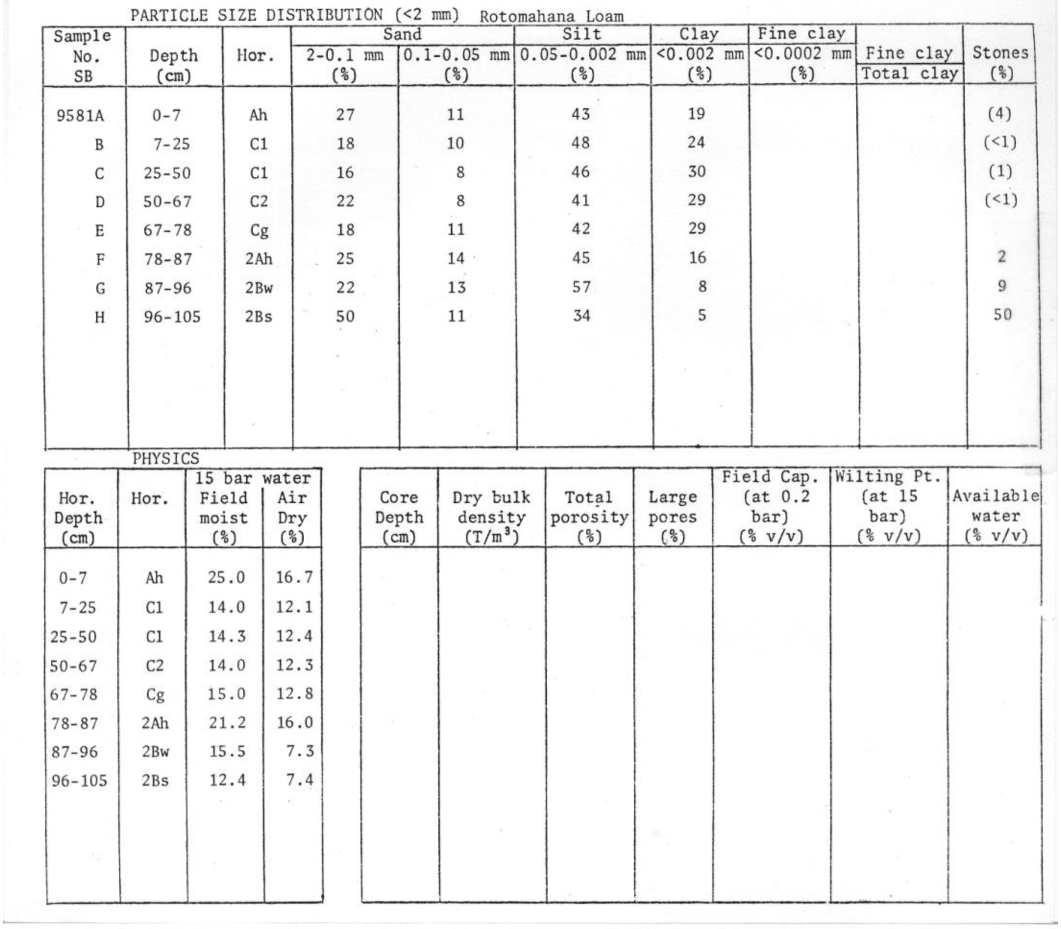
CHEMISTRY ROTOMAHANA LOAM

Sample No. SB	Depth (cm)	Hor.	pH H_2O	pH KCl	pH ΔpH	pH NaF	Exchangeable cations (meq/100 g) Ca	Mg	K	Na	H (KCl)	Al (KCl)	Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g) NH_4OAc (pH 7)	Σ Cations (pH 8.2)	Base saturation (%) Σ bases / CEC NH_4OAc	Σ bases / Σ Cations
9581 A	0-7	Ah	5.7	4.7	-1.0	7.8	14.7	4.6	2.03	0.33		0.22	29.6	29.4	21.8	28.2	51.3	77	42
B	7-25	C1	6.0	4.5	-1.5	8.8	5.9	2.76	1.81	0.49		0.14	7.5	7.4	11.3	12.3	18.5	89	59
C	25-50	C1	6.7	4.8	-1.9	8.5	8.3	3.11	1.31	1.23		0.08	5.5	5.4	14.1	13.7	19.5	(100)	72
D	50-67	C2	6.9	5.0	-1.9	8.5	8.2	3.05	0.97	1.56		0.08	4.4	4.3	14.0	13.7	18.2	(100)	76
E	67-78	Cg	6.9	5.2	-1.7	8.5	10.2	3.6	1.40	2.13		0.10	5.6	5.5	17.4	17.2	22.9	(100)	76
F	78-87	2Ah	6.5	5.5	-1.0	8.8	37	6.6	0.40	0.42		0.31	27.8	27.5	44.7	46.2	72.2	96	61
G	87-96	2Bw	6.5	5.5	-1.0	10.2	11.0	2.11	0.21	0.24		0.49	16.4	15.9	13.8	15.1	30.0	90	46
H	96-105	2Bs	6.4	5.3	-1.1	10.6	7.3	1.24	0.25	0.52		0.81	17.9	17.1	9.3	12.2	27.2	76	34

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g) H_2SO_4 (0.5 M)	Inorg.	Org.	P Retention (%)	Dithion. cit. (%) Fe	Al	Tamm ox. (%) Fe	Al	Si	Pyrophos. (%) Fe	Al	Reserves (meq/100 g) K_c	Mg_r	Extractable S (ppm)
9581 A	0-7	Ah	7.1	0.17	16	21	31	24	0.76	0.19	0.46	0.22	0.06	0.19	0.09	0.64	17	14
B	7-25	C1	0.6	0.12	17	23	6	17	0.77	0.19	0.34	0.14	0.10	0.05	0.01	0.73	26	3
C	25-50	C1	0.2	0.06	18	23	2	11	0.71	0.07	0.30	0.08	0.10	0.01	0.00	0.74	24	3
D	50-67	C2	0.2	0.05	18	24	1	10	0.72	0.07	0.27	0.08	0.09	0.01	0.00	0.81	22	2
E	67-78	Cg	0.3	0.06	18	24	2	13	0.99	0.14	0.35	0.10	0.09	0.03	0.00	0.72	19	7
F	78-87	2Ah	9.5	0.80	4	8	38	42	0.56	0.33	0.29	0.31	0.07	0.18	0.23	0.16	2.0	2
G	87-96	2Bw	3.7	0.41	4	11	26	45	0.58	0.37	0.32	0.49	0.04	0.25	0.31	0.12	1.1	4
H	96-105	2Bs	2.7	0.31	7	12	21	60	0.72	0.84	0.45	0.81	0.34	0.33	0.34	0.08	0.7	4

Mineralogy Rotomahana

Sample No. SB	Depth (cm)	Hor.	Clay Fraction (%) Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass	Sand Fraction (%) Quartz	Feldspar (acid)	Andesine	Glass	Muscovite	Biotite	Horneblende	Augite	Hypersthene	Epidote	Zoisite	Apatite	Magnetite	Plant opal
9581A	0-7	Ah			41	10		28	10			1		10																	
B	7-25	C1			40	6		26	17					11																	
C	25-50	C1			40	6		38	14					12																	
D	50-67	C2			41	4		24	16					15																	
E	67-78	Cg			56	4		14	11					10																	
F	78-87	2Ah			20				27					14			32														
G	87-96	2Bw			17				26					28			42														
H	96-105	2Bs							10								61														



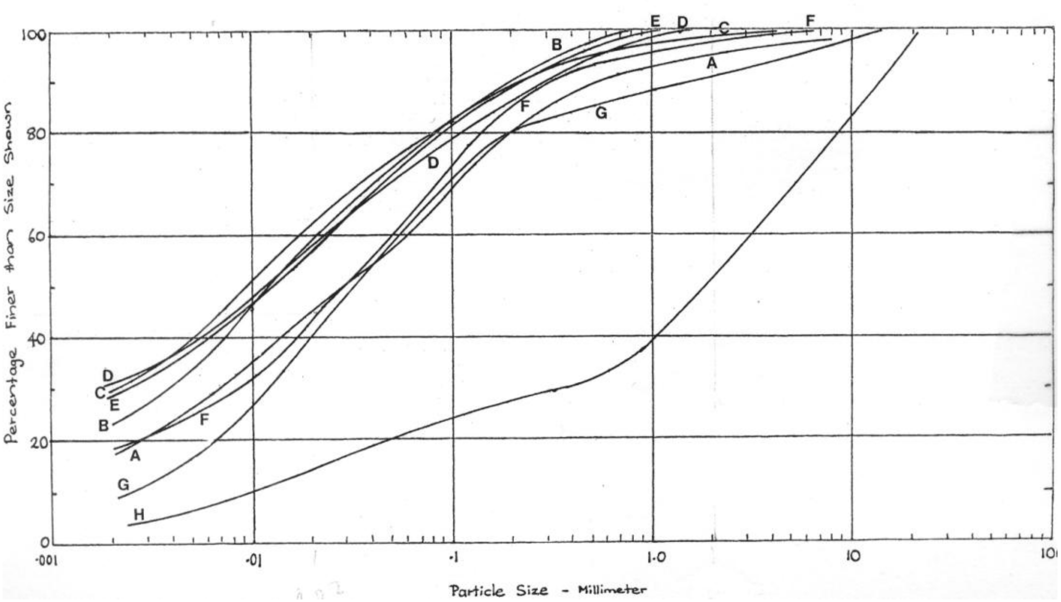
PARTICLE SIZE DISTRIBUTION (<2 mm) Rotomahana Loam

Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9581A	0-7	Ah	27	11	43	19			(4)
B	7-25	C1	18	10	48	24			(<1)
C	25-50	C1	16	8	46	30			(1)
D	50-67	C2	22	8	41	29			(<1)
E	67-78	Cg	18	11	42	29			
F	78-87	2Ah	25	14	45	16			2
G	87-96	2Bw	22	13	57	8			9
H	96-105	2Bs	50	11	34	5			50

PHYSICS

Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	15 bar water Air Dry (%)
0-7	Ah	25.0	16.7
7-25	C1	14.0	12.1
25-50	C1	14.3	12.4
50-67	C2	14.0	12.3
67-78	Cg	15.0	12.8
78-87	2Ah	21.2	16.0
87-96	2Bw	15.5	7.3
96-105	2Bs	12.4	7.4

Core Depth (cm)	Dry bulk density (T/m³)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)



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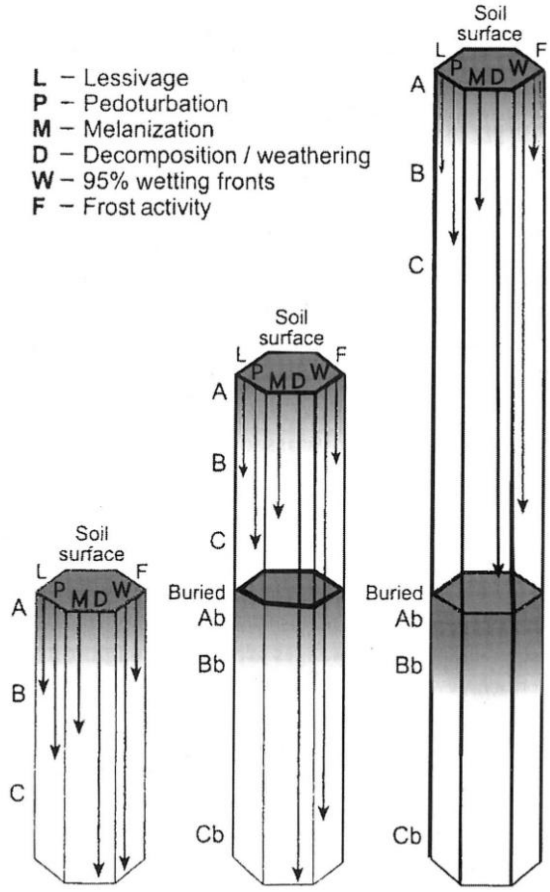

Buried brown ‘topsoil’ horizons

Buried ‘A’ horizons in NZ on tephras tend to be brownish rather than dark or black (and hence often have AB or Bw notations) and there is debate as to the reason for this.

One suggestion is that in New Zealand they have largely been developed under podocarp-broadleaved forest until very recent times (last c. 700 years) and that such soils, especially Andisols, tend have brownish rather than dark A horizons anyway (this applies in USA for Andisols under conifers: P. McDaniel, pers. comm., 2008).

Alternatively or in addition, once ‘A’ horizons are buried then they may, depending on depth of burial, become isolated from the organic cycle and hence no longer receive new organic matter to maintain their darkness via melanisation. Residual colours after removing organic matter from A horizons by H_2O_2 or burning are similar to those of buried horizons on the tephras (P.J. Tonkin pers. comm., 2006).

Finally, in some cases the depositional (burial) event may ‘scalp’ the topsoils (e.g. during emplacement of the Taupo ignimbrite), leaving effectively subsoils to represent the antecedent (now paleo) land surface. Figure at left is idealised model of buried soils at different depths and how they may be impacted by surficial (topdown) processes (from Schaetzl and Anderson, 2005, p. 622).

Impacts of deforestation and burning, and the role of bracken fern, on the properties of surficial or buried soil A-horizons

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Bracken fern (*Pteridium* spp.) is an aggressive plant that commonly invades disturbed sites. Its success as an invader is attributable, in part, to its ability to produce abundant growth, both below ground in the form of rhizomes and fine roots and above ground as fronds and stems. This biomass production has been shown to affect numerous soil properties. In describing soils of the „Pumice Lands“ (Pumice Soils or Vitrands mainly) in New Zealand, Molloy and Christie (1998) attributed black A horizons „to bracken fern, which replaced much of the forest“. Analyses of humus and phytoliths in the A horizons of soils developed especially on Kaharoa and Taupo tephras in central North Island (buried beneath 1886 Tarawera eruptives in the Rerewhakaaitu area) showed that type-A humic acids predominated and that fernland and grassland had replaced the pre-existing forests (Birrell et al., 1971; Sase et al., 1988; Hosono et al., 1991; Sase and Hosono, 1996). Pollen, phytolith and associated studies, together with tephrochronology, have shown that human-induced deforestation by burning began in New Zealand soon after Polynesian settlers arrived (e.g. McGlone, 1989; Clarkson et al., 1992; Kondo et al., 1994; McGlone et al., 1994; Newnham et al., 1998; McGlone and Wilmshurst, 1999; Watanabe and Sakagami, 1999; see also article on Polynesian settlement by Lowe, this volume). The repeated burning resulted in the formation of extensive fernlands (McGlone et al., 2005).

In northern Idaho, USA, establishment of bracken is associated with the conversion of allophanic to non-allophanic Andisol mineralogy (Johnson-Maynard et al., 1997); these changes include increased soil carbon, darker soil colours, lower pH, and increased organic forms of active Al.

Bracken biomass comparisons – New Zealand and northern Idaho, USA

	Rhizome biomass		**Frond biomass**	
Location	Mean	Range	Mean	Range
	(kg m^{-2})		(kg m^{-2})	
Nelson, New Zealand[1]	--	7.08 (max.)	--	1.41 (max.)
New Zealand (23 stands)[2]	2.92	0.91-5.19	--	--
Idaho, USA (9 stands)[3]	1.96	1.14-2.54	0.52	0.27-0.89

[1] Bray (1991)
[2] Unpublished data of D. Whitehead, Landcare Research, Lincoln, NZ, cited by McGlone et al. (2005)
[3] Jimenez, J. 2005. Accumulation of belowground C in Andisols under bracken fern (*Pteridium aquilinum*). MS thesis. Univ. of Idaho, Moscow.

In Japan, a major part of soil organic carbon in Andisols and associated soils comprises humic acids, which are characterized by their stability and aromatic (humified) structure (Shoji et al., 1993; Hiradate et al., 2004). These features arise from the presence of labile and active metals, chiefly Al and Fe, supplied by the weathering of glass and other tephric materials, which are able to bind humic substances through strong coordination bonding to form macromolecules of Al- and Fe-humic acid complexes very resistant to degradation or leaching (Hiradate et al., 2004). The resultant very dark or commonly black A horizons, typically melanic epipedons in *Soil Taxonomy* (see table), can contain up to 15% organic carbon (Hiradate et al., 2004). The Japanese pampas grass or „susuki“, *Miscanthis sinensis*, a C4 plant with large amounts of root residues, has been maintained artificially for millennia in ancient Japan to provide roofing material, straw bags, and fodder for grazing. Burning the grass in early spring before germination was common practice (buds of the pampas grass are several centimetres underground and so are not damaged) (Lowe, 2006). During burning, large amounts of very dark-coloured and charred microparticles were produced and these provided a second source of humic acids. The pampas grass has been regarded as a classic „andisolizer“ or „melaniser“ (Wada, 1986; Shoji et al., 1990, 1993; Hiradate et al., 2004).

Main properties of melanic epipedon*

- Munsell colour values and chromas of ≤ 2 (dark) throughout
- Melanic index ≤ 1.70 throughout
- $\geq 6\%$ organic C as weighted average
- Andic soil properties
- ≥ 30 cm thick

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* After Soil Survey Staff (1999, p.23)

The relative importance of these two mechanisms – (1) stabilization of humic acids by complexing reactions with Al and Fe, or (2) cultivation of *M. sinensis* and its charred derivatives as a major source of carbon in humic acids – was evaluated by Hiradate et al. (2004) using $\delta^{13}C$ analyses of humic substances in a range of soils in Japan. Hiradate et al. (2004) were able to compare the contributions from C3- or C4-plant- derived carbon because *M. sinensis* was effectively the only C4 plant species in (traditional) Japan. They found that the contribution to humic and fulvic acids of carbon derived from *M. sinensis* ranged from 18 % to 52 %. Their conclusions were that although highly-humified, i.e. dark-coloured, humic acids tended to be derived from C4-plant-derived carbon (ultimately *M. sinensis*), the dominant source of carbon for humic and fulvic acids in many cases was from C3 plants (mainly forest vegetation). Consequently, the overriding importance of active Al and Fe especially on the formation and accumulation of the dark-coloured humic acids in *Kuroboku* soils (Andisols) was reinforced (Hiradate et al., 2004).

In New Zealand the „black" A horizons generally have melanic properties, but do not meet the thickness criterion for melanic epipedons, and hence are regarded as „melanic-like". As noted above, they formed under fernland and tusssock grassland and most contain A-type humic acids (± charcoal). Non-melanic topsoils are formed under forest (most have non A-type humic acids, including Pg in P-type humic acids from deciduous trees) (see figures below). Differences between New Zealand and Japan thus relate largely to differences in human settlement history and impacts, with New Zealand having an exceptionally short prehistory of only c. 700 years (since c. 1250-1300 AD) in comparison with 10,000 years or more in Japan.

