

# ASHES AND ISSUES



**GUIDEBOOK FOR PRE-CONFERENCE  
NORTH ISLAND FIELD TRIP  
'ASHES AND ISSUES'  
28<sup>TH</sup>–30<sup>TH</sup> NOVEMBER, 2008**

***SOILS 2008* AUSTRALIAN AND NEW ZEALAND  
4<sup>TH</sup> JOINT SOILS CONFERENCE  
MASSEY UNIVERSITY, PALMERSTON NORTH  
1–5 DECEMBER, 2008**





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**NEW ZEALAND SOCIETY OF SOIL SCIENCE  
AUSTRALIAN SOCIETY OF SOIL SCIENCE  
4<sup>TH</sup> JOINT SOILS CONFERENCE, PALMERSTON NORTH  
1-5 DECEMBER, 2008**

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by

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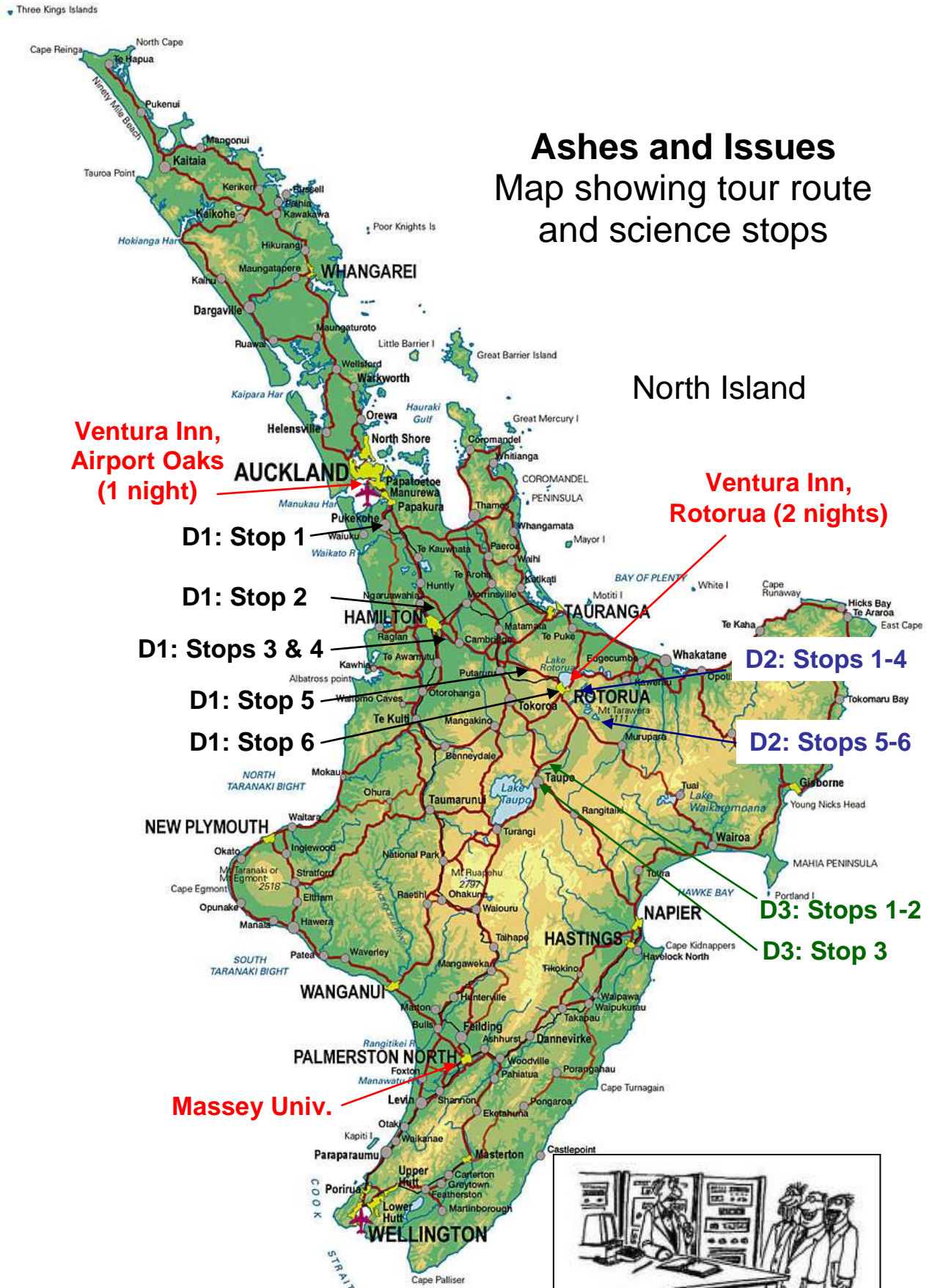
**Note**

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**Photo front cover**

Quaternary sequence of tephra and buried soils on Gordonton Rd near Hamilton. Very dark reddish-brown buried soil horizon (~1 Ma) at middle left is overlain directly by white Rangitawa Tephra (c. 350 ka) and succession of strongly weathered tephra beds and buried soil horizons (c. 350–100 ka). Thin composite cover bed at top comprises Rotoehu Ash (c. 60 cal ka) and multiple intermixed younger tephra. Modern soil is the 'two-storied' Kainui silt loam, an Aquic Kandiodult in *Soil Taxonomy* and a 'Buried-granular' Yellow Ultic Soil in NZSC (Stop 2, Day 1). Predominant clay mineral is halloysite.

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# Ashes and Issues

## Map showing tour route and science stops

North Island

Ventura Inn,  
Airport Oaks  
(1 night)

Ventura Inn,  
Rotorua (2 nights)

D1: Stop 1

D1: Stop 2

D1: Stops 3 & 4

D1: Stop 5

D1: Stop 6

D2: Stops 1-4

D2: Stops 5-6

D3: Stops 1-2

D3: Stop 3

Massey Univ.



## Itinerary in brief

### Day 1 (Fri 28<sup>th</sup> Nov): Auckland to Rotorua

8.00 am Depart Ventura Inn, Airport Oaks  
 Morning: Scientific stops 1-2  
 Lunch: Academy of Performing Arts, Univ. of Waikato, Hamilton  
 Afternoon: Scientific stops 3-6  
 6.30 pm Arrive Rotorua  
 Accommodation at Ventura Inn, Rotorua  
 7.30 pm Meal at Valentines Buffet Restaurant  
 Evening free

### Day 2 (Sat 29<sup>th</sup> Nov): Rotorua to Rotorua

8.00 am Depart Ventura Inn, Rotorua  
 Morning: Scientific stops 1-4  
 Lunch: Rerewhakaaitu Hall, Rerewhakaaitu  
 Afternoon: Scientific stops 5-6  
 5.30 pm Arrive Rotorua  
 Accommodation at Ventura Inn, Rotorua  
 7.00–9.00 pm Meal and Maori concert, Rydges Hotel

### Day 3 (Sun 30<sup>th</sup> Nov): Rotorua to Palmerston North

8.00 am Depart Ventura Inn, Rotorua  
 Morning: Scientific stops 1-3  
 Lunch: Aratiatia  
 Afternoon: Break at Taupo gardens, Taupo; no scientific stops  
 6.00 pm Arrive Palmerston North  
 6.00–7.15 pm Meal and refreshments (ice breaker) at ‘Wharerata’, Massey University  
 7.15 pm Transported to accommodation

## Acknowledgements

Numerous people have contributed in various ways to this tour: planning, providing information, providing services, speaking at various stops, and supporting or co-leading. I am very appreciative of your help – thank you. *David J. Lowe* (ed).

Haydon Jones (Scion)	Jan Weston (Landcorp Pastoral, Reporoa)
Paul McDaniel (Univ. of Idaho)	Mac Pacey (Farmer, Lake Rerewhakaaitu)
Peter Singleton (Environment Waikato)	Barry and Jan Goodwin (Farmers, Tapapa, Mamaku Plateau)
Monty Spencer (Wilcox Group)	Penny MacCormick, John Paterson (Environment BOP)
Louis Schipper (Univ. of Waikato)	Brent Green (Asarco Exploration, Perth)
Gerty Gielen (Scion)	Sarah Siebert, Vince Neall (Massey Univ.)
Peter Beets (Scion)	Colin Wilson (Univ. of Auckland)
Deniz Özkundakci (Univ. of Waikato)	Richard Chapman (Soil and Land Evaluation)
Chris Sutton (Farmer, Project Rerewhakaaitu)	Chris McKinnon, Annette Rodgers (Univ. of Waikato)
Chris McLay (Environment Waikato)	John Flynn (Grower/historian, Pukekohe)
Alan Bullick (Landcorp Pastoral, Reporoa)	Frank and Ken Balle (Growers, Pukekohe)
Aaron Karaka (Landcorp Pastoral, Reporoa)	Roger Briggs, Geraldine Cook (Univ. of Waikato)
Craig Ross (Landcare Research)	Bob Stewart, Clel Wallace (Massey Univ.)
Les Basher (Landcare Research)	Liz Hastie (Rerewhakaaitu)
Gary Orbell (Consultant, formerly DSIR)	Willem Hoebbers (Farmer, Waikato)
Stephen Campbell (Landcare Research)	Graham Shepherd (Consultant, formerly Landcare Research)
Tim Charleson (Red Stag Timber)	Jo Horrocks (Min Civil Defence & Emergency Management)
Nick Kim, Matthew Taylor (Environment Waikato)	Richard Smith (Min Civil Defence & Emergency Management)
John McCraw (Emeritus Prof, Univ. of Waikato)	Rita Ram, Sharlene Herbig (Ventura Inn, Auckland & Rotorua)
Malcolm McLeod (Landcare Research)	Dave Palmer (Scion), Reece Hill (Environment Waikato)
Amy Taylor (ARC)	Andrew Rae (Victoria Univ. of Wellington)
Wim Rijkse (Consultant, formerly Landcare Res.)	Ashley Cody (Brisbane), Laura Gould (Elsevier)
Michael Chapman (Hydraulic Modelling Services)	Vincent Knipmeijer (Oranga Catering, Univ. of Waikato)
David Hamilton (Univ. of Waikato)	Debra Kiddie (Rydges Hotel, Rotorua)
Will Esler (Rotorua)	Kake Kautai (Valentines, Rotorua)
Joy Grove (National Library)	Ray Salter (Ministry of Tourism)
	Trevor Webb (Landcare Research, Lincoln)

## Preface

Welcome to New Zealand or Aotearoa – ‘Land of the long lingering day [twilight]’ – and to our three-day pre-conference North Island field trip ‘Ashes and Issues’. We trust your stay in New Zealand is both informative and friendly and there is something for everyone on the trip. The itinerary in brief and a map of the North Island showing the main scientific stops are shown above. At the time of guidebook preparation, we have a group of 23, including four students, on the tour with participants from Japan, Taiwan, USA, UK, Australia and New Zealand. The tour leaders are Prof David Lowe (Univ. of Waikato, Hamilton) and Dr Haydon Jones (Scion Research, Rotorua). Assistant leader is Prof Paul McDaniel (Univ. of Idaho, Moscow), on leave at the Univ. of Waikato July–December, 2008. We offer a warm welcome to you all. Because we have considerable distances to travel (especially Day 3), as well as a range of stops planned, we will need to leave the hotel at 8.00 am each day.

### Themes

Our route takes us progressively towards the locus of the most recently active volcanic centres in central North Island, and so the surficial tephra deposits and buried soil horizons generally become successively younger and less weathered towards the Rotorua and Taupo areas. We will see Ultisols, Andisols (including Vitrands), and Entisols, the oldest soil being possibly ~250,000 years and the youngest 122 years (although there is a twist in that the 122 year-old soil contains 20–30% clay). The oldest buried soil dates to ~1 Ma. Tephric loess will be seen at several stops. Concepts of upbuilding pedogenesis in tephra-mantled terrains will be discussed. Topical issues relating to soil and water quality and land management of intensive horticulture, pastoral farming (especially dairying), plantation forestry and C budgeting and modelling, and municipal effluent disposal by land treatment, will be considered as well. The declining quality of water in lakes in the Rotorua region and in Lake Taupo (mainly as a result of increasing N and P), and large-scale land-use conversions from plantation forestry to dairy farming in the Taupo area, and implications, are examined on days 2 and 3 of the trip.

### Weather and clothing

Late November is regarded typically as late spring in New Zealand. The weather can be rather unpredictable and range from very warm and sunny ( $>20^{\circ}\text{C}$ ) to cold ( $<10^{\circ}\text{C}$ ), windy, and wet, sometimes all on the same day! It is essential therefore that you are prepared for changeable conditions and so you must have 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. In Rotorua, the mean daily maximum temperature for November is  $19^{\circ}\text{C}$ ; the mean daily minimum is  $9.6^{\circ}\text{C}$ . There are 10 rain-days ( $\geq 1.0\text{ mm}$  rain) on average in Rotorua in November, and the city’s mean November rainfall is 102 mm (mean annual rainfall is 1401 mm). At some sites we will be ~290 m to ~450 m above sea-level and it can get quite cold around Lake Rerewhakaaitu (where we will spend the afternoon of Day 2) if a southerly wind gets up. Because conditions underfoot could be muddy or wet in places, appropriate footwear is essential – boots are recommended. In Rotorua, will walk several hundred metres along a road in a redwood forest, and about 80 m into a pine forest, but other than those excursions we will not be hiking any distance.

### Safety

At all times be careful when we are at roadside cuttings – participants especially from Taiwan and USA please look extra carefully before crossing the road. Each participant will be issued with an orange Hi-Vis fluoro vest to wear during the stops. At some roadside stops we will put out road safety signs and traffic cones to slow traffic and minimise risk. Your assistance with this task will be appreciated. It is essential that all participants are safety conscious and responsive to traffic 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 service. You must state where you are *including the name of the town* because calls are routed through centralised call centres. Ambulance services are provided by an organisation called (Order of) St John. Be careful in New Zealand and be aware of personal safety and possessions, especially after dark.

### **Accommodation: Auckland (one night)**

All participants have been booked into **Ventura Inn, 14 Airpark Drive, Airport Oaks, Auckland**, for the night of Thurs 27<sup>th</sup> November. The accommodation includes a continental breakfast on Friday 28<sup>th</sup> Nov.

Contact details: Ventura Inn, Airport Oaks: phone +64 9 275-4540, fax +64 9 275-4546

Reservations manager: Rita Ram [Auckland.airport@venturainns.co.nz](mailto:Auckland.airport@venturainns.co.nz)

### *Tour meeting evening of Thursday 27<sup>th</sup> Nov*

We plan to hold a brief meeting of tour participants at Ventura Inn, Auckland, in either the lounge (lobby) or conference room at 8 pm. The meeting will let us introduce ourselves, check we are all here, provide a few final details about the tour and a copy of this guide book, and answer questions.

### *Internet*

There is a charge of \$9.50 for internet access at Ventura Inn, Airport Oaks (pays for 24 hrs of access). Please pick up and pay individually for your access code at the front desk if you want to use the internet at the hotel on 27<sup>th</sup> November. Wireless connections are available only in the lounge areas; broadband (wire connection required) is available in guest rooms.

### *Breakfast*

Please help yourself to breakfast (includes tea/coffee) any time Friday morning in the lobby area. We plan to depart from Ventura Inn at 8.00 am sharp. Bags must be ready for loading in the lobby by 7.45 am. Please note that we have no baggage handlers – hence your help with baggage will be greatly appreciated!

### **Accommodation: Rotorua (two nights)**

All participants have been booked into **Ventura Inn, corner Fenton and Victoria streets, Rotorua**, for nights of Friday 28<sup>th</sup> and Sat 29<sup>th</sup> November. The accommodation includes continental breakfasts on Sat 29<sup>th</sup> and Sunday 30<sup>th</sup> November, and free access to the internet for 48 hrs from arrival (wireless throughout the hotel). All participants need to pick up their free internet access codes on arrival at Ventura Inn, Rotorua.

Contact details: Ventura Inn, Rotorua: phone +64 7 350-2211, fax +64 7 350-2212

Manager: Sharlene Herbig [rotorua.gm@venturainns.co.nz](mailto:rotorua.gm@venturainns.co.nz) or [rotorua@venturainns.co.nz](mailto:rotorua@venturainns.co.nz)

### **Evening meals in Rotorua Friday 28<sup>th</sup> and Saturday 29<sup>th</sup> November**

Evening meals have been organised for both Friday (Valentines Buffet Restaurant, about 5 minutes' walk from Ventura Inn) and Saturday (Rydges Hotel), which will include a *hangi* (meal cooked in underground oven) and a Maori concert. Costs for these meals, and some drinks, will be met by us (tour leaders). Smart casual clothes are acceptable.

### **Lunches and morning/afternoon teas and special dietary considerations**

We will provide lunches each day. On Friday 28<sup>th</sup> November, we will have lunch at the Academy of Performing Arts, University of Waikato, Hamilton. On Saturday 29<sup>th</sup> and Sun 30<sup>th</sup> November we will have packed lunches. Morning and afternoon teas including biscuits will be provided from ingredients carried by us on the bus. We have short, designated stops for tea/coffee breaks and, usually, toilet access.

# Introduction to Quaternary volcanism, tephtras and tephra-derived soils in New Zealand

**David J. Lowe**

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**Richard T. Smith**

*Ministry of Civil Defence & Emergency Management, Wellington (formerly Univ. of Waikato)*

**Haydon Jones**

*Scion, Rotorua*

## Introduction

The first part of this article is derived partly from Smith et al. (2006) and Leonard et al. (2008). Other useful reviews include those of Neall (2001) and Chapter 7 (“Forges of Middle Earth”) in Graham (2008). There are numerous papers on tephtras in New Zealand, and recent reviews include Shane (2000), Alloway et al. (2007), Lowe (2008) and Lowe et al. (2008a, 2008b). A history of tephtra studies was published by Lowe (1990). The second part introduces tephtra-derived soils in New Zealand. Such soils include Entisols and Andisols (mainly Vitrandis and Udands), as reviewed by Lowe and Palmer (2005), and Ultisols. Books on these and other soils of New Zealand include New Zealand Soil Bureau (1968), Gibbs (1980), McLaren and Cameron (1996), Cornforth (1998), and Molloy and Christie (1998). An excellent web-based overview was prepared by Hewitt (2008). 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 tephtras

### 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 sorts of eruptions are called phreatomagmatic eruptions.

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 2 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 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).

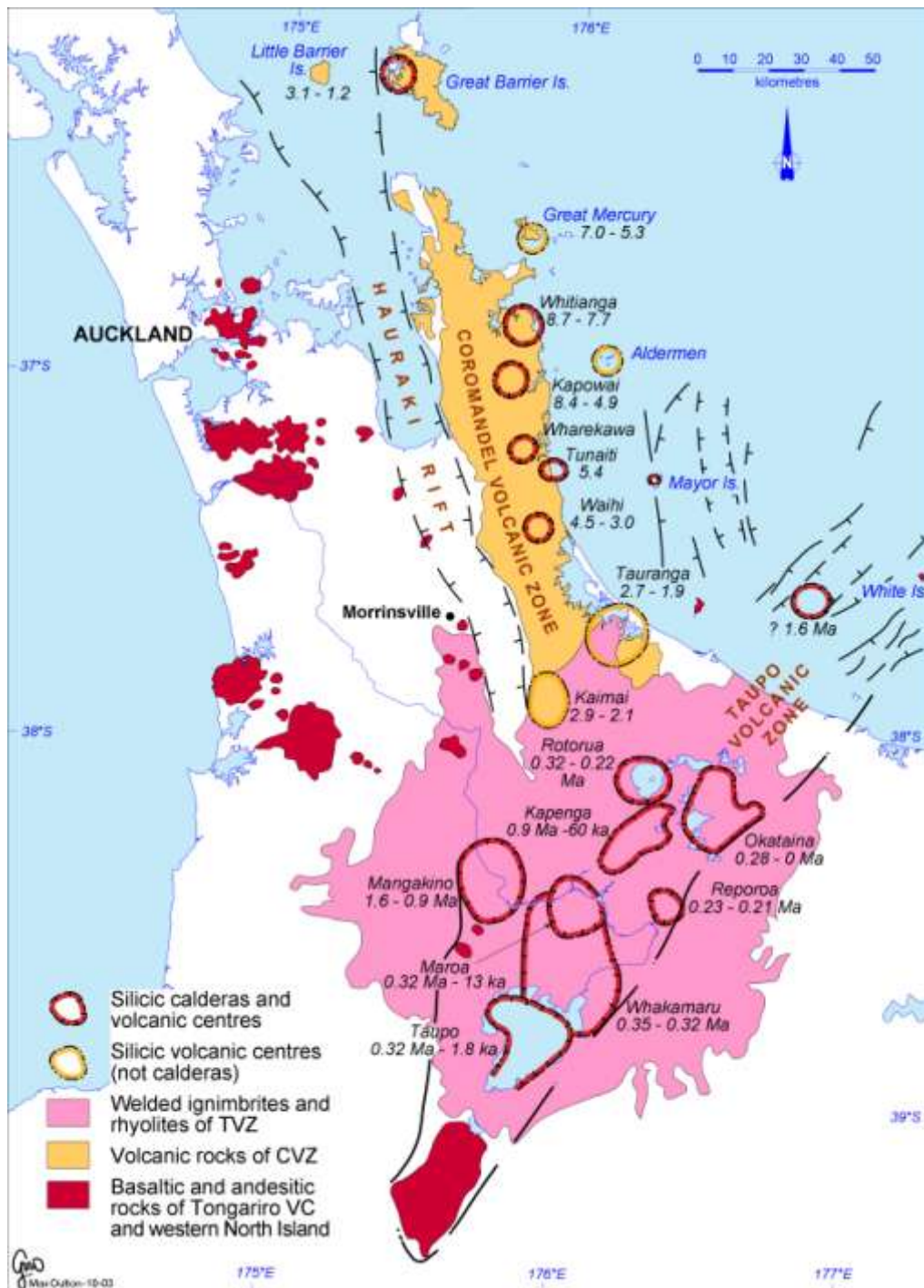
Rhyolite calderas may be active for several hundred thousand years, but large eruptions are rare, with typically thousands of years between events. Caldera collapse is not the only effect on the landscape arising from these large explosive eruptions. Huge quantities of pumice, ash and gas are pumped into the atmosphere, and through a combination of heat and momentum, a seething 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 is 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).



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

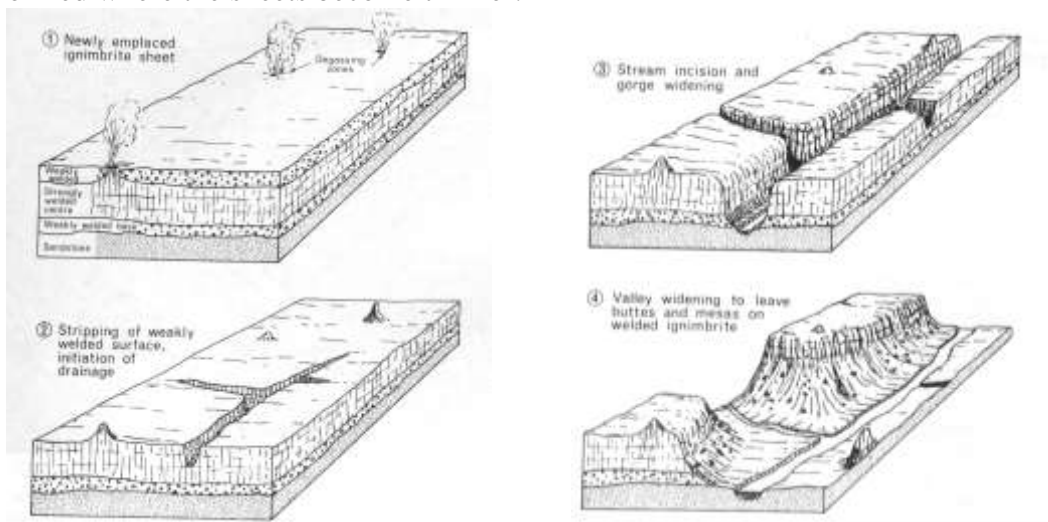
### Taupo Volcanic Zone

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-Kakaramaea 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 bookmark 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 six older calderas including Mangakino, Kapenga, Whakamaru, Reporoa, Rotorua and Maroa (a

seventh is the newly-recognised Ohakuri caldera: D.M. Gravley in Spinks et al., 2004). 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 rock, 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. 350,000 years ago are found under the seabed 1200 km east of Napier (the Rangitwa 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.

### 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, but simple erosion during glacials of softer materials is more likely (diagram designed by M.J. Selby, 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’ was by Aristotle who described an eruption on the island of Hiera in the Lipari (Aeolian) Islands near Sicily before c. 300 BC. 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 their ages, and tephrochronology, the use of tephras to connect and date sequences from place to place, and thus a powerful, widely-applied dating tool. In comparatively recent times, glass shard concentrations preserved within peats and lake sediments and ice cores, 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 (see Lowe, 2008).

### **What are ‘ash’ and ‘lapilli’?**

‘Ash’ is not ash in the sense of a burnt residue. Rather, it consists of pulverised, jagged rock particles, mineral grains (crystals), and glass shards, all defined as smaller than 2 mm in size. Fine ash is <0.06 mm, medium ash is 0.06–0.5 mm, and coarse ash is 0.5–2 mm. 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**

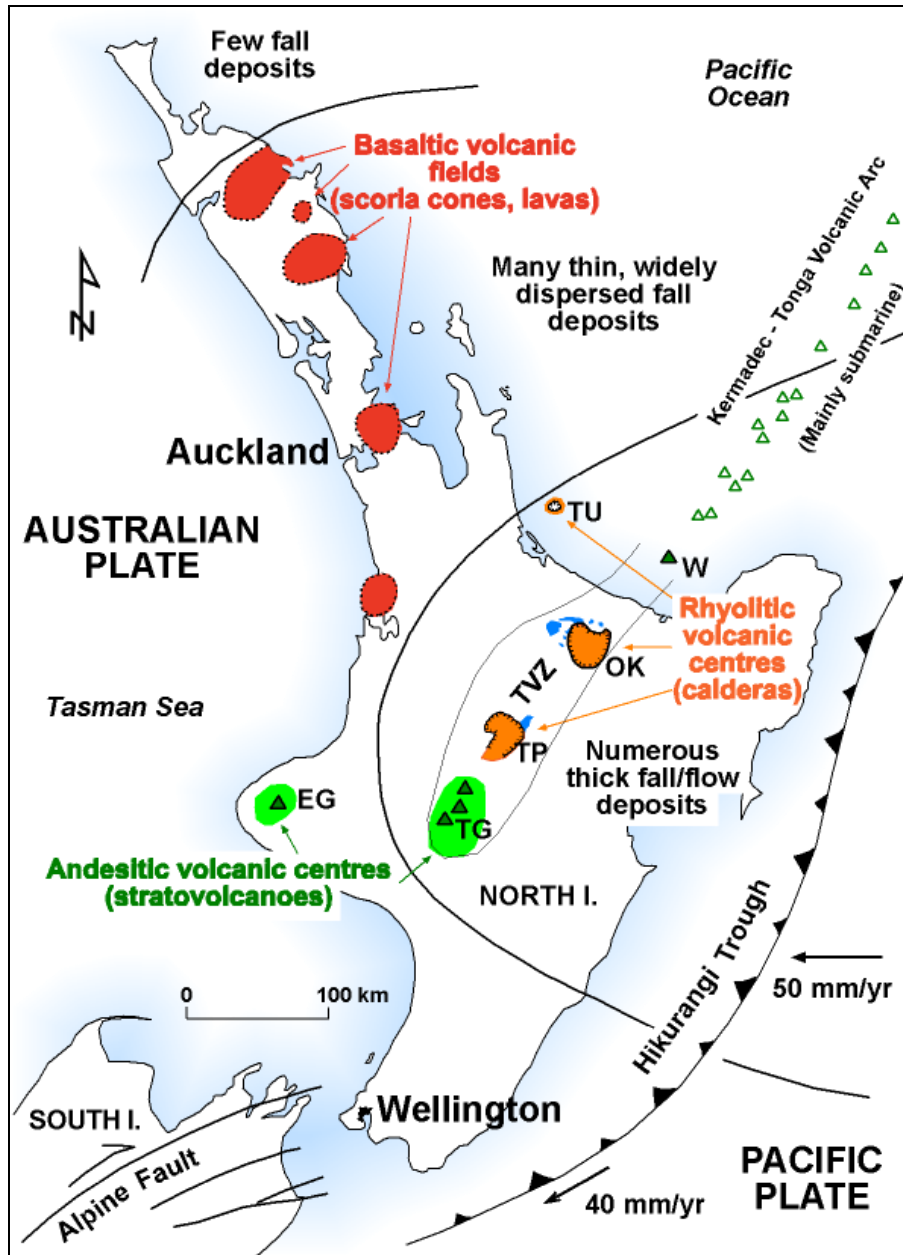
As well as erupting lavas and other materials, and modifying or building landforms comparatively close to vents, North Island volcanoes have blasted huge volumes of tephra into the air to be blown over northern New Zealand and in some cases far out to sea, more than 1000 km from source. The accumulation 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’**

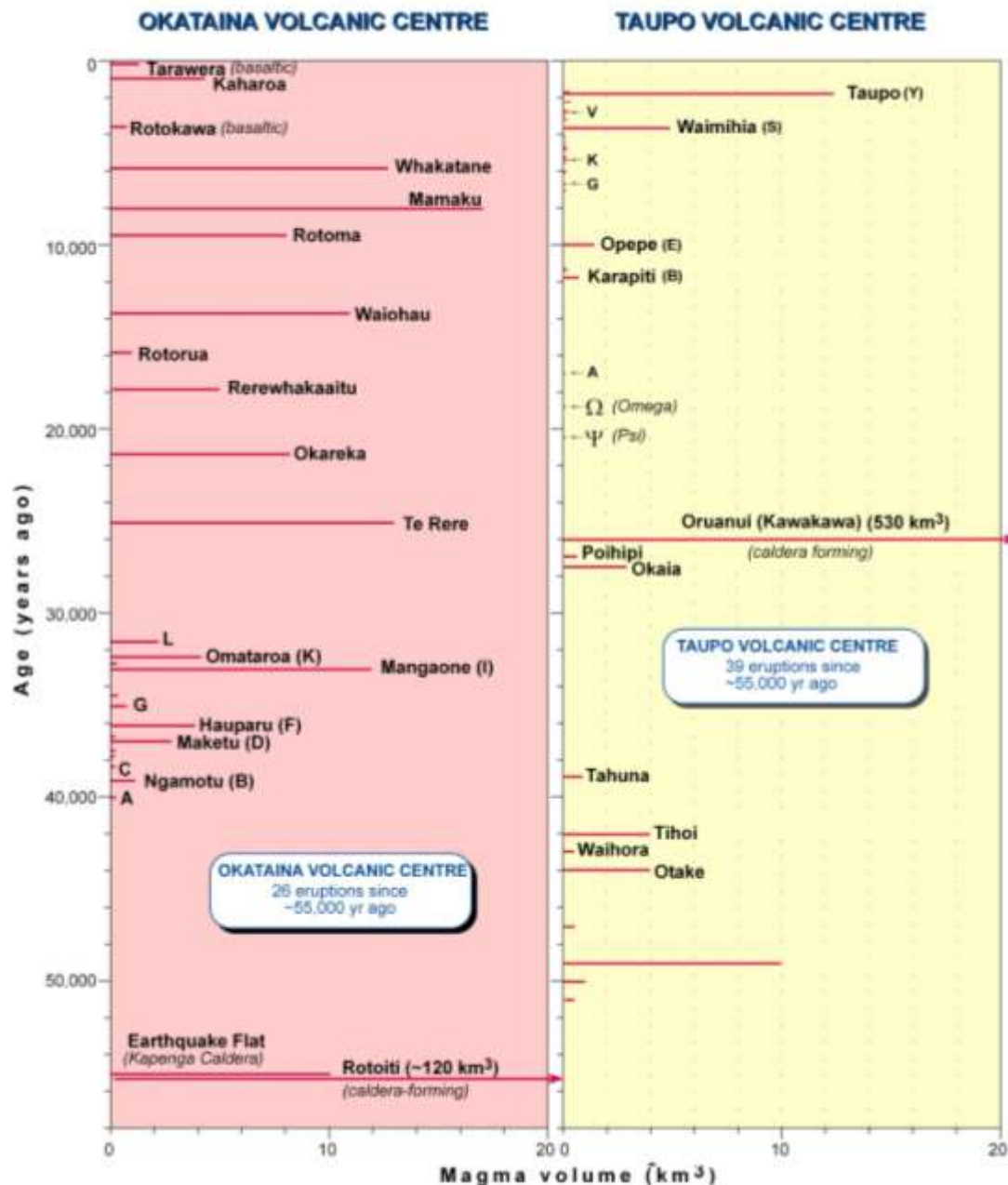
A law in geology states that the oldest deposits in a layered sequence occur at the bottom and are overlain progressively by younger deposits, the most recent therefore being right at the top (Law of Superposition). This natural arrangement means that quite often only the youngest deposits are seen in 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 tephra has been recognised so far in the South Island. They include Rangitawa Tephra, erupted c. 350,000 years ago from Whakamaru volcano, and Kawakawa Tephra, erupted c. 27,100 cal. years ago from Taupo volcano.



Map showing plate tectonic setting, the main volcanic centres that produced parent materials for many of today's 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; multiply by  $\sim 3$  to obtain approximate bulk volumes) of tephra erupted from Taupo and Okataina volcanic centres since c. 60,000 cal years ago (after Lowe et al., 2008a).

### Tephra as a unique dating tool (tephrochronology)

Tephra-fallout layers have two special features: (1) they are erupted and deposited over very short time periods, geologically speaking, usually a matter of only hours or days to a few months; and (2) they can be spread widely over land and sea to form a thin blanket that has the same age *wherever it occurs*. Therefore, once it is identified by chemical 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 looking at 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, and 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 et al., 2008a, 2008b).

### 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<sup>-1</sup> 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 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. *Kokowai* has been identified as ferrihydrite, a tiny clay mineral with a huge surface area (>200 m<sup>2</sup> g<sup>-1</sup>) 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).

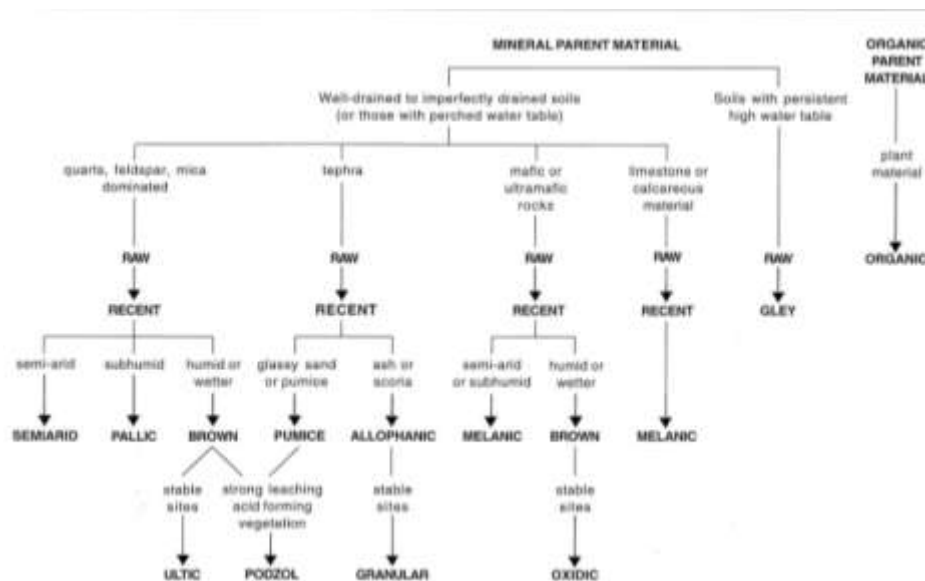
Photo (left) shows ferrihydrite seepage near Waikato River, Hamilton (see Lowe and Percival, 1993). *Photo*: David Lowe

## Tephra-derived soils in 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 p. 26).



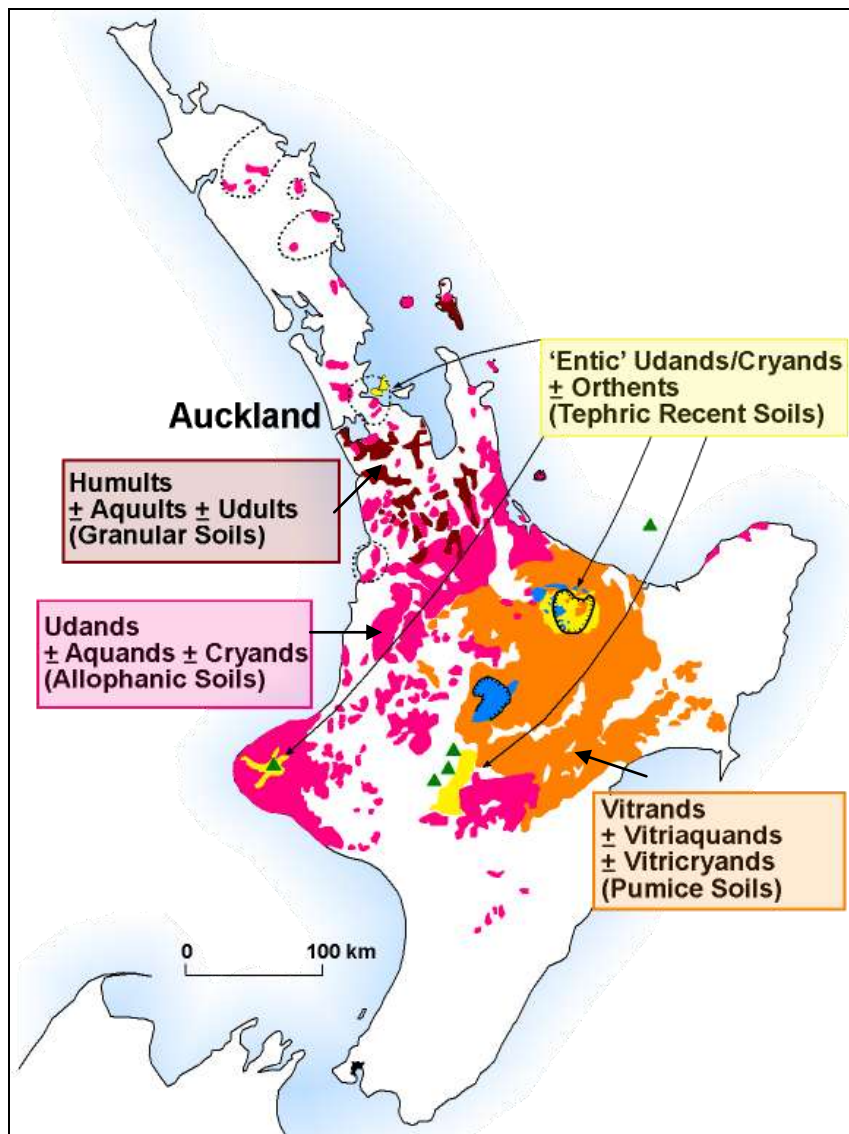
Major taxonomic development paths of New Zealand soils (from Allan Hewitt in Molloy and Christie, 1998, p.235).

### *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 (~700–2000 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 tephtras buried beneath them.



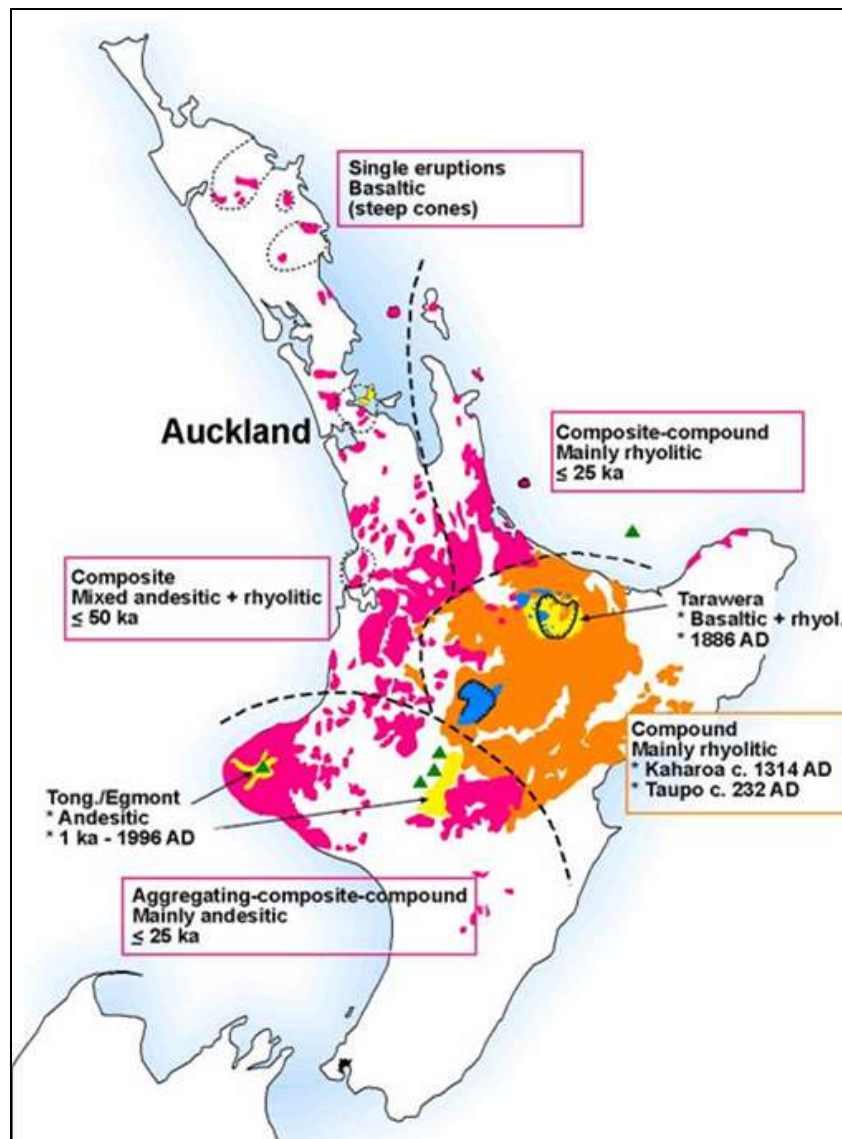
Distribution of four main groupings of tephra-derived soils in North Island (after Kirkpatrick, 1999, based on Rijkse and Hewitt, 1995; modified from Lowe and Palmer, 2005).

### *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 20,000 years to form and clearly are irreplaceable, yet they are undervalued by most people. Their name comes from the tiny 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 ( $>400 \text{ m}^2 \text{ g}^{-1}$ ) (Lowe and Palmer, 2005).

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 are not ‘rich and fertile’ – they have low natural fertility, and need regular ‘topping up’ with various nutrients especially phosphorus and potassium to maintain high productivity (Lowe and Palmer, 2005).



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 tephra, and approximate ages of the soil profiles (from Lowe and Palmer, 2005). Note: ‘Aggregating’ should read ‘Aggrading’ (lowermost box).

### *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. Examples of these soils will be seen at stops 1 and 2 on Day 1 of the tour).

### 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’.

**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.

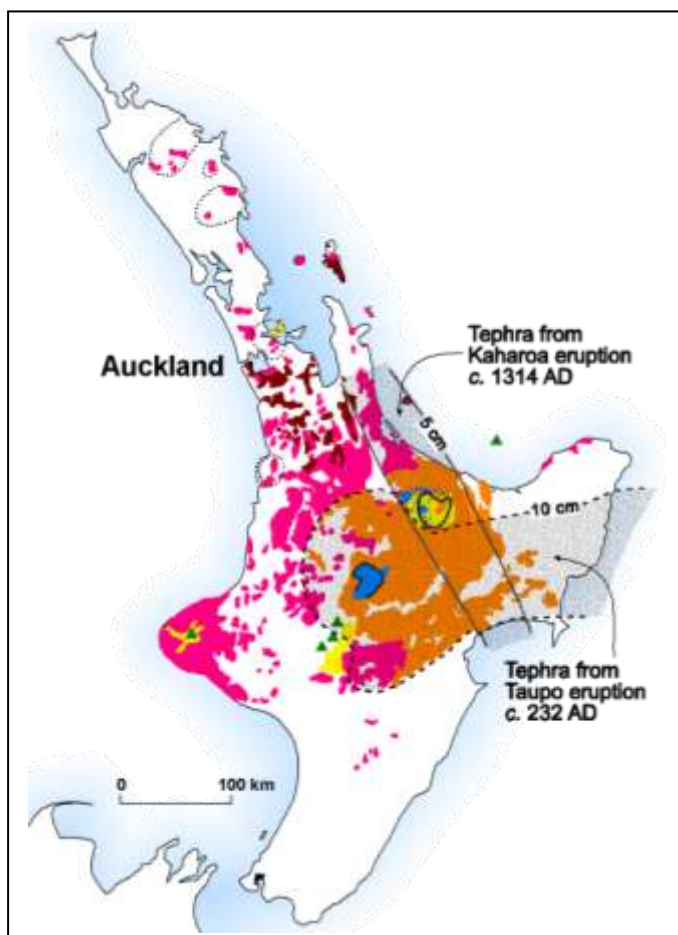
**Scenario 2** Where a tephra deposited on the land surface surface is of sufficient thickness to bury the antecedent soil below the range of soil forming processes (i.e., it becomes isolated), the buried soil becomes part of the underlying regolith and is recognised as a buried paleosol (a soil of a 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.

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 1) 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. The main soil-forming tephras and marker beds in New Zealand for the past 30,000 cal years were documented by Lowe et al. (2008a).

### 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 20<sup>th</sup> 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 inherited. 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 3).



(From Nick Kim, EW)

Map showing single isopachs of tephras deposited from Taupo eruption (c. 232 AD: Sparks et al., 1995; Hogg et al., 2009) and Kaharoa eruption (c. 1314 AD: Hogg et al., 2003), soils on which resulted in ‘bush sickness’ (Co deficiency) (from Lowe and Palmer, 2005).

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

Order	World <sup>1</sup>		New Zealand <sup>2</sup>		Main NZSC order(s)
	Land area % (ice-free)	Rank ↑	Land area %	Rank ↑	
Alfisol	9.7	4	9.9	4	Pallic Soils
Andisol	0.7	12	12.9	3	Allophanic, Pumice, Recent Soils
Aridisol	12.0	2	0.9	9	Semiarid Soils
Entisol	16.2	1	7.4	5	Recent, Gley, Raw, Anthropic Soils
Gelisols	8.6	5	0 <sup>3</sup>	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)

<sup>1</sup> After Soil Survey Staff (1999).

<sup>2</sup> 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.

<sup>3</sup> Gelisols (on frost-churned materials underlain by permafrost) probably occur in NZ's Ross Dependency, Antarctica

## Soil classification

Soil classifications throughout this guide are given in terms of the *New Zealand Soil Classification* (NZSC) of Hewitt (1998) and Clayden and Webb (1994), and in terms of *Soil Taxonomy* by Soil Survey Staff (1999, 2006).

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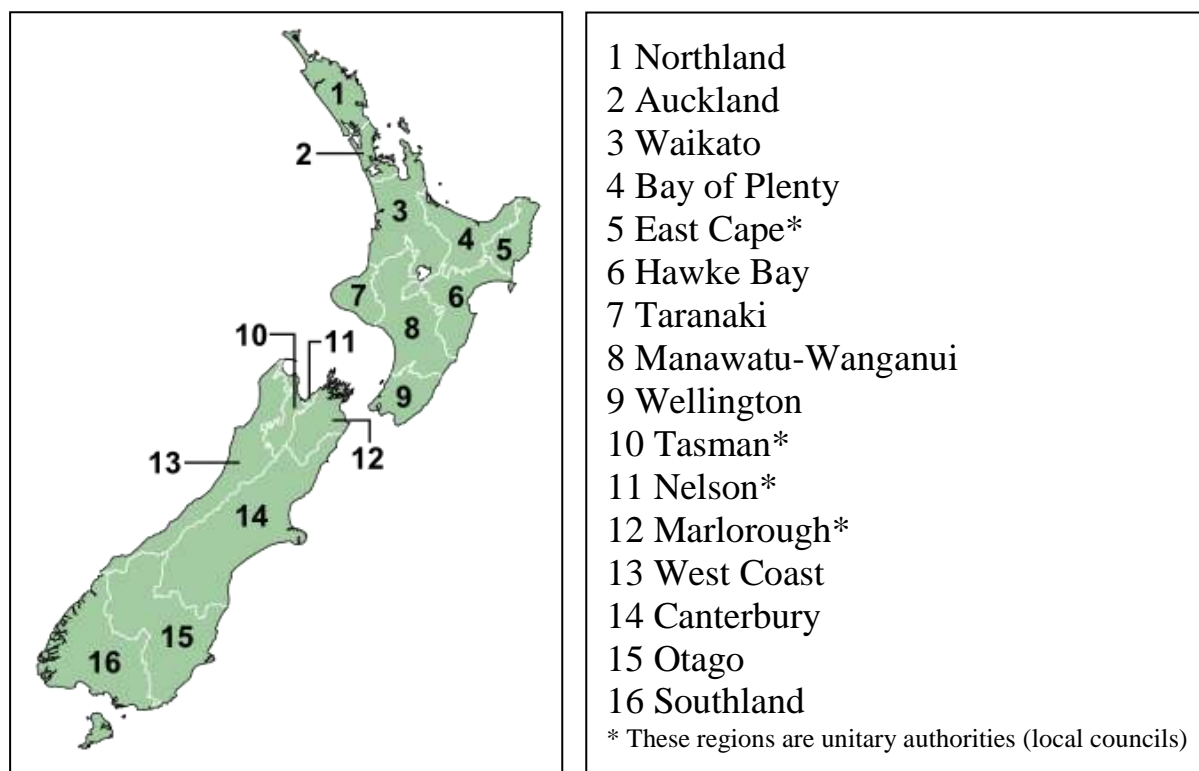
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## Introduction to regional councils in New Zealand

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. The amalgamation anticipated the responsibilities of the Resource Management Act 1991.



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. There is often a high degree of co-operation between regional and territorial councils as they have complementary roles.

The Pukekohe area is just within the Auckland Region (Pukekohe Hill, Stop 1, is only a few hundred metres from the southern boundary which runs along Hill Top Rd, Bayly Rd, and Ray Wright Rd). South of Pukekohe and Bombay, the Waikato Region takes in the Waikato basin-and-range province, through which the Waikato River flows, and southward into the northern King Country and Lake Taupo-Tongariro area, and northeastward taking in the entire Coromandel Peninsula. The Kaimai and Mamaku ranges mark the boundary with part of the Bay of Plenty Region to the east.



The Waikato Region has an area of 25,000 km<sup>2</sup>, and a population of 402,200 (June 2008 estimate), the main city being Hamilton (population ~135,000). It encompasses all or parts of twelve separate districts, the most of any region. In decreasing size, the districts are Taupo (part), Waitomo (part), Waikato, Thames-Coromandel, Otorohanga, South Waikato, Matamata-Piako, Waipa, Franklin (part), Hauraki, Rotorua (part), and Hamilton City.

Our field trip will start in the Auckland Region (run by the Auckland Regional Council, or ARC), then move quickly into the Waikato Region administered by the Waikato Regional Council (known as Environment Waikato or EW). We spend Day 2 in the area administered by the Bay of Plenty Regional Council (Environment Bay of Plenty or EBOP). On Day 3 we re-enter the Waikato Region and then south of Tongariro National Park we enter the Manawatu-Wanganui Region which is administered by the Horizons Regional Council.

## Issues in the Waikato Region: water and soil quality

**Peter Singleton**

*Environment Waikato, Hamilton*

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 3). 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.

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## Trace-element accumulation

### Nick Kim

*Environment Waikato, Hamilton*

#### 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<sub>2</sub>O<sub>5</sub>. The current voluntary limit for cadmium in New Zealand phosphate fertilisers is 122 mg Cd/kg P<sub>2</sub>O<sub>5</sub>.

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 urban 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<sub>4</sub><sup>2-</sup>). 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.

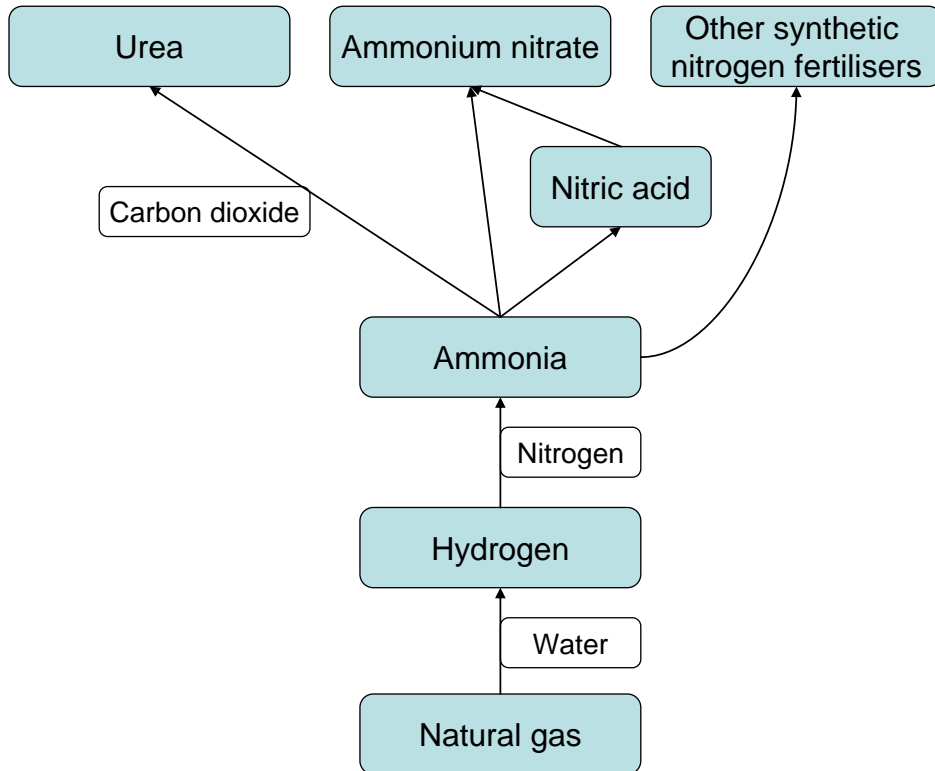
Nitrogen fertilisers tend to have a fairly low trace element content, because they are manufactured from natural gas (mainly the methane, CH<sub>4</sub>) and air (dinitrogen, N<sub>2</sub>) (Fig. 1), though some exceptions will exist (Table 1).

### 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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## Day 1: Auckland–Rotorua

### Outline for Day 1 (Friday 28<sup>th</sup> November)

**8.00 am** Depart Ventura Inn, Airport Oaks

**8.50-10.00 am STOP 1 Pukekohe Hill Reserve (Massey Memorial Lookout), Pukekohe: overview, market gardening, Pukekohe soil**

- Introduction to tour
  - Ashes: Prof David Lowe
  - Issues: Dr Peter Singleton (Environment Waikato)
- Market gardening in Pukekohe area
  - Soil resilience, erosion (<sup>137</sup>Cs), N, Cd, urbanisation issues
  - Franklin Sustainability Project (growers' perspective): Monty Spencer (A.S. Wilcox and Sons – growers, packers, and distributors of fresh produce)
- Pukekohe silt loam (Typic/Andic Kandudult)

**10.00-10.30 am** Morning tea/coffee, Pukekohe Hill Reserve

**10.50-11.00 am** Toilet stop, Bombay services, State Highway (SH) 1

**11.50-12.30 STOP 2 Gordonton Rd, Gordonton: 'old' tephras, buried soils, Kainui and Naike soils**

- Stratigraphy of sequence (~1 Ma and younger)
- Kainui silt loam (Aquic Kandudult), Naike clay (Typic Kandihumult)

**12.45-1.30 pm** LUNCH Academy of Performing Arts, University of Waikato, Hamilton

**1.40-2.15 pm STOP 3 Markevin Lane (Pencarrow Rd), Tamahere: Horotiu soils**

- Horotiu sandy loam (Vitric Hapludand), Horotiu mottled silt loam (Aquic Placudand)
- High versatility soils vs rural subdivision (lifestyle housing development)

**2.30-3.00 pm STOP 4 Swayne Rd, Hautapu: nitrogen in the dairying landscape**

- Denitrification bed experiment: Assoc Prof Louis Schipper (Univ. of Waikato)

**3.05-3.35 pm** Afternoon tea/coffee and toilet stop, Thornton Rd gardens, Cambridge

**4.15-5.15 pm STOP 5 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)

**6.00-6.20 pm STOP 6 Kuirau Park, Ranolf St, Rotorua: explosion crater**

- View results of 5-min steam eruption of 26 Jan 2001

**6.30 pm** Arrive Ventura Inn, Rotorua (Cnr Fenton and Victoria streets)

- 7.30 Dinner at Valentines Buffet Restaurant (cnr Fenton & Amohou streets, 5 min walk from Ventura Inn)
- Rest of evening free

## Day 1 – route and scientific stops



# 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 (see appendix below).

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 *et 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 terraced 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<sup>2</sup>) catchment, used predominantly for market gardening, was very low, averaging 0.5 t ha<sup>-1</sup> yr<sup>-1</sup> 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  $57 \text{ t ha}^{-1} \text{ yr}^{-1}$  over a 2.5 year measurement period (Basher et al., 1997). Soil loss during individual storm events reached more than  $10 \text{ t ha}^{-1}$ . 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  $0.4 \text{ t ha}^{-1} \text{ yr}^{-1}$ .

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 ( $^{137}\text{Cs}$ ) 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:

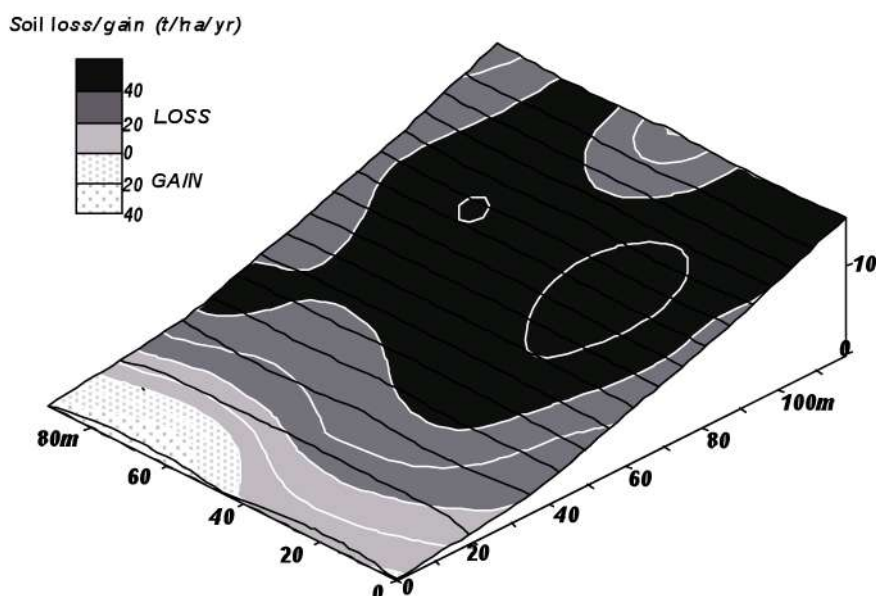
- An extremely wide range of measured  $^{137}\text{Cs}$  values indicative of both erosion and deposition (at rates up to  $100 \text{ t ha}^{-1} \text{ yr}^{-1}$ );
- Net soil loss from all fields, with the highest net loss from the steepest field (field 1);  $>30 \text{ cm}$  of soil has been lost from the upper parts of these fields ( $7.4 \text{ mm yr}^{-1}$ ), and up to  $45 \text{ cm}$  deposited in the lower parts ( $10.2 \text{ mm yr}^{-1}$ ), since 1953. The high soil deposition rates are consistent with observed accumulations of topsoil  $>1 \text{ m}$  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  $^{137}\text{Cs}$  data for three fields at Pukekohe (reference value for  $^{137}\text{Cs}$  in an undisturbed site is  $774 \text{ Bq m}^{-2}$ )

	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 $^{137}\text{Cs}$ areal activity ( $\text{Bq m}^{-2}$ )	520	688	659
Range ( $\text{Bq m}^{-2}$ )	253–1488	171–2144	419–1438
Mean $^{137}\text{Cs}$ residual (%)*	-32.8	-11.1	-12.9
Range (%)	-67 to 92	-78 to 177	-45 to 90
Net erosion rate ( $\text{t ha}^{-1} \text{ yr}^{-1}$ )	-29.7	-11.3	-7.1
Mean water erosion rate ( $\text{t ha}^{-1} \text{ yr}^{-1}$ )	-31.4	-8.2	-7.3
Mean tillage erosion rate ( $\text{t ha}^{-1} \text{ yr}^{-1}$ )	1.7	-3.1	0.2
Sediment delivery ratio (%) <sup>#</sup>	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  $^{137}\text{Cs}$  relative to the reference value – negative values represent erosion, positive values deposition.

<sup>#</sup> 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  $21 \text{ t ha}^{-1} \text{ yr}^{-1}$ . This value represents a total net loss of 9.8 cm of soil since 1952 ( $\sim 2.4 \text{ mm yr}^{-1}$ ). From discussions with Franklin District Council staff, we estimated  $5 \text{ t ha}^{-1} \text{ yr}^{-1}$  ( $\sim 0.6 \text{ mm/yr}$ ) of soil was being removed each year from drains and roads – the  $^{137}\text{Cs}$  data suggest the loss could be higher, because sediment export only accounts for  $0.5 \text{ t ha}^{-1} \text{ yr}^{-1}$  of the net loss of soil of  $21 \text{ t ha}^{-1} \text{ yr}^{-1}$ . 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  $125 \text{ mm hr}^{-1}$ . 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<sup>-1</sup> 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  $21 \text{ t ha}^{-1}$  compared with  $1 \text{ t ha}^{-1}$  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<sup>-1</sup> and in onion beds from 400 to 900 mm hr<sup>-1</sup>, whereas rates in the cultivated wheel tracks decreased from 60,000 to 8500 mm hr<sup>-1</sup>. 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  $\pm$  standard deviation) measured at June and October 1999, and January 2000

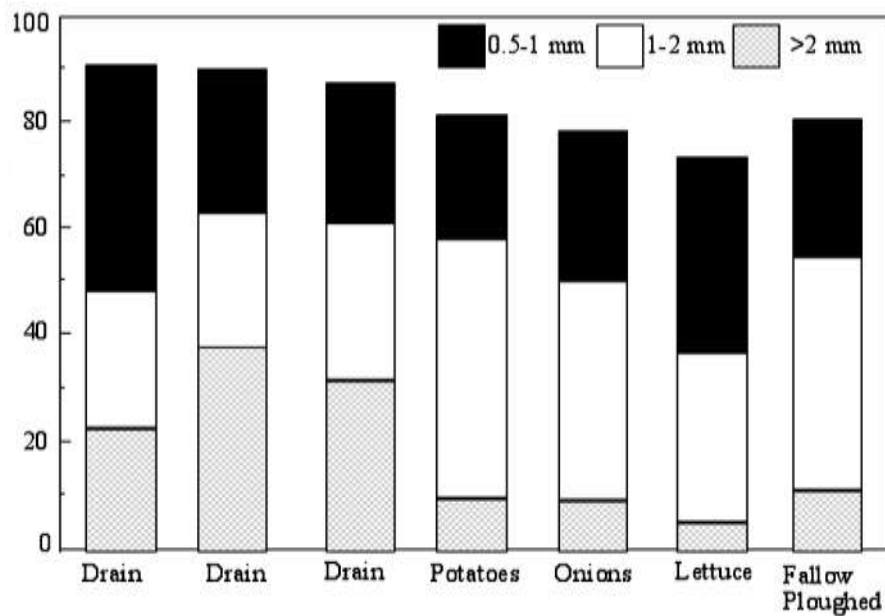
	Infiltration rate (mm hr <sup>-1</sup> )		
	June	October	January
Uncultivated wheel track	0.5 $\pm$ 0.5	12.7 $\pm$ 21.9	77.2 $\pm$ 53.7
Cultivated wheel track	60,312 $\pm$ 45,341	12,456 $\pm$ 10,668	8582 $\pm$ 4256
Onion beds	411 $\pm$ 243	485 $\pm$ 394	907 $\pm$ 674

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 suggest:

- 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  $\pm$  standard deviation) measured under cropping and pasture

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

\* Tillage pan under cropping

## Conclusions

These results suggest that erosion is largely an on-site problem with a high rate of soil redistribution within fields, but relatively little soil being transported into streams. The average net loss of soil is c. 20 t ha<sup>-1</sup> yr<sup>-1</sup> (from both the <sup>137</sup>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 <sup>137</sup>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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## Appendix: Franklin Sustainability Project

(see Environment Waikato website: <http://www.ew.govt.nz/Environmental-information/Land-and-soil/Land-use-in-the-Waikato/Soil-Management-in-the-Franklin-District/>)

In 1997, the Franklin Sustainability Project was set up to:

- test a range of sustainable land management techniques
- involve growers in planning and monitoring the techniques.

The Pukekohe Vegetable Growers Association and Agriculture New Zealand lead the project. They are testing:

- **surface water runoff management** using contour drains, grassed waterways, silt traps, and raised access ways to reduce erosion and nitrate leaching
- the use of **cover crops and mulching** to reduce erosion and nitrogen leaching, increase organic matter and improve soil structure
- **ripping and vegetating wheel tracks** to increase infiltration and reduce run off and erosion
- **reducing cultivation** to improve soil structure, boost organic matter levels, and reduce erosion
- **the impacts of subsoiling** - tilling the soil without turning it upside down - on infiltration and erosion
- **irrigation management** to improve efficiency, reduce run off and nitrate leaching
- **fertiliser management**, optimising fertiliser rates and timing to reduce nitrate leaching while maintaining production
- **integrated pest management** to reduce the use of pesticides
- **soil quality monitoring** so growers can monitor and manage changes in soil quality.

The project emphasises education and voluntary involvement. Technical advice and funding for the project are offered by Environment Waikato, Auckland Regional Council, Franklin District Council, Crop and Food Research, New Zealand Vegetable and Potato Growers Federation, Landcare Research, MAF Policy, and Ministry for the Environment.