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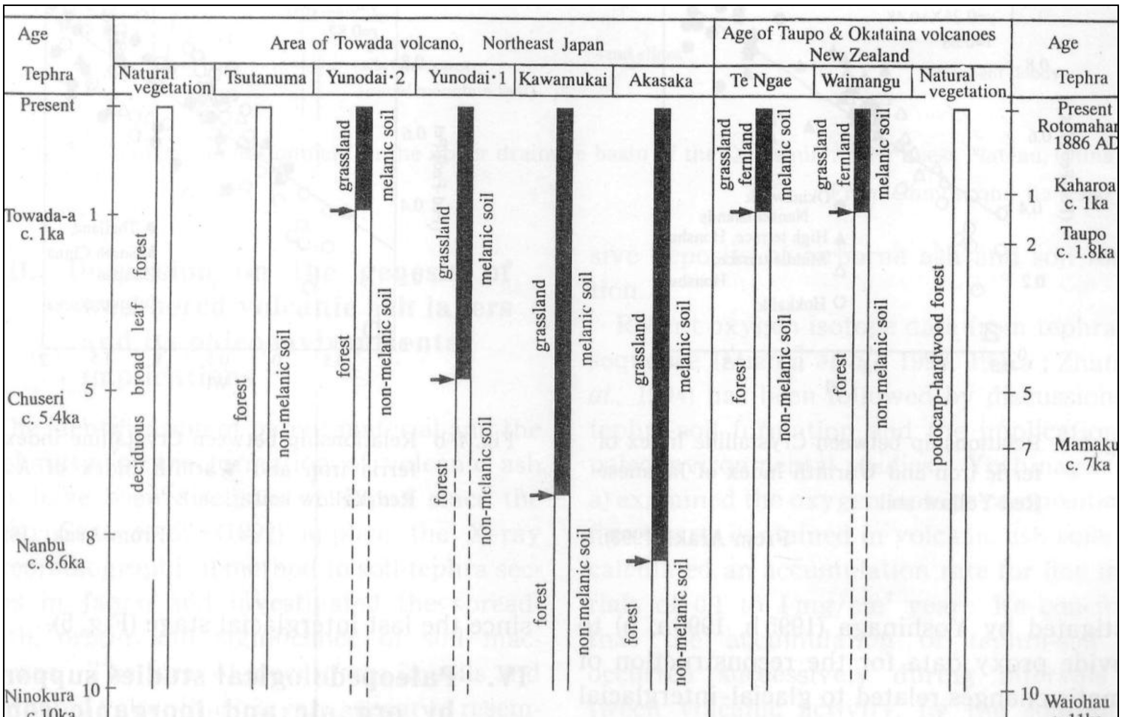
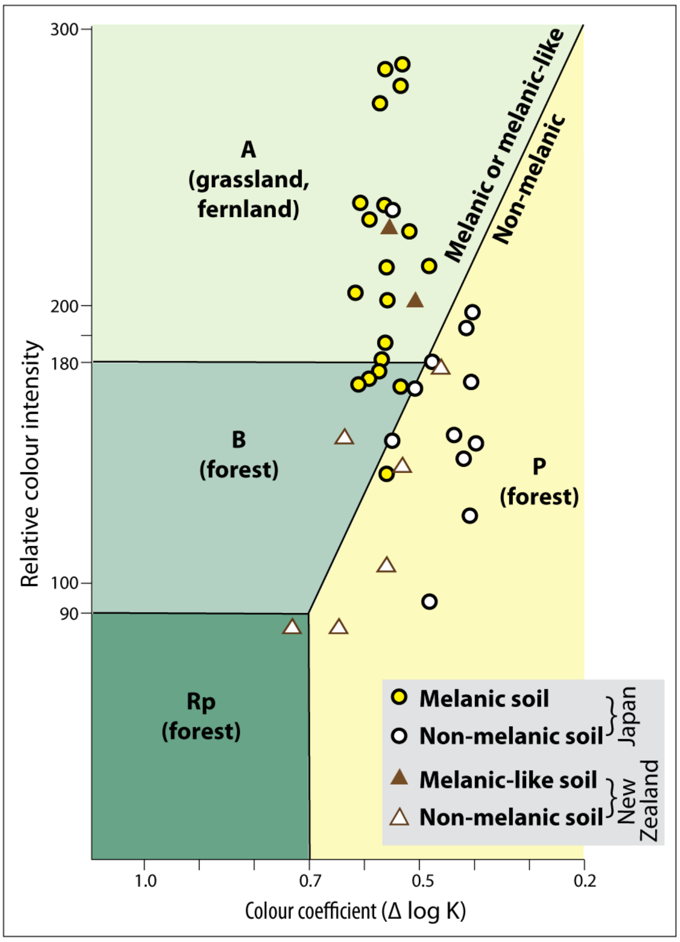
Summary from Birrell et al. (1971)

Buried horizons of an intense black colour have been found in beds of Kaharoa Ash, Taupo Pumice, and Mamaku Ash in the Rotorua and Bay of Plenty districts. They underlie material erupted in 1886, from Mt Tarawera and Lake Rotomahana. They are characterised by high organic-carbon contents, very high C/N ratios, a preponderance of humic acids in the organic constituents, and remarkably low methoxyl-carbon contents. In these respects, as well as in colour and consistence, they closely resemble the organic horizons which occur in some volcanic ash soils in Japan, but they differ in that they sometimes show both a moderately high pH, and a high content of exchangeable bases. Pollen analysis and examination of occasional plant fragments found in these horizons have shown that the previous plant cover was dominated by bracken-fern (*Pteridium aquilinum* var. *esculentum*). Analyses of this plant and its rhizomes have shown that the chemical properties of these horizons could be largely inherited from this plant, and need not result from severe acid leaching conditions acting over a long period of time, as has been suggested for similar soil horizons in Japan.

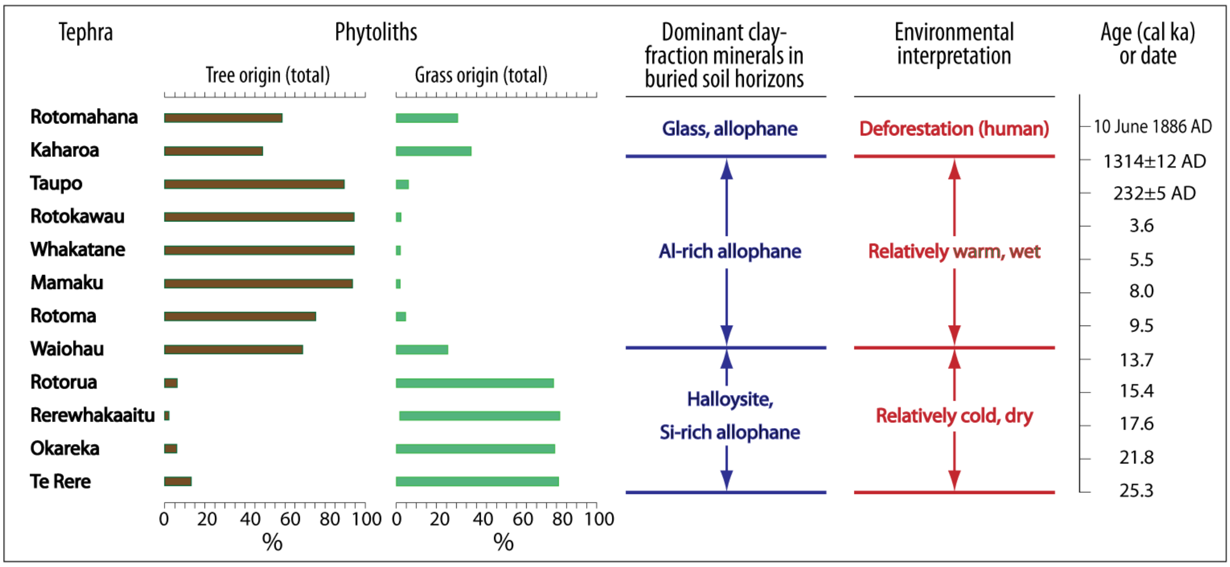


Relationship between vegetation, tephra age (in ^{14}C ka) and human impact (from Watanabe and Sakagami, 1999 – after Sase and Hosono, 1996). Note dates for initial human impact vary in Japan. Initial settlement of New Zealand occurred between c. 1250-1300 AD, a few decades prior to the Kaharoa eruption.



Comparison of humic acids from volcanic ash-derived soils in Japan and New Zealand (from Watanabe and Sakagami,1999)

Type A = grassland, fernland (melanic)
Types B, Rp, P = forest



Evidence of environmental change since c. 25,000 cal. years BP based on phytolith and clay mineral data from analysis of buried soil horizons on rhyolitic tephras at Te Ngae, near Rotorua (from Churchman and Lowe, 2010, after Newnham et al., 1999 ― based on Green, 1987; Hodder et al., 1990; Sase et al., 1988; Kondo et al., 1994)

Clay mineral assemblages of clay fractions in buried soil horizons in Rotorua-Rerewhakaaitu region (from Lowe and Percival, 1993, after Green, 1987). Democrat Rd is now Rerewhakaaitu Rd.

TABLE 2.11. Clay mineral assemblages inferred from IR spectroscopy data for clay fractions in paleosols (Bw horizons) at Te Ngae, Democrat Rd, and Tikitere sections near Rotorua (after Green 1987).

Paleosol	Te Ngae	Democrat Rd = Rerewhakaaitu Rd Tikitere^T
Ka	GL ≥Al- & Si-ALL >OM >>H, Q, +	
Tp		Al-ALL >GL > OM >>H, +
Wk	Al-ALL >Si-ALL ≥GL >OM > H, +	^{T}Al-ALL >Si-ALL >GL >OM, H, Q, +
Ma	Al-ALL >Si-ALL >GL >OM, FE, H, +	
Rm		Al-ALL >GL > OM >Si-ALL >H, +
Wh	H ≥Si-ALL >GL >>OM, Al-ALL, +	Al-ALL >Si-ALL ≥GL >H >Q, +
Rr	Si-ALL >Al-ALL ≥GL ≥H >>OM, +	H >GL >Si-ALL > OM, +
Rk	H >GL >Si-ALL >OM, Al-ALL, +	

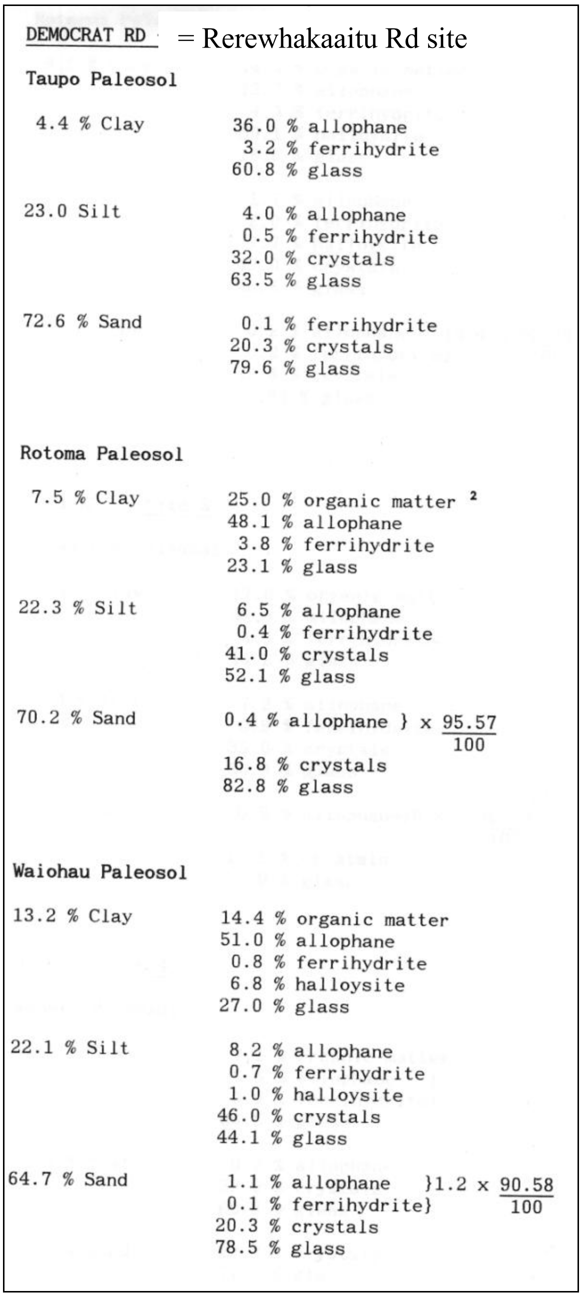
GL, glass; Al- and Si-ALL, Al-rich and Si-rich allophane; H, halloysite; OM, organic matter; FE, iron oxide mineral (e.g. ferrihydrite); Q, quartz; +, other Al and Si phase minerals (e.g. quartz, cristobalite, gibbsite).

Weight % allophane in buried soil horizons (whole soil basis) at Rerewhakaaitu Rd section (from Lowe and Percival, 1993, after Green, 1987)

Tephra & Horizon		Sample Number	wt % $Al_{(ox)}$	wt % $Al_{(py)}$	wt % $Al_{(ox)}-Al_{(py)}$	wt % $Si_{(ox)}$	Al:Si Ratio	Si Factor	wt % Allophane
Taupo	B	2	0.98	0.24	0.46	0.46	1.60	15.5	3.4*
Rotoma	B	7	1.31	neg	0.83	0.83	1.57	15.5	5.4*
Waiohau	B	17	2.00	neg	1.60	1.60	1.30	17.0	9.1*
Rotorua	B	36	0.31	neg	0.19	0.19	1.64	15.0	1.3*

Weight % ferrihydrite in buried soil horizons (whole soil basis) Rerewhakaaitu Rd section (from Lowe & Percival, 1993, after Green, 1987)

Tephra & Horizon		Sample Number	wt % $Fe_{(ox)}$	wt % $Fe_{(py)}$	wt % $Fe_{(ox)}-Fe_{(py)}$	wt % Ferrihydrite (x 1.7)
Taupo	B	2	0.35	neg	0.35	0.7*
Rotoma	B	7	0.49	neg	0.49	0.9*
Waiohau	B	17	0.40	neg	0.40	0.8*
Rotorua	B	36	0.41	neg	0.41	0.8*



DEMOCRAT RD = Rerewhakaaitu Rd site

Taupo Paleosol

4.4 % Clay	36.0 % allophane
	3.2 % ferrihydrite
	60.8 % glass
23.0 Silt	4.0 % allophane
	0.5 % ferrihydrite
	32.0 % crystals
	63.5 % glass
72.6 % Sand	0.1 % ferrihydrite
	20.3 % crystals
	79.6 % glass

Rotoma Paleosol

7.5 % Clay	25.0 % organic matter [2]
	48.1 % allophane
	3.8 % ferrihydrite
	23.1 % glass
22.3 % Silt	6.5 % allophane
	0.4 % ferrihydrite
	41.0 % crystals
	52.1 % glass
70.2 % Sand	0.4 % allophane } x $\frac{95.57}{100}$
	16.8 % crystals
	82.8 % glass

Waiohau Paleosol

13.2 % Clay	14.4 % organic matter
	51.0 % allophane
	0.8 % ferrihydrite
	6.8 % halloysite
	27.0 % glass
22.1 % Silt	8.2 % allophane
	0.7 % ferrihydrite
	1.0 % halloysite
	46.0 % crystals
	44.1 % glass
64.7 % Sand	1.1 % allophane }1.2 x $\frac{90.58}{100}$
	0.1 % ferrihydrite}
	20.3 % crystals
	78.5 % glass

Data (at left and below) for buried soil horizons on tephras at Democrat Rd (now Rerewhakaaitu Rd), about 5 km west of Stop 3, from Green (1987), Hodder et al. (1990), and Lowe and Green (1992). The Democrat Rd site (V16 141150) is the type locality for Rotoma, Waiohau, and Rerewhakaaitu tephras (Vucetich & Pullar, 1964; Froggatt & Lowe, 1990; Lowe et al., 2008).

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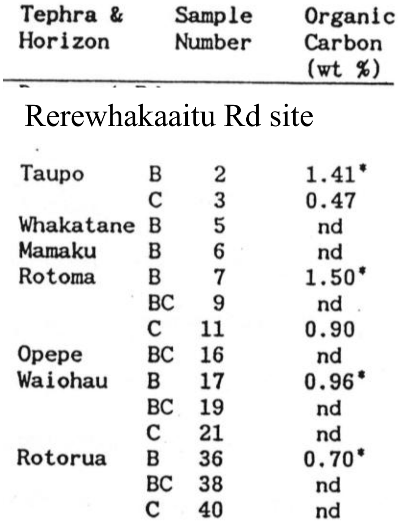
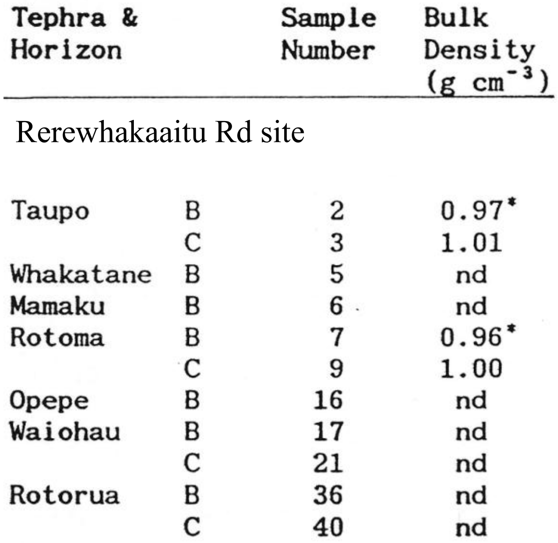


Tephra & Horizon		Sample Number	Organic Carbon (wt %)
Rerewhakaaitu Rd site			
Taupo	B	2	1.41*
	C	3	0.47
Whakatane	B	5	nd
Mamaku	B	6	nd
Rotoma	B	7	1.50*
	BC	9	nd
	C	11	0.90
Opepe	BC	16	nd
Waiohau	B	17	0.96*
	BC	19	nd
	C	21	nd
Rotorua	B	36	0.70*
	BC	38	nd
	C	40	nd



Tephra & Horizon		Sample Number	Bulk Density ($g\ cm^{-3}$)
Rerewhakaaitu Rd site			
Taupo	B	2	0.97*
	C	3	1.01
Whakatane	B	5	nd
Mamaku	B	6	nd
Rotoma	B	7	0.96*
	C	9	1.00
Opepe	B	16	nd
Waiohau	B	17	nd
	C	21	nd
Rotorua	B	36	nd
	C	40	nd

4.8 Potential impacts of ash fall on dairy farms – Rerewhakaaitu case study by Wilson and Cole (2007)

Nat Hazards (2007) 43:103–128
DOI 10.1007/s11069-007-9111-8

ORIGINAL PAPER

Potential impact of ash eruptions on dairy farms from a study of the effects on a farm in eastern Bay of Plenty, New Zealand; implications for hazard mitigation

Thomas M. Wilson · James W. Cole

Abstract This paper investigates the impact ash fall would have on dairy farming, based on a study of 'Tulachard', a dairy farming operation at Rerewhakaaitu, North Island, New Zealand. It includes analysis of the potential effects on the dairy shed and milking machine, electrical supply and distribution, water supply and distribution, tractors and other farm vehicles, farm buildings (haysheds, pump sheds, implement sheds, etc.), milk-tanker access to the farm and critical needs of dairy cows and farm to keep milking. One of the most vulnerable areas identified in the study was the cooling of milk at the milking shed, pending dairy tanker pick-up. The cooling system's condenser is exposed to the atmosphere and falling ash would make it highly vulnerable. Laboratory testing with wet and dry ash was conducted to determine its resilience to ash ingestion. It was found to perform satisfactorily during dry testing, but during wet testing significant clogging/blocking of the condenser's radiator occurred, dramatically reducing airflow through the condenser. Specific mitigation recommendations have been developed that include cleaning with compressed air and adapting farm management techniques to lessen usage of the condenser during an ash-fall event. Specific recommendations for management of dairy farm operation are given to mitigate the effects of an ash-fall event.

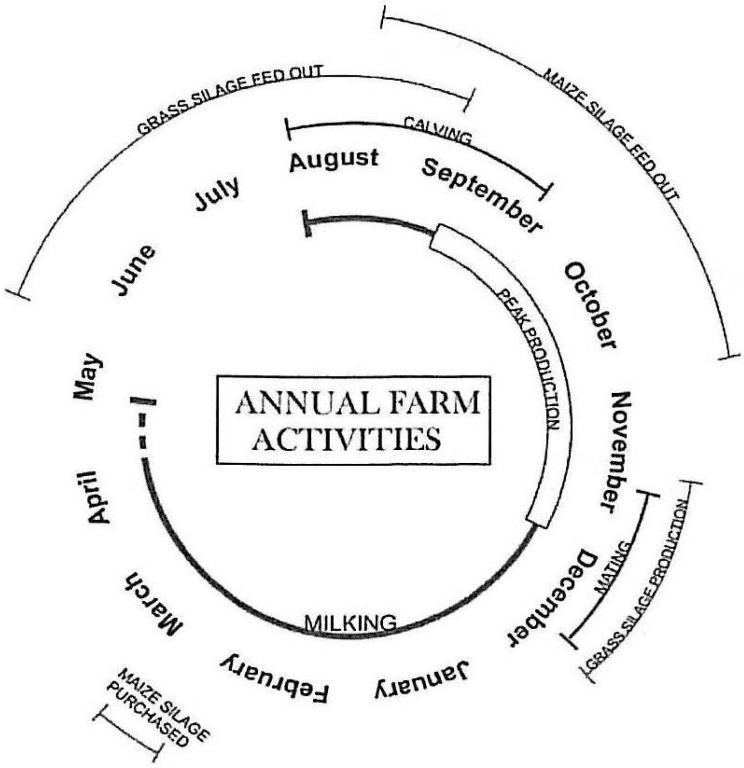


Fig. 2 The annual farm activities at the farm shows the key vulnerable periods during the year of farming operations. The farm's most important activities are closest to the centre, with activities of decreasing importance progressively further out from the centre

7 Recommendations

The effect of ash fall will depend on the magnitude, style of eruption, location of active vent zone, vent positions within the active vent zone, local topographic controls and wind directions. It is extremely hard to predict any of these factors for the next eruption, given the variety of styles of eruptions that have affected the farm during the last 22,000 years. Warning time is variable. There may be 1 year to 3 months warning for a rhyolitic eruption, while there may be only 3–4 h for a basaltic eruption.

Key recommendations to minimise the hazard are as follows:

(1) Long term planning (*periods of quiescence*)
  - Maintain power supply lines so they are in good order.
  - Develop a water supply with large tank storage capacity.
  - Develop a 'feed pad' that is easily cleared of ash for distributing supplementary feed.
  - Ensure roof pitches are greater than 30° and strengthened (perhaps to snow codes) on any new buildings.
  - Ensure the tractor is 4WD and has front bucket and blade attachments.