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*

## STOP 1 – PUKEKOHE SILT LOAM, PUKEKOHE HILL

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



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*

### 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; the Massey Memorial Lookout 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 – our tour destination – is named; and we drove up Anzac Rd to get to the summit, a fitting road to start our 4<sup>th</sup> joint Australian and New Zealand soils conference. 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 strongly 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, a full sequence of which will be seen at Stop 2, 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 on the tour, is essential to understanding the soils and their relationship with the landscape.

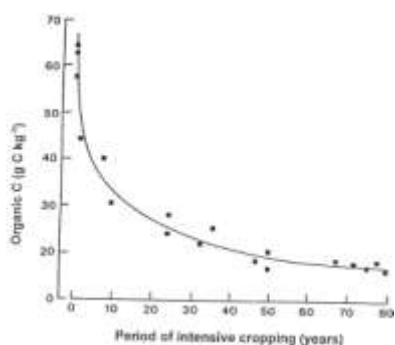
Pukekohe Hill (*pukekohe* means ‘hill with kohekohe’, the latter being a distinctive ‘tropical-looking’ tree with large leaves, *Dysoxylum spectabile*) was cleared of native broad leaved forest between 1876 and 1900, the development of the main trunk railway generating a demand for sleepers. The hard, 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<sup>2</sup>) a little 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 and 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 ( $\pm$  ~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, quite likely 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 Naike clay, which we will see at Stop 2, the Pukekohe and Patumahoe soils contain moderate allophane, gibbsite, and kaolinite, and relatively high amounts of crystalline Fe oxides, as well as halloysite (which predominates in the Naike soil) and vermiculite. Both 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  $\mu$ m) indicates that clay illuviation has occurred but the lobed appearance and non-laminated character of the clay coatings suggests neoformation (Bakker et al., 1996). The Patumahoe soil has a well developed pedal microstructure with 90 % of the material finer than 20  $\mu$ m, and many small, irregular iron oxide nodules (10-50  $\mu$ m) (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 Naike and Kainui soils (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), has 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, fungicides, 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 contributor 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) compared with sorghum, and 145 kg N/ha of N uptake compared with 62 kg N/ha uptake for sorghum.

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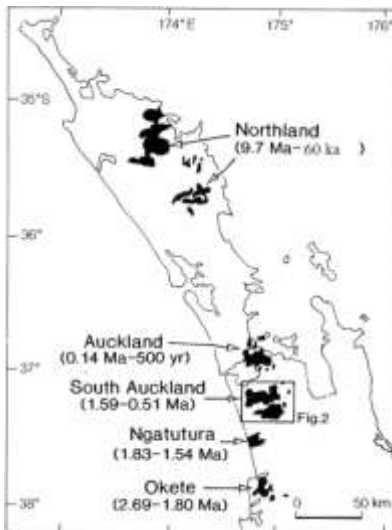
Micromorphological features in a range of tephra-derived soils in North Island including Patumahoe (from Bakker et al., 1996)

Soils	Horizon	Taspo			Timo					Homo					Naike				Patumahoe								
		Ap	Bw	BC	Ap	Bw1	Bw2	Bw3	2C	3Bw	Ap	Bw1	Bw2	Bw3	BC	2BC	2BC	Ap	Bw2	Bc1	Bc2	10Bg	11S-12S	15-25	35-45	49-59	75-82
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	83-92	
Microstructure	Granular				###	###	===	===			###	###					###										
	Spongy											===	===														
	Subangular blocky																###	###	===	===			###				
	Angular blocky																										
	Single grain																										
Coarse material >20 µm	Massive																										
	Porice fragments <sup>4</sup>	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###											
	RFP <sup>4</sup>															###											
	Quartz, feldspars															###											
	Pyroxenes, amphiboles															###											
	Mica																										
	Opaque Fe-Ti ox.																										
	White pseudomorphs																										
	Porice fragments				###	###	###	###	###	###		###	###	###	###			###						###	###		
	Feldspars																										
Alteration of coarse material	Pyroxenes, amphiboles																										
	Mica																										
Fine material <20 µm	Undifferentiated <sup>5</sup>	===	===	===	===	===	===	===	===	===	===	===	===	===	===	===											
	Stipple speckled <sup>6</sup>																										
	Striated <sup>6</sup>																										
Pedofeatures	Clay coatings															###					###	###					
	Iron (hypo) coatings															###											
	Iron nodules																										
	Depletion																										
	Excrescences	===			===	###	###	###	===	===	###	===	===	===	===	===	###	===	===	===	===	===	===	===	===	===	
Ratio				6/9	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		

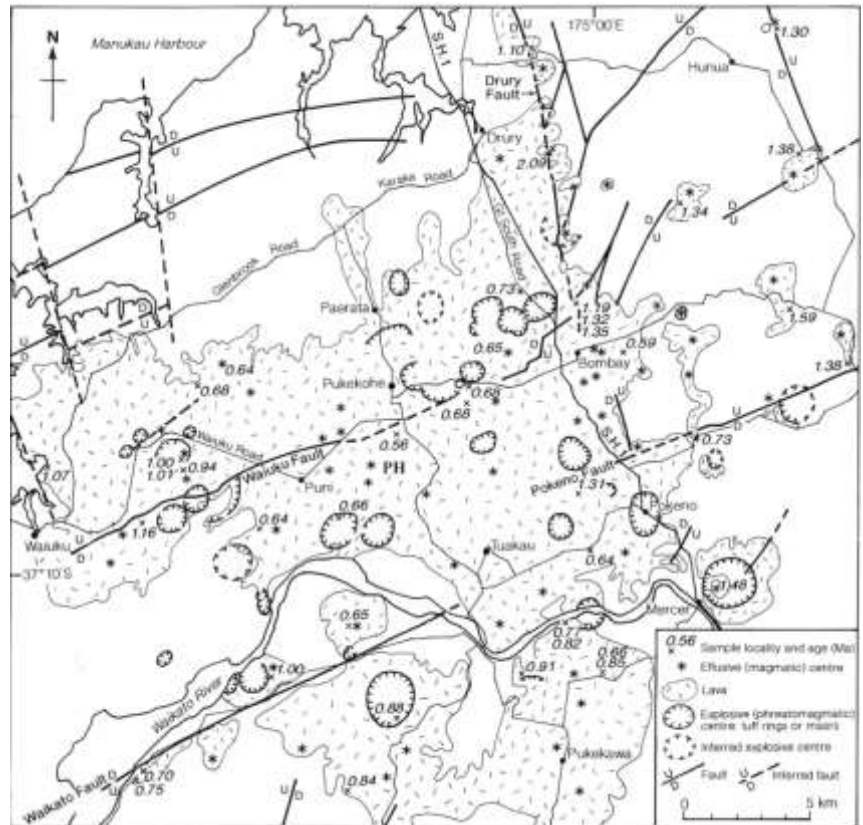
Key

<sup>1</sup>Few —,  
<sup>2</sup>Common ===,  
<sup>3</sup>Many ###.  
<sup>4</sup>Rhyolitic rock fragments.

<sup>5</sup>Isotropic.  
<sup>6</sup>Anisotropic.  
<sup>7</sup>Coarse >20 µm/fine <20 µm.



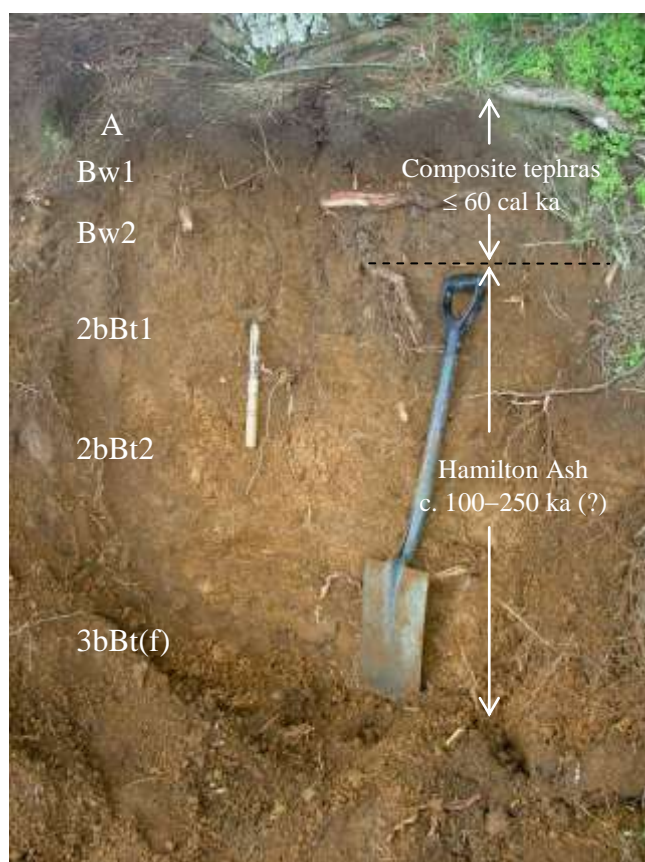
Maps of northern North Island showing locations of intraplate basalt volcanic fields (above) and South Auckland volcanic field including ages and structural patterns (right) (both from Briggs et al., 1994). PH, Pukekohe Hill



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 (profile not examined closely). Data for Pukekohe and Patumahoe soils are given on pages 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: PUKEROHO SILT LOAM Elite Lab No: SB08432  
 Description of Profile No: 8432 for Project No: SR Author: GED Date: 17-Feb-1969  
 Map reference: 0 0 Map Series: Grid ref unknown  
 Classification: Brown granular loam, US Taxonomy: Mottled-acidic Orthic Granular Soil Region: Auckland  
 Survey: Franklin County (part) FRAN Location: Northerly facing slope, Upper Queens Street roadside cutting.  
 Topdressing: Annual Rain: 1143mm Elevation: 137 m Mean Temp - Annual: 12 C Landform Genesis: Slope Landform: Slope Slope: 7 deg Aspect: 45 deg  
 Microrelief: Slope Movement: Land Use: Horticulture  
 Drainage: Moderately well Improvements: fertilised  
 Vegetation: BRACKEN-PASPALUM-MARISHMALLOW-ROOCH ROADSIDE Parent Materials: moderately weathered, ANDESITIC VOLCANIC ASH

Notes  
 SEE CARD FOR DETAILED ADDITIONAL NOTES. GROSSLY OVERDREPPED 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 cast 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 strut, 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 red white (9Gbbblite) flecks.

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	pH				H2O Moist	C (%)	N (%)	C/N	Truog P (ug/g)	Phosphorus fractions (mg %)			P remn (%)
				H2O	1M KCl	1M NaP	CaCl2						0.5 M Inorg.	Organic	Total	
				A1A	A1A	A1B	A1A						A5A	A5B	A5C	
Ap	0-15	A	-					5.9	3.70							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							76

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	Cation exchange								KCl Ex. Al (me. %)	Titratable acidity (me. %)	Reserve Mgr. Kz (me. %)	S Total (ug/g)	Phosphate est. (ug/g)
				CEC		Sum bases		NBS		Ca Mg K Na						
				A6E	A6A	A6S	A6B	A6H	A6I	A7B	A7A					
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 (%)		Acid oxalate-extractable (%)				COOH	Dithionite-sulfate extractable (%)		Stones >2mm (%)	Moisture factor
				Fe	Al	Fe	Al	Si	Mn		Fe	Al		
				A8B	A8A	A8C	A8D							
Ap	0-15	A	-			2.33	0.39						n.d.	1.045
B1	15-25	B	-			0.24	0.30						n.d.	1.080
B2	25-40	C	-			4.29	0.29						n.d.	1.043
C1	40-63	D	-			0.20	0.31						n.d.	1.040

Soil Name: PUKEROHO SILT LOAM Elite Lab No: SB08432

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

Horizon letter	Sample depth (cm)	Clay (%)	Mica	Chlo	Vermic	Illite	Smect	Kao	kaol	Hallo	Glimb	Soot	heua	Wg	Serpent	Pyro phyl	Saol	Talc
Ap	A	-	8	0	15	0	0	65			1	0	0		0	0	0	0
B1	B	-	9	0	7	0	0	65			1	0	0		0	0	0	0
B2	C	-	4	0	8	0	0	65			8	0	0		0	0	0	0
C1	D	-	4	0	0	4	0	65			20	0	0		0	0	0	0

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

Horizon letter	Sample depth (cm)	Clay (%)	Interstratified minerals										Allophane	Quartz	Feldspar	Crystals		
			Mica-ver	Mica	Mica	Mica	Chlorite	Chlorite	Chlorite	Chlorite	Chlorite	Chlorite					Chlorite	Chlorite
Ap	A	-	0	0	2	0	0	0	0	0	0	0	0	0	<1	0	0	3
B1	B	-	6	3	0	0	0	0	0	0	0	0	0	<1	0	0	1	
B2	C	-	0	0	0	0	0	0	0	0	0	0	0	<1	0	0	5	
C1	D	-	3	2	0	0	0	0	0	0	0	0	0	<1	0	0	3	

Soil Name: PUKEROHO SILT LOAM Elite Lab No: SB08432

WHOLE SOIL MINERALOGY (%)

Horizon letter	Sample depth (cm)	Carbon	Alligona	Ferrite	Mica	Chlor	Quartz	Feld	Sand	Glimb	Humat	Goeth	Lepido	Serpent	Extractable (%)		
															Fe	Al	Si
Ap	A	-			<1											0.33	0.18
B1	B	-			<1											0.28	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 Kandiodults [or Andic if in upper profile BD  $\leq 1.0 \text{ g/cm}^3$  and  $\text{Alo} + 1/2\text{Feo} > 1.0$ ]



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

Photo: David Lowe

PATUMAHOE SILT LOAM		Near	Grid ref: N47/380173
Location: 9 m SE of main track on NE boundary of second block SE of glasshouse		Slope: level	Landform: Undulating ash mantled plain
Aspect: -		Drainage class: Well drained to moderately well drained	Parent material: Hamilton Ash Formation over basalt (with palaeosol)
Vegetation: Ryegrass, white clover, docks, paspals, flatweeds. Buffer strip between track and experimental plots.			
Land use: Experimental area for horticultural crops research. Generally market gardening and dairying in surrounding district.			
Altitude (m): 91			
Rainfall (mm): 1200			
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,	Rg1 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 (skeletalans); weakly developed medium block structure crushing to strongly developed medium crumb structure; distinct wavy boundary,
Ap2 6-15	near 10YR 3/3 silt loam; moderately firm; brittle; 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 (porcellanite) many roots; few coarse and medium pores; few very fine black charcoal fragments; diffuse wavy boundary,	Rg2 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,
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,	Rg3 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,
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 (skeletalans) moderately developed fine block structure crushing to strongly developed coarse crumb structure; moderately sticky; non plastic; diffuse 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,
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 (skeletalans); diffuse wavy boundary.	3Bw 165-187	7.5YR 5/8 slippery silt loam; moderately weak; brittle; non sticky; slightly plastic; many fine white nodular inclusions (Thalioysite); many distinct 5YR 5/6 patches; many glistening crystals; few discontinuous thin cutans; no roots; distinct 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	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 <sub>2</sub> O	KCl	Ap1	NaP	Ca	Mg	K	Na				H (KCl)	Al (KCl)	CEC NH <sub>4</sub> OAc (pH 7)	I Cations (pH 8.2)	I bases CEC NH <sub>4</sub> OAc
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	27.9	24.4	47.8	(100)	58
B	6-15	Ap2	6.4	5.2	-1.2	8.2	12.9	0.98	0.34	0.40		0.00	22.6	22.6	14.6	20.9	37.2	70
C	15-26	Ap3	6.0	4.8	-1.2	8.0	10.5	0.69	0.15	0.34		0.05	24.7	24.7	11.7	20.0	36.4	59
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
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
F	58-82	Bt3	5.3	4.6	-0.7	10.7	4.8	0.39	0.03	0.34		0.25	37.8	37.6	5.8	18.6	43.4	30
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
H	98-119	Bg2	5.0	4.8	-0.2	10.9	1.9	0.86	0.02	0.49		0.05	46.0	46.0	3.3	22.7	49.3	15
I	119-134	Bg3	5.0	4.5	-0.5	10.5	0.5	0.80	0.03	1.30		0.35	35.3	35.9	2.9	20.7	38.8	12
J	134-165	2Bw	5.1	4.0	-1.1	10.0	0.3	1.00	0.03	1.66		2.9	25.5	20.4	6.3	16.0	26.7	21
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	20.9	15

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g)			P Retention (%)	Dithion. cit. (%)		Yasm ox. (%)		Pyrophos. (%)		Reserves (meq/100 g)	Extractable S (ppm)		
					H <sub>2</sub> SO <sub>4</sub> (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe			Al	
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	5.3	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	1.31	0.67	1.45	0.69	0.80	0.42	0.07	12.0	497

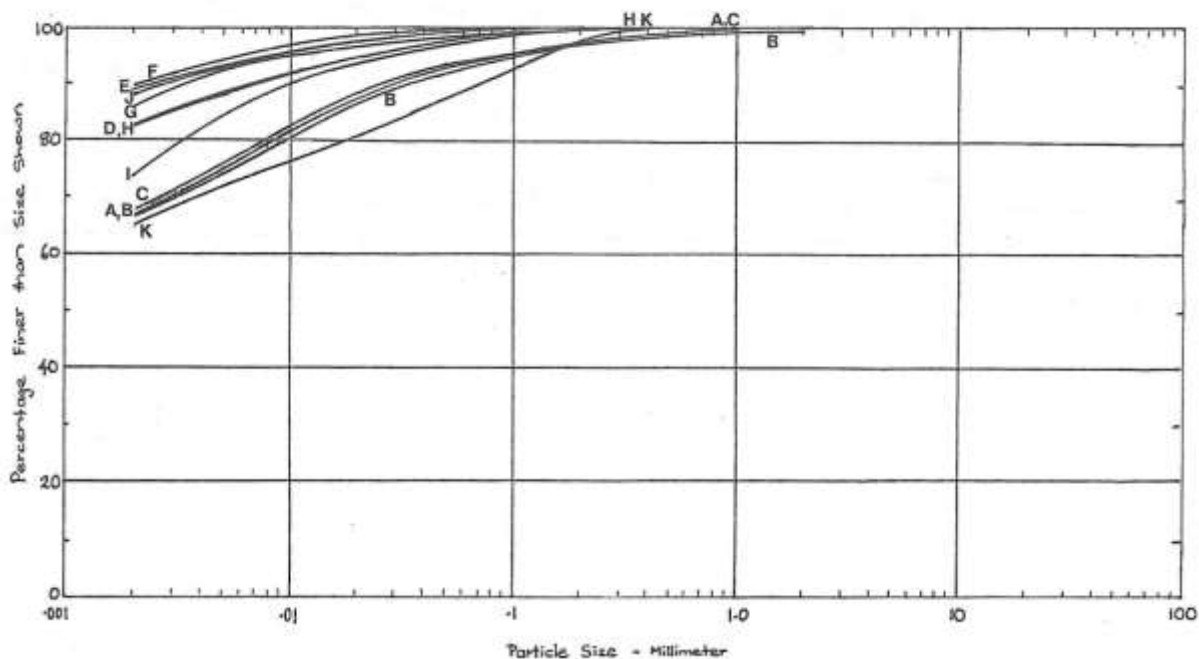
PARTICLE SIZE DISTRIBUTION (<2 mm) Patumahoe

Sample No. SB	Depth (cm)	Hor.	Sand		Silt	Clay	Fine clay	Stones (%)	
			2-0.1 mm (%)	0.1-0.05 mm (%)	0.05-0.002 mm (%)	<0.002 mm (%)	<0.0002 mm (%)		Fine clay Total clay
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 (%)	Air Dry (%)	Core Depth (cm)	Dry bulk density (T/m <sup>3</sup> )	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	Ap1	30.8	24.8	0-6	1.04					
6-15	Ap2	29.8	23.8	7-10	1.00					
15-26	Ap3	30.2	23.7	16-19	0.95					
26-38	Bt1	45.8	31.0	20-23	0.90					
38-58	Bt2	53.4	33.2	31-34	0.78					
58-82	Bt3	64.4	31.4	-	-					
82-98	Bg1	71.0	31.4		1.06					
98-119	Bg2	75.5	30.8		0.94					
119-134	Bg3	68.2	34.4		0.81					
134-165	2Bw	64.4	42.2		0.78					
165-187	3Bw	55.2	31.7		-					

SB 9578 Patumahoe



Sample No. SB	Depth (cm)	Hor.	Clay Fraction (%)													Sand Fraction (%)														
			Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrated Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Hemite	Quartz	Feldspar (acid)	Andesine	Glass	Kaolinite	Biotite	Hornblende	Augite	Hypersthene	Epidote	Cristobalite	Quartz Ag.	Magnetite
9578A	0-6	Ap1		2	9			42	17	20	1	1	7					a	C	C		R	S	tr	R	tr	S	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	S
D	26-38	Bt1		4	20			17	33	15	tr	tr	10					a/A	c	C		S		S		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	S	R
F	58-82	Bt3			16			11	40	21	tr	tr	11					a/A	c/S	c	S		R		tr	tr	S	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			66	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	H		a	a			S	S	S		

Sample No. SB	Hor.	Total Element Analysis (%)											Total Element Analysis (ppm)											Ign. loss (%)
		Fe	Mn	Ti	Ca	K	P	Si	Al	Mg	Na	Cr	Ni	Cu	Zn	Rb	Sr	Y	Ba					
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	15.0	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	0.05	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

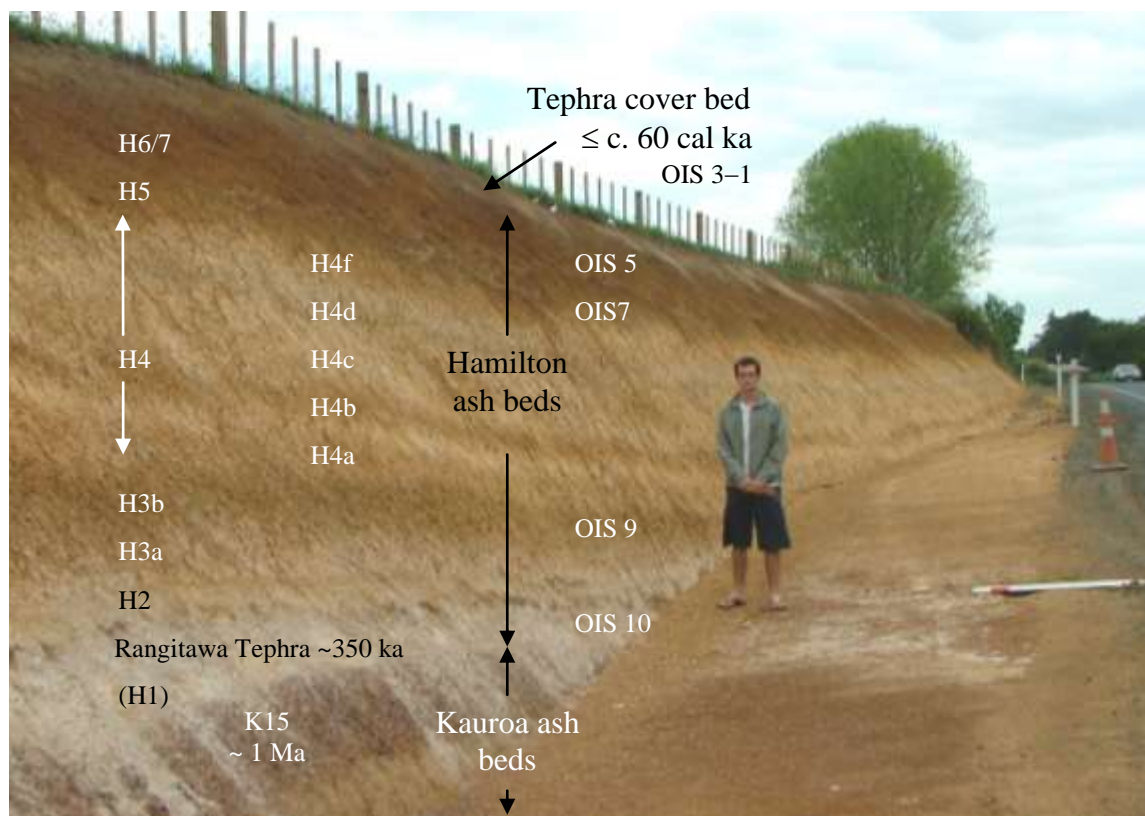
NZSC: Allophanic Oxidic Granular Soils; tephric, rhyolitic; clayey; slow  
 Soil Taxonomy: Clayey, mixed, thermic Andic Palehumults

## STOP 2 – KAINUI SILT LOAM & NAIKE CLAY, GORDONTON RD

Location S14 133859, elevation ~60 m asl, rainfall 1200 mm pa

*Please be very careful of traffic at this stop.*

At this stop are several remarkable features both stratigraphic and pedological, and a ‘two-storied’ soil, the Kainui silt loam alongside (in just a few places) the Naike clay. Both soils are Ultisols. The sequence of tephra beds and buried soil horizons spanning about 1 million years was exposed in 2007 by road works.



Provisional stratigraphy of Gordonton Rd section. Seb provides the scale. *Photo: David Lowe*

### Stratigraphy

(1) At the base of the section is the tiny remnant of an ancient landsurface represented by a buried, clay-rich soil  $>0.78$  Ma on the basis of its reversed magnetism and other evidence (Horrocks, 2000; Lowe et al., 2001). Several undifferentiated beds visible beneath it are likely to be c. 1 Ma or older. These old tephra beds at the base of the Gordonton Rd section (northern end) are part of the so-called Kauroa ash bed sequence, the uppermost unit being the Waiterimu ash member or K15 (Ward, 1967; Lowe and Percival, 1993; Lowe et al., 2001).

(2) Overlying K15, with an unconformity, is the white ~0.5-m thick Rangitawa Tephra aged 0.35 Ma, one of the most widespread tephtras in the southwest Pacific region that fell during Marine Oxygen Isotope (MOI) Stage 10. Rangitawa Tephra is overlain in turn by a ~3-m thick sequence of weathered, yellowish brown to brown to reddish brown clayey tephra beds and buried soils – the Hamilton ash beds – that represent MOI stages 9 to 5. The uppermost distinctive, dark reddish-brown buried soil, known as the Tikotiko ash member or bed H6/7 (Ward, 1967; see below), represents probably the Last Interglacial (OIS 5) paleo-landsurface.

(3) At the top is a thin, silty cover bed mantle of intermixed late Quaternary tephras about 0.4–0.6 m thick, occasionally overthickened in hollows up to ~1.2 m in thickness, that have accumulated incrementally over the past c. 60,000 years (OIS 3–1). As at Pukekohe Hill, the base of the cover bed has been identified as Rotoehu Ash (c. 60 cal ka) but it is evident from detailed mineralogical and geochemical studies that the component tephras making up the composite mantle have been strongly intermixed during upbuilding pedogenesis (Lowe, 1981, 1986, 2000). Nearby lakes, formed c. 20–18 cal ka following deposition of the volcanogenic alluvium of the Hinuera Formation (see stops 3–4), have preserved >40 multiple, thin, visible tephra layers within their sediments (e.g. Green and Lowe, 1985; Lowe, 1988). These tephras each range in thickness from a few millimetres to several centimetres and in this area amount to an estimated ~37 cm in total thickness (Lowe, 1988). Together with tephras deposited between c. 60 and 20 cal ka, they form the parent material of the upper part of the Kainui soil (Lowe, 1986). The thin tephras preserved in the lake sediments are both rhyolitic (predominant) and andesitic and were derived from six volcanic centres 70 to 200 km away (Lowe, 1988). There are likely to be numerous very thin (< 1 mm) ‘non-visible’ tephras or sparse concentration zones of glass shards, known as cryptotephras (Alloway et al., 2007a), in the lake sediments as well as the visible layers. 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 the Kainui soil as ‘dustings’ from small-scale eruption plumes.



(Above)  
Lake Maratoto, south of Hamilton, was formed c. 20 cal ka. *Photo*: David Lowe

(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). *Photo*: David Lowe

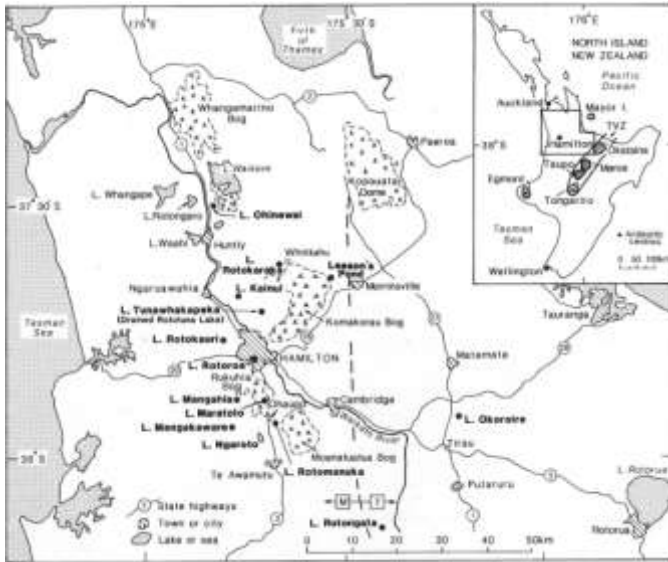


Tuhua c. 7 cal ka  
(Mayor Is./Tuhua VC)

Mamaku c. 8 cal ka  
(Okataina VC)

Rotoma c. 9.5 cal ka  
(Okataina VC)

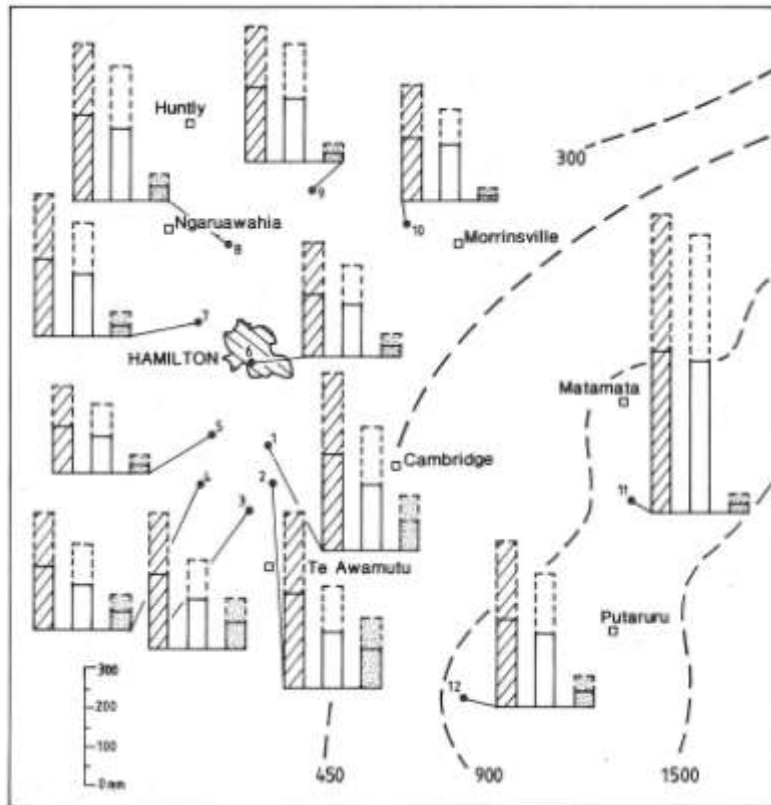
Opepe (E) c. 10.1 cal ka  
(Taupo VC)



(Left) Central Waikato area showing locations of lakes cored to obtain detailed post-c. 20 cal ka tephra record. Gordonton Rd section is near L. Tunawhakapeka. (Right) Cores from Lake Rotomanuka sliced open to show tephra layers preserved in dark lake sediments (from Lowe, 1988).

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.

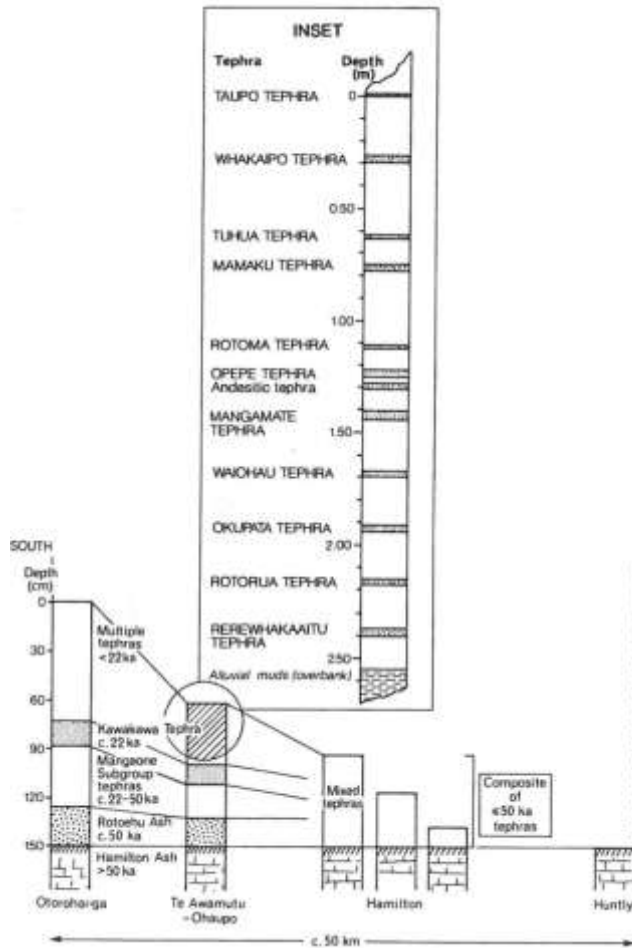
Thickness and compositional relationships based on measurements of tephras in lake cores. Bars with hatching = total thickness of all tephras  $\leq$  c. 20 cal ka; blank bars = rhyolitic tephras; stippled bars = andesitic tephra. Solid bars = actual measurements, dashed bars = thicknesses corrected 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; see also data p.71).