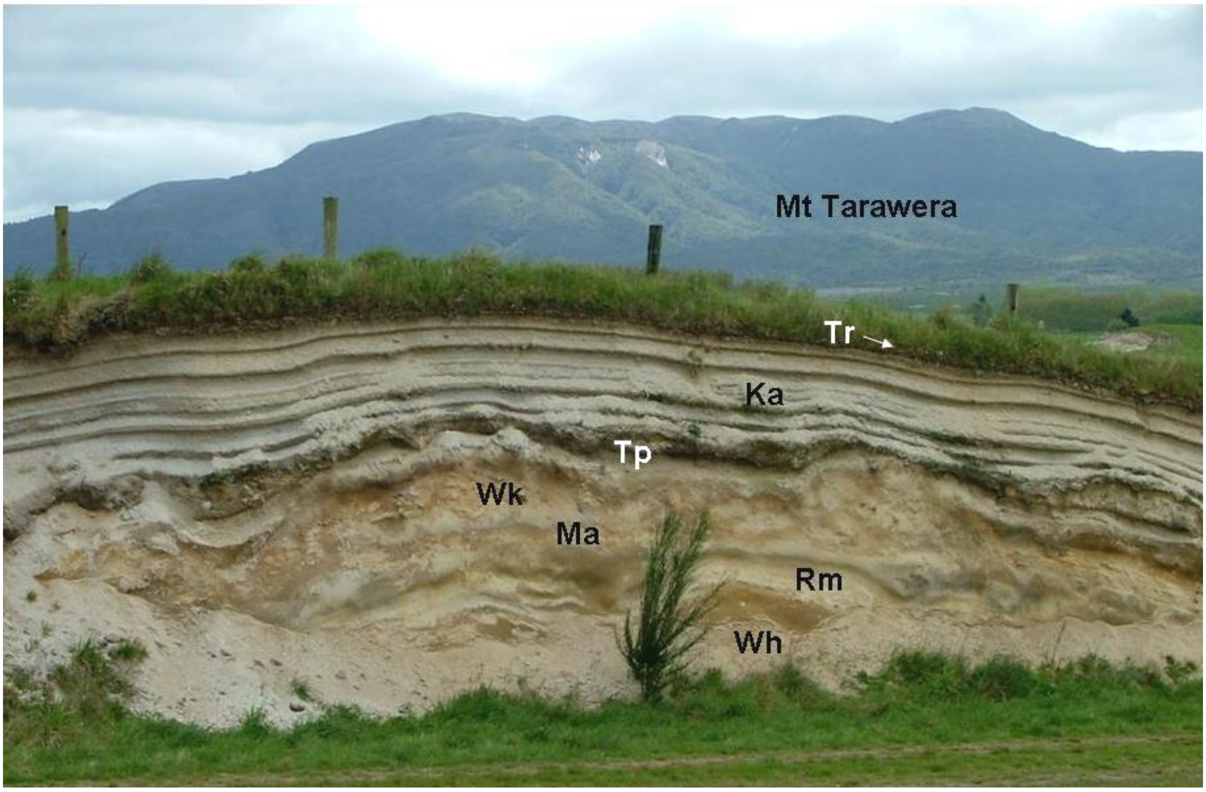
(2) Medium term planning (*12 to 3 months out from eruption*)
  - Conduct a vulnerability analysis of equipment and facilities to determine which would be the most affected by ash fall, and which are adequately and inadequately protected (http://volcanoes.usgs.gov).
  - Identify appropriate methods of protecting vulnerable equipment and facilities from ash.
  - Off load non-essential stock (i.e. beef cows, sick animals in the herd, dry milkers, old cows).
  - Increase reserves of supplementary feed (i.e. buy in or produce more; alternatively use less by off loading stock).
  - Ensure tractor and milking machine have been serviced recently.
  - Attempt to stockpile tractor engine and milking machine filters (air, oil, pulsators and milk), lubricating oil, brake and hydraulic fluids, and seals.
  - Purchase an air compressor or ensure it is in good working order.
  - Ensure diesel tank is maintained at a high level.
  - Have ladders and brooms (roof cleaning).
  - Ensure sump, drainpipes and drain grills are clear. Make sure sump pump is in good working condition.
  - Be prepared for false alarms; predicting a volcanic eruption is difficult.

(3) Short term planning (*immediately before an eruption*)
  - Cover all essential equipment (either within sheds or under a covering).
  - Move essential stock (milking herd) close to the milking shed.
  - Store transportable supplementary feed close to areas where it would be distributed (i.e. feed pad, paddocks close to the milking shed).
  - Ensure enclosed water storage tanks are at their maximum (especially if surface water is the farm's water supply).
  - Place ladders for access to key roofs in a secure way for easy safe cleaning. Plan to have a lot of time to clean roofs (prevent injury).
  - *Do not put stock onto the road* in the hope of finding somewhere better as they will hinder emergency service's and evacuee's mobility. They have a greater chance of survival on their farm (Neild et al. 1998).
  - Conduct any maintenance on tractor, milking machine and other key machinery (e.g. change filters). If there is time purchase new filters.

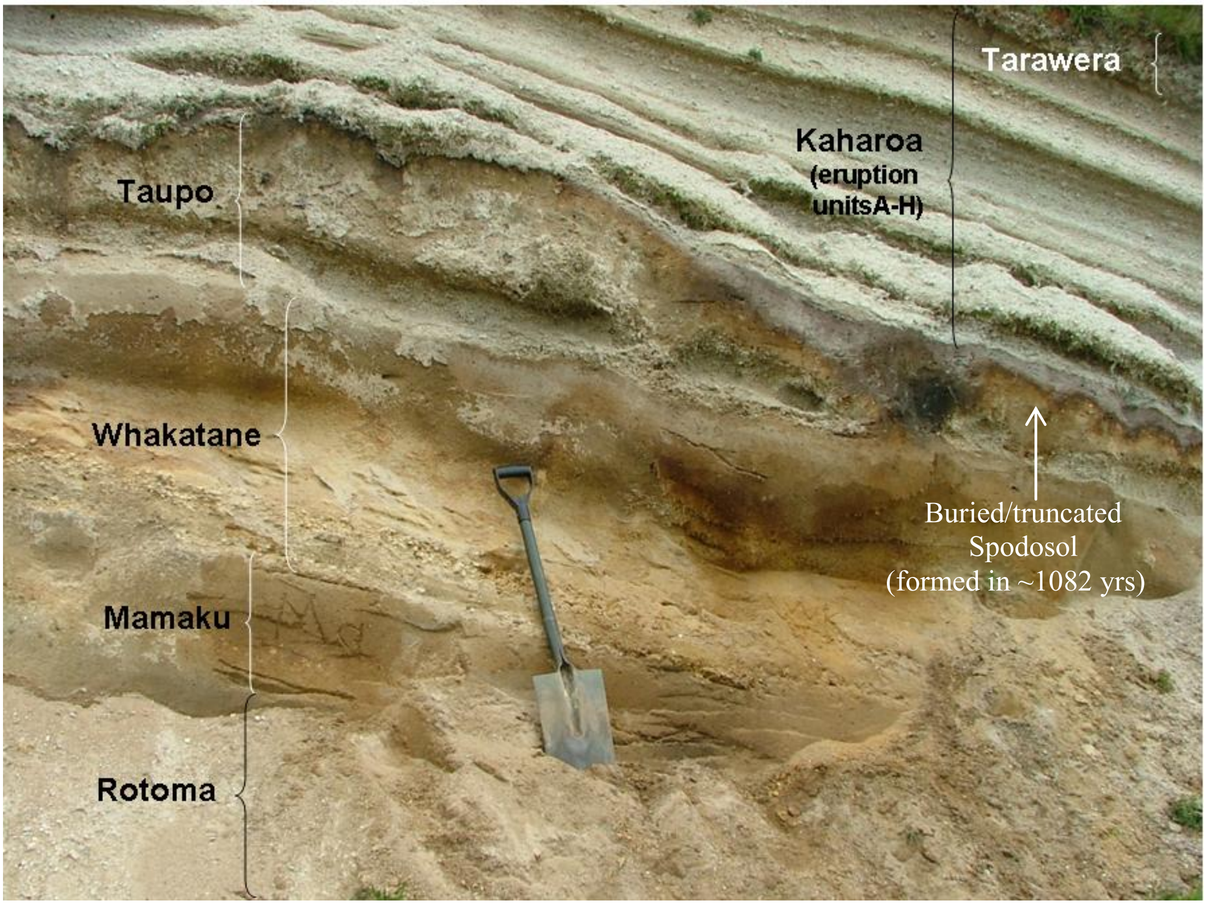
(4) During eruption
  - Keep ash out of buildings, machinery, vehicles, downspouts, water supplies and wastewater systems (e.g. dairy shed drains) as much as possible. The best way to prevent damage is to reduce machinery usage as much as possible, shutting down, closing off or sealing equipment. However, critical farm functions such as milking should be preceded by removal of as much ash as possible before operating equipment.
  - Minimize human exposure to airborne ash by using dust or filter masks and minimising travel.
  - Remove ash from roofs to prevent collapse and on going remobilisation. Take your time whilst cleaning roofs and wear a mask whilst doing so. Try to undertake the activity when you are alert and physically fresh.
  - Plan each day, in terms of what activities are critical, required and optional. These may change each day so be prepared to remain flexible. Develop a priority list of facilities that must be kept operative versus those that can be shut-down during and after ash falls.
  - Stay aware of the condition of your cows; they are the most important part of your farm.
  - Do not put stock onto the road in the hope of finding somewhere better as they will hinder emergency service's and evacuee's mobility. They have a greater chance of survival left on your farm.
  - Prioritize and sequence areas for cleanup (top to bottom).

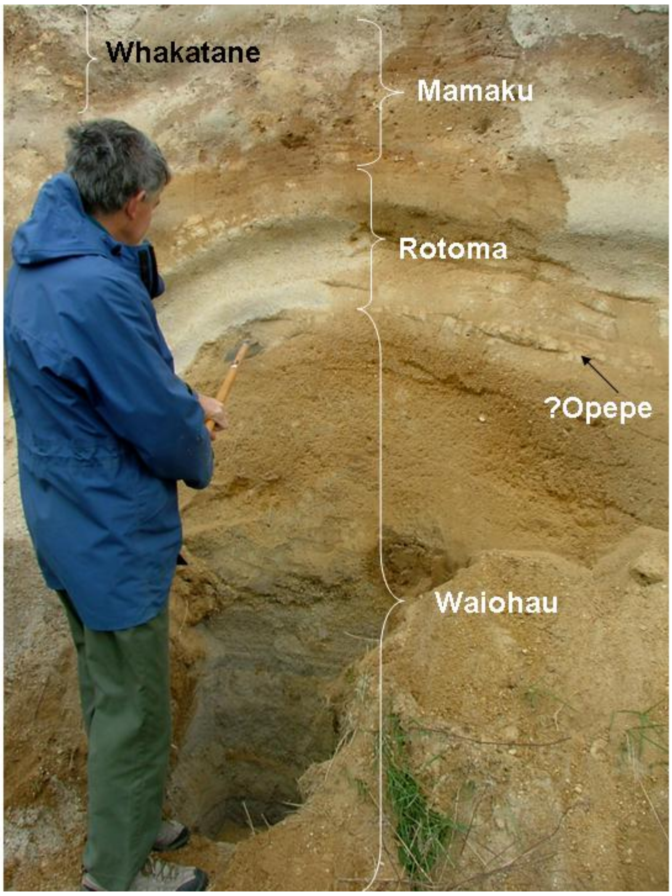
Other Tephras and Buried Soil Sequences: Matahina gravel, Ash Pit Rd

Location V16 188155, elevation 440 m asl, rainfall ~1500 mm pa



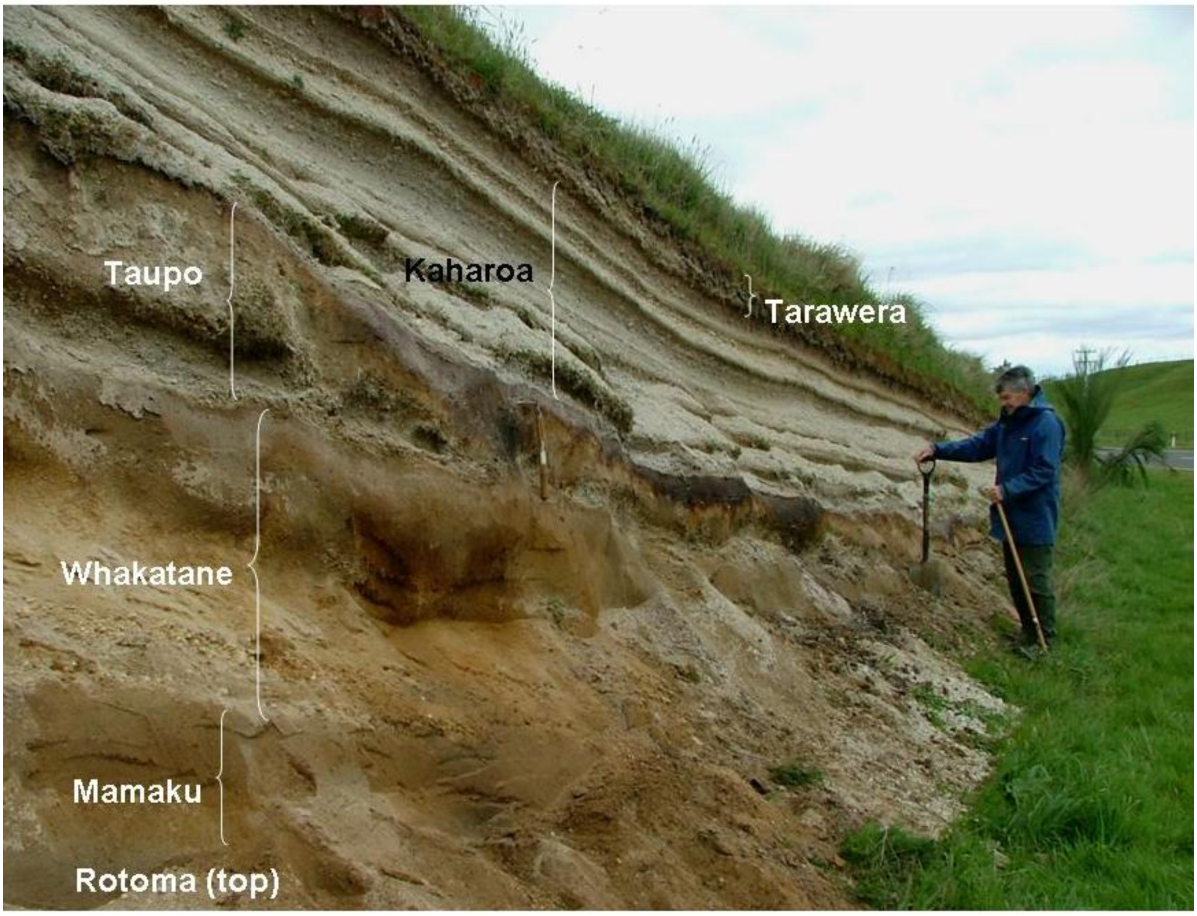
Stratigraphy of section on Ash Pit Road (approx. 4 m high). Photos: David Lowe





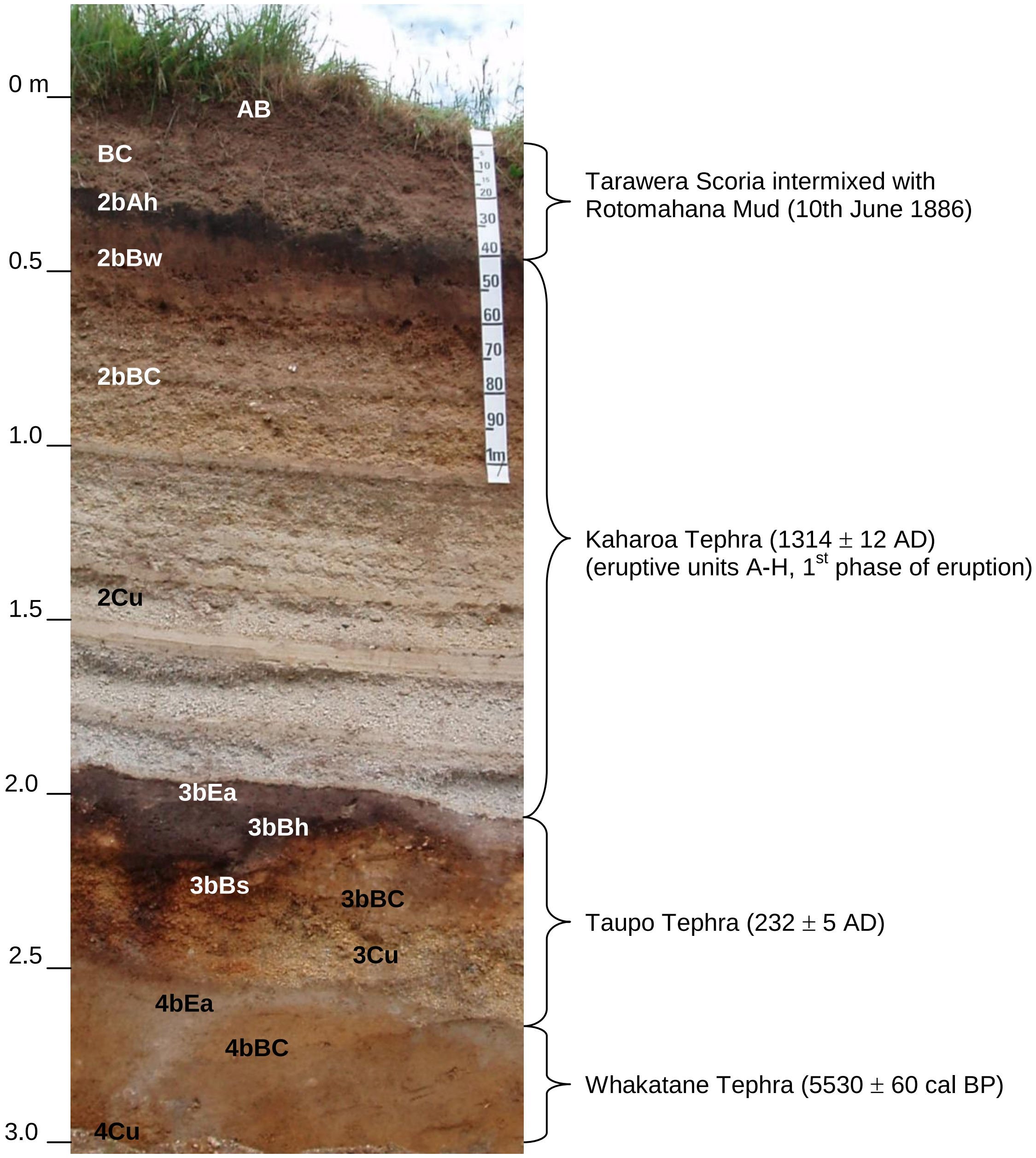
Tephra names and ages

Tr, Tarawera (10 June 1886)
Ka, Kaharoa (1314 ± 12 AD)
Tp, Taupo (Y) (232 ± 5 AD)
Wk, Whakatane (5530 ± 60 cal. BP)
Ma, Mamaku (8005 ± 45 cal. BP)
Rm, Rotoma (9505 ± 25 cal. BP)
Op, Opepe (E) (10,075 ± 155 cal. BP)
Wh, Waiohau (13,635 ± 165 cal. BP)



Matahina gravel

NZSC: Allophanic Orthic Pumice Soils; tephric, basaltic/rhyolitic; loamy/cindery; rapid
Soil Taxonomy: Ashy-skeletal/pumiceous, mixed/glassy, subactive (?), mesic
Vitrandic Udorthents



Modern soil and buried soil horizons and tephra layers at Ash Pit Rd section. *Photo, stratigraphy and horizonation*: Haydon Jones, Loretta Garrett, David Lowe, and Wim Rijkse

Note from Wim Rijkse

Matahina gravel is a moderately leached soil with base saturations fluctuating from 71% in Tarawera Tephra, to 51% in the paleosol on Kaharoa Tephra, and 19% in Kaharoa lapilli, to finally 67% in the paleosol on Taupo Tephra (Vucetich et al., 1960). Exchangeable cations are of low values except sodium which is medium. Available phosphorus presumably is low.

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4.9 Polynesian settlement of New Zealand and the impacts of volcanism on early Maori society: an update

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Timing of Polynesian settlement

Models of settlement

Various lines of evidence indicate that the „homeland‟, or *Hawaiiki*, of the early Polynesian settlers of Aotearoa was eastern Polynesia (e.g. see Sutton, 1994; Howe, 2003). Establishing the timing of settlement has been problematic, however. The most recent and reliable evidence, both from archaeological and natural sites, points consistently to initial settlement between c. 1250–1300 AD (called the late settlement model). Wilmshurst et al. (2008) suggested a settlement date of c. 1280 AD (see below). The application of tephrochronology to the issue is well established (Newnham et al., 1998; Lowe et al., 2000; Lowe and Newnham, 2004). The Kaharoa Tephra was erupted from Mt Tarawera in winter of 1314 ± 12 AD, as determined from the wiggle-match dating of a log of celery pine (tanekaha, *Phyllocladus* spp.) killed in the eruption (Hogg et al., 2003). It provides a key marker enabling both archaeological and palaeoenvironmental sites – which record the earliest forest clearances accompanying settlement – to be dated. The impacts on soils of Polynesian deforestation by burning were noted by Lowe and McDaniel (2008).

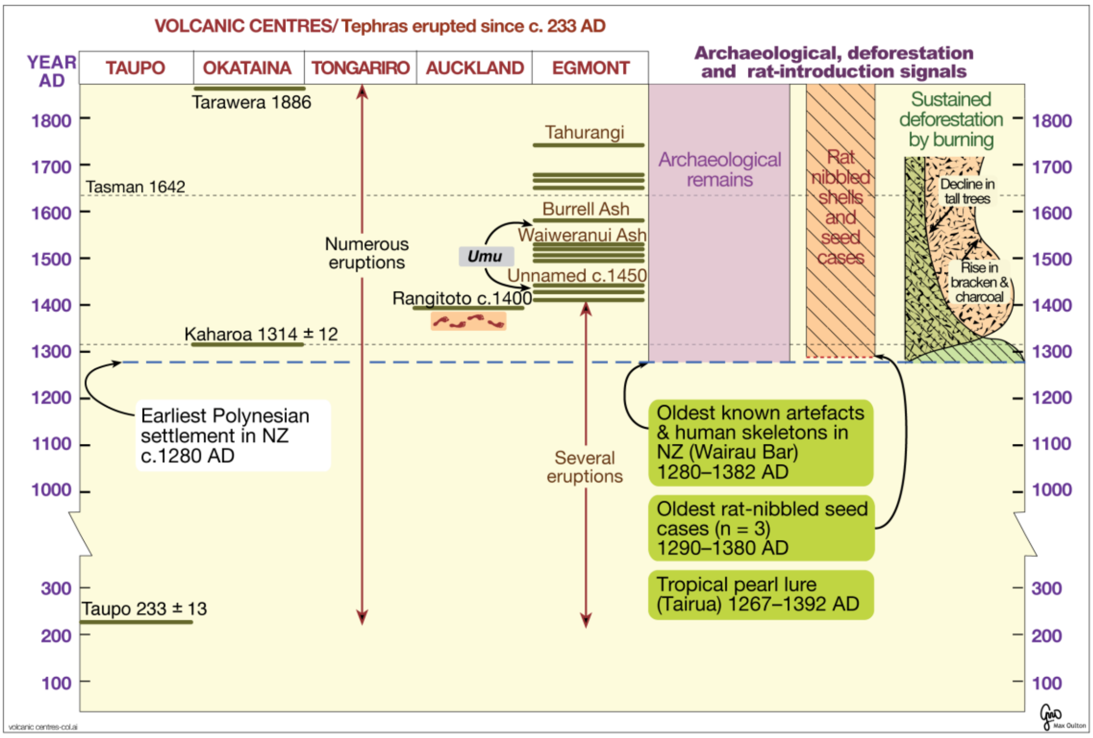
An earlier, transient contact at c. 50–150 AD, based on Pacific rat-bone (*Rattus exulans*) (known as *kiore*) dates obtained from avian predator sites, was proposed by Richard Holdaway (1996) on the premise that the rats, an introduced predator to New Zealand, accompanied the early Polynesian seafarers as a food source or stowaways. The results were very controversial because there is no supporting archaeological or ecological evidence for the presence of humans or rats in New Zealand until much later (c. 1250 AD). Holdaway has developed models involving the rapid spread of the rats over both islands and attributed the decline (possibly extinction) in some birds and other animals to predation by *kiore* well before c. 1250 AD. In 1987, Doug Sutton, formerly at Auckland University and now at Waikato University, had published a paper suggesting early settlement of New Zealand (approximately 0–500 AD) on the basis mainly of disturbance indicators in pollen records, primarily short-lived increases in bracken. That there was no evidence apart from the pollen record disturbances (just as easily accounted for by natural factors such as lightning, volcanic eruption impacts, or storms) was explainable according to Sutton by a tiny population which was „archaeologically invisible‟. Thus the „old‟ rat-bone dates seemed to support his hypothesis (called the early settlement model).

As well as lacking any archaeological or ecological evidence (such as change in vegetation as recorded by pollen profiles) for the „early‟ arrival, problems with rat-bone ages had emerged during the dating of archaeological sites where ages of various cultural material (including charcoal, wood, eggshell, marine shell, and large bone) were all in good agreement with one another and with other sites, but rat-bone ages from the same layers were sometimes older by more than 1000 years. Critics suggested various explanations for the anomalously old rat bone ages. The most obvious thing to do was to re-date the „old‟ rat bone material but it was reported, after a period of embargo by Te Papa, that no bone material was left. Thus, the question was: how to test the two competing hypotheses and especially to verify or otherwise the „old‟ rat-bone ages? Janet Wilmshurst (Landcare Research, Lincoln) and Tom Higham at Oxford University (formerly at Waikato University) came up with two approaches. The first was to use an alternative method for dating the arrival of rats which bypassed the need for bone dating. This was done by obtaining AMS (accelerator-based) radiocarbon ages on unequivocally rat-gnawed woody seed cases preserved in sediments. Wilmshurst and Higham dated numerous seeds at three sites, one on Coromandel Peninsula and two in Taranaki (i.e. opposite sides of North Island). The results were extremely clear: all rat-gnawed seeds were younger than about 780 ± 70 cal. years old (Wilmshurst and Higham, 2004). The results at the Coromandel sites were confirmed by the unequivocal identification of Kaharoa Tephra there − just one rat-gnawed seed was found beneath the Kaharoa layer, but dozens were above it, all with young ages. The conclusion from this work was that rats arrived after c. 1250 AD, and not before. The rat-gnawed seed dates were supported by a similar study by Fred Brook who dated rat-gnawed landsnail shells in Northland: no snail shells had been nibbled before c. 1250−1300 AD (Brook, 2000). Together, the newly dated rat-gnawed seeds and snail shells (from widely spaced sites) showed that it was extremely unlikely that there were any rats in the North Island before c. 1250−1300 AD, but plenty after that date. Further studies at four coastal South Island sites showed all rat-gnawed seeds to be young, the maximum age obtained being 702 ± 32 cal BP (Wilmshurst et al., 2008). From around 50 dated seeds in total, the oldest three gnawed seeds are dated at 1290−1380 AD (2 sd range).

The second approach was to re-examine independently the original avian predator deposits and collect new materials for dating and re-analysis. The results from one site were published by Anderson and Higham (2004) − that site was Earthquakes #1, north Otago, one of Holdaway"s key sites. Anderson and Higham (2004) obtained two new radiocarbon dates for pigeon bones and two on rat bones: the pigeon-bone dates were as reported in the first series (i.e., „young") but the two rat-bone dates were much younger than in the first series, suggesting that the „old" rat-bone ages from that site were not reliable for estimating the timing of human settlement. Wilmshurst et al. (2008) have now collected rat-bone and bird-bone samples from other avian predator sites in the South Island, and obtained well-documented museum specimens, from Holdaway"s original sites. All were dated younger than c. 1280 AD, the maximum age obtained on artefacts at the Wairau Bar, the oldest archaeological site known in New Zealand (moa egg shells found with human skeletons there are dated at 1280-1382 AD: Higham et al., 1999). Wilmshurst et al. (2008) thus concluded that initial Polynesian settlement of New Zealand was c. 1280 AD, and that the „old" rat-bone dates of Holdaway (1996) were all flawed (irreproducible, too old). It remains possible, however, that Sutton"s original model − that a small, environmentally and archaeologically invisible group of people arrived in New Zealand well before c. 1280 AD – is correct, but there is currently little firm evidence in support of it (see Sutton et al., 2008).

Impacts of volcanism on early Maori society

Early Maori in northern New Zealand witnessed probably only one rhyolitic eruption (Kaharoa), two basaltic eruptions (Rangitoto, c. 1400 AD; Tarawera, 1886 AD), and numerous andesitic eruptions (dozens to possibly hundreds) from the frequently active volcanoes of Tongariro Volcanic Centre, Whakaari (White Is.), and Taranaki/Mt Egmont (Lowe et al., 2002). Eruptions from Tongariro, Ngauruhoe and Ruapehu, and from Whakaari, probably had relatively little direct impact because there were few or no people living near them. In contrast, minor or short-lived impacts on more distant communities within range of tephra fallout, especially in eastern North Island (e.g. Bay of Plenty, Hawke"s Bay), would have been relatively common. Several eruptions, notably the Kaharoa event, the biggest eruption in prehistory, and some of the Taranaki events, including the Newall and Burrell eruptions, potentially had devastating consequences for relatively few people. Early Maori had a strong awareness of volcanism generally and may have developed a spiritual „disaster culture" to reduce the impacts of eruptions in proximal locations. An initial response mechanism to avoid the effects of future natural disasters may have been the placement of a *rahui*, meaning prohibited access, on a devastated area. Subsequently, a more religious or superstitious restriction, or *tapu*, would be applied (Lowe et al., 2002). Further aspects of volcanism and Maori spiritualism were described by Cashman and Cronin (2008).



Summary of stratigraphy and ages of tephras, erupted from five volcanic centres since c. 232 AD, and their relationship with archaeological, nibbled seed/shell data, and deforestation signals in northern and eastern North Island (right) (after Lowe et al., in press) (note latest age estimate for Taupo eruption is 232 ± 5 AD; Hogg et al., 2009). The Kaharoa Tephra provides a settlement datum for inferred human-induced burning and deforestation in much of northern and eastern North Island, matching the earliest settlement dates of c. 1250–1300 AD from many sites containing archaeological remains including the ancient Wairau Bar artefacts and skeletons (Higham et al., 1999) and the tropical pearl lure at Tairua (Schmidt and Higham, 1998), the oldest known rat-nibbled snail shells and seeds (Wilmshurst et al., 2008), and the earliest reliable dates for sustained deforestation elsewhere in New Zealand (Newnham et al., 1998; McGlone and Wilmshurst, 1999; McWethy et al., 2009).

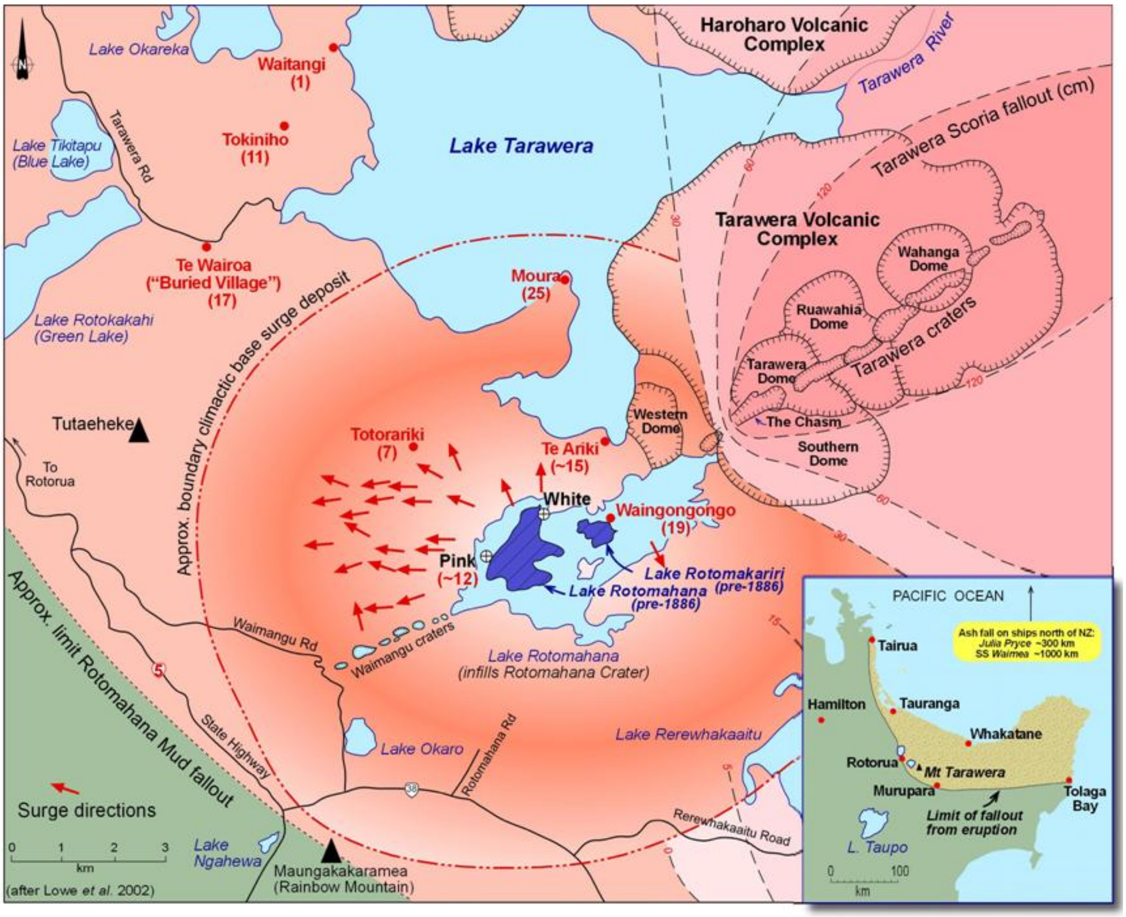
In contrast, other sacred areas were designated as accessible places of refuge or sanctuaries for all citizens (e.g. *marae*, a ceremonial meeting place). This interpretation has some similarities with Japan where Shinto shrines and their surrounds, which are sacred and inviolate areas, represent religious places both of worship and refuge that may have been initially established in safe zones in response to earlier natural disasters (Lowe et al., 2002). The beneficial and spiritual aspects of volcanism are numerous and include preferential occupation of volcanic cones as fortified villages, the use of volcanic materials (e.g. obsidian, pumice) for tools, geothermal activity for hot-water supplies, and the use of volcanogenic iron oxides (especially ferrihydrite) from seepages or soils as pigments for functional and ceremonial purposes (Lowe et al., 2002).

Tarawera eruption and catastrophic impacts

The Tarawera eruption of 10 June, 1886, was the biggest and most destructive eruption in New Zealand during the historical (European) period. It was a basaltic rather than rhyolitic event, but was nevertheless very explosive: the resulting scoria fall („Tarawera Scoria") has a dispersal similar in extent to that of the Vesuvius 79 AD pumice fall and is one of the few known examples of a basaltic deposit of plinian type from a fissure source (Walker et al., 1984; see also Sable et al., 2006; Carey et al., 2007). The eruption cored out a series of craters in a 7-km-long fissure through the antecedent rhyolite domes (including those emplaced during the Kaharoa event) of Mt Tarawera, and then generated more craters along an 8-km-long southwest extension of the fissure across the Rotomahana basin (which contained two shallow lakes and large silica sinter aprons, the „Pink" and the „White" terraces, asssociated with extensive hydrothermal activity) to Waimangu. Narratives (summarized authoritatively by Keam, 1988) indicate that after a series of precursory earthquakes from ~12.30 am, the eruption began at Ruawahia Dome at about 2.00 am on 10 June, 1886, and then gradually extended both northeastward and southwestward. At ~2.10 am the eruption intensified with the ascent of a tephra plume from the vicinity of Ruawahia Dome up to ~9.5 km. By 2.30 am craters along the whole length of the fissure were erupting, with the Rotomahana extension beginning to erupt possibly at ~3.20 am. By 3.30 am, craters along the entire 17 km-length of the fissure from Wahanga to Waimangu were in eruption. This paroxysmal stage of the eruption was over by 6.00 am when most activity ceased.

The erupted products were exclusively pyroclastic (no lava flows were generated, although basalt dikes were emplaced). The total volume (as deposited) of Tarawera Scoria is ~2 km^3 (Walker et al., 1984). The eruption along the Rotomahana and Waimangu extension was mainly phreatomagmatic (interaction between basalt magma and hydrothermal water) and phreatic. The explosive expansion of superheated water fragmented the country rock containing the hydrothermal system, plus subordinate lake sediment, to produce surge beds and fall deposits („Rotomahana Mud") that rained out over much of the Bay of Plenty and beyond (~0.5 km^3 as deposited). Near Rotomahana, the surge beds were emplaced violently by hot and fast-moving turbulent pyroclastic surges or density currents up to ~6 km from source (Nairn, 1979). Lightning during the eruption set fire to a house in Te Wairoa and to the forest on the north shore of Lake Tarawera; strong winds flattened many trees at Lake Tikitapu; and suffocating gases and falling mud and ash made breathing difficult at Te Wairoa, where most buildings were buried or collapsed under the weight of ~1 m of mudfall. A notable exception was *Hinemihi*, a large meeting house where most survivors were sheltered, because wooden forms for seating guests during Maori performances were used to prop up the roof.

All but seven of the 108 known fatalities arising from the Tarawera eruption were Maori (the true number of deaths may have been ~120, but the oft-cited ~150 is erroneous). The majority of deaths were the result of the Rotomahana explosions, especially the lethal, scorching pyroclastic surges and blasts. Clearly the event had a profound impact on Maori (and others) in the Te Wairoa and Rotomahana area especially, but trauma was felt throughout the extensive fallout zone in the Bay of Plenty and eastern North Island (Keam, 1988). For example, some groups of Maori in the region of the Rangitaiki and Tarawera rivers, north of Tarawera, became refugees at Matata. Although they had escaped with their lives and without serious injury, their possessions were buried by ~15–30 cm of tephra (some were retrievable by excavation), many potato pits were lost and those with livestock had no feed for them and so many starved (Keam 1988; Lowe et al., 2002). These people were eventually resettled in 1903–1905. The plight of these and other Maori seem minor in comparison with the difficulties of those from Te Wairoa-Rotomahana: apart from the lives lost, all possessions had been buried and many crushed. Among livestock, most smaller animals were killed, but dogs, pigs, cattle and horses that survived wandered loose and starving. The main livelihood of the region, tourism, had been destroyed, literally overnight. (Whilst Maori continued to participate in the tourist trade, its control effectively moved into European hands from 1894 with the opening of the railway line to Rotorua.) However, perhaps the biggest societal impact, according to Keam (1988), was the loss of land. For thirty years, Maori groups in the region had been generally secure in possession of their land and property. In previous times, under the old order, the prospect had always existed that a group might lose homes and land through warfare, but by the time of the Tarawera eruption, the people, long-established traders with European settlers, had become accustomed to a newfound security. The eruption rather than warfare (against which there could at least be retaliatory or conciliatory action to make-good losses) had destroyed that security and dispossessed the people of the land, which they had prized most. Offers of resettlement for the surviving group, mainly the Tuhourangi subtribe or clan (*hapu*), were received from various parts of central and eastern North Island and beyond, but most settled at Whakarewarewa and Ngapuna, both near Rotorua. Eventually gifts of land were formally ratified and provided a home for most of the Tuhourangi people. Other Tuhourangi settled for a time in the Bay of Plenty and Coromandel. After 30-50 years almost all the refugees or their descendants had returned to Whakarewarewa or Ngapuna and the gifted land was returned to the donors (Keam, 1988; Lowe et al., 2002).



Map of Tarawera area showing locations of the main craters of the 10 June 1886 fissure eruption across Tarawera Volcanic Complex, Rotomahana Crater (including pre-eruption lakes Rotomahana and Rotomakariri), and Waimangu craters (after Lowe et al., 2002). Locations of villages and associated fatalities (numbers in parentheses) are based on Keam (1988). Fatalities were all Maori apart from six Europeans at Te Wairoa and one European and three (part) Maori at Waingongongo. (There was an additional death at an unknown locality.) On the night of the eruption nearly half of Te Ariki's 27 residents were camped at Pink Terrace (Otukapuarangi). Inset shows eastern North Island and documented limits of tephra fallout from the eruption (based on maps by Thomas, 1888). Ash fell on several ships at sea, the farthest being **Julia Pryce** ***(c. 300 km) and*** **S.S. Waimea** ***(c. 1000 km) north of North Island (Keam, 1988).***

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4.10*A* Landuse and Lake Water Quality

CASE STUDY: LAKE OKARO AND WETLANDS, OKARO RD

Lake Okaro and its restoration (elevation 420 m asl, rainfall ~1500 mm pa)

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Geology and soils in Lake Okaro area

Lake Okaro was formed c. 700 years ago, probably during the Kaharoa eruption (1314 ± 12 AD), by a phreatic (i.e. steam) eruption (Lowe and Green, 1992; Lowe, 2006). The geology and soils of the area were described by Cross (1963), and soil units were recorded on the Rerewhakaaitu sheet (scale 1: 31,680) by Vucetich and Cross (1978) (also in Vucetich and Wells, 1978). Soils on the lake‟s western margins were mapped mainly as Rotomahana silt loam, mottled phase. Studies of rill erosion on the hills to the north of Lake Okaro, and on mechanisms and effects of the phreatic and secondary hydrothermal eruptions that formed the lake, were undertaken by Hardy (2005). The rilling, well exposed between Waimangu and Lake Okaro, is formed entirely in the ~1 m-thick mantle of Rotomahana Mud deposited in the area on 10 June 1886. The rill formation was rapid, beginning within days of the eruption and ending within a few years. The reason the rill erosion ceased is unknown but is possibly related to the permeability of underlying layers (Hardy, 2005). Rills are defined as centimetre to decimetre scale erosion channels cut by water running down a slope. Gullies are defined on a metre scale. In the USA, rills are described as small, runoff channels that can be obliterated by conventional tillage whereas gullies are large, runoff channels that cannot be obliterated by conventional tillage (Schoeneberger et al., 2002).