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

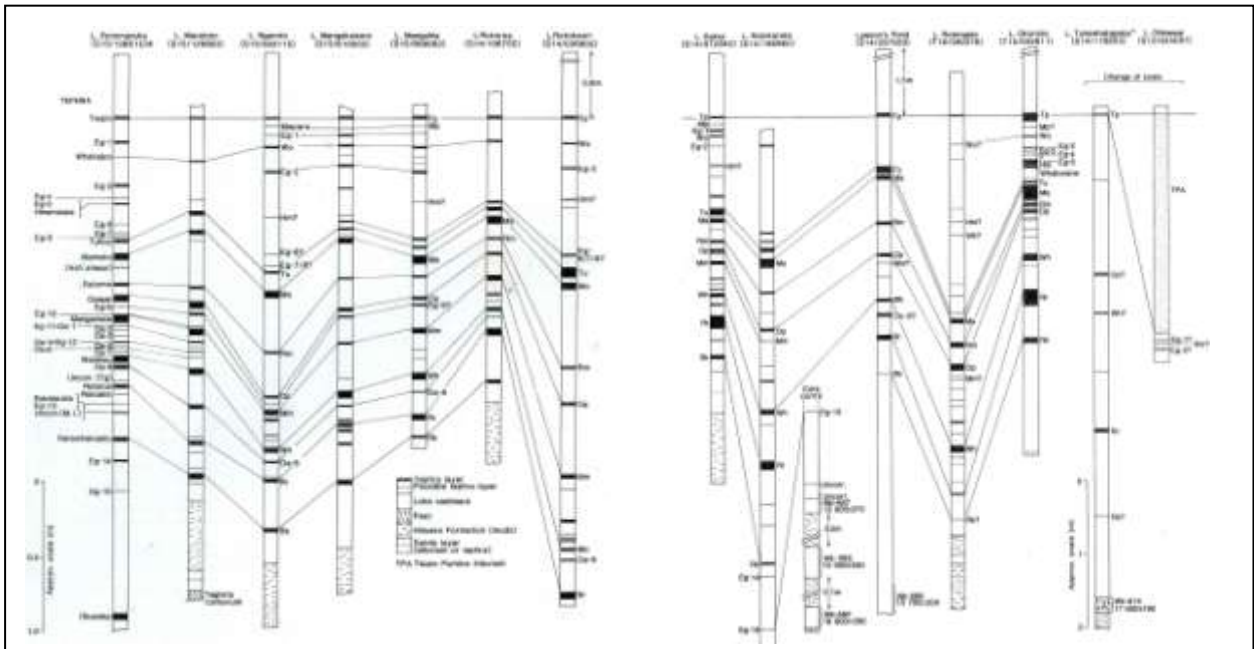
Area	Total visible thickness in cores (average)	Compaction - corrected thickness (visible x1.75)	Estimated dissemination thickness (visible x0.1)	Total equivalent dry-land thickness (approx.)
Hamilton-Ohaupo	25	44	2.5	47
Whitikahu-Morrinsville	20	35	2.0	37
Okoroire-Tirau	42	74	4.2	78

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



**Figure 10.4** Transect across the Hamilton Basin showing the simplified stratigraphy and age of late Quaternary tephra deposits overlying Hamilton Ash on the low hills. Marker beds are distinguishable in the field in the south (Otorohanga and Te Awamutu-Ohaupo profiles) but around Hamilton the tephra deposits, thinning away from their sources, become intermixed to form a composite cover bed with no distinguishable marker beds. Where this cover bed is eroded, exhumed Hamilton Ash occurs at the surface, as for the Huntly profile, but thin late Quaternary tephras are present further north towards Auckland. The inset shows the stratigraphy of prominent tephra layers preserved in lake sediments in a core from Lake Maratoto, a 17 000-year-old peaty lake about midway between Ohaupo and Hamilton (see Figure 10.5). It indicates potential contributions of specific tephras as probable parent materials in the upper soil profile (hatching). ka = 1000 years BP. After Lowe (1986).

Ages in  $^{14}\text{C}$  yr ka. Otorohanga and Ohaupo soils (Hapludands) occur at sites marked by columns 1 and 2; Kainui soils (Udults) at site marked by columns 3-5 ('Hamilton'  $\cong$  Gordonton Rd); and Naikē soils (Humults) at site marked by column 6 ('Huntly') (from Selby and Lowe, 1992).



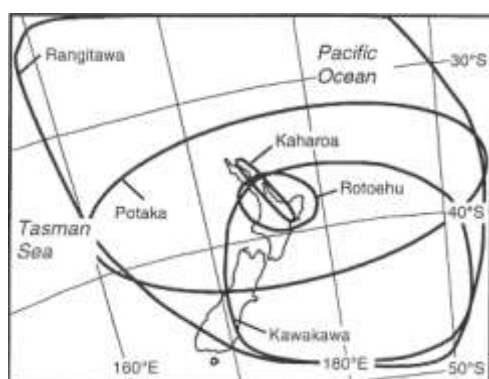
Stratigraphy and correlation of post- c. 20 cal ka visible tephras in cores from 14 Waikato lakes (from Lowe, 1988)

### Kauroa and Hamilton ash bed sequences

The *Kauroa Ash Formation* comprises a sequence up to ~12 m thick of extremely weathered, clay-rich (~70–90% <2- $\mu$ m clay), multiple tephra deposits and associated buried soil horizons, together with interbedded loess (Ward, 1967; Pain, 1975; Horrocks, 2000; Lowe et al., 2001, 2008). The formation was defined in the Waikato area by Ward (1967). The sequence near Raglan is underlain by basaltic deposits dated at c. 2.25 Ma (Briggs et al., 1989), and overlain by the Hamilton Ash Formation, of which the lowermost member (H1 or Rangitawa Tephra) is dated at c. 0.35 Ma (see below). Salter (1979) divided the Kauroa ash sequence into 15 major members, K1 (base) to K15 (top), and this framework, modified in part, has been used subsequently (Briggs et al., 1994; Horrocks, 2000; Lowe et al., 2001). Distinctive sand-sized ‘micaceous’ or platy minerals in beds K3 and K12 are kaolinite books and stacks (Salter, 1979). K1 was dated at  $2.24 \pm 0.29$  Ma by Lowe et al. (2001) using the zircon fission-track method, confirming the previous age. Members K2 and K3 gave indistinguishable ages between  $1.68 \pm 0.12$  and  $1.43 \pm 0.17$  Ma. Member K12, a correlative of Oparau Tephra and Ongatiti Ignimbrite, was dated at  $1.15 \pm 0.15$  Ma, consistent with an age of 1.2–1.3 Ma obtained by various methods on Ongatiti Ignimbrite (Briggs et al., 2005). From palaeomagnetic measurements, members K13 to K15 (top unit) are aged between c. 1.2 Ma and 0.78 Ma (Horrocks, 2000; Lowe et al., 2001). We use an age of c. 1 Ma.

The *Hamilton Ash Formation* comprises a sequence, up to ~6 m thick, of strongly weathered, clay-textured (~60–85% <2- $\mu$ m clay) multiple rhyolitic tephra beds and associated paleosols (Lowe and Percival, 1993; Briggs et al., 1994; Lowe et al., 2001). The sequence may also contain intercalated loessic beds at some sites. The beds are widespread throughout the Waikato and Coromandel regions and extend northward to the Pukekohe area. The sequence is underlain, usually with a marked erosional unconformity, by the Kauroa Ash, of which the uppermost member has an age of ~ 1 Ma (noted above). In turn the Hamilton ash beds are overlain by the composite cover bed of younger multi-sourced tephtras, the basal tephra being Rotoehu Ash c. 60 ka (e.g., see age models in Berryman et al., 2000; Newnham et al., 2004; Wilson et al., 2007).

Ward (1967) divided the Hamilton Ash Formation into members numbered from H1 (basal unit) to H9. However, members H8 and H9 (formerly defined as the ‘Mairoa Ash Member’, but now known to comprise Rotoehu Ash and younger tephtras) are redundant, and so the uppermost beds are H6 and H7 (top unit). These two beds together define the Tikotiko Ash Member. The basal member in the sequence, the Rangitawa Tephra (known previously in the Waikato region as Ohinewai Ash, and elsewhere as Mt Curl Tephra), is characteristically pinkish- to brownish-grey in colour, silty, halloysitic, and contains distinctive sand-sized golden ‘platy’ minerals identified as 2:1:1 interstratified micaceous-kaolinite intergrades (Lowe and Percival, 1993, after Shepherd, 1984). A thin (c. 5 cm) yellowish layer containing coarse sand-sized quartz crystals marks the base of the tephra.



Map showing distal isopachs of five tephtras: Potaka (~1 Ma), Rangitawa (~350 ka), Rotoehu (~60 cal ka), Kawakawa (~27 cal ka), and Kaharoa (~1314 AD) (from Shane, 2000)

Rangitawa Tephra is a distal correlative of Whakamaru-group ignimbrites of similar age derived from Whakamaru caldera (Kohn et al., 1992). Correlation was based on similarities of stratigraphic position and mineralogy, and on major element compositions of glass (Lowe et al., 2001). The tephra was dated by Lowe et al. (2001) using the zircon fission-track technique at  $0.38 \pm 0.04$  Ma. This age matches those obtained by various methods on Rangitawa Tephra of 0.34–0.35 Ma (Pillans et al., 1996; Alloway et al., 2007a), supporting correlation. Member H5 is estimated to be c. 240–190 ka in age, and the youngest members of the sequence, H6–H7, are estimated to be c. 180–80 ka in age (Lowe et al., 2001) (an approximate age of c. 100 ka is used here for the paleo-landsurface).

### Pedological interest

Other interesting features at this site include the markedly irregular boundary between the uppermost cover bed and the dark reddish brown ‘Last Interglacial’ or OIS 5 buried soil – probably the hollows represent tree-overturn pits. Secondly, prominent, approximately horizontal to wavy, thin (1–3 cm), grey clay veins are evident in upper parts of the sequence. They seem to more or less lie along the lower boundary of the dark reddish brown Last Interglacial unit (bed H7/6) and the underlying buried brown soil horizon/unit, probably bed H5. Following Shepherd (1994), Lowe et al. (2001) considered that bed H5 represented soil formation during OIS 7. If so, then it is speculated here that the veins may mark impeded drainage along the OIS 7 paleo-landsurface which is wavy and in places irregular like the tree-overturned surface at the top of the OIS 5 soil now buried by the cover bed tephras (Rotoehu Ash and younger deposits). Manganese concretions (redox segregations or concentrations) occur commonly near the base of this cover bed where drainage is impeded for several months each year by the slowly permeable underlying clayey soil (e.g. Lowe, 1986, 1991; McLeod, 1992). Perhaps the grey veins then are equivalent reductimorphic features – i.e. low chroma mottles (redox depletions) – that developed in tephric materials deposited during OIS 6 over the antecedent clayey and slowly permeable soil formed in OIS 7. Several of the veins tested at this site are currently reduced based on the Childs’ test and so may represent both relict and modern features (sometimes the veins mimic the concave curvature marking the base of the overlying cover beds lying on the OIS 5 paleosurface). The grey clay veins are commonplace in the uppermost weathered Hamilton ash beds sub-parallel to and near the modern land surface in other parts of the Hamilton Basin. Ward (1967) attributed them to soil-forming processes rather than a relict of parent material variations and noted an association with dense root mats in places. He also tentatively linked them with vegetation assemblages containing kauri (*Agathis australis*).



Possible tree overturn features shown up by contrasting colours and textures of pale cover bed tephras (OIS 3-1) and dark reddish-brown soil in weathered upper Hamilton Ash unit H6/7 (OIS 5). Layers of grey (low chroma) clay veins are evident at top of brown unit H5 (OIS 7?) level with Seb’s head. Naike soils occur infrequently where the cover bed is missing. *Photo:* David Lowe

### Kainui soil

The main (modern) soil evident at this site is the *Kainui silt loam* which comprises two parts, the uppermost silty cover bed of late Quaternary tephras, the base of which is Rotoehu Ash (c. 60 ka), and part of the buried clay-rich soil developed on strongly weathered Hamilton ash bed H7/6. In 'Soils of New Zealand' Part 3 (1968) the 'Hamilton clay loam' at Church Rd site is better considered as part of the Kainui series (Lowe, 1981). Kainui soils have been mapped and described by Bruce (1979), Wilson (1980), and McLeod (1984, 1992). The data below are from McLeod (1992) (see also Lowe, 1981). The upper subsoil horizons formed in the tephra cover bed are often sufficiently pale and weakly structured to qualify as E horizons in Clayden and Hewitt (1989) because they contrast with darker buried Bt horizons below. In other cases they are better considered perhaps as pale Bw horizons and occasionally BE horizons. In many instances they exhibit redox features including few to abundant manganese concretions especially towards the boundary with the buried Bt horizon, and subhorizons are labelled accordingly. McLeod (1992) suggested that the upper subsoil horizons are eluvial, which might imply that the underlying Bt horizon complements them as part of a sequum. However, the boundary between the lower E and the 2bBt is a lithological discontinuity (Lowe, 1986) and so the E and Bt horizons have not been 'connected' throughout the entire period of soil genesis. If unrelated, then a 'pale' Bw notation might be more suitable than Ew.



The two-storied Kainui soil is a classic example of the result of progressive upbuilding pedogenesis (Lowe, 2000). The rate of accumulation of tephras since the fall of c. 60-cal ka Rotoehu Ash (~ 25 cm thick here based on a mineralogical abundance model of Lowe, 1981) is on average only about 1 mm per century (about the same rate as very slow loess accumulation on the West Coast, South Island) (Lowe et al., 2008). Thus topdown processes have operated continuously for the past c. 60,000 years while the land surface has been rising very slowly. Each part of the profile has at some point been an A horizon.

The tephra cover bed and the associated Kainui soil are typically halloysitic, not allophanic, because soil solution levels of silicon at this and other sites northward of Hamilton remain high (>~10 ppm) because of slow permeability of the underlying buried soil, markedly dry summers from time to time, and other reasons (Lowe and Percival, 1993; Lowe, 1986, 1995) (see also Singleton et al., 1989). For many years, the non-allophanic character of the relatively young tephra mantle (considered to be loess at one stage because of this character) was a puzzle because allophanic soils occur on late Quaternary tephras south of Hamilton and in upland areas to the west and east of the Hamilton Basin (McCraw, 1967).

However, the development of a rainfall-distribution based silicon leaching model by Parfitt et al. (1983, 1984), supported by stratigraphic and other evidence by Lowe (1986), provided an explanation (Lowe, 2002). As noted by Lowe (1991), the Kainui silt loam was ‘the leopard that changed its spots’ (i.e., it represents genesis in an environment sufficiently different for relatively recent tephra materials to weather directly to halloysite rather than to allophane as occurs not far to the south). Where the cover bed mantle exceeds about 1 m or so in thickness (typically in tree-overturn hollows), the drainage through the composite tephras is less constrained by the impermeable buried clayey soil on Hamilton ash because it is deeper, and consequently allophane can be found in the A and upper Ew (or Bw) horizons (Lowe, 1981, 1986).

### **Naike soil**

The *Naike clay* is formed on weathered Hamilton ash, i.e. without the silty cover bed mantle (apart from perhaps ~10-15 cm forming an A horizon with silt). It is very similar to soils of the Hamilton series. The Naike soils are thus exhumed buried soils (buried paleosols) from which any subsequent tephras have been eroded, and are likely to be at least c. 100-125 ka, possibly older if earlier beds in the Hamilton Ash sequence have been exhumed. Like the Pukekohe and Patumahoe soils, the Naike soil is sticky when wet and topsoils have very limited workability in this condition, but the Naike clay is firmer, denser and more compacted. Bulk densities exceed  $1 \text{ g/cm}^3$  in Bt horizons. The clay mineral assemblage of the Naike soil is predominantly halloysite without the ‘moderating’ influence of allophane and gibbsite that occur in the Pukekohe area. The Naike soil has a well developed, strong pedal microstructure with 90% of the material finer than  $20 \mu\text{m}$  (Bakker et al., 1996). Topsoils, however, tend to be more “cloddy” and never seem to attain the same level of “tilth” as Pukekohe or Patumahoe soils (G.E. Orbell pers. comm., 2008).

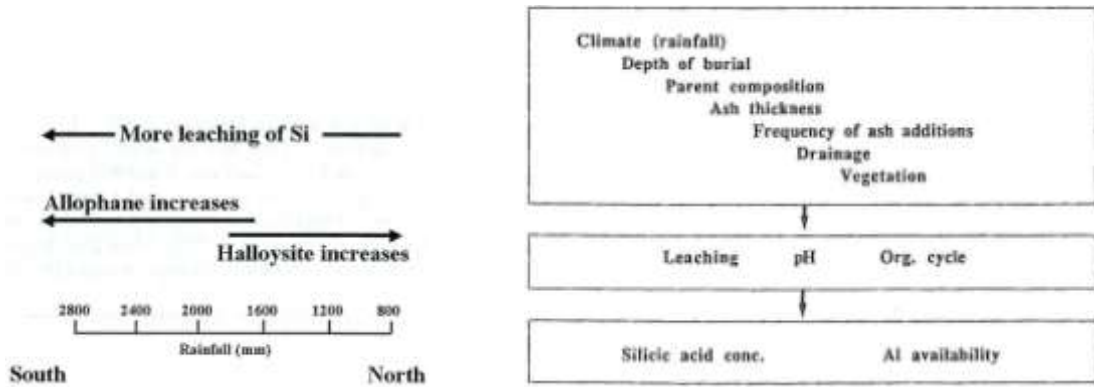
The Naike soil becomes more weathered with depth, suggesting upbuilding pedogenesis has predominated. Large quantities of microlaminated, anisotropic clay coatings (halloysite or kaolinite, the less-ordered character observed micromorphologically strongly favouring the former) are present in Bt horizons and are the result of clay illuviation (fine clay: total clay ratios of 0.7 to 0.8 support this inference) (Bakker et al., 1996). The clay coatings have been responsible for impeding drainage (and thus further reducing loss of Si and favouring more halloysite production). Cutans in a bBtg horizon have iron hypocoatings. The gleying is a more recent process than the clay illuviation because the hypocoatings are superimposed upon the clay coatings (Bakker et al., 1996). Large amounts of Fe oxide coatings observed in both Patumahoe and Naike soils provide the reddish brown to strong brown colours in the Bt horizons of both soils.

The differences between the Naike and Patumahoe soils, despite similar parent materials, were attributed by Bakker et al. (1996) to slightly different climatic and vegetation histories at each site: pollen studies have shown that the Pukekohe area has probably always been under forest cover, whereas the Hamilton Basin has additionally experienced a drier, grass or shrub-dominated vegetation cover during the last glacial period (e.g., Newnham et al., 1989, 1999; Alloway et al., 2007b) and presumably earlier glacial periods as well including OIS 6. Thus Bakker et al. (1996) inferred that the Patumahoe and Pukekohe sites were effectively warmer and wetter, thereby favouring the formation of allophane and presumably gibbsite and Fe oxides through enhanced Si leaching. In contrast, the postulated drier conditions (during the glacial) for the Naike site may have been sufficient to reduce Si leaching to levels favouring halloysite formation. Data on Naike are available in Parfitt et al. (1981, p. 78-83), Bakker et al. (1996), and in ‘Soils of New Zealand’ Part 3 (p. 90-91). Naike or Hamilton soils have been described and mapped in the Waikato area by Bruce (1978, 1979), Wilson (1980), McLeod (1984) and Singleton (1991).

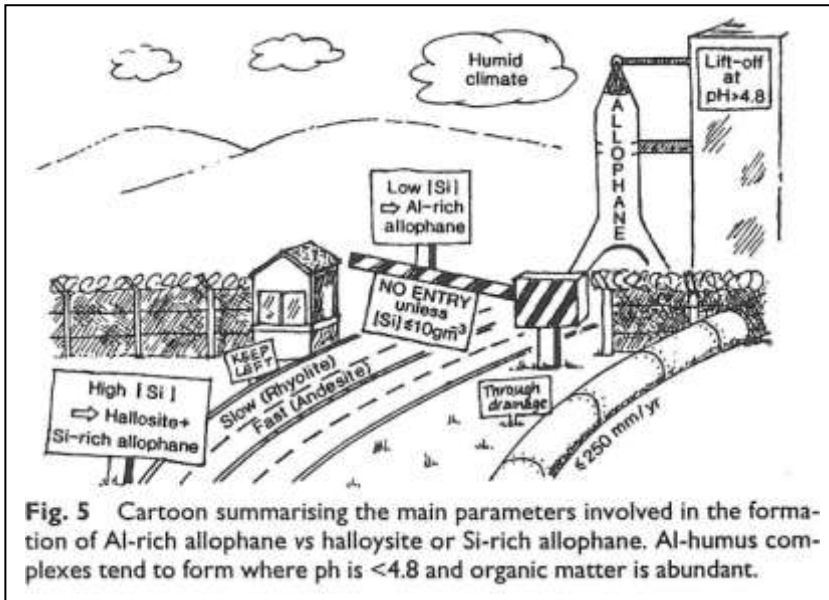
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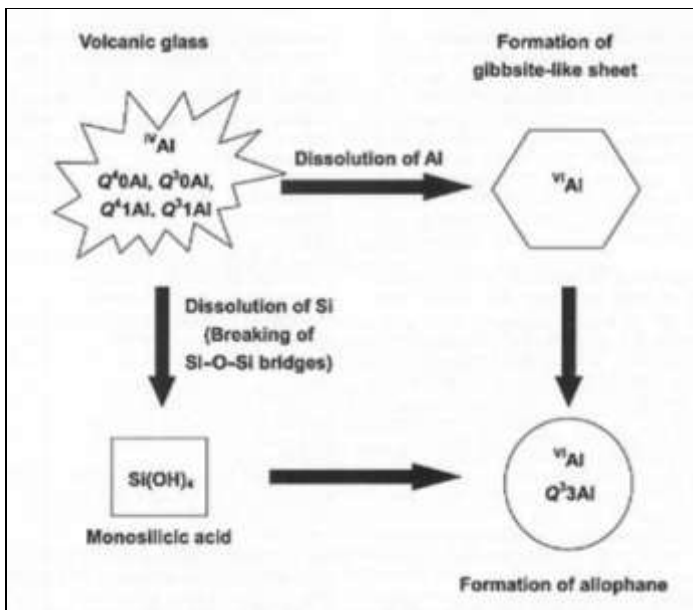
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(Left) Simplified rainfall-based Si-leaching model for the formation of Al-rich allophane and halloysite from weathering of tephras in the Waikato region (from Lowe, 2002, after Parfitt et al., 1983). A more comprehensive model is given by Lowe (1986) and Lowe and Percival (1993). (Right) Some factors governing clay formation in volcanic ash materials (humans could be added, e.g., via burning/deforestation) and the key 'elements' (!) of silicic acid concentration and Al availability (from Lowe, 1995).



Cartoon summarising model (from Lowe, 1995; see also Singleton et al., 1989).



Model based on Japanese studies for the formation of allophane from glass (from Hiradate and Wada, 2005).

## Description and data for Kainui silt loam

Hauraki Plains survey (by Malcolm McLeod and Brian Daly(?))

B. Nos. SB9801A-F  
 id Nos. HC 12 9- F

SOIL SET: \_\_\_\_\_ Est./Thm. Mod./Var. \_\_\_\_\_  
 CLASSIFICATION (in full)—Common: \_\_\_\_\_  
 Technical: \_\_\_\_\_  
 SURVEY: *Hauraki Plains County* Collector: *MM BD* Date: *9-8-82* Pit/Comp. (cores) \_\_\_\_\_  
 LOCATION—County: *Hauraki Plains* Survey District: *H. P.* Block: \_\_\_\_\_ Cult'd./Uncult'd./Virgin \_\_\_\_\_  
 Orientation: \_\_\_\_\_ Section: \_\_\_\_\_ Topdr./Untopdr. \_\_\_\_\_  
 Exact Location: *Top NE corner of paddock* Farmer: \_\_\_\_\_  
 Grid Ref. *NEAMS 1752 900052*

Altitude: \_\_\_\_\_ ft (30 m) Rainfall: *1200 - 1400* mm Raindays (>0.01"): \_\_\_\_\_ (>0.05"): \_\_\_\_\_ Mean Annual Temp.: *13.6* (°C)

Field No.	Lab. No.	Horiz.	Depth in cm	DESCRIPTION—Colour, Texture, Consistence, Structure, Boundary, etc.
HC12 a	9801 A	Ap	0-16	10YR 3/2 with some 10YR 4/2 wash mixing from below; silt loam; moderately weak; brittle; few fine pores; weak fine root breaking to crumb; many fine roots; distinct irregular boundary.
HC12 b	9801-B	Ew1	16-32	10YR 5/3 silt loam; very weak; brittle; many medium pores; weak fine root breaking to crumb; few fine roots; indistinct wavy boundary.
HC12 c	C	Ew2	32-47	10YR 5/4 clay loam; moderately weak; brittle; many medium & coarse pores; weak fine root structure; few fine roots; indistinct wavy boundary.
HC12 d	2bBt(g)		47-86	7.5YR 4/6 with horizontal veins 7.5YR 6/2 plus organic matter down cracks 7.5YR 4/2; clay; moderately firm; brittle; very few medium pores; abundant clay films; moderately developed medium & coarse blocky breaking to fine blocky; few fine roots down cracks; distinct wavy boundary.
HC12 e	9801 3bBt(f)	E	86-108	7.5YR 4/6 with few medium distinct 10YR 5/8 mottles; clay; brittle; moderately weak; few medium pores; very firm in situ; weak medium blocky; many clay films; no roots.
		F	@ 190	

**DJL note** \* Colour criteria qualify these upper subsoil horizons as E horizons (Clayden and Hewitt, 1989) but note that there is a lithological discontinuity at 47 cm depth where 2bBt(g) horizon is recognised. McLeod (1992) suggested that the upper subsoil horizons = eluvial horizon.

SITE—Slope: *6* Nature of Slope: \_\_\_\_\_  
 Aspect: *SE* Exposure: \_\_\_\_\_  
 Microfeatures: \_\_\_\_\_  
 Erosion: *Slight creep.*  
 Disturbance: \_\_\_\_\_  
 Drainage: *Moderately well drained*

VEGETATION (over sample)—Height: *10cm* Main Species: *Pasture grasses*  
 (at site)—Height: *10cm* Main Species: \_\_\_\_\_  
 Type of Vegetation: \_\_\_\_\_  
 History: \_\_\_\_\_

Root Distribution: \_\_\_\_\_  
 PARENT MATERIAL: *47cm moderately argillised late Pleistocene rhyolitic and andesitic volcanic ash over strongly argillised Pleistocene rhyolitic and andesitic volcanic ash.*  
 Parent Rock: \_\_\_\_\_

### Classification: Kainui silt loam

NZSC: Podzolic<sup>1</sup> [or 'Buried-granular'] Yellow Ultic Soils; tephric, mixed rhyolitic and andesitic<sup>2</sup>; silty/clayey; moderate/slow

Soil Taxonomy: Clayey, halloysitic, thermic Aquic [or Oxyaquic] Kandiodults

<sup>1</sup>It is possible that the 'organic matter down cracks' noted for 2bBt(g) in above description might be MnO<sub>2</sub> (pyrolusite) coatings, abundant in lower subsoils (near boundary upper/lower parts of profile) of many Kainui soils. For 'Podzolic' subgroup Hewitt (1998) requires ≥10% humus coatings or coatings of colour value ≤4, and pH ≤4.8 in the E horizon if present. My preferred classification is to add a new 'Buried-granular' subgroup, rather than use Podzolic subgroup, to encompass widespread Kainui soils.

<sup>2</sup>See Clayden and Webb (1994) p. 14 – differentiated using ferromagnesian mineral assemblages of sand fractions (see also compositional data in Lowe, 1981, 1986, 1989)



Kainui

FABRIC-RELATED ANALYSIS

Kainui 2/1/10m

Lab no.	Horiz. Depth (cm)	Sample Depth (cm)	As sampled		1/3 bar		GOLE	Total porosity (%)	Large pores (%)	Water content (% w/w at tensions (bar))						Field capacity (% w/w)	15 bar water (% w/w)	Shrinkage (mm)
			w.c. (%)	Bulk Density (T/m <sup>3</sup> )	w.c. (%)	Bulk Density (T/m <sup>3</sup> )				0.025	0.06	0.1	0.2	0.4	1.0			
PA 43A	0-16	5-8	38.3	1.19				51.2	3.5	47.7	45.2	42.6	40.3	38.1	42.6	17.8	24.9	
B		9-12	31.0	1.19				51.8	13.1	38.7	36.7	34.7	32.3	30.2	34.7	17.7	16.4	
1114 A	16-32	21-24	24.0	1.45				42.5	6.8	35.7	34.7	33.6	31.9	29.3	33.6	20.5	13.1	
B		25-28	24.3	1.48				41.9	5.4	36.3	35.6	34.4	32.6	29.6	34.4	20.8	13.6	
1115 A	32-47	36-39	25.8	1.45				43.3	5.1	38.1	37.2	36.3	34.9	32.5	36.3	30.2	6.2	
B		40-42	28.4	1.37				45.9	5.1	40.9	40.1	39.5	38.8	37.4	37.5	28.9	10.6	
1116 A	47-86	63-66	42.3	1.20				54.0	2.1	51.9	51.1	49.2	48.0	46.2	49.2	50.3	0.0	
B		67-70	47.0	1.14				56.0	1.2	54.9	54.7	54.6	54.5	53.9	54.6	47.8	7.0	
1117 A	86-108	93-96	69.3	0.93				65.2	6.6	59.7	57.2	56.0	55.5	54.7	56.8	50.6	5.4	
B		97-100	60.1	1.00				61.6	5.0	62.4	62.1	62.0	61.6	60.9	62.0	54.9	7.3	

CLAY MINERALOGY (%):

Lab No.	Horiz.	Depth	Mica/Biotite	Chlorite	Vermiculite	Smectite	Kaolin Group	Halloysite	Interstratified Minerals				Short Range Order Min.		Feldspar	Quartz	Calcite	Gypsum	Hematite	Cribellate
									Mica-Verm	Mica-Smect	Mica-Chlor	Int. Hyd. Mica	Allophane & Imogolite	Ferrihydrite						
889801 A	Op	0-16				52														
B	Ev 1	16-32	9		7	5	68													
C	Ev 2	32-47	5		6	3	80													
D	2+ Bt (g)	47-86	3		5	5	81													
E	3+ Bt (f)	86-100	2		6	8%														

Notes:  
By Formamide Test 80% of the Kaolin group minerals is Halloysite



Feeding out during Waikato drought 2008 (photo 4 April 2008 by David Lowe)

**Description and data for Naike heavy silt loam  
Rotowaro (near Huntly)**

**NAIKE HEAVY SILT LOAM**

Location: 11 m west of roadside pump house, north of woolshed  
 Aspect: 40°E Altitude (m): 100 Rainfall (mm): 1240 Slope: 8° Landform: Side slope of northern oriented spur of hill  
 Vegetation: Ryegrass, white clover, brometop, pampalium, thistles, after broadleaf/podocarp forest Drainage class: Moderately well drained  
 Land use: Sheep, dairying, (coal mining) Parent material: Hamilton Ash Formation Grid ref: N56/1

Horizon Depth (cm)	Horizon	Profile Description	Horizon Depth (cm)	Profile Description
Ap 0-12	10YR 3/2 heavy silt loam; strong fine nut (peds very hard); moderately firm; brittle; abundant coarse pores; abundant roots, many clean quartz crystals or glass shards; diffuse wavy boundary,	Btg 97-131	7.5YR 5/6 (moist) 7.5YR 6/6 (rubbed) clay; moderately sticky; moderately plastic; moderately firm; brittle; many distinct fine and medium 5YR 4/6 mottles; few fine roots; moderately developed medium block structure; many coarse at medium pores; few thin discontinuous cutans; many very fine pinkish white flecks; diffuse wavy boundary	
Bw 12-20	7.5YR 4/6 (moist) 10YR 4/4 (rubbed) clay loam; slightly sticky; slightly plastic; moderately firm; brittle; abundant 10YR 3/2 casts of Ap horizon; abundant roots; very few very thin cutans; strong fine nut structure; many coarse pores; diffuse wavy boundary,	Bwg 131-153	5YR 5/6 (moist) 7.5YR 6/6 (rubbed) clay; moderate sticky; very plastic; moderately firm; brittle; moderately developed medium block structure; few very coarse many coarse and medium pores; abundant fine and medium pinkish white flecks (7 gibbsite) few fine and medium diffuse 5YR 4/4 mottles; few fine roots; few very thin discontinuous cutans; indistinct wavy boundary,	
Bt1 20-48	7.5YR 4/6 (moist) 7.5YR 5/6 (rubbed) clay; moderately sticky; moderately plastic; moderately firm; brittle; few coarse many medium pores; many thin continuous cutans; (no grains showing through coatings); strongly developed medium nut structure; many roots; diffuse wavy boundary,	Cg1 153-165	7.5YR 5/8 (moist) 7.5YR 6/6 (rubbed) clay; slight sticky; very plastic; moderately firm; brittle; w developed coarse block structure; many coarse m medium pores; abundant coarse and medium pinkish white (7.5YR 8/2) (7gibbsite/halloysite) nodules; faint diffuse 5YR 4/4 patches; very few fine root indistinct wavy boundary,	
Bt2 48-73	7.5YR 4/6 (moist) 7.5YR 5/6 (rubbed) clay; slightly sticky; moderately plastic; moderately firm; brittle; strongly developed medium block structure; many roots; many thin continuous cutans (no grains showing through); moderately firm; brittle; (peds are very firm); many fine and very fine pinkish white flecks; moderately developed medium block structure; diffuse wavy boundary,	Cg2 165-181	7.5YR 6/6 (moist) 7.5YR 7/6 (rubbed) clay; slight sticky; very plastic; abundant very coarse and cc 7.5YR 7/4 distinct mottles; abundant fine and med 5YR 5/8 distinct mottles; many diffuse 2.5Y 7/4 patches; many coarse and medium pores; very few roots; moderately firm; semi-deformable; moderate weakly developed coarse block structure; few ver discontinuous cutans; distinct wavy boundary,	
Bt3 73-97	between 7.5YR 4/6-5/6 (moist) 7.5YR 5/8 (rubbed) clay; slightly sticky; moderately plastic; moderately firm; brittle; few roots; many fine pinkish white flecks; few faint diffuse fine 5YR 4/4 mottles; many very thin continuous cutans; moderately developed medium block structure; diffuse wavy boundary,	2Rt 181-215	5YR 4/6 (no change on rubbing) clay; slightly sti slightly plastic; moderately firm; brittle; many medium diffuse near 5Y 7/3 patches; many coarse a pores; weakly developed coarse block structure; many thin continuous cutans; few coarse prominent quartz grains.	