Lake Okaro and water quality

Lake Okaro has an area of 0.28 km^2 and maximum depth of 18 m. It is monomictic and is typically thermally stratified for eight months of the year, from October until June. Limnological records for Lake Okaro extend back to 1955 (Jolly, 1977) when no cyanobacteria were observed in the lake. By contrast, a persistent cyanobacterial bloom was observed in 1963 (Forsyth et al., 1988). Today, Lake Okaro is the most eutrophic lake in the Rotorua region as a result of excess nutrients which promote primary production and algae growth. To meet statutory obligations, Environment Bay of Plenty, as part of its Land and Water Plan, planned the following restorative measures: (i) a phosphorus-absorbent lake-bed cap; (ii) a constructed wetland to remove primarily N from stream flows (iii); the protection of all riparian margins in the catchment; and (iv) the introduction of best management practices to reduce N leaching from land-use over time. The Regional Water and Land Plan for the Bay of Plenty sets water quality targets for the Rotorua lakes on the basis of trophic level index (TLI) (Burns et al., 1997). TLI values are determined annually from annual mean surface water concentrations of chlorophyll *a*, total nitrogen (TN), total phosphorus (TP), and Secchi-disk depth (SD) (Table 1). In the Lake Okaro Action Plan (2006), the TLI goal for the lake is 5.0. Between 1991 and 2008 the TLI of Lake Okaro ranged between 5.09 and 5.94 (Table 1), which classifies the lake as supertrophic (TLI 5.0–5.99).

Table 1 Trophic level index (TLI) for Lake Okaro

Period	Chloro *a* [mg m^{-3}]	SD [m]	Total P [mg m^{-3}]	Total N [mg m^{-3}]	TLI	TN:TP ratio
Jul 1991 - Jun 1992	24.44	1.18	115.78	1289.67	5.66	11.14
Jul 1992 - Jun 1993	27.75	1.73	91.67	1015.67	5.45	11.08
Jul 1993 - Jun 1994	12.35	1.60	101.10	1259.33	5.35	12.46
Jul 1994 - Jun 1995	12.15	1.56	138.00	1192.71	5.43	8.64
Jul 1995 - Jun 1996	22.85	1.55	165.83	1271.83	5.68	7.67
Jul 1996 - Jun 1997	42.74	1.54	146.78	1492.44	5.87	10.17
Jul 1997 - Jun 1998	81.68	1.43	119.33	1246.33	5.94	10.44
Jul 1998 - Jun 1999	55.90	1.61	126.00	1754.00	5.94	13.92
Jul 1999 - Jun 2000	-	-	-	-	-	-
Jul 2000 - Jun 2001	17.10	2.02	99.17	1013.54	5.30	10.22
Jul 2001 - Jun 2002	-	-	-	-	-	-
Jul 2002 - Jun 2003	26.54	1.85	107.94	936.54	5.44	8.68
Jul 2003 - Jun 2004	19.73	2.28	103.66	984.78	5.31	9.50
Jul 2004 - Jun 2005	77.18	1.43	92.76	1266.94	5.85	13.66
Jul 2005 - Jun 2006	16.62	2.25	93.33	1012.39	5.24	10.85
Jul 2006 - Jun 2007	20.48	2.39	74.22	703.10	5.09	9.47
Jul 2007 - Jun 2008	27.56	1.87	48.54	926.68	5.19	19.09

Nutrient sources in Lake Okaro

Nitrogen (N) and phosphorus (P) are the key drivers of water quality in Lake Okaro. The catchment area (3.89 km^2) has been almost entirely cleared of native vegetation and is now used as pasture, mostly for dairy production, resulting in increased nutrient runoff both indirectly and through two small unnamed streams that enter the lake from the north-west. Around half of the P inputs and a third of the N inputs to Lake Okaro are from the lake-bed (Fig. 1). This internal loading occurs when the bottom waters become anoxic during thermal stratification (during summer and autumn) (Fig. 2), causing bottom sediments to release N in the form of ammonium (NH_4-N) and P in the form of orthophosphate (PO_4^{3-}). As winter arrives surface water temperature approaches bottom water temperature, causing the lake to mix and distributing the released nutrients throughout the water column. This release promotes algal growth until nutrients are depleted, causing algae to die off and to be deposited on the lake-bed. In spring, the cycle begins again as the water column stratifies and decomposition of organic matter consumes oxygen in the isolated bottom waters.

Restoration of Lake Okaro

The first attempt at in-lake removal of phosphorus was with the application of 13 m^3 of alum on 16 and 17 December, 2003. Alum was applied as aluminium sulphate and achieved a concentration of 0.6 g Al m^{-3} in the epilimnion (0–3 m). This low Al concentration was chosen by Environment Bay of Plenty in order to avoid buffering of the lake, which has relatively low alkalinity. Intensive monitoring was carried out from 2 December 2003 to 13 January 2004 to document the before-and-after effects of the alum application (Paul et al., 2008).

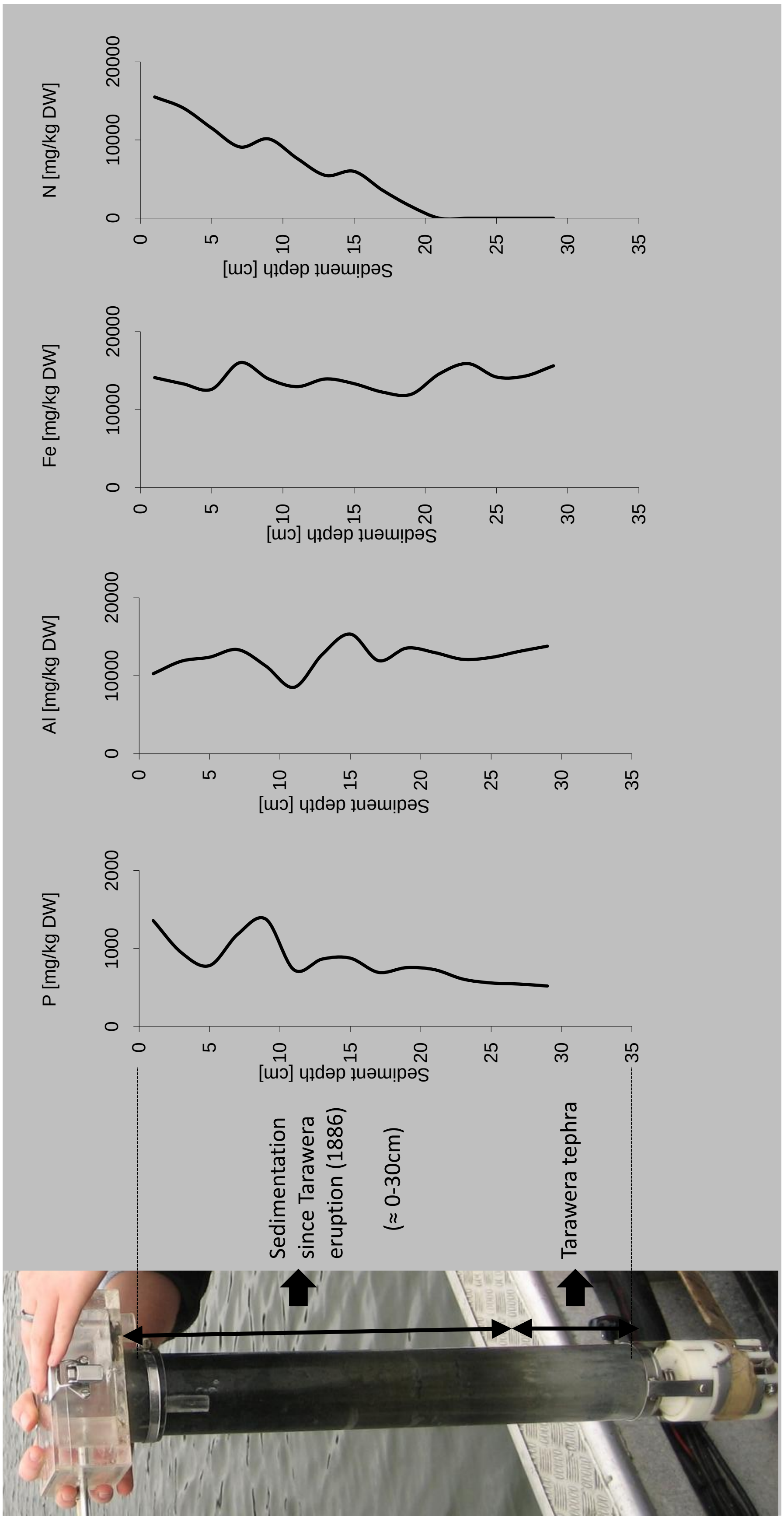

Fig. 1 Sediment core from Lake Okaro and vertical profiles of phosphorus (P) (mg kg DW^{-1}), aluminium (Al) (mg kg DW^{-1}), iron (Fe) (mg kg DW^{-1}), and nitrogen (N) (mg kg^{-1} DW) (N profile courtesy of Dennis Trolle, University of Waikato)

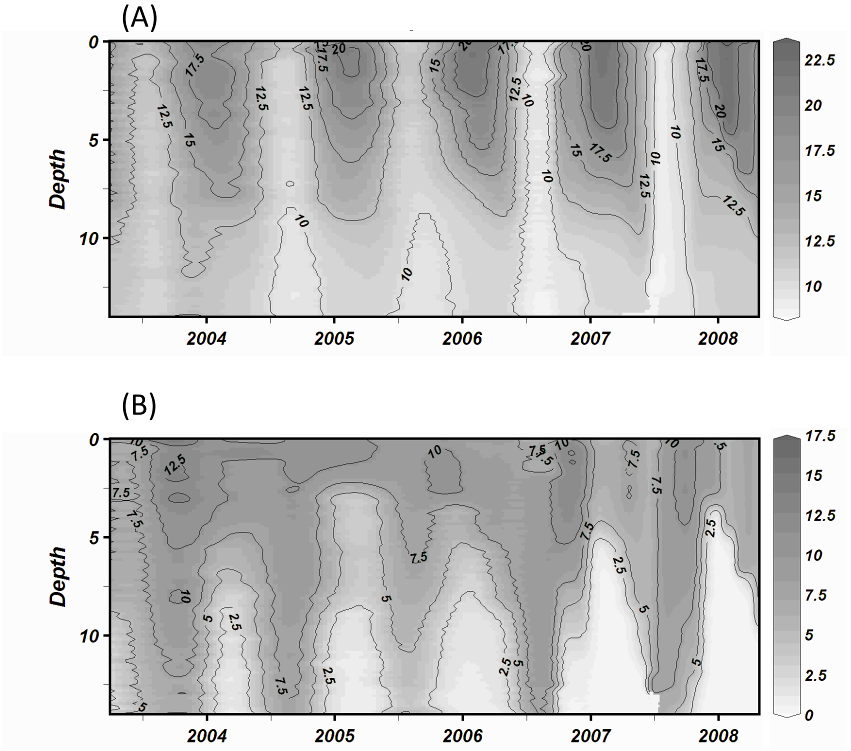

Fig. 2 Temperatures (°C) in Lake Okaro (A), and dissolved oxygen concentrations (mg L^{-1}) in Lake Okaro (B) for the period March 2003 until June 2008

In February 2006, a 2.3 ha surface-flow, constructed wetland was implemented to intercept the two small unnamed stream inflows. With full establishment of the plants the annual percentage removal of total N and total P was estimated to be 45% (165-210 kg yr^{-1}) and 10-15% (5-6 kg yr^{-1}), respectively (Tanner et al., 2007). More than 60,000 plants, including tall spike-rush, lake clubrush, and jointed twigrush were planted in the shallow areas. A number of other species have also colonised the wetland during the natural regeneration progress. In addition to the wetland, some riparian protection works including fencing and planting of native species along the stream banks and lake margins have been carried out. According to objective 16 (Regional Water and Land Plan), the goal for the Rotorua lakes, and therefore Lake Okaro‟s catchment, is the complete riparian protection of all streams and lake margins. Environment Bay of Plenty aims to complete all riparian protection works by the end of 2012.

Between 25 and 28 September 2007, 110 t of modified zeolite (Z2G1, developed by Scion, Rotorua), equivalent to a dose rate of 350 g m^{-2}, was applied to Lake Okaro. Modified zeolite was designed to be applied as a sediment capping agent with a high affinity for phosphorus. The restoration targets for this application were two fold. Firstly, the application would be deemed successful if phosphorus levels in the hypolimnion were reduced below historical levels (2002-2007) (i.e. below the natural environmental variation). A reduction to less than 50% of historical values was considered a reasonable outcome. Secondly, a reduction in mean summer phytoplankton (chlorophyll *a*) and increased water clarity would be used as success criteria in order to convey the effects of the restoration in terms that are meaningful to the general public.

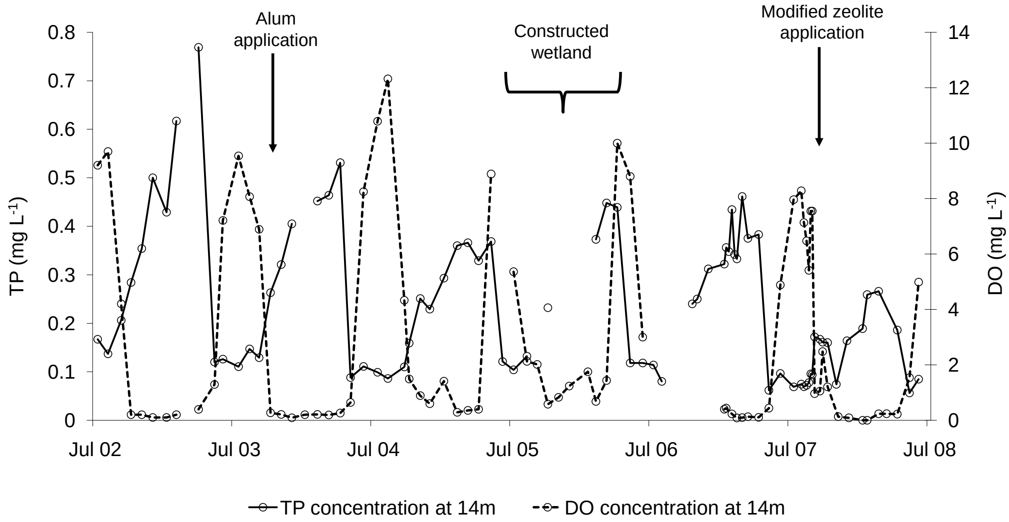

Fig. 3 Temporal trend of total phosphorus (TP) concentrations (mg L^{-1}) and dissolved oxygen (DO) concentrations (mg L^{-1}) for Lake Okaro at 14 m depth for period July 2002 until June 2008. Graph modified from Özkundakci et al. (2010).

A second application of Z2G1 was carried out in Lake Okaro in August 2009. This time, a slurry injection technique was used for applying a fine (grain size <0.7 mm) zeolite material to the surface of the lake. The fine material caused injection plumes to merge at about 10-15m behind the barge which ran a path on continuous injections clockwise around the near-shore an moving slowly into the middle of the lake in several circuits.

The measured TLI of Lake Okaro between July 2005 and Jun 2008 was lower for all three years than any year between 1991 and Jun 2005. Therefore, the three restoration projects carried out on Lake Okaro seem to have had a combined effect. The 2003 alum application was only marginally successful in reducing TP from the water column and internal load, probably due to the low dose rate (Paul et al., 2008). However, the constructed wetland and riparian protection have shown high efficacy in reducing external loading of TP, and TP concentration in Lake Okaro appears to have responded quickly to reduced loading (Fig. 3). Lake Okaro still remains eutrophic. The performance of the fine second Z2G1 application to the lake looks promising and the results should be available soon. Further research to investigate the individual effects of the successive restoration programme is underway with the focus on internal P cycle. Research has been carried out on the reactivity of various organic phosphorus species in the sediments, at what rates they are transformed and made available again for biological uptake, and which forms can be considered as refractory and thus will be buried in deeper sediment layers (Özkundakci, 2010).

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Lake Okaro

Wetland soon after completion at Lake Okaro (2005) (LERNZ website)

4.10*B* Land use impacts on lake water quality

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Human activities such as residential settlement, farming, forestry and recreation all affect nutrient levels in lakes. Water quality is falling in some Rotorua lakes. This is because they have too much nitrogen and phosphorus. These nutrients feed the algae which degrade water quality. Nutrient levels have increased markedly over the past few decades, and continue to rise. The major pressures on the lakes are the effects of the expanding small communities around lakes and intensification of farming. The pressures show up as deterioration in lake quality. Usually short-term events occur where the water quality becomes noticeably affected. In the worst cases, such as at Lake Rotorua, the lake condition is seriously affected for much of the year.

Aerial view of Rotorua City at the southern end of Lake Rotorua. Mokoia Island in distance. Photo: Toshiro Nagasako

Many communities dispose of waste to septic tanks. Nutrients, particularly nitrogen from this source, eventually flow into the lake through the groundwater to boost production of algae.

Bacteria can also contaminate the lake edge in the „paddle" zone. The main source of nutrients into the eutrophic (nutrient-rich) lakes is livestock farming. About one third of the pastoral farming in the lake catchment is dairying and the rest is primarily in low intensity sheep and beef grazing. The more intensive farming puts pressure on lake quality as a result of higher stocking rates and the leaching of N from urine patches. The primary source of P is from sediment generated through surface runoff and stream bank erosion.

The Regional Water and Land Plan for the Environment Bay of Plenty Region sets water quality targets for the Rotorua lakes on the basis of trophic level index (TLI). Values of TLI are determined annually from annual mean surface water concentrations of chlorophyll *a*, total nitrogen and total phosphorus, and Secchi-disk depth.

Values of variables defining the boundaries of different trophic levels

Nutrient enrichment category	Trophic state	Trophic level	Chloro *a* (mg/m^3)	Secchi depth (m)	Total P (mg/m^3)	Total N (mg/m^3)
Low	Oligotrophic	2.0 to 3.0	< 2	> 7.0	< 10	< 200
Medium	Mesotrophic	3.0 to 4.0	2 – 5	3.0 - 7.0	10 – 20	200 – 300
High	Eutrophic	4.0 to 5.0	5 – 15	1.0 – 3.0	20 – 50	300 – 500
Very high	Supertrophic	5.0 to 6.0	15-30	0.5 – 1.0	50 – 100	500 – 1500
Extremely high	Hypertrophic	6.0 to 7.0	> 30	< 0.5	> 100	> 1500

Characteristics and water quality of the Rotorua lakes

	Mean depth (m)	Max depth (m)	Lake area (ha)	Catchment area (ha)	Long axis (km)	Lake type based on trophic level index
Okaro	12.5	18	32	407	0.7	Supertrophic
Rotorua	11	44.8	8,079	52,346	15	Eutrophic
Rotoehu	8.2	13.5	795	5,673	4.6	Eutrophic
Rotoiti	31.5	93.5	3,460	12,462	15	Eutrophic
Rotomahana	60	125	897	7,994	6.2	Mesotrophic
Rerewhakaaitu	7	15.8	579	3,816	3.8	Mesotrophic
Okareka	20	33.5	342	1,958	2.8	Mesotrophic
Rotokakahi	17.5	32	452	1,872	4.3	Mesotrophic
Tikitapu	18	27.5	146	567	1.6	Oligotrophic
Okataina	39.4	78.5	1,104	5,676	6.2	Oligotrophic
Tarawera	50	87.5	4,165	14,494	11.4	Oligotrophic
Rotoma	36.9	83	1,104	2,914	5.2	Oligotrophic

Further farming intensification is constrained by „Rule 11" in the Regional Water and Land Plan (see below). This set of rules does not allow an increase in N and P loss above a property"s benchmark level (2001–2004 average). However, the N loss increases from historic farming intensification have been delayed by large reservoirs of old-age groundwater. Nitrogen inputs to lakes will continue to rise as the „younger" N works its way through the groundwater, emerging at seeps and springs. Research is gaining momentum into methods of reducing nutrient outputs. Some N and P entering the lakes have a natural source. However, the pressures on the Rotorua lakes are mostly from the intensification of agriculture and growth in lakeside communities.

Steps to improve water quality

Some of the contributing factors and steps to improve water quality are listed below.

Lake	Water quality problems	Steps to improve water quality
Okareka	Moderate risk of cyanobacterial blooms.	Action plan operational. Sewerage reticulation. Lake edge wetlands. Treatment of hypolimnetic water with flocculants to remove phosphorus. Environmental programmes for landowners. Land use change for lower nutrient export.
Okaro	Severe cyanobacterial blooms (alternates between blue-green and green algal). Previous scientific reports dating back to 1966 describe Lake Okaro a having „clear water" with a pH of 7. Today the lake has a very low clarity and a surface water pH in excess of 8.	Action plan operational. Chemical flocculant trials, constructed wetland and riparian retirement. Environmental programmes for landowners.
Okataina	None - low risk of cyanobacterial blooms. Possible water quality degradation that could come from lake level changes or other natural fluctuations.	Action plan process beginning to investigate the causes of lake quality decline. Environmental programmes for landowners.
Rerewhakaaitu	Risk of cyanobacterial blooms during summer where lake is shallow and calm. Water quality fluctuations noted in the past.	Local projects undertaken in catchment with landowners. Trials of treatment boxes to remove nitrogen from streams. Phosphorus-absorbing socks in the Mangakino Stream. Environmental programmes for landowners.
Rotoehu	Severe cyanobacterial blooms (have been more persistent since an increase in nutrients in 1993). 2003/04 summer had no cyanobacterial blooms, but a large bloom returned in the 2004/05 summer along with a large hornwort infestation.	Action plan process underway. Riparian retirement programme. Constructed wetlands. Treatment box to remove stream nitrate. Hornwort harvesting trial to remove nutrients
Rotoiti	Severe cyanobacterial blooms in Okawa Bay (have become more persistent in past few years). Isolated blooms in eastern lake area. Receives nutrient rich water from Lake Rotorua (~72% nutrients are from Rotorua). Massive algal bloom in early 2003.	Action plan process underway. Riparian retirement. Sewage reticulation for lakeside settlements. Diversion of inflow from Ohau Channel down the Kaituna River.
Rotokakahi (Green Lake)	Moderate risk of cyanobacterial blooms. Water quality is lower than in the 1950s, but there has been no discernible change since 1970/71.	Actions to improve lake water quality to be negotiated with lake owners.
Rotoma	None. Low risk of cyanobacterial blooms.	Action plan process beginning. Sewage reticulation and nutrient management for farmland. Environmental programmes for landowners.
Rotomahana	Occasional cyanobacterial blooms.	No action at this time, until July 2008. Environmental programmes for landowners.
Rotorua	Experience water quality decline between 1978 and 1983. Foam (associated with kirchneriella algae species). Isolated blooms of nuisance algae. Moderate risk of cyanobacterial blooms.	Action plan process underway. Rotorua District Council diversion of treated sewage to land disposal in 1991, and further improvements in progress. Riparian retirement since 1970 as part of Kaituna Catchment Control Scheme. Diversion of nutrient rich spring flows investigated. Flocculant dosing of

		nutrient-rich streams. Stormwater upgrades. Environmental programmes for landowners.
Tarawera	Occasional cyanobacterial blooms. Bacterial issues from septic tanks around some lakeshore areas.	Action plan process beginning. Land use change to lower nitrogen and phosphorus export encouraged. Planning for future sewage reticulation. Environmental programmes for landowners.
Tikitapu (Blue Lake)	Probable lake water decline from septic tanks from camping ground and public amenities. Low risk of cyanobacterial blooms.	Sewerage reticulation as part of the Lake Okareka scheme. Action plan process beginning.

Environment Bay of Plenty Regional Council's (EBOP) Rule 11

Rule 11 is a commonly used term for a collection of rules in the proposed Regional Water and Land Plan that will restrict landowners in catchments of some of the Rotorua lakes from increasing the amount of N and P leaving their property. The „Rule 11‟ regulations are part of a wide-ranging programme of action called the Rotorua Lakes Protection and Restoration Action Programme. This is a joint project by Environment Bay of Plenty, Rotorua District Council, and Te Arawa Maori Trust Board. These rules have important implications for land use, development and management in certain lake catchments. Rule 11 has a single goal: to protect lake water quality. Nutrient benchmarks must be set for all properties larger than 4,000 m^2 in five lake catchments: Rotorua, Rotoiti, Rotoehu, Okareka, and Okaro. It will "put a line in the sand" and stop further increases of N and P inputs from activities such as agriculture.

Work has started on the setting of nutrient benchmark levels for rural properties, although there have been delays in the benchmarking process. In most cases, the benchmark will be an average of the annual N and P losses between mid-2001 and mid-2004. There are also rules to limit losses from small properties, and to control sewage and stormwater discharges from urban areas. After levels are set, landowners will not be able to change or intensify land use without taking steps to fully offset any increased loss of N or P. For example, they could balance out extra stock numbers by planting and fencing off streambanks. Environment Bay of Plenty reviews Rule 11 for each affected lake catchment; such a review is due. A review *may* change how nutrient issues are addressed (P. MacCormick pers. comm., Oct 2008).

Ohau Channel diversion wall

The Ohau Channel Diversion Wall is located in Lake Rotoiti at the outlet of the Ohau Channel, which links Lake Rotorua and Lake Rotoiti. The wall is 1275 metres long and is designed to stop water flowing from Lake Rotorua, with its higher nutrient levels, into the main body of Lake Rotoiti via the Ohau Channel. Instead, water is diverted directly down the Kaituna River, preventing it from degrading Lake Rotoiti‟s water quality. The wall cost just under $10 million to build and was funded by Environment Bay of Plenty and central Government. It was opened on 20th October 2008. The diversion will prevent 64 tonnes of N and 13 tonnes of P entering the main body of Lake Rotoiti from Lake Rotorua each year through the Ohau Channel. The diversion is expected to improve Lake Rotoiti‟s water quality within five years, as research has shown that 50-60 % of the nutrients entering the lake come through the Ohau Channel. It is not expected to have any significant impact on Kaituna River quality. Buoys and lights mark the wall and safe navigation areas around it to ensure that people using the channel and lake can do so safely.

Sewage reticulation

In response to concern over the health of Rotorua‟s lakes and the effect of lakeside settlements, Council in 2004 commenced the establishment of rural sewerage schemes to remove effluent input into the lakes. Over the next ten years, Rotorua District Council is spending $95 million on sewerage scheme projects. Approval has been given to commence design development and construction of four new areas, known as Mourea, Okawa Bay, Brunswick and Rotokawa sewerage areas. Investigation is being undertaken into treatment options for Okere, Otaramarae and Whangamarino sewerage areas, and funding has been earmarked for proposed Okareka, Tarawera, Gisborne Point/Hinehopu, Hamurana and Rotoma Sewerage Areas.

Riparian protection

Voluntary riparian protection of stream, wetland and lake margins on private land has been encouraged since the 1970s with the Kaituna Catchment Scheme. Subsequently regional grant schemes have continued and today grants of up to 75% of establishment costs are provided by Environment Bay of Plenty with their Environmental Programmes initiative to assist landowners with riparian protection, erosion control and biodiversity protection. According to objective 16 of the Regional Water and Land Plan, the goal for the Rotorua Lakes‟ catchment is the complete riparian protection of all streams and lake margins and Environment Bay of Plenty is aiming to complete all riparian protection works by the end of 2012.

Further information

Recent overviews are also given by Hamilton (2003, 2005) and Hamilton et al. (2007). For further detailed information on the links between (for example) land-use and water quality, ages of groundwater in the Rotorua region, nutrient loads of Lake Rotorua, and the likely impacts of the Ohau Channel diversion wall, see Environment Bay of Plenty‟s website and numerous technical reports: http://www.envbop.govt.nz/Water/Lakes/Technical-Reports.asp. The University of Waikato is leading the Lake Ecosystem Restoration New Zealand programme which is a series of projects that aim to restore indigenous biodiversity in lakes (www.lernz.co.nz).

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4.11 Stop 4 – Kuirau Park Explosion Crater, Ranolf St

Location U16 946361, elevation ~290 m asl, rainfall 1400 mm pa

Kuirau Park is situated near the flanks of the rhyolite dome of Hospital Hill, and hosts a geothermal field consisting of hot pools, mud pools, steaming ground, and silica sinter deposits. The mud pools are dark grey to dark brown in colour and contain minerals produced by hydrothermal activity and alteration of the surrounding rock, including pyrite, sulphur and clay minerals. At around 3.40 pm on 26th January 2001, and without warning, a powerful steam explosion occurred from one of the mud pools (known as Spring 721; Cody, 2003). It produced a dark grey eruption column about 100 m high (height estimates ranged from ~70 to ~150 m) and mud and ballistic blocks, up to ~1 m across, that splattered over trees, the car park, and reached the helicopter pad on the edge of the hospital. The large blocks were thrown about 50 m from the vent whereas smaller blocks <~0.1 m in size landed 100 m away; fine muds were dispersed downwind up to ~1.5 km to the east as far as Queen Elizabeth Hospital (Cody, 2003; Cody and Scott, 2005). The volume of ejected material was c. 1200 m^3 (Cody, 2003). As timed by a witness, the eruption lasted about four and a half minutes (the sign by the road is in error). The muddy eruption column made a very loud, steady hissing noise and was surrounded by white steam clouds which swirled off to the east (Cody, 2003). Prior to the eruption, S721 was a turbid muddy pool with a water level about 0.7 m below ground surface and at 48-63° C with a pH range of 2.8-4.7 (Cody, 2003). Note the following:

1. The strongly directed blast of the eruption, inclined at about 70° to the east, „aimed" at the hospital. The ejected material may have been „propelled" up an inferred sloping fault plane between the park and the hospital rhyolite dome (Cody, 2001).

2. The strongly bimodal clast size of the ejecta, consisting of dark grey to dark brown fine mud (fine-ash size), and large blocks (>64 mm in diameter) consisting mainly of Oruanui Ignimbrite (of the Kawakawa/Oruanui eruption c. 27,100 cal yr BP), containing spherical accretionary lapilli, derived from 10–20 m beneath the mud pools. Most of these blocks have now disintegrated.

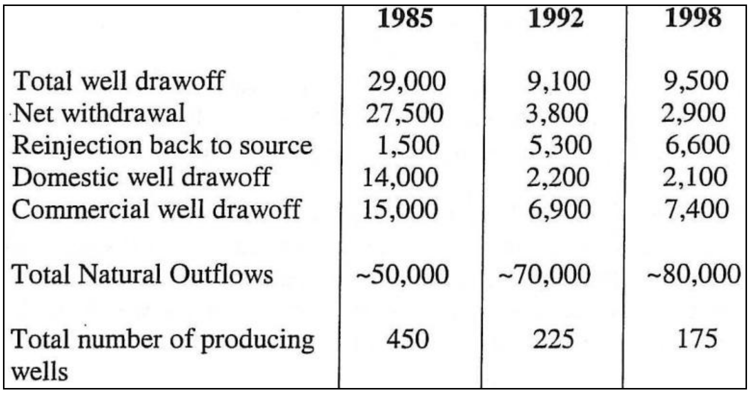
3. The damage to the trees because of the weight of wet mud.

Kuirau Park and adjacent Ohinemutu hot springs on the shores of Lake Rotorua became notably more active from 1989 with hot and boiling outflows resuming from long dormant, cooler and non-flowing springs. This activity has taken place since well/bore closures in 1987 (see below) and since the re-injection of well waste waters. For example, in June 2001, a collapse hole (now filled with warm water) appeared in the cricket pitch (see Cody, 2001). Two further hydrothermal eruptions occurred close to S721 in Kuirau Park on 6 November 2003, and another occurred at Ohinemutu on 17 March 2005 (Cody and Scott, 2005).

Geothermal fields and the 'bore war'

Geothermal fields in the TVZ provided a hot-water supply for cooking, bathing, and medical treatment for early Maori. In 1859, German geologist Ferdinand Hochstetter described separate springs for bathing, cooking and laundry, and vapour baths and winter huts that had been built on the warm sinter terraces in the Rotorua area. Especially in winter, the baths were communal meeting places. A medical officer was appointed in Rotorua in 1882. A bathhouse opened the same year, and a sanatorium in 1886. In 1902 Englishman Arthur S. Wohlmann became superintendent of the sanatorium (McKinnon, 2007). He was also publicist for the spa and the government balneologist (an expert on medicinal springs). Wohlmann oversaw the building of the Bath House in Government Gardens, which opened in 1908. In 1914 the New Zealand Government published a book by Wohlmann, *The Mineral Waters and Spas of New Zealand*, which promoted numerous therapeutic benefits, imagined or otherwise, said to arise from bathing in thermal waters, an activity still central to tourism today. Tourism in Rotorua provided about 18% of all local employment in c. 2000 (Cody, 2001).

In Rotorua, the first hot water wells were drilled by hand-operated rigs during the 1920s (Cody, 2001). In the 1940s at least 70 wells were known, all in the northern and central part of the town‟s business district. In the mid-20th Century, drilling in Rotorua was free of any control and hence large quantities of hot water were taken and disposed of into groundwaters. A serious post-war electricity shortage in the 1950s led to more wells being drilled to heat homes and domestic water. In the 1970s, increases in oil costs led to another period of well drilling, and around 450 wells were recorded in 1985 (see table below). Natural heat flows between 1967 and 1985 dropped by ~30% because of the increased drawoff by commercial and domestic users, and some hot spring activity diminished or ceased – for example, the Tarewa group of springs on the western side of Kuirau Park ceased activity in November 1981 (they resumed boiling in March 1998) (Cody, 2001).



	1985	1992	1998
Total well drawoff	29,000	9,100	9,500
Net withdrawal	27,500	3,800	2,900
Reinjection back to source	1,500	5,300	6,600
Domestic well drawoff	14,000	2,200	2,100
Commercial well drawoff	15,000	6,900	7,400
Total Natural Outflows	~50,000	~70,000	~80,000
Total number of producing wells	450	225	175

Summary of well numbers and mass withdrawals in tonnes per day since 1985 in Rotorua (from Cody, 2001)

Before 1886, around 130 geysers were regularly active in five major fields in the Rotorua-Taupo area but the Tarawera eruption (1886), a dam at Orakeikorako, and the geothermal power projects reduced geysers to barely a dozen. The Wairakei geothermal power station began providing energy on completion in 1958, and a second geothermal station was finished at Ohaaki (Broadlands) in 1989. Together Wairakei and Okaaki provide about 5% of New Zealand‟s energy needs. To preserve the last geysers at Whakarewarewa in Rotorua, the central Government, acting primarily on the advice of geophysicist Ron Keam and geologist Ted Lloyd, launched the „Bore War‟ in 1987 by closing down many private bores despite „heated‟ opposition from many Rotorua citizens. Within three years, substantially fewer wells were operating, and the geysers were saved. Vilified at the time of the bore closures, Keam and Lloyd in 2002 were awarded Science and Technology Silver Medals by the Royal Society of New Zealand for their foresight and courage. Since 1991, the Rotorua Geothermal Field has operated, uniquely, under a legally constituted management plan aimed at reversing the effects of the previously encouraged well drawoff and use of hot water. The objectives are to protect the natural surface geothermal activity and to help sustain local tourism (Cody, 2001). As well as human impacts, natural events are also recognised as important in governing the level of geothermal activity, and include unusual rainfall intensities or shortages, earthquakes, and ground cementation by sinter or sulphur (Cody, 2001).

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4.12 Transit from Rotorua (Stop 4) to Tapapa (Stop 5)

General model for landscape development of southern Mamaku Plateau

- involves emplacement and erosion of ignimbrites and application of tephrochronology for age control (from Hill et al., 1999).

A REVISED SOIL STRATIGRAPHIC INTERPRETATION OF THE GEOMORPHOLOGY AND LATE QUATERNARY EROSION HISTORY OF THE SOUTHERN MAMAKU PLATEAU.

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The Mamaku Plateau is located on the northern edge of the Taupo Volcanic Zone, east of Tokoroa in the central North Island. It rises from 200 mASL along its western margin to 700 mASL in the south east. The southern Mamaku Plateau consists of five superimposed late Quaternary ignimbrites (Lynch-Blosse, 1998) with the Mamaku Ignimbrite (220±10 ka) and the Whakamaru Ignimbrite (320±20 ka) being the uppermost and lowermost exposed. Deposition of thick ignimbrite units in valleys and thin units on interfluves has resulted in inversion of relief. Four episodes of strath cutting and valley incision into ignimbrite are recognised from the sequence of overlying loess and tephra cover beds. Valley widening occurs by processes such as toppling (Bakker, 1997). The basal loess and/or tephra on the erosion surfaces denoting the cessation of each episode of strath cutting and valley incision are; (a) pre Rotoehu loess, (b) pre KawaKawa loess, (c) Rotorua Tephra, and (d) Taupo Ignimbrite. The distribution of the coverbed soil stratigraphic units have been mapped in relation to the different land components within the southern Mamaku Plateau.

The four episodes of strath cutting and valley incision can be synthesised into five topographically recognised stages of landform evolution. Stage 1 occurs in the softer upper and welded middle parts of the Mamaku Ignimbrite where erosion episodes (a) and (c) are recognised. Stage 2 represents valley incision through the welded Pokai Ignimbrite unit, forming vertical free-faces, and extends into the underlying less welded Pokai and Waihou ignimbrites. Erosion episodes (c) and (d) are recognised. Stages 3 and 4 are characterised by incision and widening of valleys into the Waihou, Waimakariri and Whakamaru ignimbrites. A thin capping of Mamaku ignimbrite and Pokai ignimbrite occurs on the interfluves between the valleys. Stages 3 and 4 are distinguished by plannar and convex interfluves respectively. Erosion episodes (a), (b), (c) and (d) are recognised. In Stage 5 the removal of the capping Pokai Ignimbrite has resulted in a concavo-convex hilly topography in the underlying Waihou and Waimakariri ignimbrites. Erosion episodes (a), (b), (c) and (d) are recognised. The erosion history of the Mamaku Plateau prior to the deposition of the pre Rotoehu loess can not be inferred.

This study provided a stratification of the soil landscape to be used for the effective application of site specific forest management practices in the 35 000 ha of Kinleith Forest on the southern Mamaku Plateau. The coverbed stratigraphy together with its soil stratigraphic interpretation and soil landform relationships have been used to map nine land systems.

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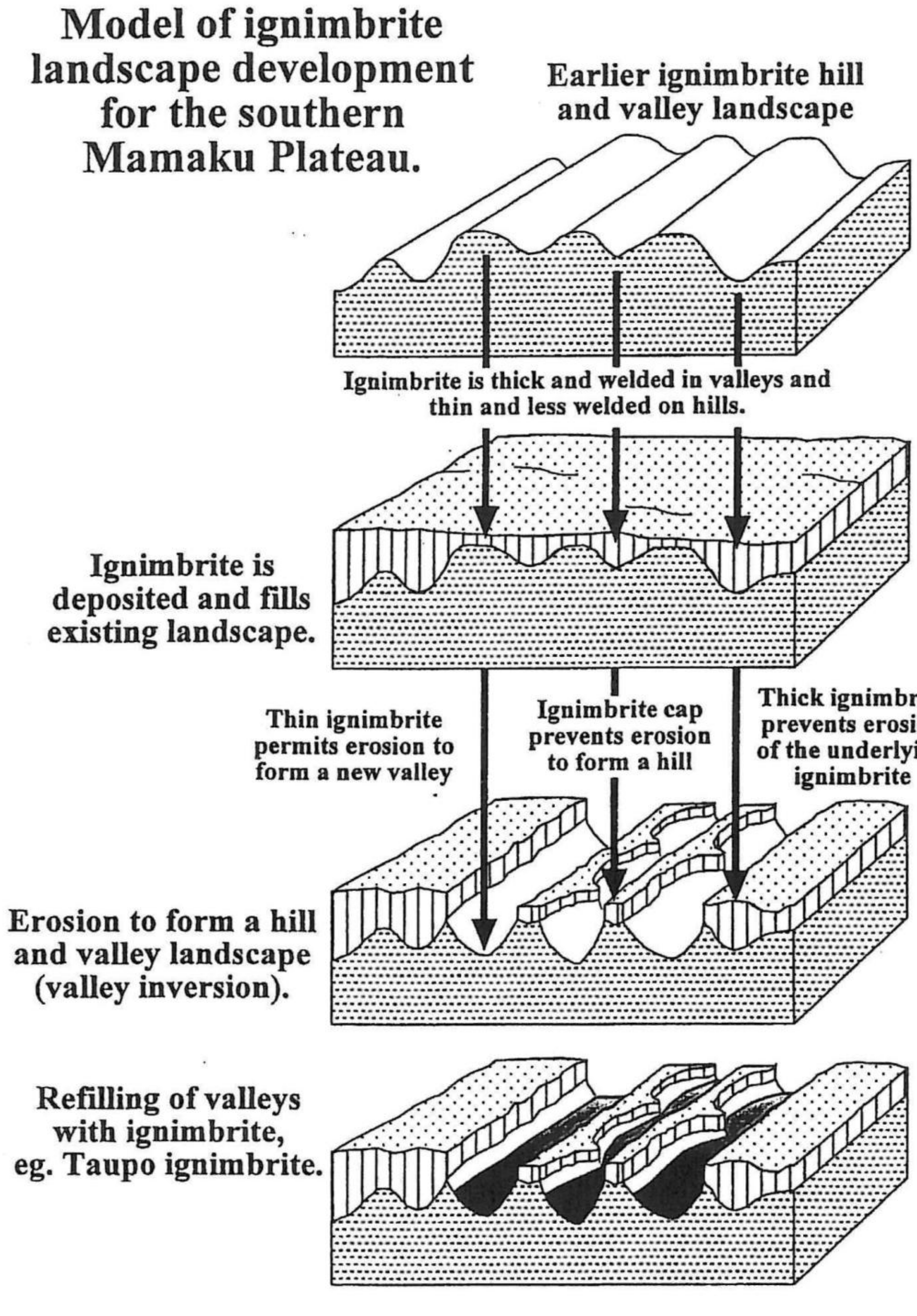
(see also reference next page)



Model of ignimbrite landscape development, southern Mamaku Plateau (from Hill et al., 1999). The plateau surface is mantled with tephras and loess of varying thickness and age, with pre-c. 15 cal. ka deposits missing (eroded) from uppermost parts of the plateau. Modern soils include Spodosols developed in Taupo Ignimbrite where it is present (Tihoi soils) and on older Holocene tephra beds elswhere (Mamaku soils). Palmer et al. (2005) demonstrated that plantation forestry on Tihoi soils was essentially sustainable from a nutrient viewpoint.