CLASSIFICATION - N.Z. Genetic: Brown granular loam

**Classification: Naike heavy silt loam**

**NZSC:** Typic Oxidic Granular Soils; tephric, rhyolitic; clayey; slow  
**Soil Taxonomy:** Clayey, halloysitic, thermic Typic Kandihumults

CHEMISTRY		NAIKE																		
Sample No. SB	Depth (cm)	Hor.	pH					Exchangeable cations (meq/100 g)					Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CSC (meq/100 g)			Base saturation (%)	
			H <sub>2</sub> O	KCl	ΔpH	NaF	Ca	Mg	K	Na	H (KCl)	Al (KCl)				MH	OH	Σ Cations (pH 8.2)	I bases (CSC NH <sub>4</sub> OH)	E bases (Σ Cations)
9579	A	0-12	Ap	5.6	4.5	-1.1	8.7	10.8	1.83	0.86	0.28		0.26	27.8	27.5	14.1	25.4	41.6	54	33
	B	12-20	Bw	5.6	4.4	-1.2	9.3	6.3	1.46	1.15	0.43		0.32	20.7	20.4	9.6	17.8	30.0	52	31
	C	20-48	Bt1	5.3	4.1	-1.2	9.6	3.4	1.10	0.44	0.94		1.5	21.3	19.8	7.4	16.1	27.2	27	22
	D	48-73	Bt2	5.2	3.9	-1.3	9.6	1.9	0.88	0.10	1.15		2.9	23.4	20.5	6.9	16.0	27.4	25	15
	E	73-97	Bt3	5.3	3.9	-1.4	9.8	1.5	0.78	0.06	1.21		3.0	23.7	20.7	6.6	15.5	27.5	23	13
	F	97-131	Btg	5.5	3.9	-1.6	9.7	1.4	0.67	0.16	1.41		2.3	18.5	16.2	5.9	14.0	22.1	26	16
	G	131-153	Bwg	5.4	3.9	-1.5	9.7	1.2	0.47	0.13	1.28		2.8	18.1	15.3	5.9	12.7	21.2	24	15
	H	153-165	Cg1	5.3	3.9	-1.4	9.7	0.9	0.40	0.05	1.08		2.4	15.4	13.0	4.8	11.4	17.8	21	13
	I	165-181	Cg2	5.3	3.9	-1.4	9.7	0.9	0.37	0.05	0.96		2.0	13.5	11.5	4.3	10.1	15.8	23	15

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g)			P Retention (%)	Dithionite sol. (%)		Tannin ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)	
					H <sub>2</sub> SO <sub>4</sub> (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K <sub>c</sub>	Mg <sub>r</sub>		
9579	A	0-12	Ap	6.6	0.48	39	45	56	52	2.8	0.79	0.49	0.32	0.03	0.64	0.32	0.07	1.5	17
	B	12-20	Bw	2.5	0.16	8	11	14	63	3.2	0.82	0.39	0.35	0.02	0.81	0.46	0.06	0.9	24
	C	20-48	Bt1	1.0	0.06	4	6	5	70	3.6	0.76	0.27	0.34	0.02	1.03	0.33	0.05	0.7	188
	D	48-73	Bt2	0.7	0.03	4	5	6	75	3.6	0.80	0.24	0.38	0.02	0.97	0.32	0.04	0.7	329
	E	73-97	Bt3	0.6	0.03	5	6	5	75	3.6	0.84	0.33	0.46	0.06	0.90	0.33	0.03	0.7	314
	F	97-131	Btg	0.4	0.01	4	5	2	70	3.1	0.60	0.19	0.29	0.04	0.45	0.19	0.04	0.5	321
	G	131-153	Bwg	0.3	0.01	4	4	0	64	2.3	0.47	0.18	0.29	0.04	0.27	0.13	0.04	0.6	279
	H	153-165	Cg1	0.2	0.01	4	2	0	58	1.08	0.41	0.11	0.24	0.06	0.13	0.10	0.05	1.4	225
	I	165-181	Cg2	0.2	0.01	3	2	0	51	1.59	0.35	0.09	0.21	0.04	0.09	0.11	0.06	2.2	186

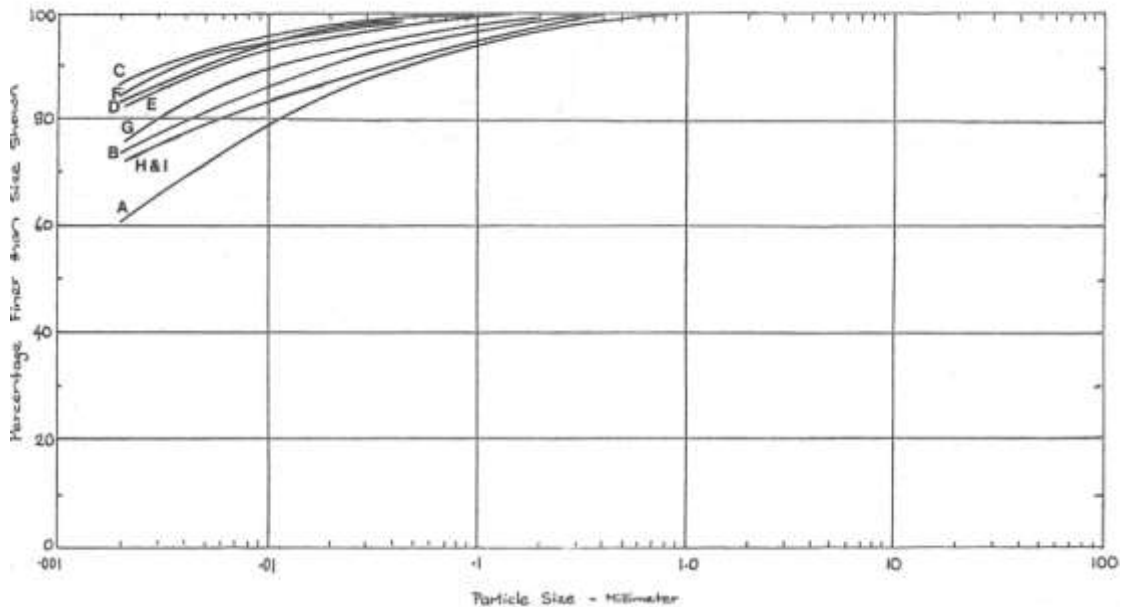
PARTICLE SIZE DISTRIBUTION (<2 mm) Naike

Sample No. SB	Depth (cm)	Hor.	Sand		Silt	Clay	Fine clay	Fine clay Total clay	Stones (%)
			2-0.1 mm (%)	0.1-0.05 mm (%)	0.05-0.002 mm (%)	<0.002 mm (%)	<0.0002 mm (%)		
9579A	0-12	Ap	6	3	30	61	41	0.67	(<1)
B	12-20	Bw	3	3	19	75	60	0.80	
C	20-48	Bt1	1	0	12	87	70	0.80	
D	48-73	Bt2	1	1	15	83	63	0.76	
E	73-97	Bt3	1	1	16	82	59	0.72	
F	97-131	Btg	1	1	13	85	57	0.67	
G	131-153	Bwg	2	2	20	76	50	0.66	
H	153-165	Cg1	5	3	21	71	40	0.56	
I	165-181	Cg2	5	4	19	72	39	0.54	

PHYSICS

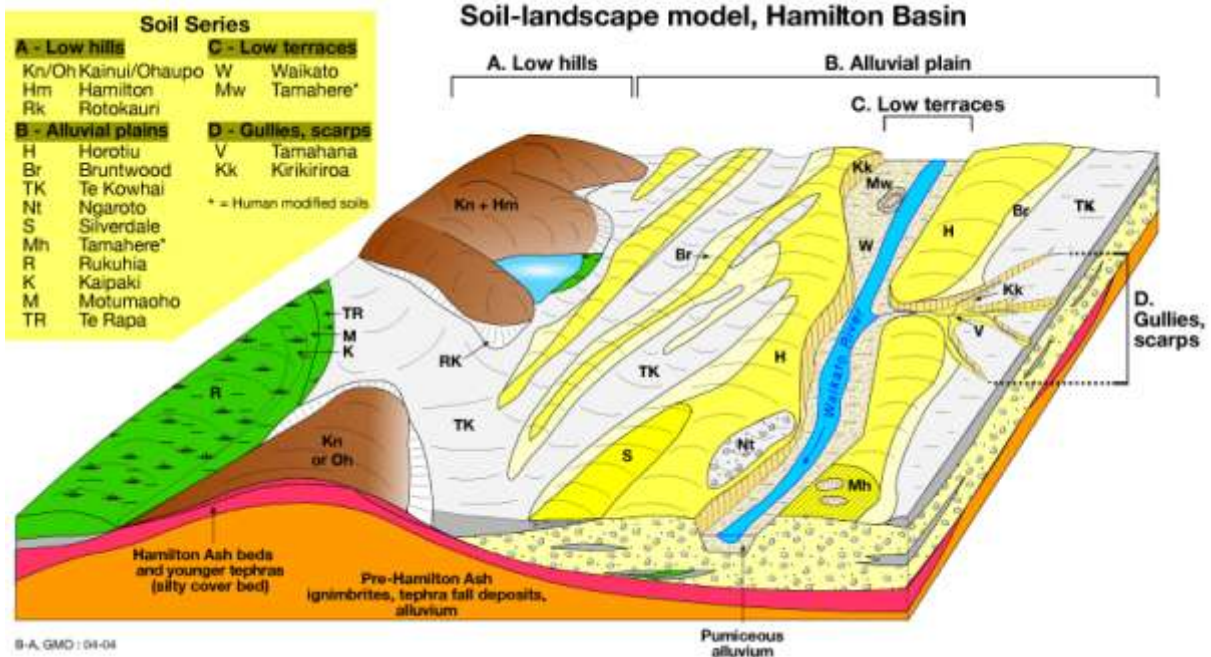
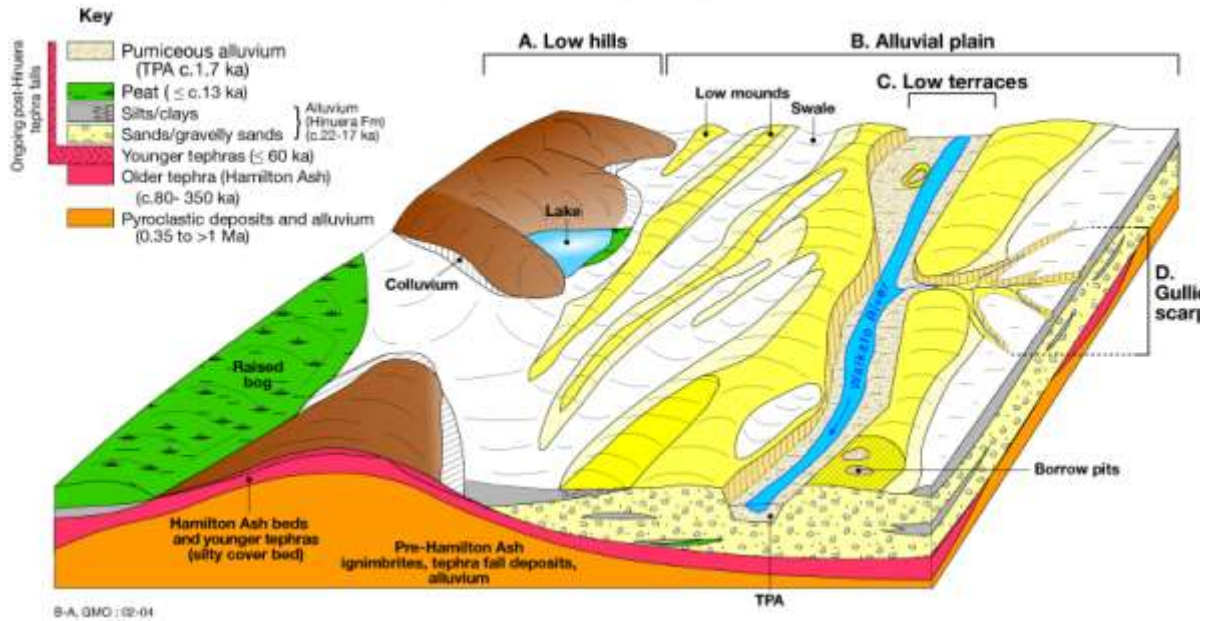
Hor. Depth (cm)	Hor.	15 bar water		Core Depth (cm)	Dry bulk density ( $T/m^3$ )	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
		Field moist (%)	Air Dry (%)							
0-12	Ap	28.7	24.8	3-5	0.85					
12-20	Bw	35.6	28.5	6-9	0.92					
20-48	Bt1	45.3	34.6	13-16	0.98					
48-73	Bt2	50.7	36.4	17-20	0.91					
73-97	Bt3	52.4	36.4	20-48	1.14					
97-131	Btg	57.0	40.2	48-73	1.11					
131-153	Bwg	53.4	39.3	73-97	0.94					
153-165	Cg1	48.4	36.6	97-131	0.93					
165-181	Cg2	42.8	33.4	131-165	1.01					
				165-181	1.02					

SB 9579 Naike





**Main landscape units and geological materials, Hamilton Basin**



(Upper) Main landscape units and geological materials in the Hamilton Basin and (lower) associated soil series (constructed by D.J. Lowe after McCraw, 1967; Bruce, 1979; Singleton, 1991). Hamilton soils are similar to Naikē soils (not depicted on map). The regional geology was described by Kear and Schofield (1978) and Edbrooke (2005); the geomorphology was described by Selby and Lowe (1992).

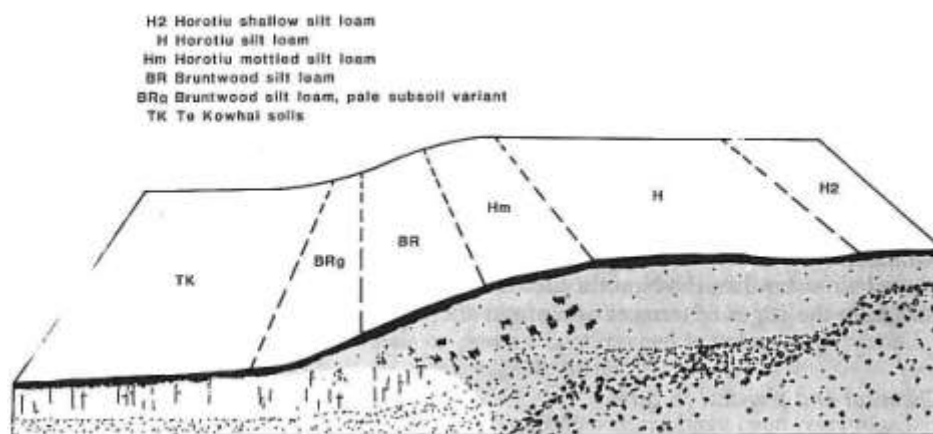
### STOP 3 – HOROTIU SANDY LOAM, HOROTIU MOTTLED SILT LOAM, MARKEVIN LANE (PENCARROW RD)

Location S15 179679, elevation ~50 m asl, rainfall ~1200 mm pa

Two soils for the price of one!



Landscape positions for Horotiu mottled silt loam (left) and Horotiu sandy loam (right) in Markevin Lane off Pencarrow Road. The road cuts down through a terrace on volcanogenic alluvial sediments of the Hinuera Formation near the Waikato River. A thin mantle (~50-70 cm) of tephras (overlying the Hinuera Formation) forms the uppermost lithology (Lowe, 1988). Rate of tephra accumulation since c. 18 cal ka is ~4 mm per century. See soil-landscape model previous page. Detailed landscape position model is given below. *Photos:* David Lowe. Nearby on lower terrace and elsewhere along the Waikato River in the Hamilton Basin are Maori-modified soils (Tamahere series) developed for growing sweet potato (kumara) brought from eastern Polynesia but ultimately derived from South America (see review by Gumbley et al., 2004).



Soil-landscape model showing relationship between soils of the Horotiu series, especially H and Hm, and Bruntwood and Te Kowhai series (from Singleton, 1991)

#### **Classification: Horotiu sandy loam**

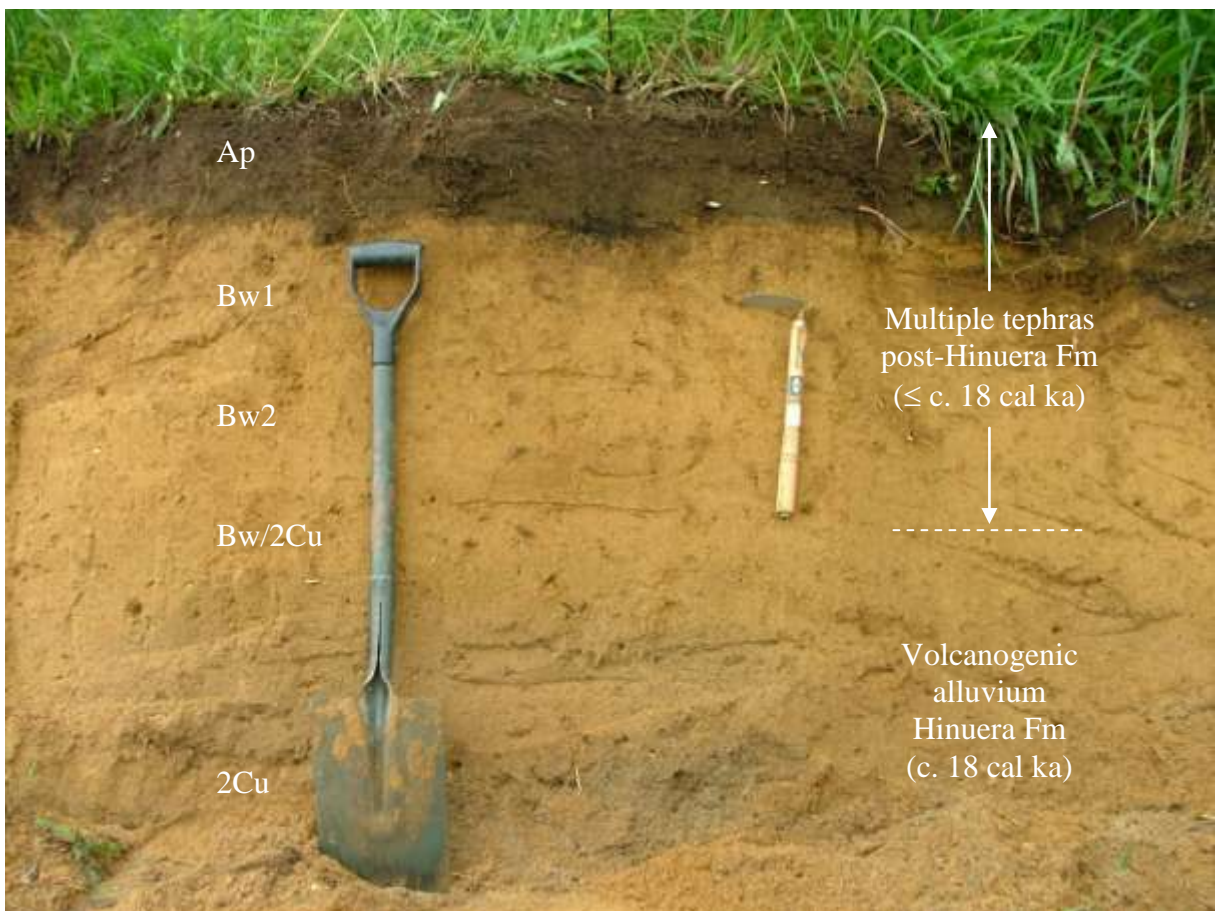
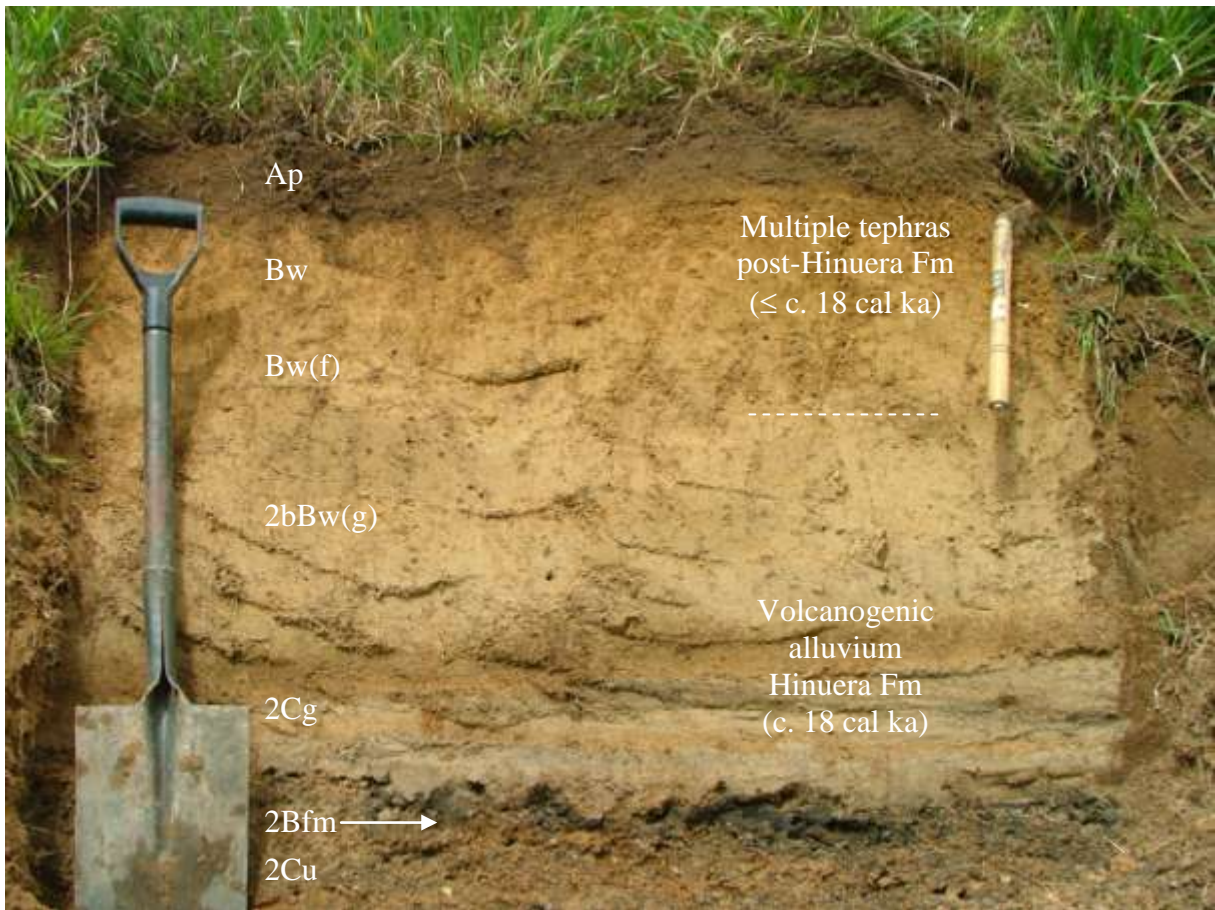
**NZSC:** Typic Orthic Allophanic Soils; tephric, mixed rhyolitic and andesitic; loamy/sandy [silty/sandy at Pony Club site]; moderate/rapid

**Soil Taxonomy:** Medial/sandy-skeletal, thermic Vitric Hapludands

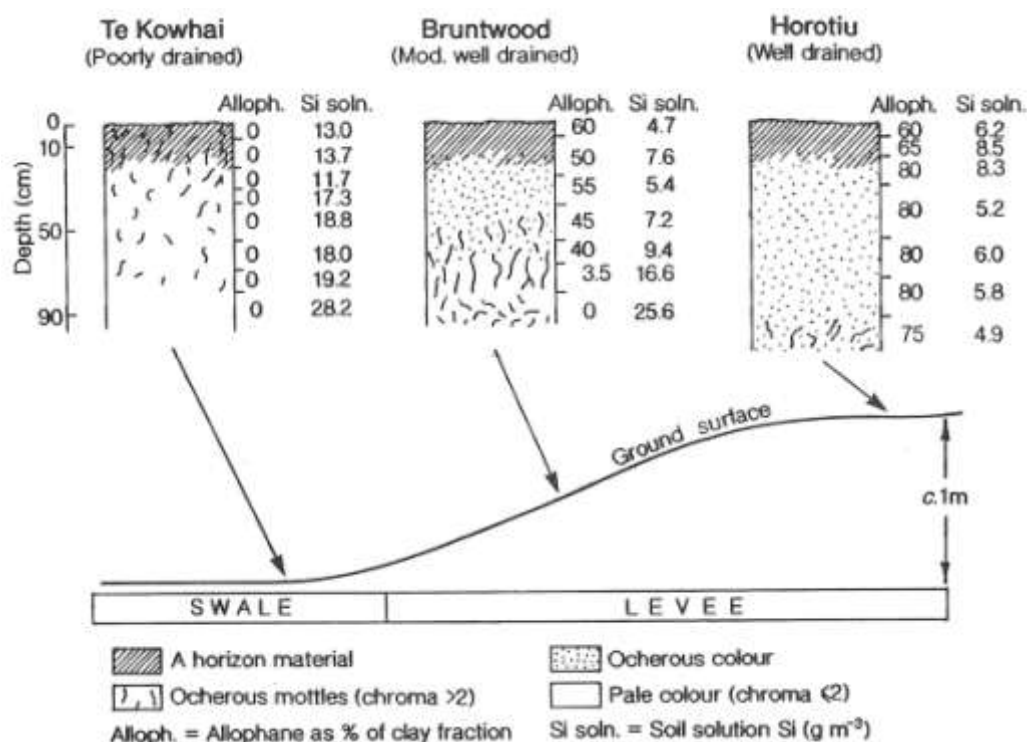
#### **Classification: Horotiu mottled silt loam**

**NZSC:** Mottled Impeded Allophanic Soils; tephric, mixed rhyolitic and andesitic; silty/fine sandy; moderate/slow

**Soil Taxonomy:** Medial/fine-silty, thermic Aquic Placudands



Provisional stratigraphy and horization of (top) Horotiu mottled silt loam (uncertain!), and (bottom) Horotiu sandy loam.



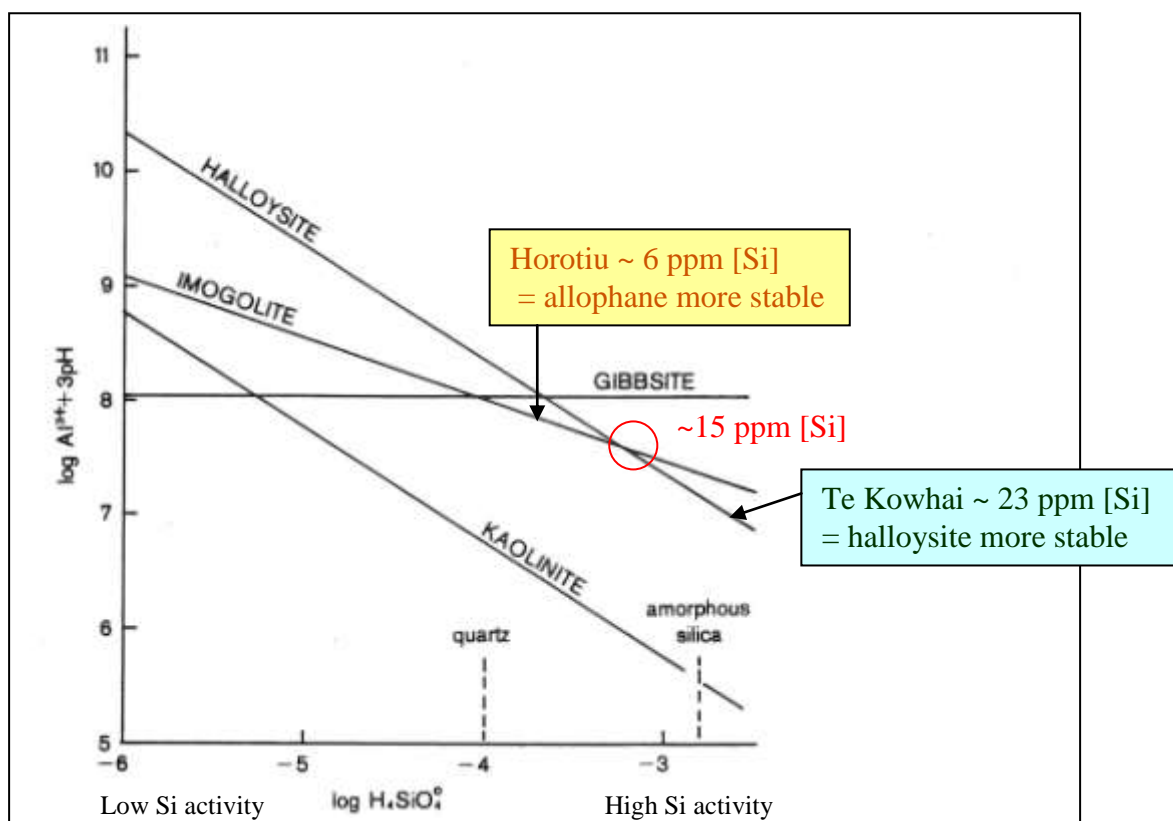
Horotiu–Bruntwood–Te Kowhai soil drainage leaching sequence and associated mineralogical and soil-solution analyses at Ruakura (after Singleton et al., 1989) (reproduced from Lowe and Percival, 1993). The soil solution studies confirmed the general leaching model proposed by Parfitt et al. (1983, 1984) and Lowe (1986). The threshold value of about 10 to 15 ppm of silicon in soil solution matched closely thermodynamic stability diagrams because below ~10 ppm, allophane is more stable than halloysite whereas above ~10 ppm the reverse is true and halloysite is more stable (Lowe, 1995).

**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)	Horizon	Fe <sub>py</sub> (%)	Al <sub>py</sub> (%)	Fe <sub>ox</sub> (%)	Al <sub>ox</sub> (%)	Si <sub>ox</sub> (%)	Soil soln Si (g m <sup>-3</sup> )	Atomic ratio <sup>A</sup>	A (% of clay)	H (% of clay)
<i>Horotiu silt loam, well drained (Sample No. SB9944)</i>										
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
<i>Bruntwood silt loam, moderately well drained (SB9952)</i>										
0–7	Aw1	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	— <sup>B</sup>	0	75
<i>Te Kowhai silt loam, poorly drained (SB9945)</i>										
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

<sup>A</sup> (Al<sub>ox</sub>–Al<sub>py</sub>)/Si<sub>ox</sub>

<sup>B</sup> 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 (from 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 stability (Lowe and Percival, 1993). Generally, stability increases downwards in the figure (solubility decreases).

### 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 (?).

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## 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): 50 Rainfall (mm): 1270  
 Vegetation: Improved pasture species - rye grass, white clover  
 Land use: Dairying, stud stock (include race horses),  
 orchards, maize, cropping

Flat to gently undulating  
 Slope: 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)	Description
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,
Ca	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).