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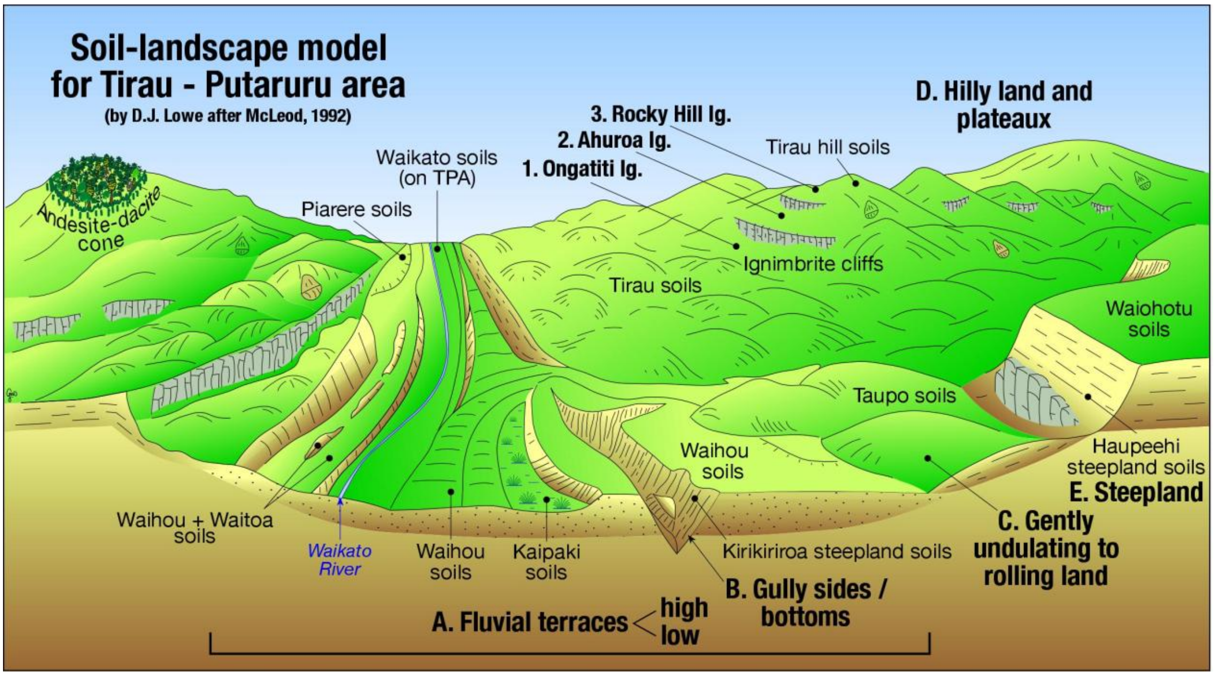


Soil-landscape model for the Tirau-Putarura area and Tapapa (Stop 5). The three main welded ignimbrite units (~1.23 Ma to 0.9 Ma) form distinctive plateaux in the landscape and are mantled with tephra-fall deposits and subordinate tephric loess. Fluvial terraces are also mantled with tephras. TPA, Taupo Pumice Alluvium (c. 250 AD). Diagram by D.J. Lowe after McLeod (1992a). Aspects of the stratigraphy, geomorphology, and soils of the Mamaku Plateau area include study by Benny et al. (1988), Bakker (1997), Macky (1997), Lynch-Blosse (1998), Hill (1999), Palmer (2002), and Palmer et al. (2005). Note that the **nine-unit landscape model** *was developed near this area by Dalrymple et al. (1968) (M.J. Selby pers comm., 1973).*

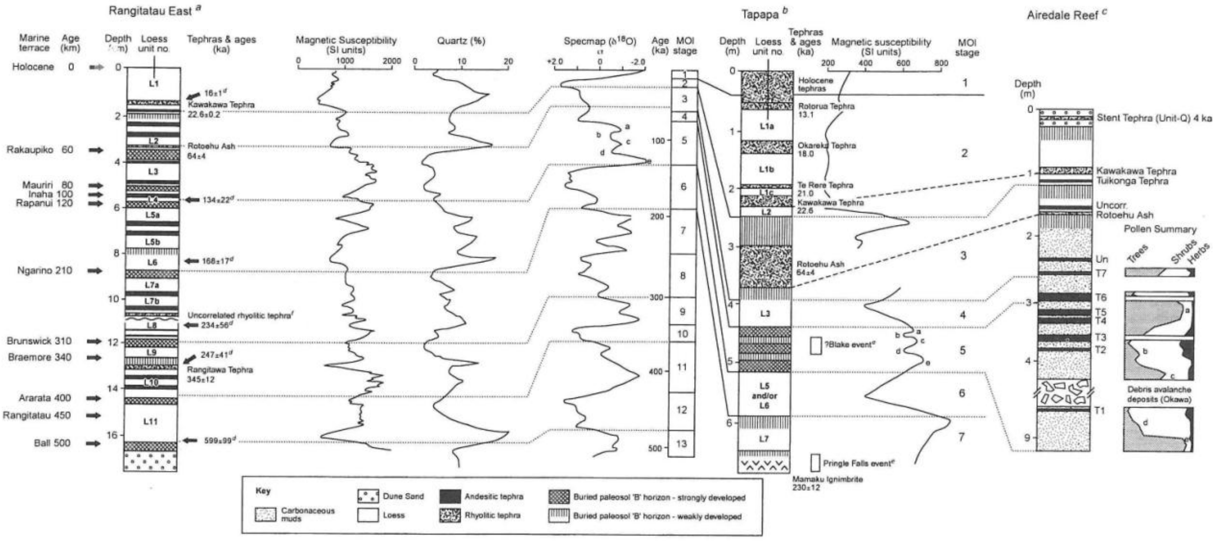
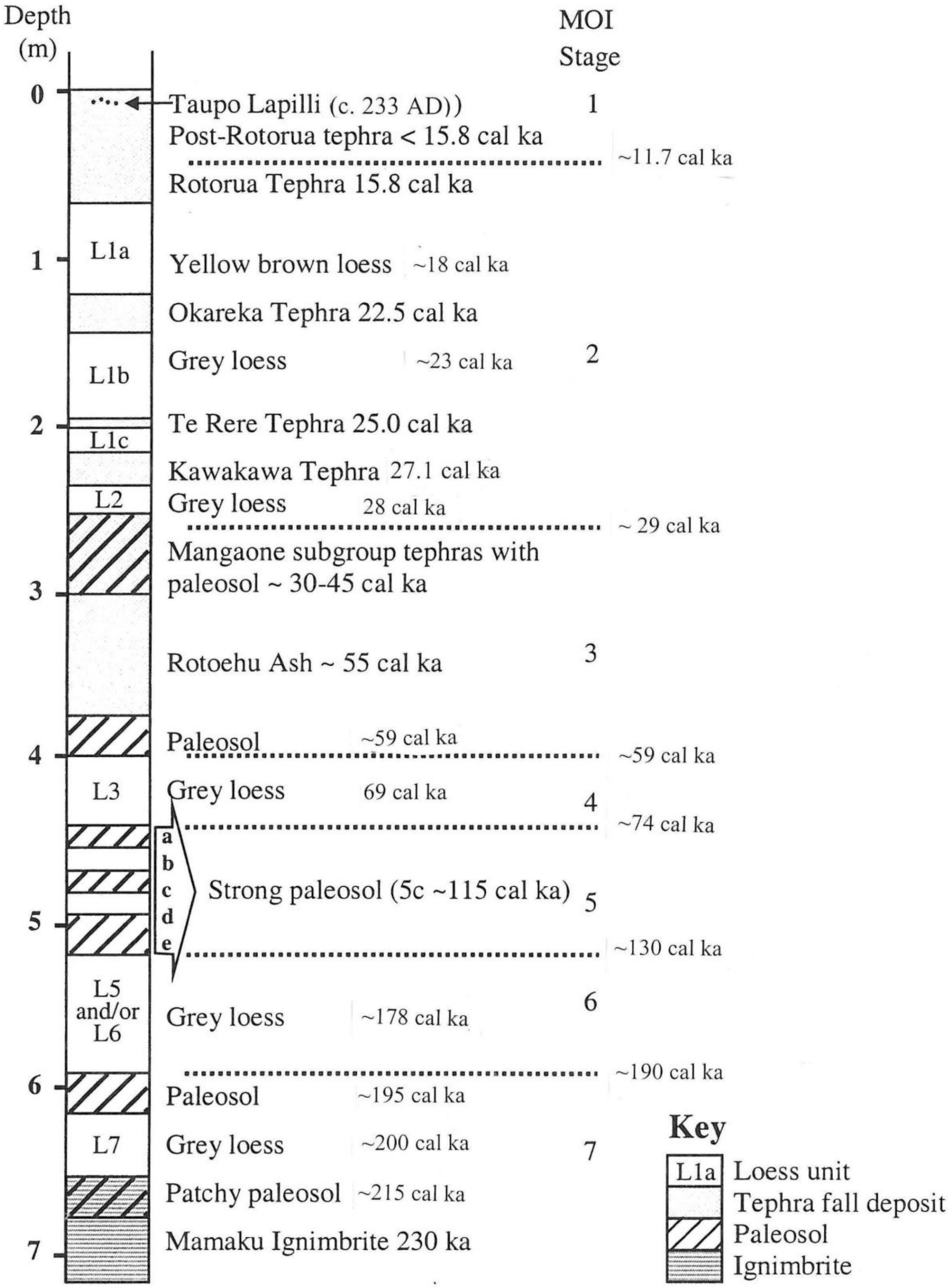


Figure 4 Records of climatic fluctuations at three terrestrial sites in North Island that date back to *c.* 500 ka, based on analyses of tephra-bearing loess deposits, associated palaeosols and palynology. The sections provide different levels of information for various time slices: (a) Rangitatau East section is near Wanganui (after Palmer and Pillans, 1996); (b) Tapapa section is on western Mamaku Plateau (after Kimber *et al.*, 1994; Shane *et al.*, 1994; Lowe and Begét, unpublished data); (c) Airedale Reef section is near New Plymouth, Taranaki (after Newnham and Alloway, 1999); (d) TL ages (after Palmer and Pillans, 1996); (e) magnetic reversals are possibly equivalent to the Blake event (Froggatt, 1988; Lyons, 1996) and the Pringle Falls event (Shane *et al.*, 1994); (f) this uncorrelated rhyolitic tephra occupies the same stratigraphic juxtaposition as the Mamaku Ignimbrite and hence may be a correlative

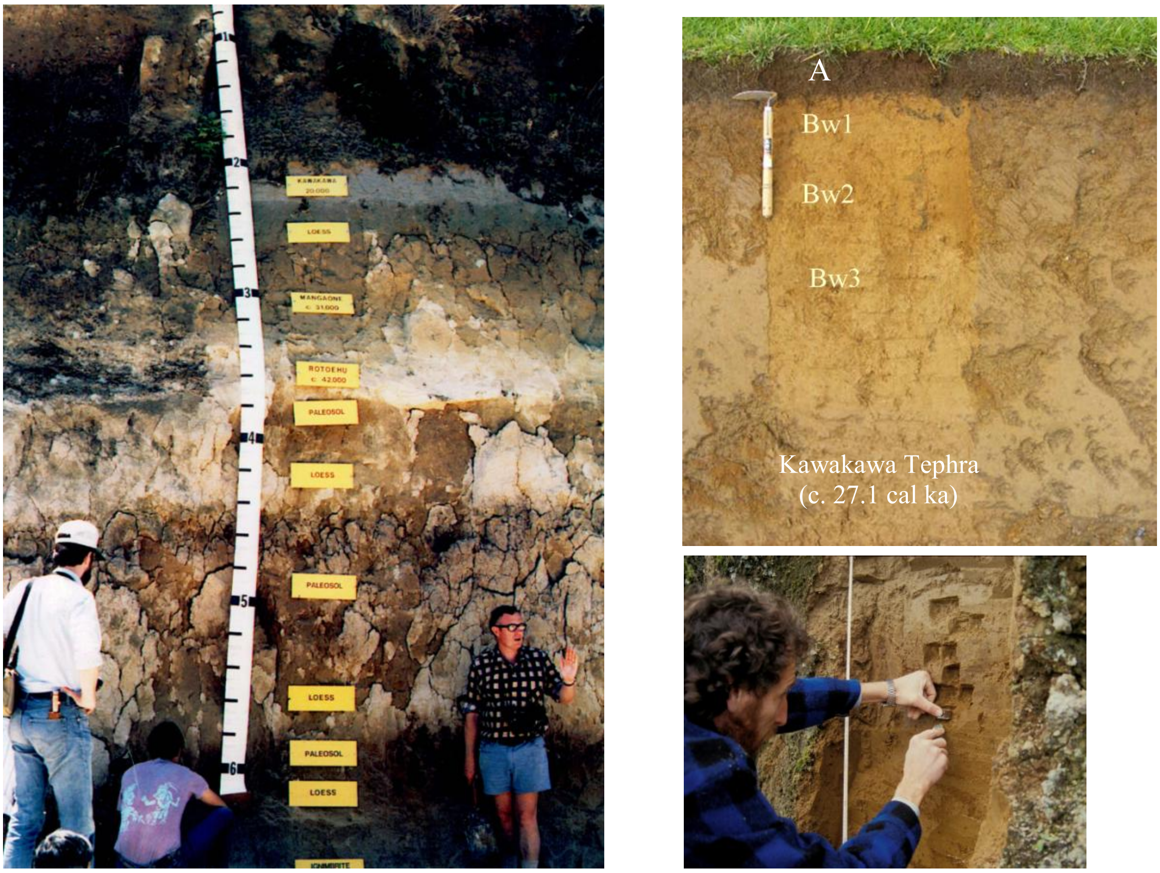
(Above) Correlation of Tapapa section (Stop 5) with Rangitatau East section near Wanganui and Airdale Reef section near New Plymout, and MOI stages (from Newnham et al., 1999).

4.13 Stop 5 – Tirau silt loam, Goodwin Farm, Tapapa Rd

Location T15 635524, elevation 260 m asl, rainfall ~1600 mm pa

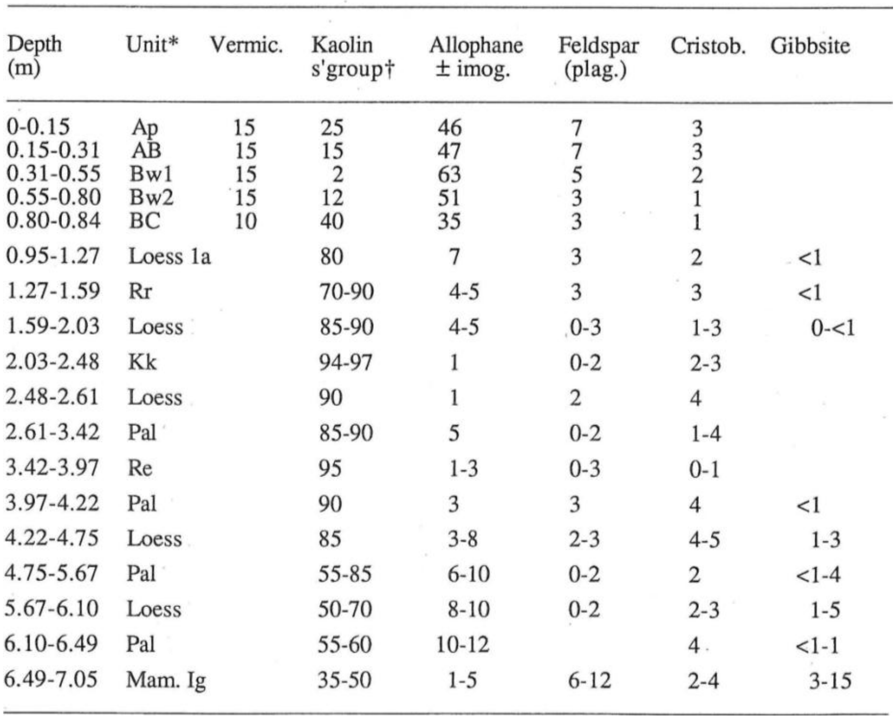


Stratigraphy and chronology of Tapapa sequence and correlation with marine oxygen isotope (MOI) stages (based mainly on Kimber et al., 1994; Lowe and Briggs, 1994; and unpublished age and palaeomagnetic data of D.J. Lowe, J.E. Begét, J.D. Green and B.J. Pillans; see also Froggatt, 1988, and Shane et al., 1994). RotoehuAsh has been most recently dated at c. 61 ka (Wilson et al., 2007).

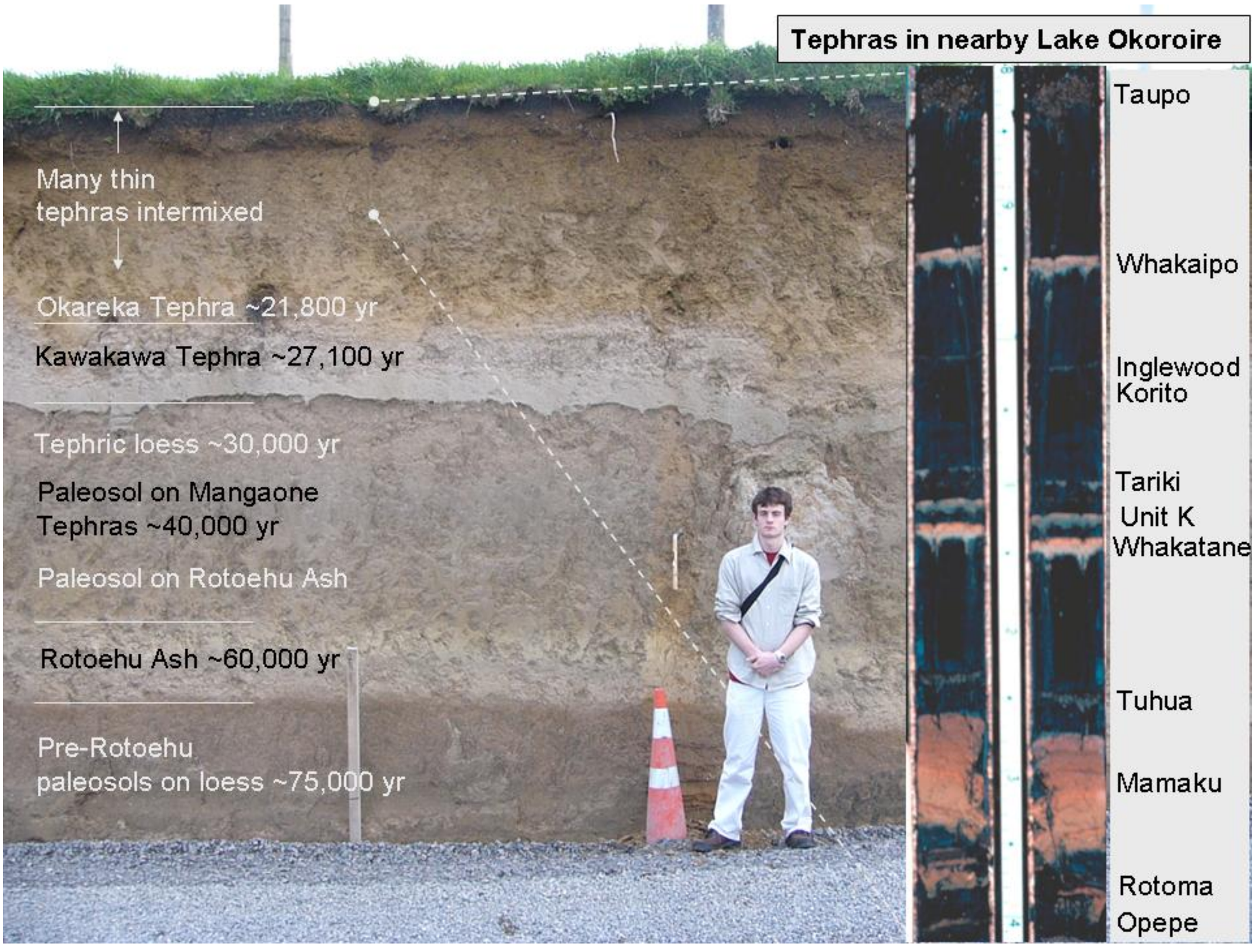


(Left) Main part of Tapapa section as it was in February, 1987 (Derek Milne doing the talking). Grey layer near ~2 m depth mark is Kawakawa/Oruanui tephra. It is primary ash but slightly weathered and hence cohesive. The gritty layer at the base of Kawakawa/Oruanui tephra is mostly unit 7 (Wilson, 2001); accretionary lapilli are often most visible on the top contact of that layer (C.J.N. Wilson pers. comm., 2008). (Top right) Tirau silt loam. (Above) Brad Pillans (ANU) sampling at Tapapa to undertake palaeomagnetic analysis (June 1996). Photos: David Lowe

Mineralogy (%) of clay fractions (<2 µm) of Tapapa materials (from Lowe and Percival, 1993, after D.N. Eden unpublished data, 1993). Halloysite dominates the kaolin subgroup minerals.