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)

CHEMISTRY		HOROTIU 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 <sub>2</sub> O	KCl	dptl	NaF	Ca	Mg	K	Na	H (KCl)			Al (KCl)	M, OAc (pH 7)	I Cations (pH 8.2)	I bases CEC, M, OAc	I bases I Cations	
9434																			
A	0-18	Ap	4.8	4.3	-0.5	10.2	2.9	0.29	0.44	0.16		1.07	31.0	49.9	4.9	25.1	34.8	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	13.8	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	Ca 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

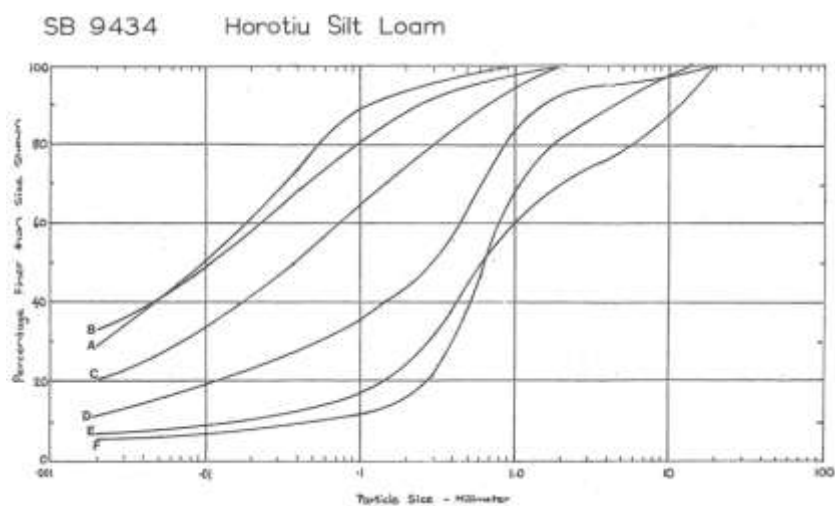
  

Sample No. SB	Depth (cm)	Hor.	Total C (%)		Total N (%)		P (mg/100 g)		P Retention (%)	Dithionite sol. (%)		Tannin ox. (%)			Pyrophenol. (%)		Reserves (mg/100 g)		Extractable S (ppm)
			C	N	H <sub>2</sub> SO <sub>4</sub> (0.5 M)	Org.	Fe	Al		Fe	Al	Si	Fe	Al	K <sub>c</sub>	Mg <sub>c</sub>			
9434																			
A	0-18	Ap	8.2	0.67	51	65	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	1.54	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	56	1.13	0.15	0.27	0.21	0.11	0.03	0.06			1	
F	72-75 75-100	Ca 2C	0.1	0.01	16	23	6	36	0.54	0.08	0.13	0.09	0.05	0.00	0.02			0	

## PHYSICS

Hor. Depth (cm)	Hor.	15 bar water		Core Depth (cm)	Dry bulk density (T/m <sup>3</sup> )	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
		Field moist (%)	Air Dry (%)							
0-18	Ap	25.6	22.3	2-9	0.80					
18-34	Bw1	43.9	20.5	20-27	0.62					
34-43	Bw2	37.5	18.3	35-42	0.72					
43-55	BC1	23.4	14.8	49-56	0.96					
55-72	BC2	13.5	10.5							
75-100	2C	3.7	3.3							

Sample No. SB	Depth (cm)	Hor.	Sand		Silt	Clay	Fine clay	Fine clay Total clay	Stones (%)
			2-0.1 mm (%)	0.1-0.05 mm (%)	0.05-0.002 mm (%)	<0.002 mm (%)	<0.0002 mm (%)		
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			



Sample No. SB	Depth (cm)	Hor.	Clay Fraction (%)															
			Mica-Saectite	Mica-Vermiculite	Saectite	Vermiculite	Interlayered Hydrated Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass	
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

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

Soil name	Possible nutrient deficiencies		Stocking rates (stock units/ha)	
	Pasture	Stock	Present <sup>1</sup>	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

<sup>1</sup> 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 at left. The Horotiu soils are 'elite' or highly versatile soils 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 allowed and urbanisation with lifestyle blocks has become an issue.



This picture shows the landsurface at Markevin Lane on which Horotiu series occur on higher levees (at right – note hedge line elevations). The slight changes in elevation arose from differing depositional environments of the high-energy, braided ancestral Waikato River system that was active from c. 20–18 cal ka. The landsurface has subsequently been mantled with thin distal tephras since the river became entrenched after c. 18 cal ka. *Photo*: David Lowe.

## STOP 4 Denitrification wall: Swayne Rd, Hautapu

Location S15 276683, elevation ~60 m asl, rainfall 1180 mm pa

Soils near the site have been mapped as Bruntwood soils\*; Eureka soils occur in the floor of the adjacent paleochannel (McLeod, 1984).

**Bruntwood:** NZSC: Typic Gley Allophanic Soils; Tephric, mixed rhyolitic and andesitic; silty; moderate/slow

**Soil Taxonomy:** Typic Endoaquands [or Aquic Hapludands]

**Eureka** NZSC: Typic Orthic Gley Soils

**Soil Taxonomy:** Typic Endoaquepts?

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### FIVE YEARS OF NITRATE REMOVAL, DENITRIFICATION AND CARBON DYNAMICS IN A DENITRIFICATION WALL

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(First received 24 July 2000; accepted in revised form 22 January 2001)

**Abstract**—Denitrification walls are a useful approach for removing nitrate from shallow groundwater, but little is known about the sustainability of nitrate removal, which is dependent on the continued supply of organic carbon to denitrifying bacteria. To address this question, we monitored nitrate removal, denitrification and carbon dynamics in a pilot-scale denitrification wall for 5 yr. The wall continuously removed more than 95% of the incoming nitrate in groundwater, which ranged from 5 to 15 mg N L<sup>-1</sup>. We did not detect decreases in total carbon during the 5-yr study. Available carbon declined for the first 200 days after the wall was constructed but has since remained relatively constant. While microbial biomass has varied between 350 and 550 µg C g<sup>-1</sup> there was no downward trend, suggesting that carbon availability was not limiting the size of the microbial population. However, there was a large decrease in denitrifying population, as indicated by declines in denitrifying enzyme activity. Despite this decrease, denitrification rates have remained high enough to remove nitrate from groundwater and denitrification was limited by nitrate rather than by carbon. Our data demonstrates that there was sufficient available carbon in this denitrification wall to support denitrification and nitrate removal for at least 5 yr. © 2001 Elsevier Science Ltd. All rights reserved

**Key words**—denitrification, groundwater, nitrate, carbon

#### INTRODUCTION

Excess nitrogen inputs into water bodies are of concern because they can lead to undesired eutrophication (Vitousek *et al.*, 1997). Much of the excess nitrogen originates from nitrate leaching from intensive land uses to groundwater, which then enters surface waters. There is a consequent need to identify land management practices that decrease nitrogen inputs from groundwater to surface waters. One such approach is the construction of denitrification walls (Robertson and Cherry, 1995, 1997; Schipper and Vojvodić-Vuković, 1998, 2000).

Denitrification walls are constructed by mixing a carbon source, such as sawdust, into the soil below the water table as a permeable wall perpendicular to the groundwater flow. The added carbon source stimulates nitrate reduction to nitrogen gases by denitrification. Field studies have demonstrated that denitrification walls remove nitrate from groundwater (Robertson and Cherry, 1995; Schipper and Vojvodić-Vuković, 1998). We confirmed that denitrification was a major mechanism for observed rates of nitrate loss (Schipper and Vojvodić-Vuković, 2000).

The sustainability of denitrification walls are poorly known. Continued functioning of these walls is dependent on a continuous supply of degradable carbon to denitrifying bacteria as an energy source. Estimates of sustainability based on the stoichiometric consumption of carbon by nitrate have suggested that the carbon source might last for more than 15 yr (Robertson and Cherry, 1995). Recently, Robertson *et al.* (2000) demonstrated that denitrification walls could remove nitrate for at least 6 yr. In this previous study, the focus was on measuring nitrate removal from groundwater. Long-term information on carbon availability and denitrification rates has not been published and may indicate when a denitrification wall is nearing the end of its operational life.

Here, 5 yr of monitoring of a denitrification wall incorporating some of the author's earlier data are reported (Schipper and Vojvodić-Vuković, 1998, 2000). Nitrate removal from groundwater and changes in microbial biomass, the denitrifying population and the amounts of total and available carbon were measured during the monitoring period.

#### MATERIALS AND METHODS

##### Site description and construction

The study was conducted at the Bardowie farm (37°57'S, 175°27'E), Cambridge, North Island, New Zealand. The

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\*An alternative might be Silverdale clay loam, pale subsoil variant (see Singleton, 1991), but this possibility needs to be checked.

farm was spray-irrigated with effluent from the nearby Hautapu Dairy Factory. The average nitrogen loading in 1999 was  $700 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  (G. Wiseman pers. comm.). Nitrate concentrations were up to  $50 \text{ mg NL}^{-1}$  in some groundwater bores. The denitrification wall was constructed in January 1996 by digging a trench (35 m long, 1.5 m deep, and 1.5 m wide) that intercepted shallow ground water. This shallow groundwater had lower nitrate concentrations ( $5\text{--}15 \text{ mg NL}^{-1}$ ) than other parts of the farm. The soil excavated from the trench was mixed with  $40 \text{ m}^3$  of sawdust (*Pinus radiata*) then returned to the trench. A network of groundwater wells (slotted polyvinyl chloride pipe, 60 mm diameter) was installed in three transects parallel to the wall: 10 directly upslope, 10 in the wall, and 10 downslope of the wall. The groundwater in these wells were periodically sampled and analysed for nitrate concentration using a standard colorimetric technique (Blakemore *et al.*, 1987).

#### Soil sampling and analysis

Periodically soil samples were taken from below the water table in the wall using a dutch auger. Samples were placed in plastic bags and returned to the laboratory where they were stored at  $4^\circ\text{C}$  until analysis within 2 weeks. Gravimetric soil water content was determined following overnight drying at  $105^\circ\text{C}$ . Total C in samples was periodically measured using a combustion furnace (LECO CNS-2000, NSW, Australia).

Denitrifying enzyme activity (DEA) was measured using a modified method of Tiedje *et al.* (1989). This method is a surrogate measure of the size of the population of denitrifying bacteria. Soil (10 g fresh weight) was weighed into airtight bottles (100 mL) and amended with a 20-mL solution containing glucose ( $0.2 \text{ g L}^{-1}$ ), potassium nitrate ( $0.1 \text{ g L}^{-1}$ ), and chloramphenicol ( $0.12 \text{ g L}^{-1}$ ). The headspace was flushed with nitrogen gas, and 10 mL acetylene was added to inhibit reduction of  $\text{N}_2\text{O}$  to  $\text{N}_2$ . Bottles were incubated with shaking (200 rpm) at  $28^\circ\text{C}$ . After 15 and 75 min, headspace samples were removed and analysed for  $\text{N}_2\text{O}$  using a gas chromatograph (Philips PU4410, Cambridge, UK) equipped with an electron capture detector. Operating conditions were: an oven temperature of  $60^\circ\text{C}$ , injector temperature of  $160^\circ\text{C}$ , and detector temperature of  $350^\circ\text{C}$ . The carrier gas was 10% methane in argon at a flow rate of  $40 \text{ mL min}^{-1}$  through a 4 m column of Poropak Q.

Actual denitrification rates in the wall were determined as previously described by Schipper and Vojvodić-Vuković, (2000). Soil samples (10 g fresh weight) were spiked with nitrate and statically incubated in airtight bottles (100 mL) at the temperature measured in the wall. Sufficient nitrate (as a solution of  $\text{KNO}_3$ ) was added to each sample to match the average nitrate concentration in the upslope wells for each sampling date. The headspace was replaced with  $\text{N}_2$  gas and then acetylene (10 mL) was added. Bottles were incubated for 15 min to allow equilibrium between headspace and dissolved gases, then headspace samples were taken after a further duration of 1, 5, and 7 h. Gas samples were analysed for  $\text{N}_2\text{O}$  as described above. We calculated two rates of denitrification. The amount of  $\text{N}_2\text{O}$  formed during the first hour was termed the initial denitrification rate, and the amount of  $\text{N}_2\text{O}$  formed between 5 and 7 h was termed the potential denitrification rate. Denitrification rates were calculated on a volumetric basis using a bulk density of  $0.87 \text{ t m}^{-3}$  (Schipper and Vojvodić-Vuković, 2000) after adjusting for water content.

To determine available carbon, soil (10 g fresh weight) was weighed into bottles (610 mL) and statically incubated at  $25^\circ\text{C}$  for 7 days when a headspace sample was taken and analysed for  $\text{CO}_2$  using an infrared gas analyser (Series 225, Analytical Development Ltd Corporation, Hoddesdon, England). Microbial biomass carbon was determined by chloroform-fumigation of soil (25 g fresh weight) followed by extraction with 100 mL of  $0.5 \text{ M K}_2\text{SO}_4$  (Vance *et al.*, 1987). Total organic carbon (TOC) in the  $\text{K}_2\text{SO}_4$  extracts

were determined using a total organic carbon analyser (Model TOC-5000, Shimadzu Corporation). Non-fumigated controls were similarly extracted and analysed for TOC. A  $k_{\text{OC}}$  factor of 0.41 was used to convert the TOC flush to microbial biomass.

## RESULTS AND DISCUSSION

In terms of sustainability this denitrification wall has removed nitrate from groundwater for almost 5 yr (Fig. 1). To date, nitrate concentrations have only been elevated downslope of the wall when the water table dropped below the wall. At this time the nitrate in groundwater passed beneath the active denitrification zone. These results concur with the findings of Robertson and Cherry (1997) and Robertson *et al.* (2000) who measured nitrate removal in denitrification walls for at least 6 yr. Furthermore, by the end of this study, there was no decrease observed in the performance of the wall.

Continued nitrate removal by denitrification is dependent on a continued supply of degradable organic matter as an energy source. Denitrifying bacteria are not known to degrade complex polymeric carbon found in substrates such as sawdust, instead they are reliant on a consortium of microorganisms to release more simple organic compounds (Beauchamp *et al.*, 1989). The measure of available carbon is an attempt to quantify the dynamics of more degradable carbon that may be accessible to denitrifying bacteria. In this study, available carbon initially declined for the first 200 days but has since stabilised (Fig. 2). This suggests that there is a continued slow release of carbon from the sawdust to support the microbial population. Evidence for this supposition was the maintenance of the microbial biomass, which has remained constant throughout the study (Fig. 2).

In contrast to the relatively stable microbial biomass, the size of the denitrifying population, (as indicated by the DEA) has been more variable throughout the study. DEA was originally very high

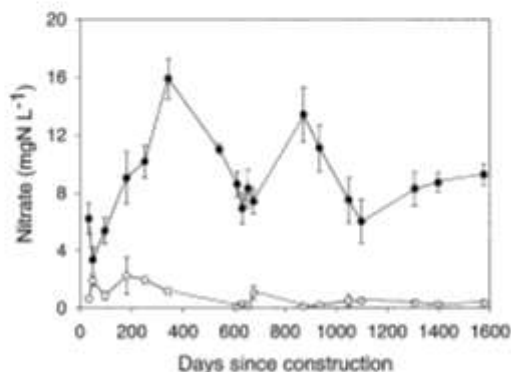


Fig. 1. Groundwater nitrate concentrations since construction in January 1996, (●) upslope of the denitrification wall, and (○) in the wall. Error bars are standard errors ( $n = 8$ ).

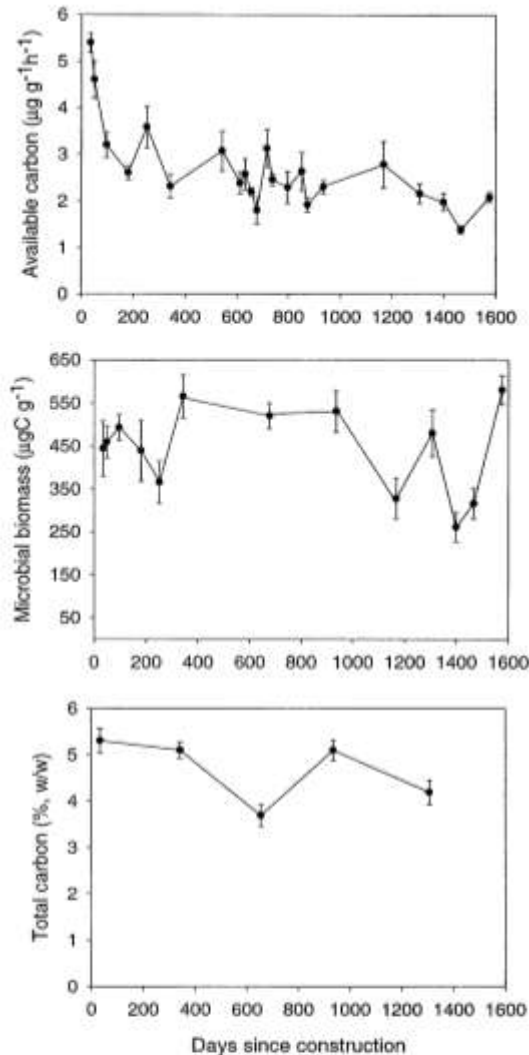


Fig. 2. Temporal changes in different carbon pools in the denitrification wall since construction: (a) available carbon, (b) microbial biomass carbon, and (c) total carbon. Error bars are standard errors ( $n = 8$ ).

following construction but subsequently decreased (Fig. 3). The reasons for this large initial decline in DEA are not clear because nitrate inputs and carbon availability have not greatly changed during the last three years. Despite the decline in DEA, and its high variation, initial denitrification rates were more stable (Fig. 3). During the last 2 years, these initial denitrification rates have not declined and have remained high enough to account for nitrate loss previously measured from groundwater studies (Schipper and Vojvodić-Vuković, 2000). That denitrification rates were still high enough to account for nitrate removal further suggests denitrification was not limited by carbon availability. In fact,

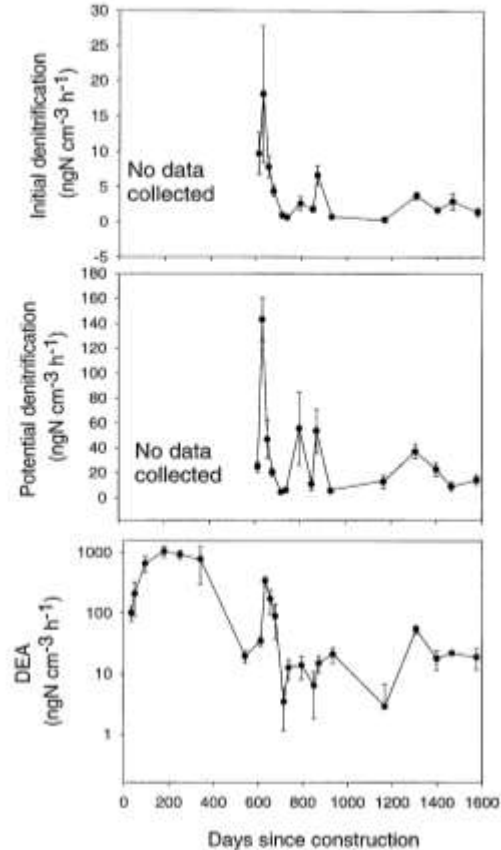


Fig. 3. Temporal dynamics in denitrification in the denitrification wall: (a) initial denitrification rates, (b) potential denitrification rates, and (c) denitrifying enzyme activity, note log scale on y-axis, error bars are standard errors ( $n = 8$ ).

potential rates of denitrification were always greater than initial rates (Fig. 3), indicating that denitrification remains limited by nitrate concentration rather than carbon (Schipper and Vojvodić-Vuković, 2000).

There were no measurable losses of total carbon in the denitrification wall, which is similar to studies of other walls (Benner *et al.*, 1999; Robertson *et al.*, 2000) where it was estimated that less than 10% of total carbon had been lost during a six-year period. Losses of this magnitude would be difficult to measure accurately because of the problems in sampling mixtures of soil and sawdust, which are not likely to be completely homogeneous. It may be better to follow availability of carbon and/or microbial biomass rather than total carbon to monitor sustainability of the carbon supply.

Attempting to predict how long this wall will continue to remove nitrate is difficult, because the total carbon content is apparently only changing slowly. There have been a number of other studies

using organic matter (sawdust, compost) in treatment walls for remediation of nitrate or acid mine waste drainage (Robertson and Cherry, 1997; Benner *et al.*, 1999; Robertson *et al.*, 2000). Authors have attempted to predict the longevity of the carbon in their treatment walls using the stoichiometric equations of organic matter decomposition using nitrate and/or sulphate as electron acceptors. It was estimated that there was sufficient carbon for groundwater cleanup for more than 15 yr. To date, these treatment walls have continued to remove nitrate for more than 6 yr (Robertson *et al.*, 2000). While these are the best estimates available, stoichiometric relationships do not take into account that anaerobic degradation of complex organic matter continues to occur by fermentation in the absence of external electron acceptors such as nitrate and sulphate. Anaerobic degradation rates are generally limited by the initial cleavage of complex polymeric carbon molecules rather than by the consumption of simple carbon compounds during anaerobic respiration (Schink, 1999). Consequently, it is likely that the lifetime of a denitrification wall may be over-estimated if carbon loss was calculated using stoichiometric approaches.

The rate of total carbon degradation will most likely be strongly influenced by the concentrations of oxygen entering the wall. Unlike other electron acceptors (such as nitrate or sulphate) oxygen also plays a role in the degradation of organic matter as a reactant which directly attacks complex organic matter (Schink, 1999). In other studies (Robertson and Cherry, 1997; Benner *et al.*, 1999; Robertson *et al.*, 2000) water table heights were constant and to maximise anaerobic conditions the tops of these walls were sealed above the watertable to minimise oxygen inputs. Conversely, in this denitrification wall, the water table fluctuated seasonally so that during the year, parts of the wall were above the water table. As a result, the sawdust in the wall potentially would have been exposed to oxygen, promoting some aerobic decomposition. However, even when the water table was below the wall, soil samples were wet and supported denitrification (Schipper and Vojvodić-Vuković, 2000) suggesting that anaerobic conditions still existed to a large degree. Anaerobic decomposition rates are generally slower than aerobic rates (Bridgman *et al.*, 1998) so it is likely that degradation of organic carbon in walls receiving oxygen would have been more rapid than in permanently-saturated walls.

#### CONCLUSIONS

It was found that a denitrification wall can support nitrate removal from groundwater for at least 5 yr in accordance with findings by Robertson *et al.* (2000). Our measurements showed a large decline in denitrifying enzyme activity during this time; however,

denitrification rates were still sufficient to account for nitrate removal. Microbial biomass throughout the 5 yr was relatively stable suggesting that there is a continuing release of carbon from the decaying sawdust as an energy supply. This was supported by measurements of the availability of carbon, which were relatively stable after a large decrease during the first 6 months. It was recommended that care be taken when estimating longevity of sawdust in denitrification walls using stoichiometric equations with nitrate as the sole electron acceptor. Sawdust will continue to degrade in anaerobic environments in the absence of nitrate, in which case stoichiometric approaches would over estimate the length of time the sawdust will last. Further work is still required to determine the longevity of organic matter in treatment walls that are constructed in a range of soil and groundwater environments, particularly where oxygen inputs vary.

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- (Note: map was begun in June 1938 and included input from J.D. McCraw, P.J. Tonkin, G.E. Orbell, H.A. Hughes, C.F. Sutherland, J. Bell and others)

## Groundwater and the Hinuera Formation: a broad flat basin containing 50% water and 50% sediment – lake or land?

**Mike Chapman**

*Hydraulic Modelling Services, Hamilton*

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.

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).

Occasional large continuous aquifers exist in several areas – for example, at the Hautapu Dairy Factory a series of bores intersecting a well-defined aquifer supply the factory with 2.5 m<sup>3</sup>/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.



Slightly undulating surface of the Hinuera Formation – the low gravelly ridge (levee) in foreground drops away to a flat swale towards the right and background (note effluent sprayers). Despite being mantled with numerous thin tephra since c. 18 cal ka (~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.

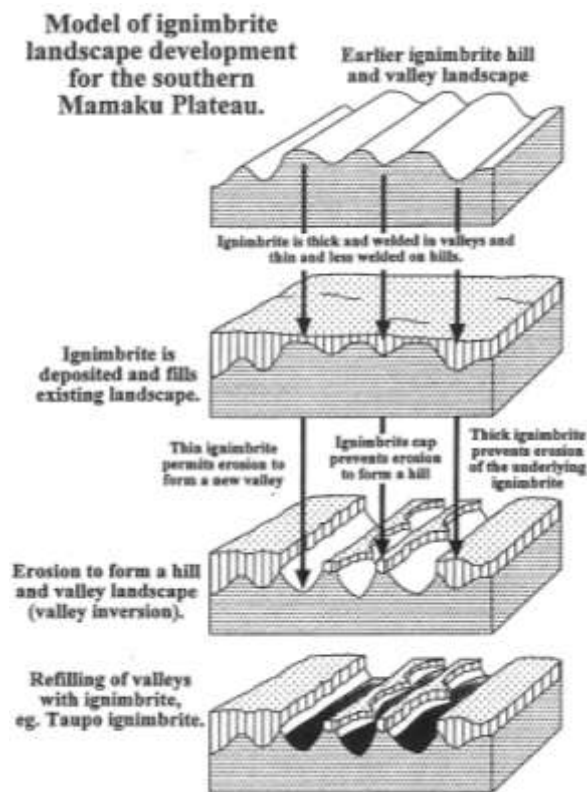


Cross stratified fluvial gravelly sands of the c. 18 cal. ka Hinuera Formation (overlain by ~0.6 m of tephra) exposed by paleochannel occupied by the Mangaone Stream near Hautapu. Sediments comprise mainly quartzo-feldspathic assemblages with rhyolitic rock fragments and subordinate pumice and heavy minerals. Modern soil is Horotiu sandy loam.

*Photos: David Lowe*

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### 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 Tukurua 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-Blaise, 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 interflaves 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 covered 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 Waitou ignimbrites. Erosion episodes (c) and (d) are recognised. Stages 3 and 4 are characterized by incision and widening of valleys into the Waitou, Waimakariri and Whakamaru ignimbrites. A thin capping of Mamaku ignimbrite and Pokai ignimbrite occurs on the interflaves between the valleys. Stages 3 and 4 are distinguished by planar and convex interflaves 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 Waitou 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 Kiteith Forest on the southern Mamaku Plateau. The covered stratigraphy together with its soil stratigraphic interpretation and soil landform relationships have been used to map nine land systems.

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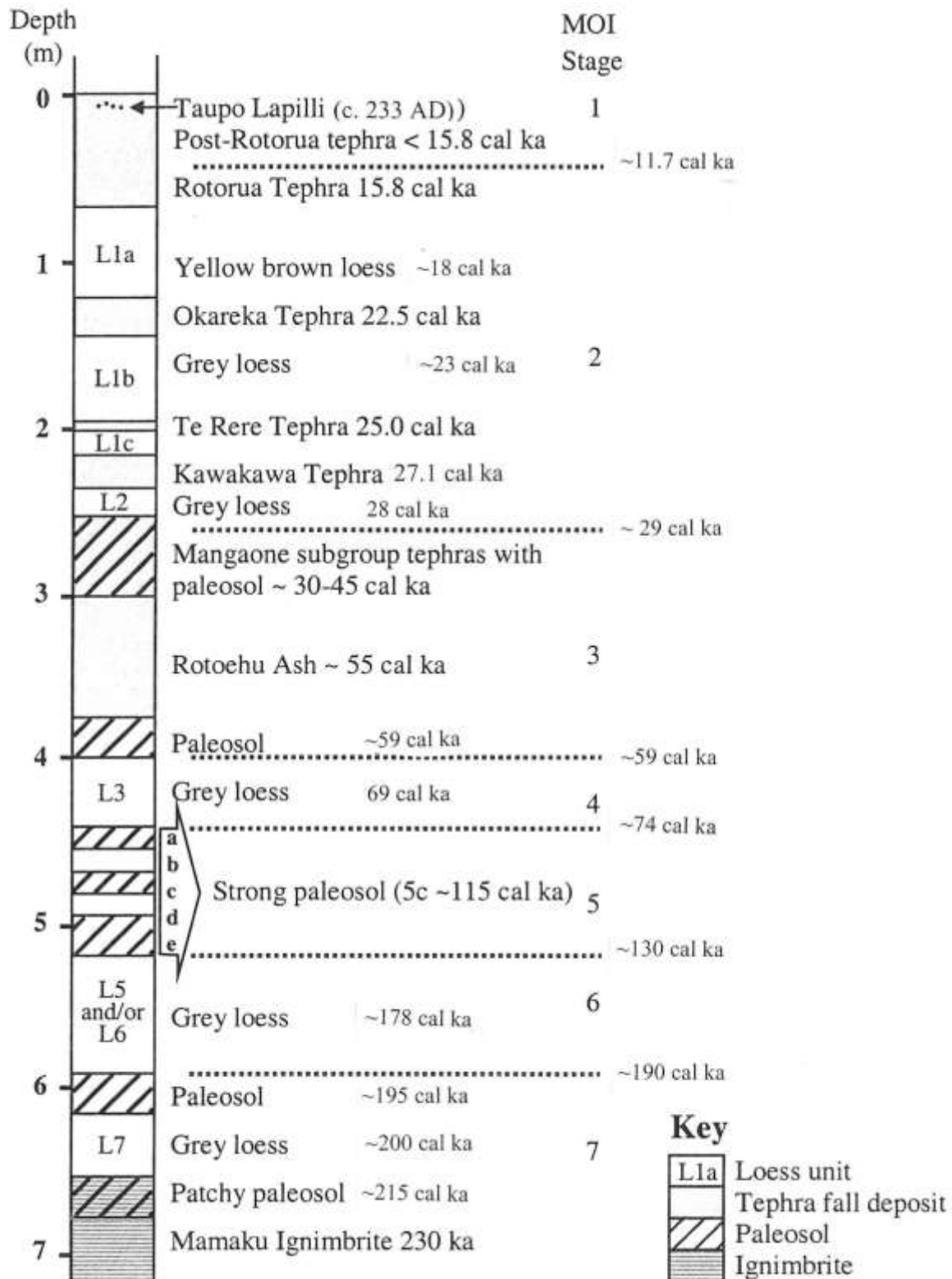
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General model for landscape development of southern Mamaku Plateau involving emplacement and erosion of ignimbrites and tephrochronology for age control (from Hill et al., 1999).

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## 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 provisional 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).

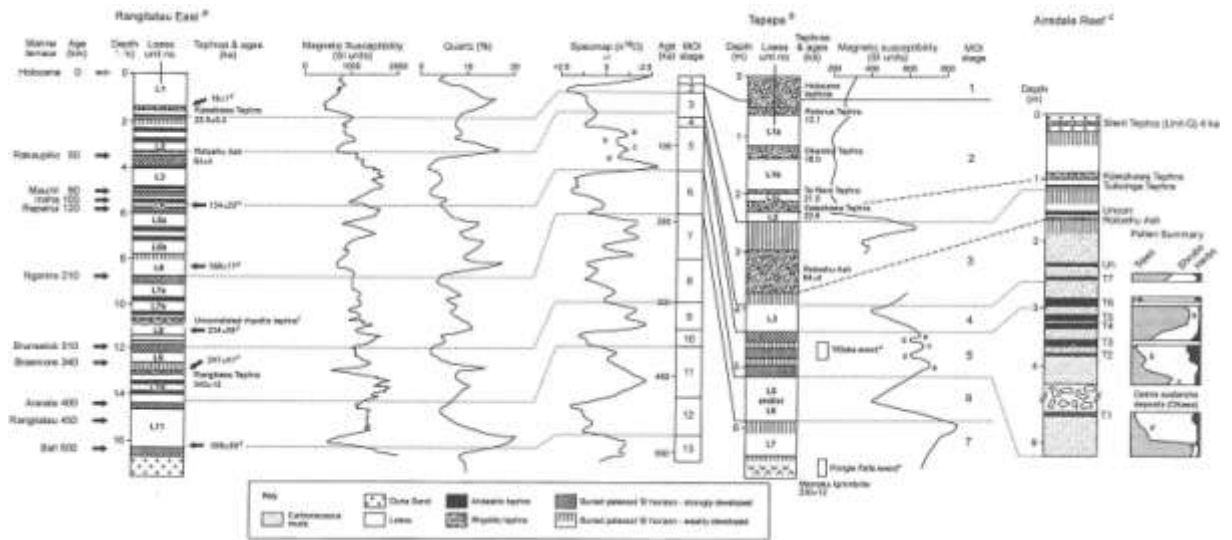


(Left) Main part of Tapapa section as it was in February, 1987 (Derek Milne doing the talking). Grey layer near ~2 m depth mark is Kawakawa/Oruanui tephra. It is primary ash but slightly weathered and hence cohesive. The gritty layer at the base of Kawakawa/Oruanui tephra is mostly unit 7 (Wilson, 2001); accretionary lapilli are often most visible on the top contact of that layer (C.J.N. Wilson pers. comm., 2008). (Right) Brad Pillans (ANU) sampling at Tapapa to undertake palaeomagnetic analysis (June 1996). *Photos: David Lowe*

Mineralogy (%) of clay fractions (<2 um) of Tapapa materials (from Lowe and Percival, 1993, after D.N. Eden unpublished data, 1993)

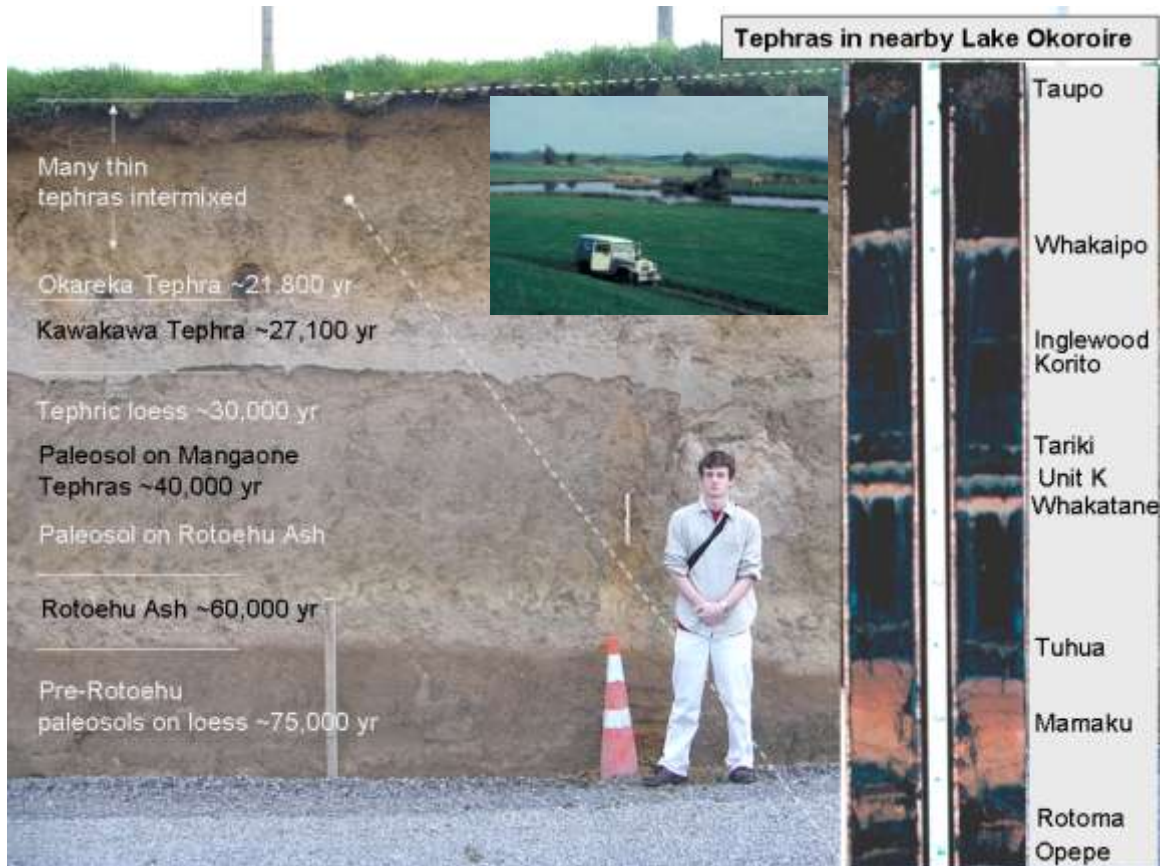
Depth (m)	Unit*	Vermic.	Kaolin s'group†	Allophane ± imog.	Feldspar (plag.)	Cristob.	Gibbsite
0-0.15	Ap	15	25	46	7	3	
0.15-0.31	AB	15	15	47	7	3	
0.31-0.55	Bw1	15	2	63	5	2	
0.55-0.80	Bw2	15	12	51	3	1	
0.80-0.84	BC	10	40	35	3	1	
0.95-1.27	Loess la		80	7	3	2	<1
1.27-1.59	Rr		70-90	4-5	3	3	<1
1.59-2.03	Loess		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

†Mainly halloysite

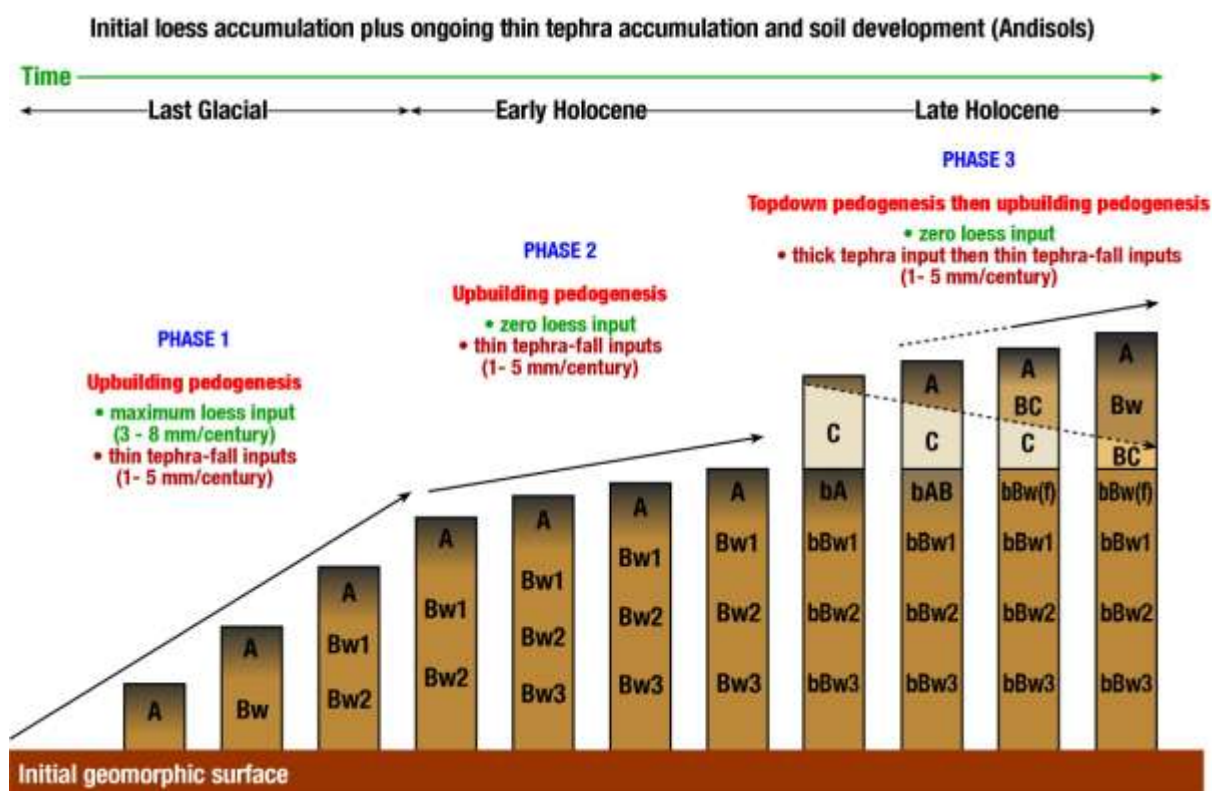


**Figure 4** Records of climatic fluctuations at three terrestrial sites in North Island that date back to c. 500 ka, based on analyses of tephra-bearing loess deposits, associated palaeosols and palynology. The sections provide different levels of information for various time slices: (a) Rangitatau 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

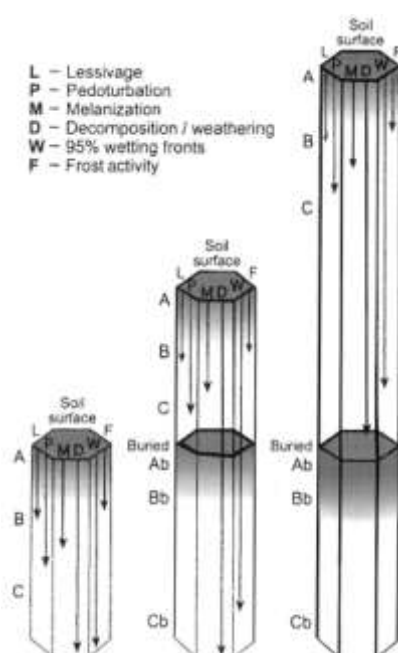
Correlation of Tapapa section with Rangitatau East section near Wanganui and Airedale Reef section near New Plymouth (from Newnham *et al.*, 1999).



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 based on the identification of likely contributing Holocene tephra layers present in c. 20-cal ka Lake Okoroire (the lake, insert photo, is about 10 km NW of Tapapa, ~12 km NW of Leslie Rd) (see also Pullar and Birrell, 1973). Photos: David Lowe



Model of soil development in the eastern Waikato area via upbuilding pedogenesis (constructed by D.J. Lowe 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. ~1 mm per century for the Kainui soil since c. 60 cal ka, and ~4 mm per century for the Horotiu soil since c. 18 cal. ka). Most of the time the upbuilding is progressive 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). How much 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 as depicted in the diagram below, and diagenesis.



### Buried brown 'topsoil' horizons

Buried 'A' horizons in New Zealand 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 to 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).

Horizon		Depth (cm)	PROFILE DESCRIPTION
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 pedis; 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 (1992) 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 soil-landscape model below). 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; tephritic, 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 (meq/100 g) (pH 8.2)	Acidity-Al (meq/100 g)	EC/EC	CEC (meq/100 g)		Base saturation (%)			
			H <sub>2</sub> O	KCl	spH	NaF	Ca	Mg	K	Na				H	Al	NH <sub>4</sub> Cl	Cl <sup>-</sup> Cations	I bases	II bases
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	25.4	25.4	5.2	10.5	28.6	50	18
	D	51-74	3Bw3	6.4	5.9	-0.9	9.3	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	0.05	18.3	18.3	7.5	13.2	25.8	57	29

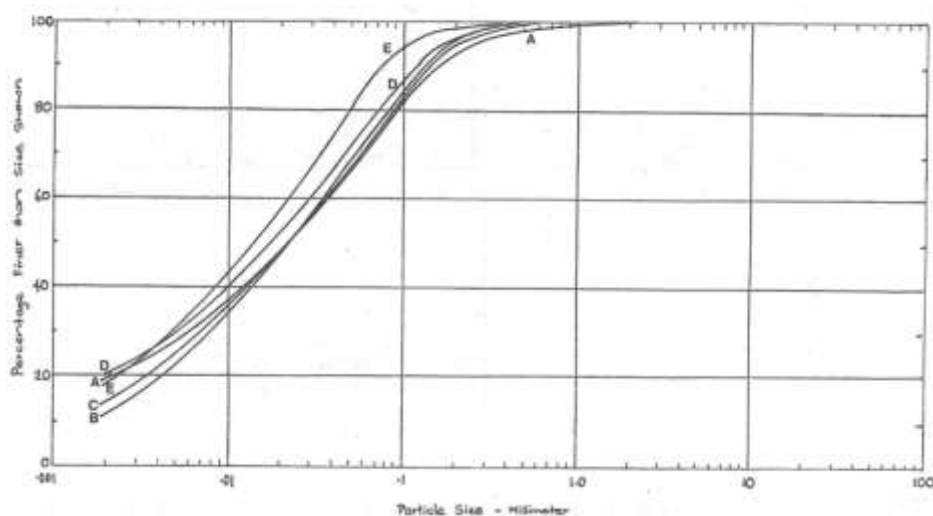
  

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (µg/100 g)			P Retention (%)	Dithion. cit. (%)		Tann. ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)	
					H <sub>2</sub> SO <sub>4</sub> (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K <sub>2</sub>	Mg <sub>R</sub>		
9432	A	0-18	Ap	7.9	0.71	129	128	121	88	0.81	0.83	0.59	5.3	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		Core Depth (cm)	Dry bulk density (T/m <sup>3</sup> )	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
		Field moist (%)	Air Dry (%)							
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					

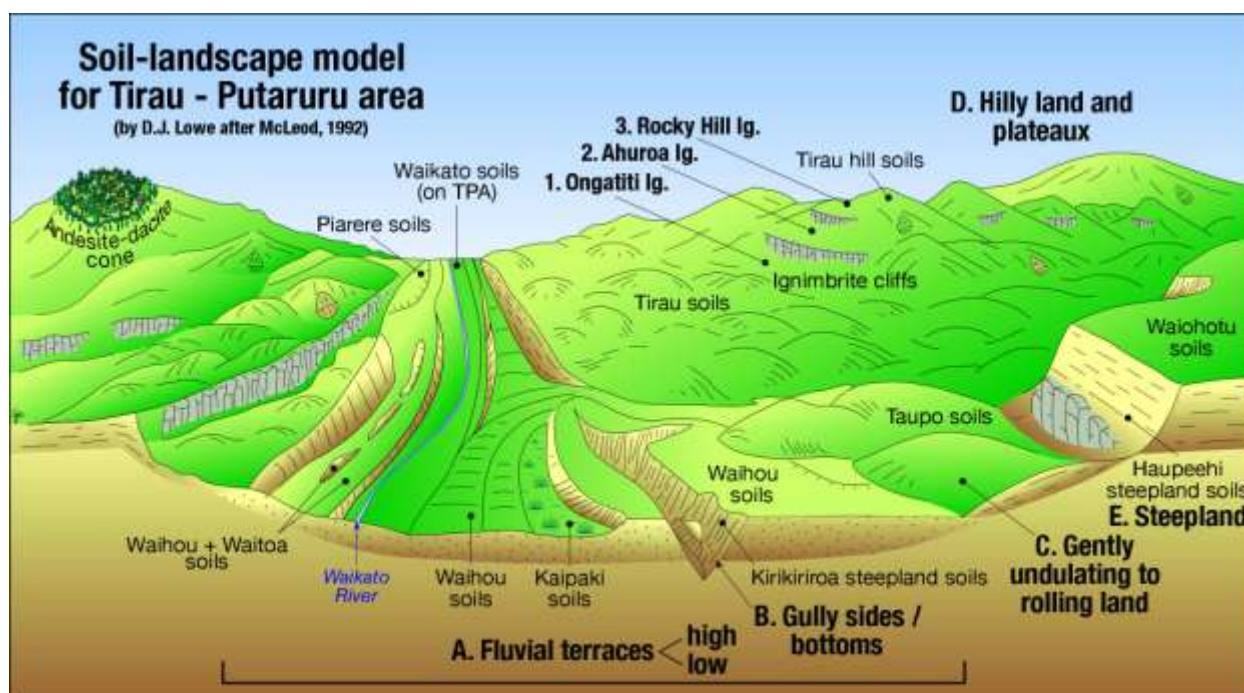
PARTICLE SIZE DISTRIBUTION (<2 mm) TIRAU SILT LOAM									
Sample No. SB	Depth (cm)	Hor.	Sand		Silt	Clay	Fine clay	Fine clay Total clay	Stones (%)
			2-0.1 mm (%)	0.1-0.05 mm (%)	0.05-0.002 mm (%)	<0.002 mm (%)	<0.0002 mm (%)		
9432A	0-18	Ap	18	17	46	19			
B	18-30	Bw1	17	16	56	11			
C	30-51	2Bw2	17	16	54	13			
D	51-74	3Bw3	14	16	50	20			
E	74-100	3C	6	14	62	18			

SB 9432 Tirau Silt Loam



Mineralogy TIRAU

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
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



Soil-landscape model for the Tirau-Putaruru area and Tapapa. 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. 1.7 cal ka). Diagram constructed by D.J. Lowe after McLeod (1992). Aspects of the stratigraphy, geomorphology, and soils of the Mamaku Plateau area include work by Bakker (1997), Macky (1997), Lynch-Blosse (1998), Hill (1999), Palmer (2002) and Palmer et al. (2005). Note that the famous hypothetical nine-unit landscape model was developed in this area by Dalrymple et al. (1968) (M.J. Selby pers comm., 1973). Bakker (1997) used it for her studies and modified it a little.

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## STOP 6 – 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 26<sup>th</sup> 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<sup>3</sup> (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 (~27,100 years old), 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-20<sup>th</sup> 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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## Day 2: Rotorua–Rotorua

### Outline for Day 2 (Saturday 29<sup>th</sup> November)

**8.00 am** Depart Ventura Inn, Rotorua

**8.15-9.30 am STOP 1 Radio Hut Rd, Whakarewarewa Forest: loess, tephra, Whakarewarewa soil, plantation forestry**

- Introduction to Rotorua Land Treatment System, Whakarewarewa Forest: Dr Gerty Gielen (Scion, Rotorua)
- Stratigraphy of sequence (~18 cal ka and younger)
- Whakarewarewa sandy loam (Vitric Hapludand)
- Pine plantation forestry, C budgeting, sampling and modelling: Dr Peter Beets, Dr Haydon Jones (Scion)
- Forest walk (weather/time permitting) to Visitors' Centre (or bus)

**10.00-10.30 am** Morning tea/coffee and toilet stop, Visitors' Centre, Long Mile Drive (note display of catchment model of Whakarewarewa Forest)

**10.40-11.30 am STOP 2 Red Tank Rd, Whakarewarewa Forest: RLTS spray block 2**

- Spray irrigation and efficacy (N, P, pharmaceuticals): Dr Gerty Gielen (Scion)

**11.40-12.00 am STOP 3 Wetland RLTS, Whakarewarewa Forest**

- Denitrification in wetlands: Dr Gerty Gielen (Scion)

**12.20-12.50 pm STOP 4 Okaro Rd near Waimangu: Lake Okaro [toilet available]**

- Land-use impacts on lake water quality in Rotorua region (N, P)
- Lake water quality experiments Lake Okaro: Deniz Özkundakci (PhD student, Univ. of Waikato)

**1.00-1.40 pm** LUNCH Rerewhakaaitu Hall, Rerewhakaaitu

**1.50-2.50 pm STOP 5 Brett Rd, Rerewhakaaitu: Holocene tephra 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" EBOP: Chris Sutton (local farmer)

**3.10-4.00 pm STOP 6 Ash Pit Rd, Rerewhakaaitu: tephra and buried soils (incl. buried Podzol), Matahina soil**

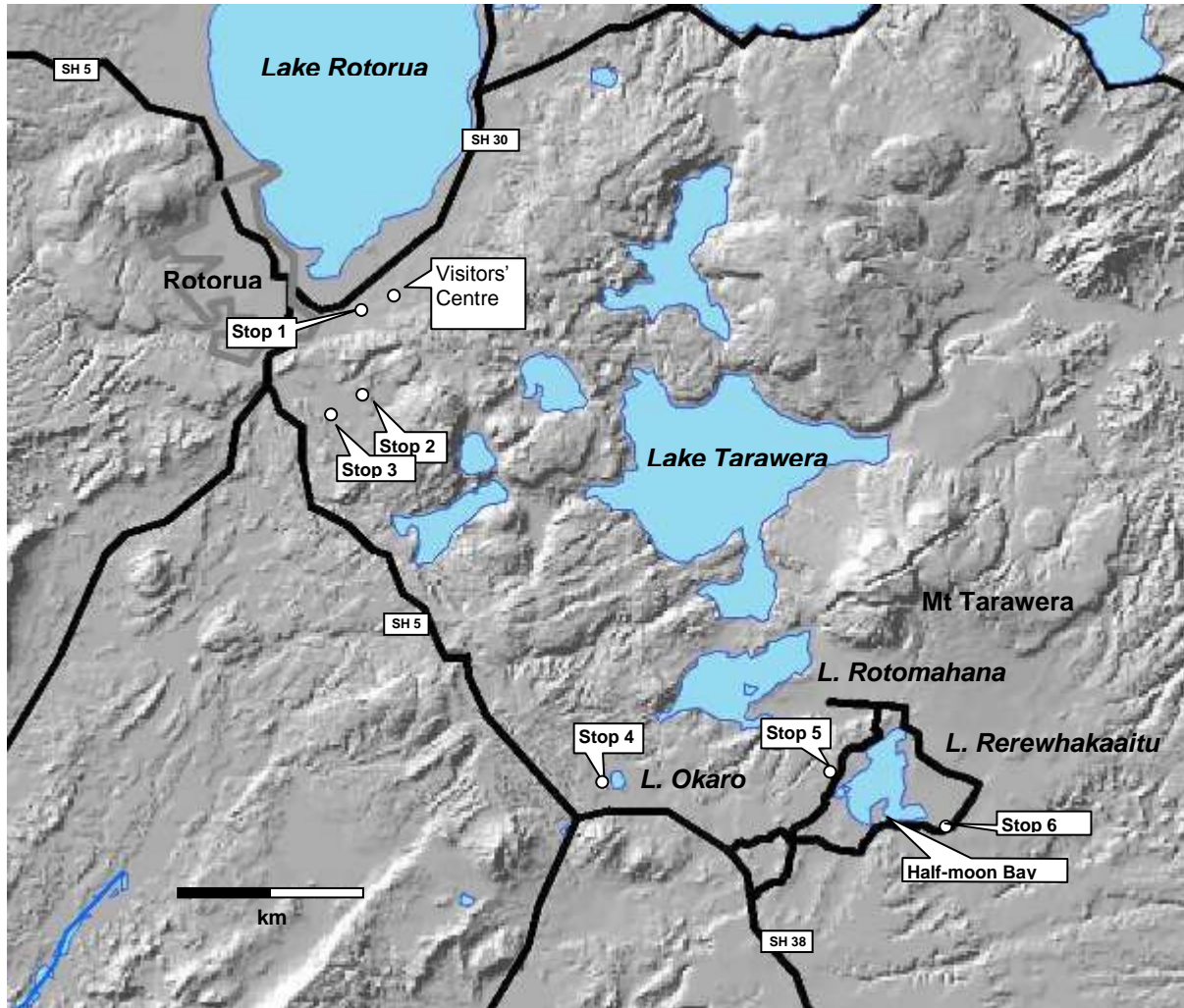
- Stratigraphy of sequence (~13.8 cal ka to 10 June 1886 Tarawera eruption)
- Matahina gravel (Vitrandic Udorthent)

**4.10-5.00 pm** Afternoon tea/coffee and toilet stop, Half-Moon Bay, Lake Rerewhakaaitu  
- Lakeside refreshments

**5.20** Arrive Ventura Inn, Rotorua

- 6.45 pm Depart for Rydges Hotel (bus)
- 7.00 Dinner (hangi) followed by Maori concert at Rydges Hotel (Fenton St); finish by ~9.00 pm

## Day 2 – route and scientific stops





Aerial view of Rotorua City at the southern end of Lake Rotorua. Mokoia Island in distance.  
*Photo: Toshiro Nagasako*

## **An introduction to the Rotorua Basin: an iconoclastic view**

**Will Esler**

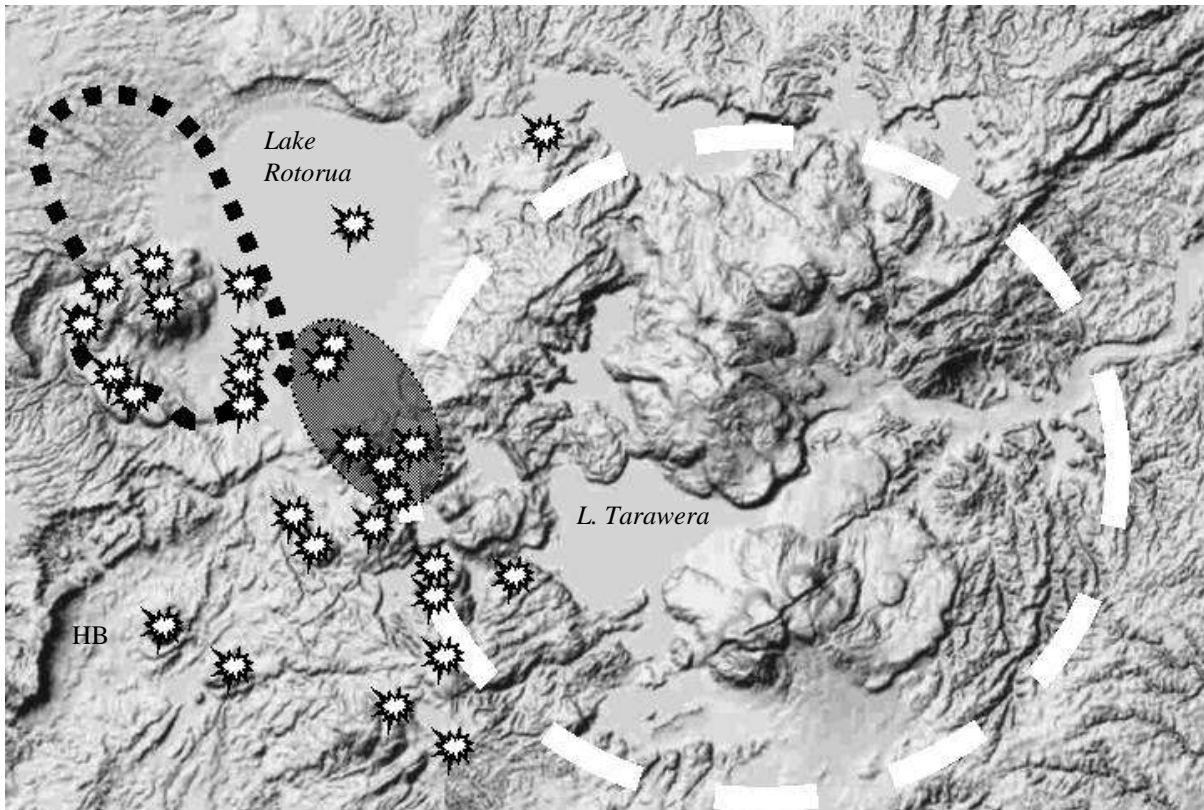
*Former PhD student, Department of Earth and Ocean Sciences, University of Waikato*

### **Basin formation**

For over forty 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 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<sup>3</sup>. 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 real Mamaku Ignimbrite caldera is probably next to the Horohoro Bluffs south of Rotorua. This eruption overlapped with that of the Ohakuri

Igimbrite a little farther south, and probably tapped the same big magma chamber. Extreme regional extension of the Taupo Fault Belt accompanied or closely followed 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.



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.

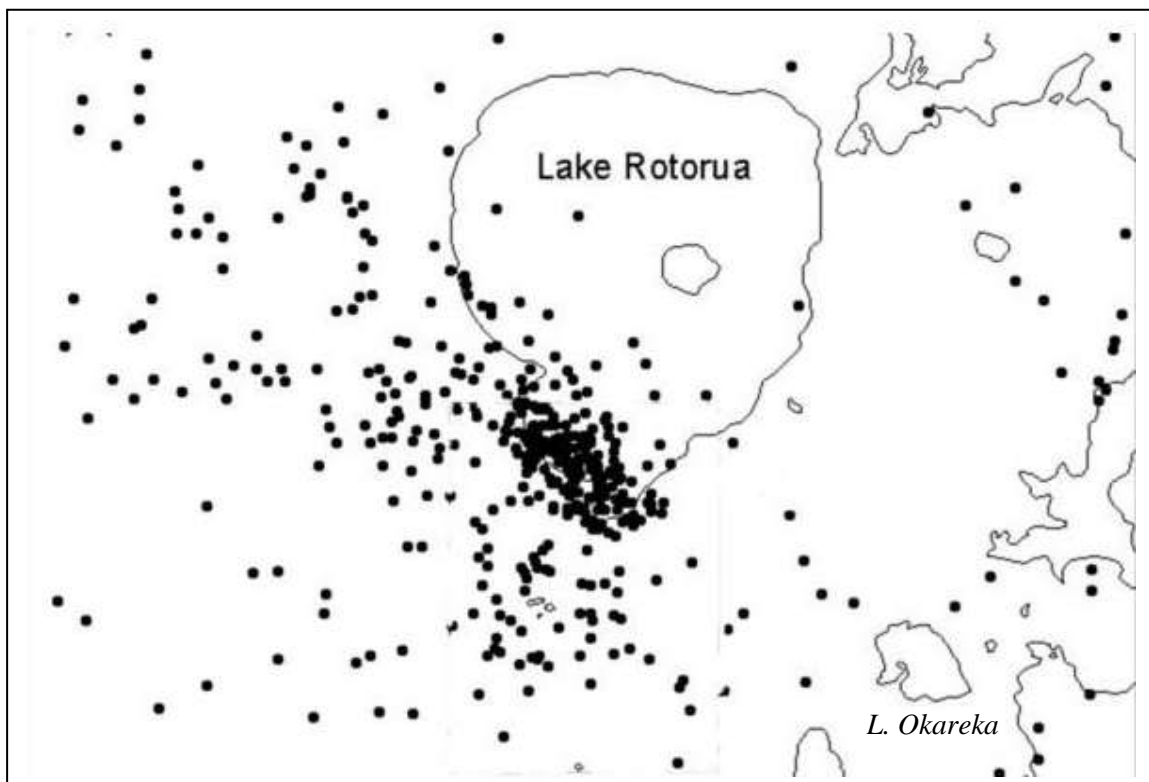
Residual Mamaku Igimbrite magma was probably responsible for the hydrothermal conversion of voluminous glassy lake sediments to zeolite in the Ngakuru area. The ‘type’ TVZ rhyolite dome, Haparangi, probably erupted from this magma. The soft top of the Mamaku Igimbrite was severely eroded by frost, rain and wind during the Last Glacial Maximum, and in earlier cold periods. The famous isolated tor-like features of the Mamaku Plateau and the lesser known ‘great walls’ were sculpted at this time. The suggestion that the tors represent fumarolic hardening immediately after the ignimbrite eruption has minimal evidence to support it.

The Ngongotaha and Pukehangi rhyolite massifs, and small domes in the city area erupted after the Mamaku Igimbrite from an unrelated chamber of volatile-poor glassy magma. Much of the ‘caldera’ collapse in the city area followed, not preceded, this voluminous rhyolite extrusion. Slightly later, extensional faulting perpendicular to the TVZ 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 tephra. 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 relatively 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' not long 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.

### 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.



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)

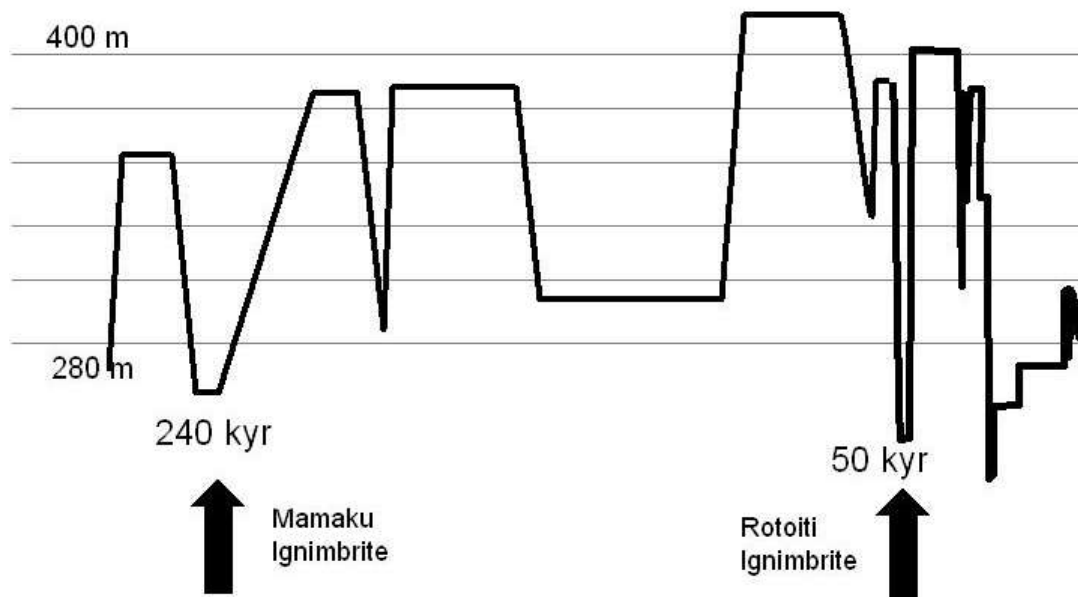
Within the sediments are more than 40 recognised tephras preserved in exquisite detail. Many more await coring. Electron microprobe analysis of glass to obtain major element chemistry is the most useful tephra identification technique, along with mineral assemblages. Tephras from Okataina, Taupo, Taranaki, 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).

### 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), and the lake drained completely at least twice. One of these highstands preceded the Mamaku Ignimbrite eruption. Before about 70 ka, Lake Rotorua had at 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 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 at about 60 ka during Tikitere Graben formation. The eruption of Rotoiti Ignimbrite soon after 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.