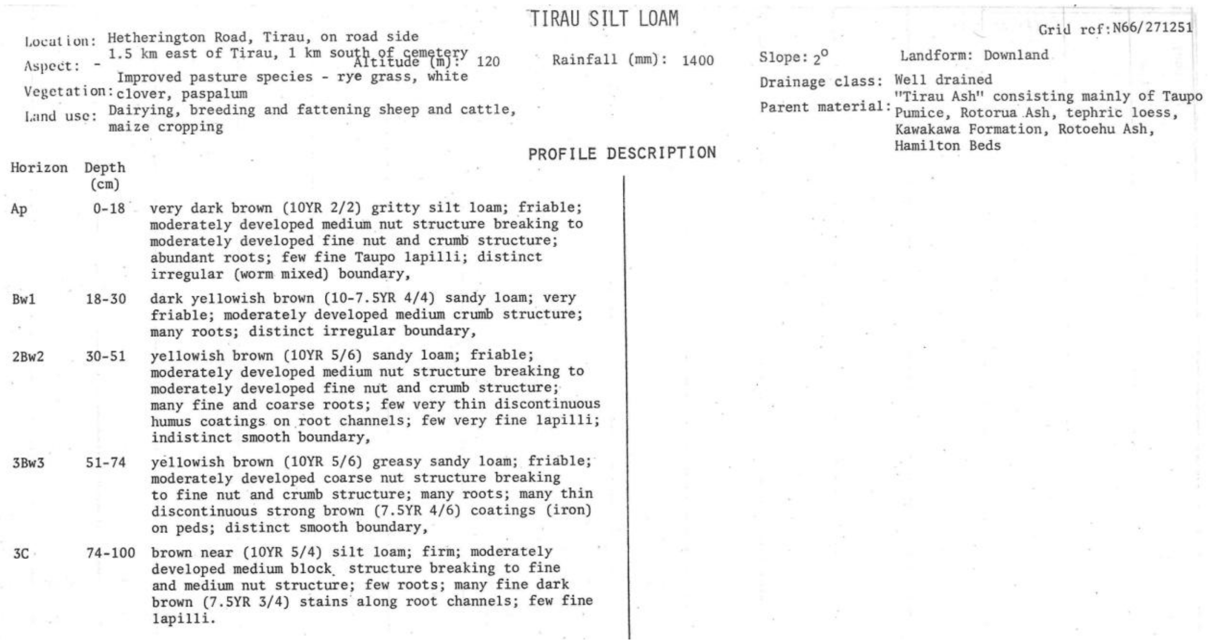


Depth (m)	Unit*	Vermic.	Kaolin s'group†	Allophane ± imog.	Feldspar (plag.)	Cristob.	Gibbsite
0-0.15	Ap	15	25	46	7	3	
0.15-0.31	AB	15	15	47	7	3	
0.31-0.55	Bw1	15	2	63	5	2	
0.55-0.80	Bw2	15	12	51	3	1	
0.80-0.84	BC	10	40	35	3	1	
0.95-1.27	Loess 1a		80	7	3	2	<1
1.27-1.59	Rr		70-90	4-5	3	3	<1
1.59-2.03	Loess		85-90	4-5	0-3	1-3	0-<1
2.03-2.48	Kk		94-97	1	0-2	2-3	
2.48-2.61	Loess		90	1	2	4	
2.61-3.42	Pal		85-90	5	0-2	1-4	
3.42-3.97	Re		95	1-3	0-3	0-1	
3.97-4.22	Pal		90	3	3	4	<1
4.22-4.75	Loess		85	3-8	2-3	4-5	1-3
4.75-5.67	Pal		55-85	6-10	0-2	2	<1-4
5.67-6.10	Loess		50-70	8-10	0-2	2-3	1-5
6.10-6.49	Pal		55-60	10-12		4	<1-1
6.49-7.05	Mam. Ig		35-50	1-5	6-12	2-4	3-15



Section on Leslie Rd (~5 km SW of Tapapa) showing stratigraphy for <c. 80-ka part of sequence and illustrating the composite nature of the Tirau silt loam (upper 1-2 m of section) based on the identification of likely contributing Holocene tephra layers present in cores taken from c. 20-cal ka Lake Okoroire. Photos: David Lowe

Lake Okoroire is about 10 km NW of Tapapa, ~12 km NW of Leslie Rd) (see also Pullar and Birrell, 1973). The lake stratigraphy was recorded by Lowe (1988). Photo: David Lowe



TIRAU SILT LOAM

Grid ref: N66/271251

Location: Hetherington Road, Tirau, on road side 1.5 km east of Tirau, 1 km south of cemetery
Aspect: -
Altitude (m): 120
Rainfall (mm): 1400
Slope: 2°
Landform: Downland
Vegetation: Improved pasture species - rye grass, white clover, paspalum
Drainage class: Well drained
Land use: Dairying, breeding and fattening sheep and cattle, maize cropping
Parent material: "Tirau Ash" consisting mainly of Taupo Pumice, Rotorua Ash, tephric loess, Kawakawa Formation, Rotoehu Ash, Hamilton Beds

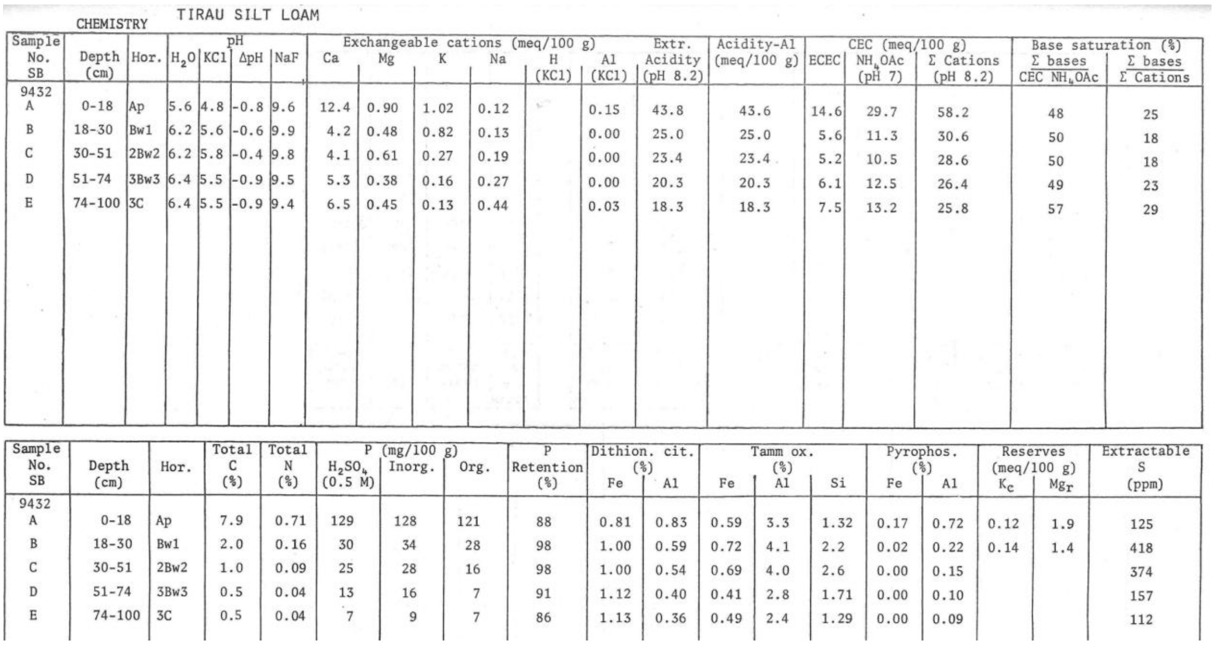
PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-18	very dark brown (10YR 2/2) gritty silt loam; friable; moderately developed medium nut structure breaking to moderately developed fine nut and crumb structure; abundant roots; few fine Taupo lapilli; distinct irregular (worm mixed) boundary,
Bw1	18-30	dark yellowish brown (10-7.5YR 4/4) sandy loam; very friable; moderately developed medium crumb structure; many roots; distinct irregular boundary,
2Bw2	30-51	yellowish brown (10YR 5/6) sandy loam; friable; moderately developed medium nut structure breaking to moderately developed fine nut and crumb structure; many fine and coarse roots; few very thin discontinuous humus coatings on root channels; few very fine lapilli; indistinct smooth boundary,
3Bw3	51-74	yellowish brown (10YR 5/6) greasy sandy loam; friable; moderately developed coarse nut structure breaking to fine nut and crumb structure; many roots; many thin discontinuous strong brown (7.5YR 4/6) coatings (iron) on peds; distinct smooth boundary,
3C	74-100	brown near (10YR 5/4) silt loam; firm; moderately developed medium block structure breaking to fine and medium nut structure; few roots; many fine dark brown (7.5YR 3/4) stains along root channels; few fine lapilli.

Description of Tirau soil at Hetherington Rd, near Tirau (T15/546556) (~18 km from Tapapa) from Parfitt et al. (1981) (see also Bakker et al., 1996). At Tapapa the soil was mapped by McLeod (1992a) as part of the Tirau series, which occur on rolling land grading to higher terraces (elevational range 70-400 m) and with a thermic temperature regime. However, Tirau soils have very similar parent materials to soils of the Waiohotu series that occur at usually higher elevations on high-level terraces (plateau surfaces, elevational range 250-500 m) under higher rainfall (Waiohotu 2000-2400 mm pa, Tirau 1400-2000 mm pa) and mesic temperature regimes (see diagram of soil-landscape model). The Waiohotu soils have slightly coarser textures (gritty silt loams vs silt loams), lower pHs (Waiohotu 4.5-5.9, Tirau 5.6-6.4), greater leaching, and until recently have not normally been used for maize production (M. McLeod pers. comm., 2008). Tapapa is at the thermic/mesic boundary (Aldridge, 1982).

Classification: Tirau silt loam

NZSC: Typic Orthic Allophanic Soils; tephric, mixed rhyolitic and andesitic; silty/loamy; moderate
Soil Taxonomy: Medial, thermic/mesic Typic Hapludands



CHEMISTRY TIRAU SILT LOAM

Sample No. SB	Depth (cm)	Hor.	pH				Exchangeable cations (meq/100 g)						Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g)		Base saturation (%)	
			H_2O	KCl	ΔpH	NaF	Ca	Mg	K	Na	H (KCl)	Al (KCl)				NH_4OAc (pH 7)	Σ Cations (pH 8.2)	$\frac{\Sigma \text{ bases}}{\text{CEC } NH_4OAc}$	$\frac{\Sigma \text{ bases}}{\Sigma \text{ Cations}}$
9432																			
A	0-18	Ap	5.6	4.8	-0.8	9.6	12.4	0.90	1.02	0.12		0.15	43.8	43.6	14.6	29.7	58.2	48	25
B	18-30	Bw1	6.2	5.6	-0.6	9.9	4.2	0.48	0.82	0.13		0.00	25.0	25.0	5.6	11.3	30.6	50	18
C	30-51	2Bw2	6.2	5.8	-0.4	9.8	4.1	0.61	0.27	0.19		0.00	23.4	23.4	5.2	10.5	28.6	50	18
D	51-74	3Bw3	6.4	5.5	-0.9	9.5	5.3	0.38	0.16	0.27		0.00	20.3	20.3	6.1	12.5	26.4	49	23
E	74-100	3C	6.4	5.5	-0.9	9.4	6.5	0.45	0.13	0.44		0.03	18.3	18.3	7.5	13.2	25.8	57	29

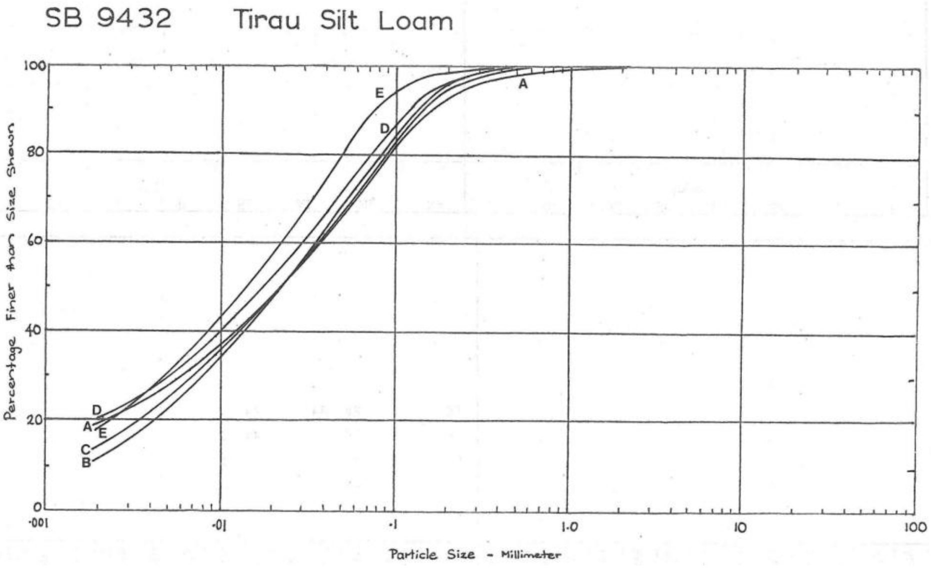
Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g)			P Retention (%)	Dithion. cit. (%)		Tamm ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)
					H_2SO_4 (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K_c	Mg_r	
9432																		
A	0-18	Ap	7.9	0.71	129	128	121	88	0.81	0.83	0.59	3.3	1.32	0.17	0.72	0.12	1.9	125
B	18-30	Bw1	2.0	0.16	30	34	28	98	1.00	0.59	0.72	4.1	2.2	0.02	0.22	0.14	1.4	418
C	30-51	2Bw2	1.0	0.09	25	28	16	98	1.00	0.54	0.69	4.0	2.6	0.00	0.15			374
D	51-74	3Bw3	0.5	0.04	13	16	7	91	1.12	0.40	0.41	2.8	1.71	0.00	0.10			157
E	74-100	3C	0.5	0.04	7	9	7	86	1.13	0.36	0.49	2.4	1.29	0.00	0.09			112

PHYSICS

Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	15 bar water Air Dry (%)	Core Depth (cm)	Dry bulk density (T/m³)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
0-18	Ap	31.1	23.3	2-9	0.75					
18-30	Bw1	33.7	15.7	20-27	0.71					
30-51	2Bw2	33.6	16.5	34-41	0.69					
51-74	3Bw3	34.7	22.0	58-65	0.79					
74-100	3C	33.9	20.4	80-87	0.87					

PARTICLE SIZE DISTRIBUTION (<2 mm) TIRAU SILT LOAM

Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9432A	0-18	Ap	18	17	46	19			
B	18-30	Bw1	17	16	56	11			
C	30-51	2Bw2	17	16	54	13			
D	51-74	3Bw3	14	16	50	20			
E	74-100	3C	6	14	62	18			

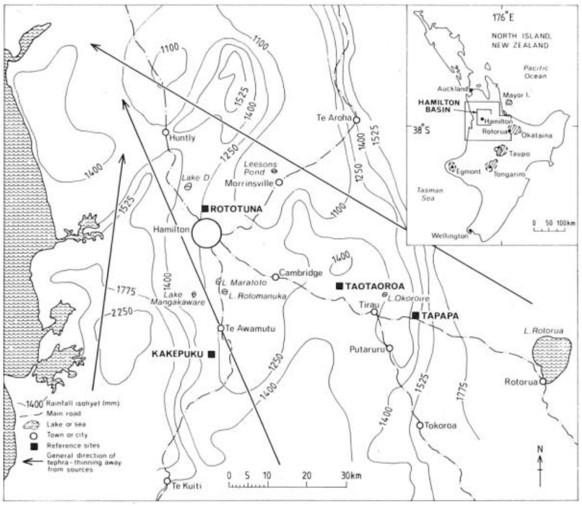


Mineralogy TIRAU

Sample No. SB	Depth (cm)	Hor.	Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass
			Clay Fraction (%)														
9432A	0-18									8				65			27
B	18-30									6				75			19
C	30-51									4				80			16
D	51-74									9	tr			55			36
E	74-100									21	tr		tr	48			31

Contributions of rhyolitic vs andesitic tephra fallout over the region

Map (below left) shows locations of four tephra-soil sequences (including Tapapa) in the Waikato region and the relative andesitic vs rhyolitic character of samples from each based on three lines of evidence: (1) ferromagnesian mineral assemblages (ternary diagram below right); (2) V/Mn ratios of titanomagnetites; and (3) comparative thicknesseses of rhyolitic vs andestic tephras identified using glass compositions in lake cores nearest the sections (diagram at bottom of page) (after Lowe, 1986). All sites contain both rhyolitic and andesitic components: the most rhyolitic site is at Tapapa (~95% rhyolitic), and the least rhyolitic is at Kakepuku (~55% rhyolitic). The proportion of subordinate andesitic material increases towards the southwes (see Lowe, 1989).



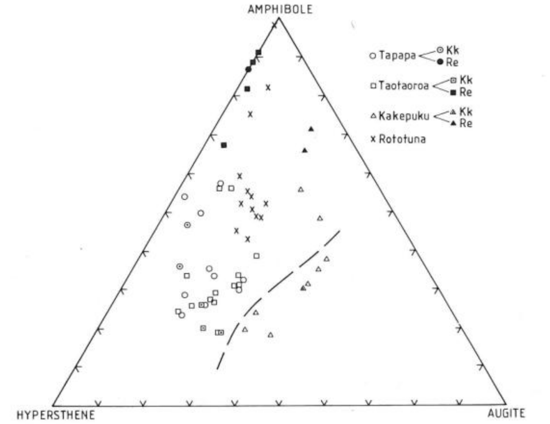
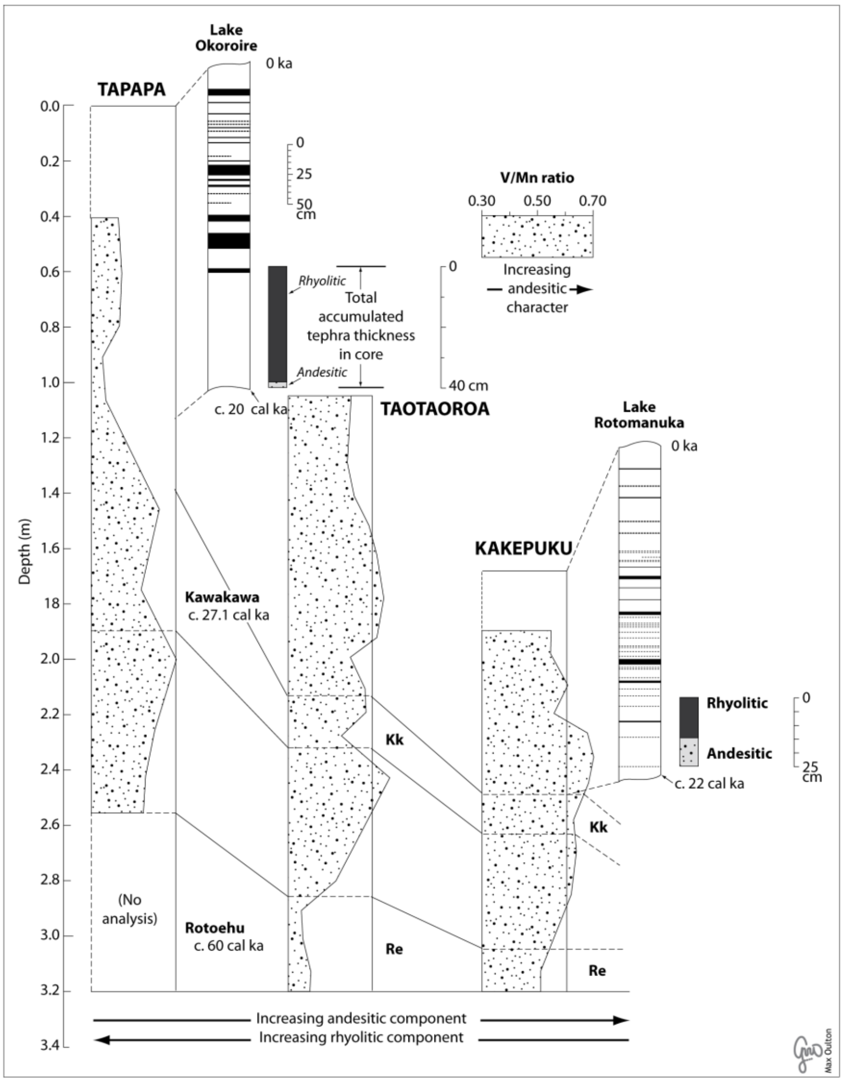


FIG. 7. Ternary diagram showing relative abundances of amphibole (calcic and basaltic hornblende, cummingtonite), augite (clinopyroxene), and hypersthene (orthopyroxene) in the heavy mineral assemblages of the 2–4ϕ (250–63 μm) size fractions (summed to 100%) in the samples from the four reference sites. The diagram illustrates that the Kakepuku site (with highest proportions of augite) has a greater component of andesitic tephras than the other sites, particularly in the post-Kawakawa Tephra deposits (separated by the dashed line) (cf. Fig. 8).



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