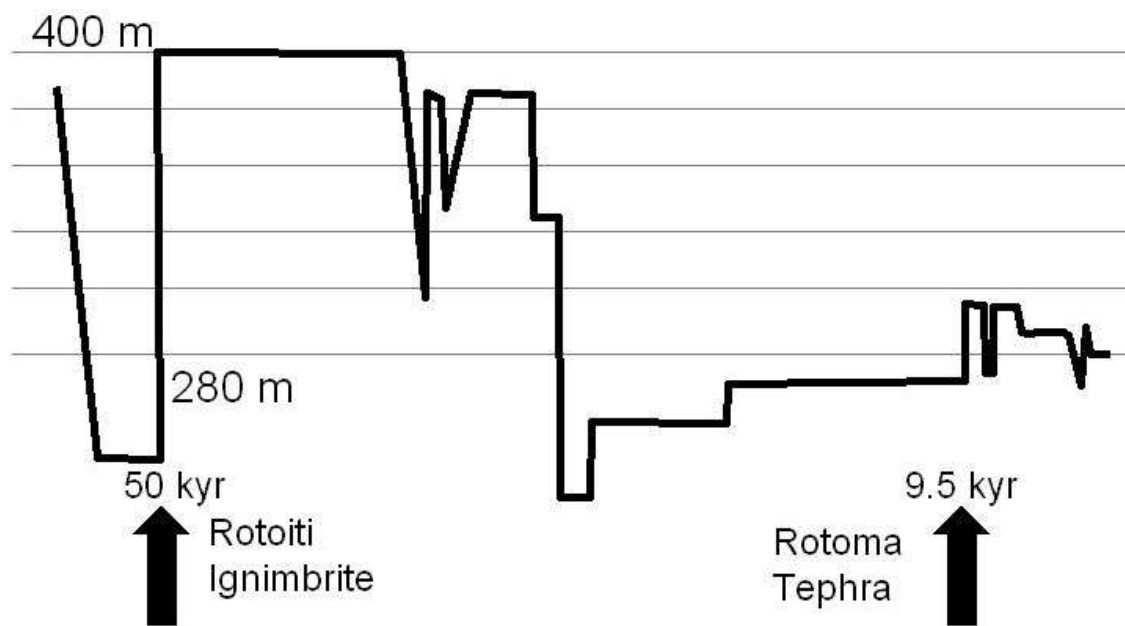
Pattern of changing levels of Lake Rotorua since c. 250,000 years ago. Present lake level is c. 280 m asl. The Rotoiti eruption episode is variously dated between c. 50 and 60 cal. ka (Wilson et al., 2007) (W.R. Esler, unpubl. data)

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 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 before Maori occupation of the area.

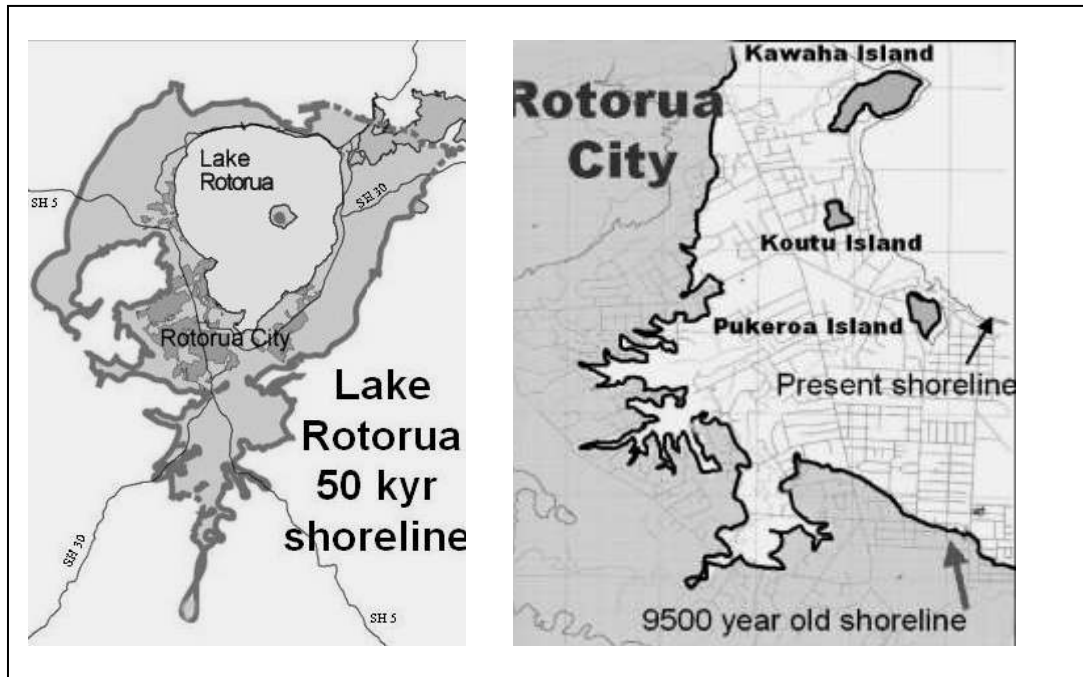
Lava dams of the Rotoma eruptive period c. 9505 cal. yr BP raised Lake Rotorua 17 m above the present level. Surface drainage into the Kaituna River resumed at this time. Periodic down-faulting averaging almost 2 mm/year in the Okere Falls area now exerts gross control over lake level, although episodes of seepage to groundwater have partially drained the lake at least three times in the past 8000 cal. years. Lake 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. The reasons for this are mysterious, because most clasts of Kaharoa Tephra pumice (c. 1314 AD) do not float long enough to raft. Landslides may be to blame instead.

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.

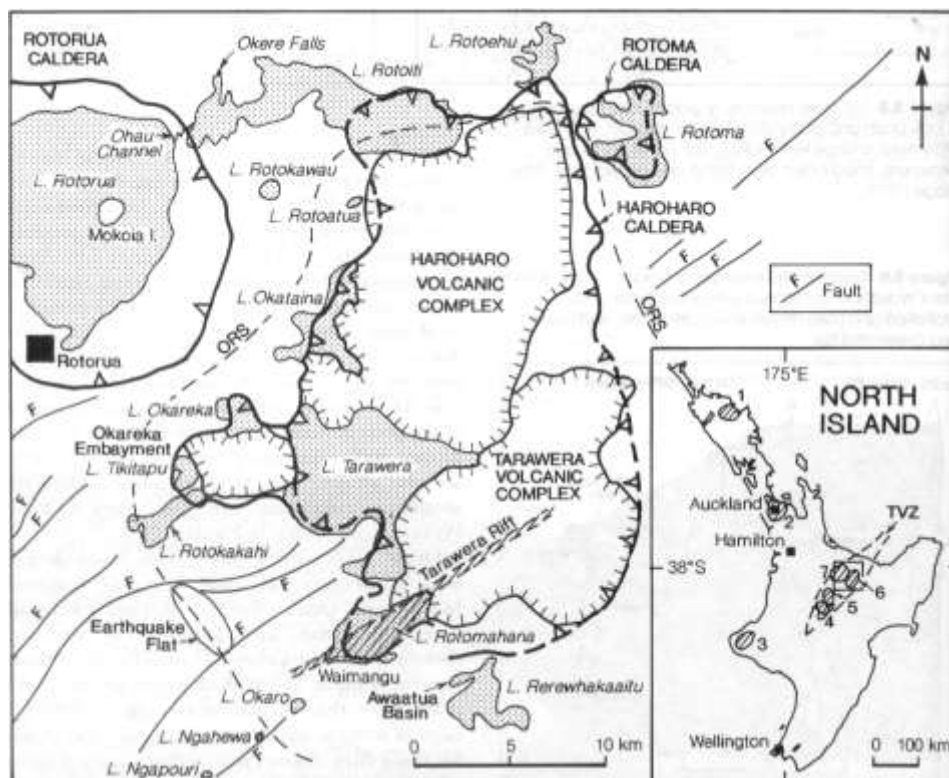


Changing levels of Lake Rotorua since c. 60,000 years ago. Present level is c. 280 m asl (W.R. Esler, unpubl. data)





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)



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 is disputed (see article above by W.R. Esler, this volume).

## Land use impacts on lake water quality

### Amy Taylor

*Auckland Regional Council, Auckland (formerly at Environment Bay of Plenty)*

### Peter Singleton

*Environment Waikato, Hamilton*

### Deniz Özkundakci

*Centre for Ecology and Biodiversity Research, University of Waikato, Hamilton*

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.

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 <i>a</i> (mg/m <sup>3</sup> )	Secchi depth (m)	Total P (mg/m <sup>3</sup> )	Total N (mg/m <sup>3</sup> )
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
<b>Okareka</b>	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.
<b>Okaro</b>	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.
<b>Okataina</b>	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.
<b>Rerewhakaaitu</b>	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.

<b>Rotoehu</b>	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
<b>Rotoiti</b>	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.
<b>Rotokakahi (Green Lake)</b>	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.
<b>Rotoma</b>	None. Low risk of cyanobacterial blooms.	Action plan process beginning. Sewage reticulation and nutrient management for farmland. Environmental programmes for landowners.
<b>Rotomahana</b>	Occasional cyanobacterial blooms.	No action at this time, until July 2008. Environmental programmes for landowners.
<b>Rotorua</b>	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.
<b>Tarawera</b>	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.
<b>Tikitapu (Blue Lake)</b>	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.

### 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<sup>2</sup> 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 20<sup>th</sup> 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>.

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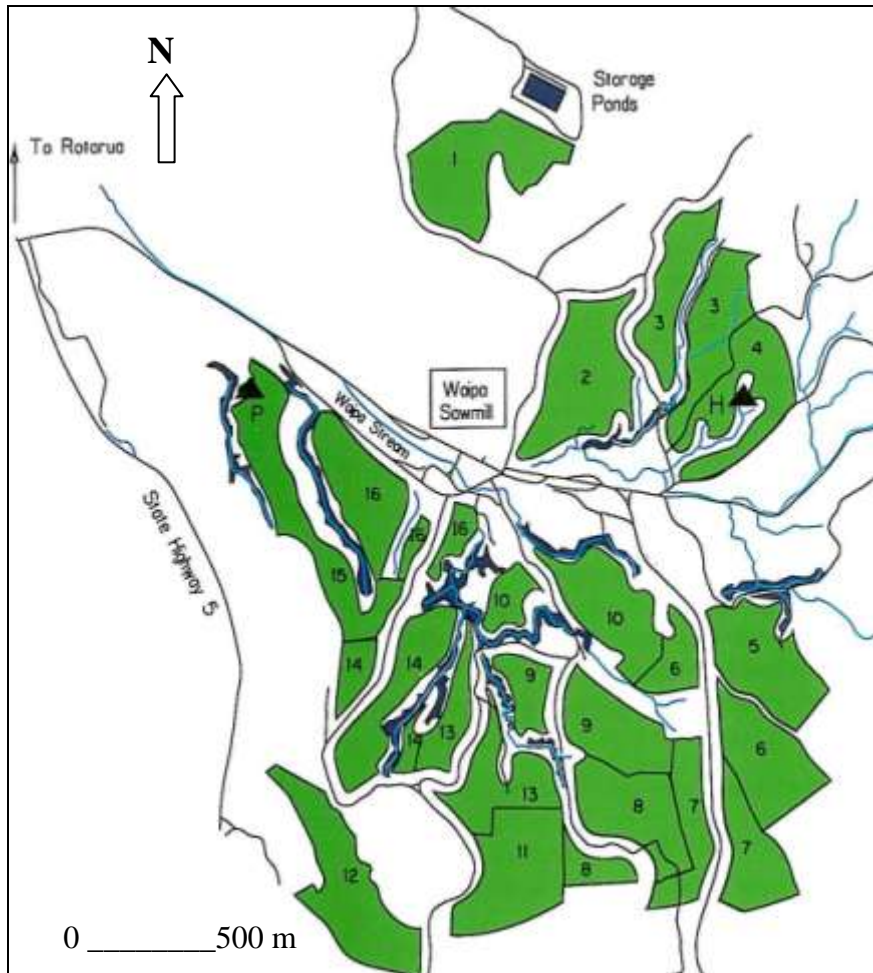


Basic field trips







# Rotorua sewage effluent irrigation scheme

**Gerty Gielen**

*Scion, Rotorua*



## Legend

- Irrigation blocks (numbered) 
- Wetlands 
- Streams 
- Roads 
- Pilot irrigation trial site 
- Hydrologic study site 

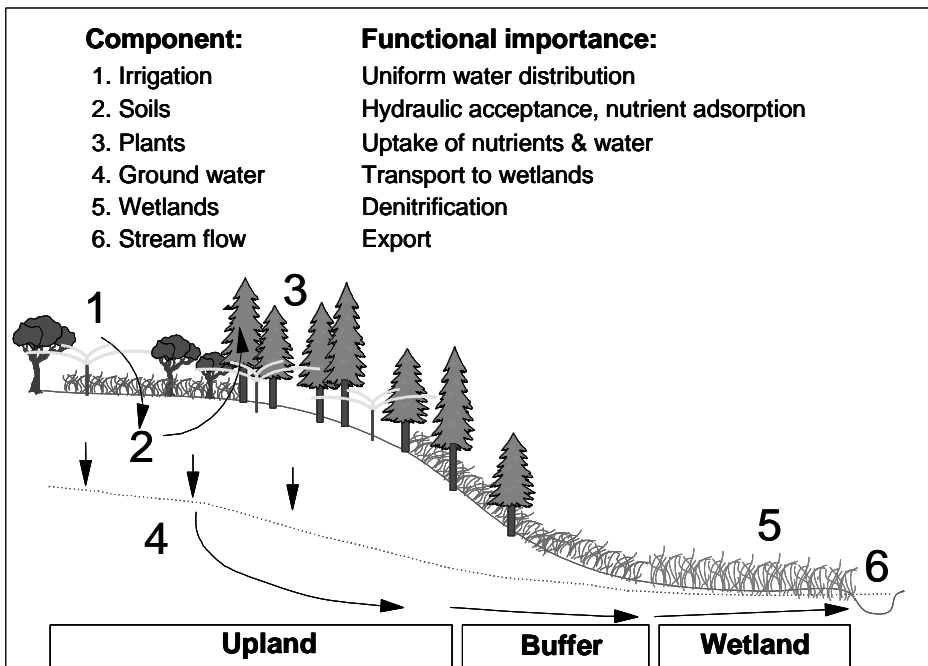


**Spray irrigation areas and wetlands and Waipo Stream. Waipo Mill site shown also.**

**Sewage effluent concentrations, loadings for major nutrients and irrigation details**

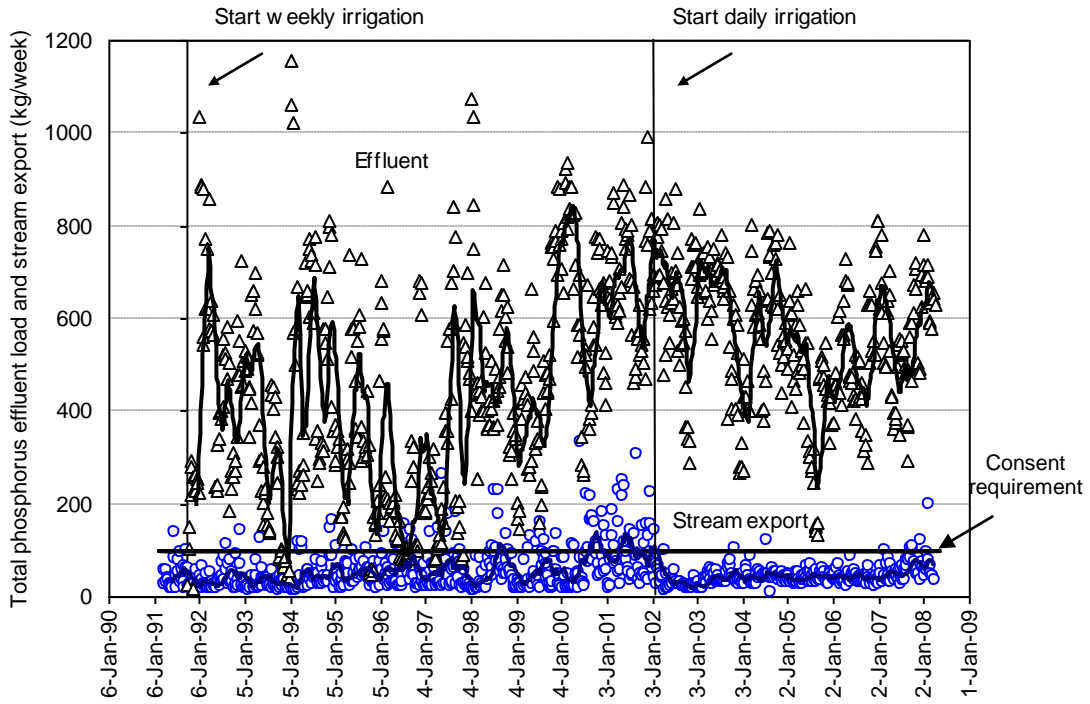
<b>Constituent</b>	<b>Mean concentration (standard deviation) (g/m<sup>3</sup>)</b>	<b>Mean area loading (kg/ha.year)</b>
pH	7.3 (0.2)	NA
Total nitrogen	10.6 (2.5)	395
Oxidised nitrogen	6.5 (2.4)	236
Kjehldahl nitrogen	4.2 (2.7)	155
Ammonium nitrogen	2.6 (2.8)	96
Total phosphorus	3.6 (1.7)	130
Dissolved reactive phosphorus	3.3 (1.7)	121
Total organic carbon	7.1 (3.0)	263

Average daily volume	19,000 m <sup>3</sup> /day
Average irrigation rate	70 mm/week
Current irrigation frequency	Daily irrigation for approximately 2 hours
Irrigation commenced	October 1991
Land treatment system:	
Total area	350 ha
Irrigated areas	193 ha
Number of spray blocks: 14	14 ha each
Wetlands	47 ha
Buffer zones, harvest rotation areas and future scheme expansion	110 ha
<b>Current consent conditions</b>	N stream export 30,000 kg/year P export 3,000 kg/year

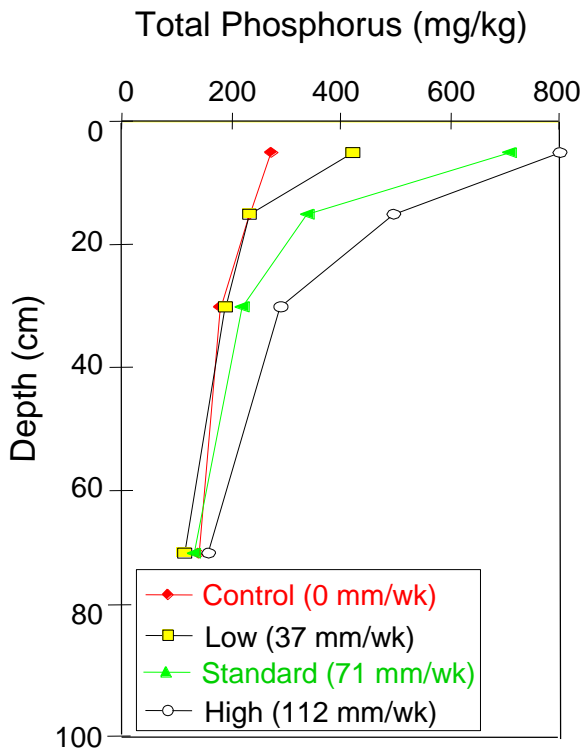


**Schematic cross section of a land based system for wastewater treatment employing upland and wetland components of landscape design**

**Total phosphorus effluent loading and stream export**  
Including 3 month moving average trend line (RDC, 2008).



**Soil phosphorus content after 4 years of irrigation**  
(K. Hopkins, MSc project)

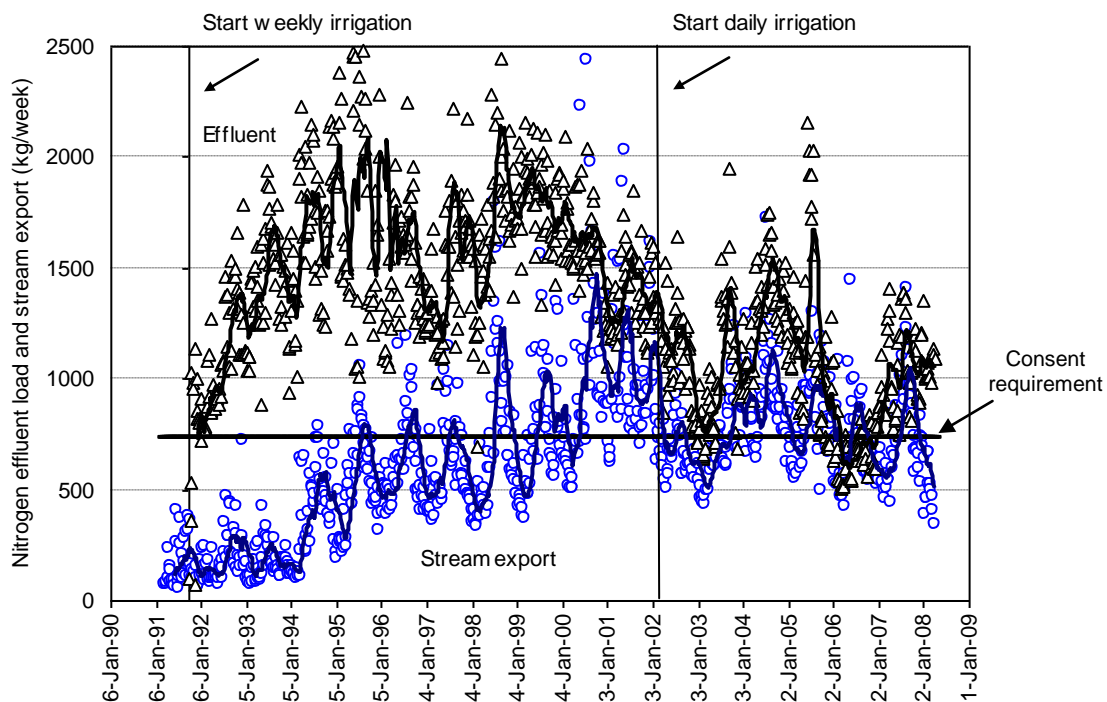


Significance groupings

Depth (cm)	Control	Low	Standard	High
0-10	c	b	a	a
10-20	b	b	ab	a
20-40	a	a	a	a
40-100	a	a	a	a

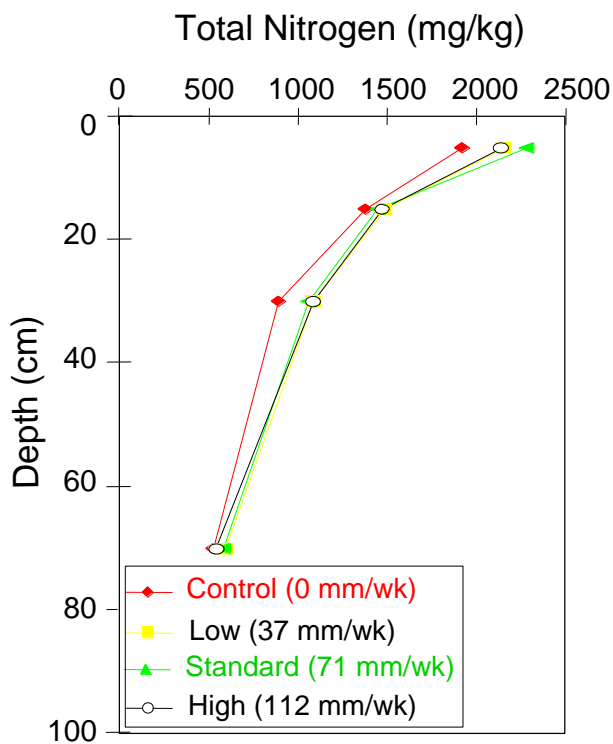
### Total nitrogen effluent loading and stream export

Including 3 month moving average trend line (RDC, 2008).



### Soil nitrogen content after 4 years of irrigation

(K. Hopkins, MSc project)



### Significance groupings

Depth (cm)	Control	Low	Standard	High
0-10	a	a	a	a
10-20	a	a	a	a
20-40	a	a	a	a
40-100	a	a	a	a

### Distribution of effluent applied nitrogen within landscape components of the Rotorua land treatment scheme

<b>N-flux pathway &amp; reference</b>	<b>Relative magnitude (% applied N)</b>	<b>Duration of study (years)</b>
<b>Soil storage</b>		
(McLay et al., 2000)	43%	4
(Tozer et al., 2005)	46%	11
<b>Upland soil denitrification</b>		
(Barton et al., 2000)	< 1%	1
<b>Tree uptake</b>		
(Tomer et al., 2000)	8%	5
(Tozer et al., 2005)	13%	11
<b>Understory</b>		
(Tozer et al., 2005)	1.5%	11
<b>Soil leaching</b>		
(Gielen et al., 2000)	39%	5
<b>Wetland denitrification</b>		
(Tozer et al., 2005)	3%	11
<b>Stream export</b>		
(Tomer et al., 2000)	32%	6
(Tozer et al., 2005)	29%	11

### Factors impacting on pharmaceutical leaching following sewage application to land (after Gielen et al., 2008)

**Abstract** Sewage effluent application to land is a treatment technology that requires appropriate consideration of various design factors. Soil type, level of sewage pre-treatment and irrigation rate were assessed for their influence on the success of soil treatment in removing pharmaceuticals remaining after conventional sewage treatment. A large scale experimental site was built to assess treatment performance in a realistic environment. Of the factors investigated, soil type had the biggest impact on treatment performance. In particular, carbamazepine was very efficiently removed (>99%) when irrigated onto a volcanic sandy loam soil (Hapludand). This was in contrast to irrigation onto a sandy soil ('Quartzipsamment') where no carbamazepine removal occurred after irrigation. Differences were likely caused by the presence of allophane in the volcanic soil which is able to accumulate a high level of organic matter. Carbamazepine apparent adsorption distribution coefficients ( $K_d$ ) for both soils when irrigated with treated sewage effluent were determined as 25 L kg<sup>-1</sup> for the volcanic soil and 0.08 L kg<sup>-1</sup> for the sandy soil. Overall, a volcanic soil was reasonably efficient in removing carbamazepine while soil type was not a major factor for caffeine removal. Removal of caffeine, however, was more efficient when a partially treated rather than fully treated effluent was applied. Based on the investigated pharmaceuticals and given an appropriate design, effluent irrigation onto land, in conjunction with conventional sewage treatment may be considered a beneficial treatment for pharmaceutical removal.

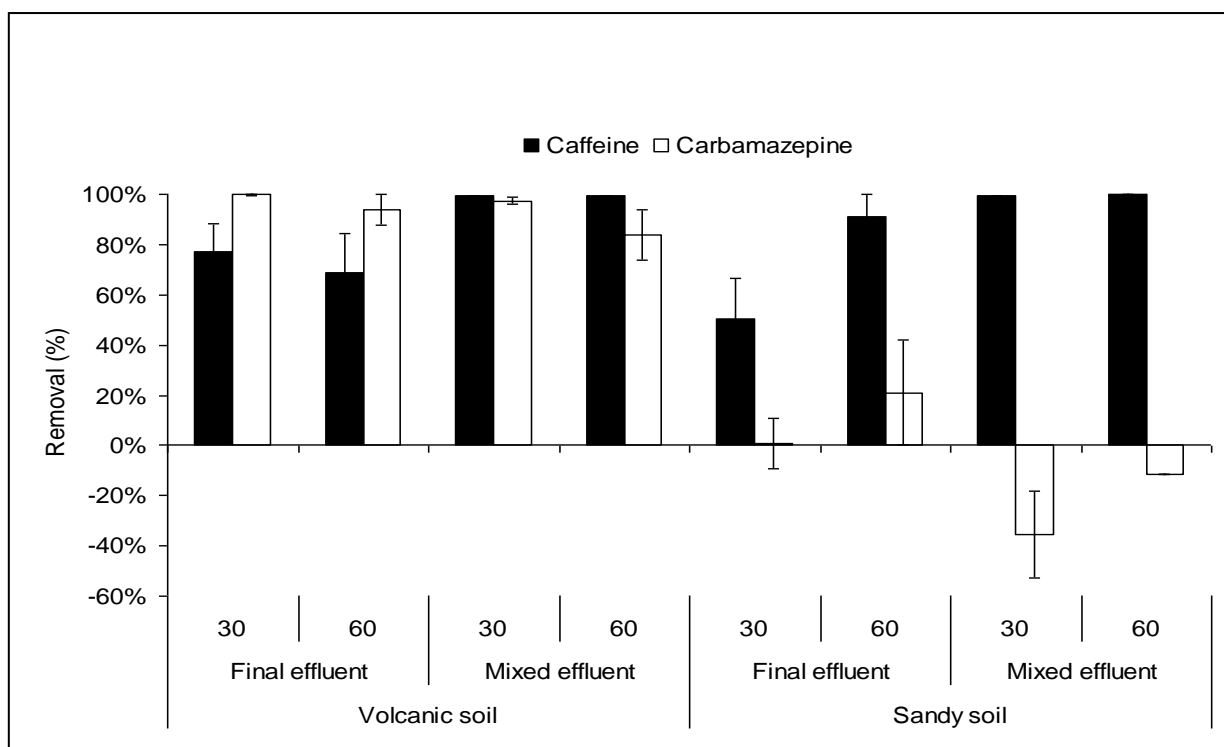
## Leaching experiment



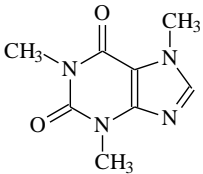
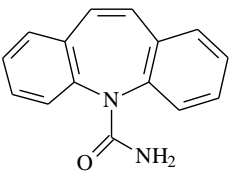
### Leaching experiment soil characteristics

	Volcanic soil	Sandy soil
Soil type	Whakarewarewa sandy loam	Reconstructed
<i>Soil Taxonomy</i>	Vitric Hapludands	Designed to approximate Typic Quartzipsamments
<i>NZ Soil Classification</i>	Vitric Orthic Allophanic Soils	Designed to approximate Sandy Raw Soil
C (%) (0–0.1 m)	8.4 %	0.8 % (peat enriched)
C (%) (0–0.9 m)	3.0 %	0.2 %
N (%)	0.20 %	0.01 %
pH	5.1	6.4
CEC (cmol <sup>c</sup> /kg)	7.1	3.0
Water holding capacity	53 %	48 %

**Removal efficiencies and standard errors for caffeine and carbamazepine in the volcanic soil and sand irrigated with final or mixed effluent at either 30 or 60 mm week<sup>-1</sup>**



**Estimated mass balance for caffeine and carbamazepine in the Rotorua land application scheme in February 2006**

	<b>Caffeine</b>	<b>Carbamazepine</b>
		
Final effluent concentration (ng L <sup>-1</sup> )	109 ± 24	709 ± 33
Soil content top 0.1 m (µg kg <sup>-1</sup> )	14 ± 3	217 ± 18
Removal efficiency large scale leaching experiment: volcanic soil irrigated with 60 mm week <sup>-1</sup> final effluent (%)	69%	94%
	Daily load	
Final effluent (mg day <sup>-1</sup> )	2,190	14,240
Top soil (mg day <sup>-1</sup> )	360	5,740
Soil water leachate (mg day <sup>-1</sup> )	680	880

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## ■ RHYMES WITH ORANGE



## Summary of main rhyolitic tephras deposited in the Rotorua region during the last c. 27,000 cal years

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) <sup>¶</sup>	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; reforestation 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).

<sup>¶</sup>Most ages are given in calibrated or calendar (cal) years (95% probability range) before present (BP), 'present' being 1950 in the <sup>14</sup>C timescale (based on Bayesian probability 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).

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## Overview of soils of Whakarewarewa Forest Park, Rotorua

Rijske (1979) mapped the soils in the Rotorua Lakes area at a scale of 1: 50 000. Three soils predominate in the Whakarewarewa Forest Park: (1) Haparangi, (2) Whakarewarewa, and (3) Ngakuru soils (and their steepland equivalents). They are all developed on layers of tephra (i.e. they are multisequal soils) and so the resulting deep, free draining profile features represent mainly upbuilding pedogenesis. The soils are similar to one another in that they are developed in a number of rhyolitic tephra deposits, as listed in the table above (note that usually not all tephra are present at any one locality, and in most profiles there are likely to be thin deposits of andesitic and other tephra additional to those listed). Older deposits (e.g. loess, Rerewhakaaitu Tephra) form the lower subsoils (about 2 m depth) of profiles in some localities. However, the soils are separated from one another mainly according to the approximate thickness of Taupo Tephra (Tp) in the upper parts of the profile and the presence or absence of Rotomahana Mud as shown below (after Rijkse, 1979, 1992).

### **Key features and classifications of the predominant soils in Whakarewarewa Forest**

Feature	Soil series		
	Haparangi	Whakarewarewa	Ngakuru
Rotomahana Mud	Absent	Often present	Absent
Thickness of Tp	~30-50 cm	~15-30 cm	~0-15 cm
NZSC	Buried-allophanic Orthic Pumice Soils	Vitric Orthic Allophanic Soils	Typic Orthic Allophanic Soils
Soil Taxonomy	Typic Udivitrand	Vitric Hapludand	Typic Hapludand

Thin Rotomahana Mud (erupted from Tarawera June 10, 1886) is commonly found in the Whakarewarewa soils where it is evident as pale grey 'blobs' (up to 8 cm thick) in the topsoil but it is not always obvious especially where logging activities have disturbed surface horizons. Subsoils (beneath Taupo) are typically yellowish-brown Bw or BC or Cu horizons. Some may qualify as AB horizons. Rotorua Tephra is particularly thick in the area (2-3 m in places) and usually coarse grained (coarse ash to lapilli and blocks) because it is <10 km from its source vents in the dome complex area between lakes Tikitapu and Okareka (Smith et al., 2004).

### **References**

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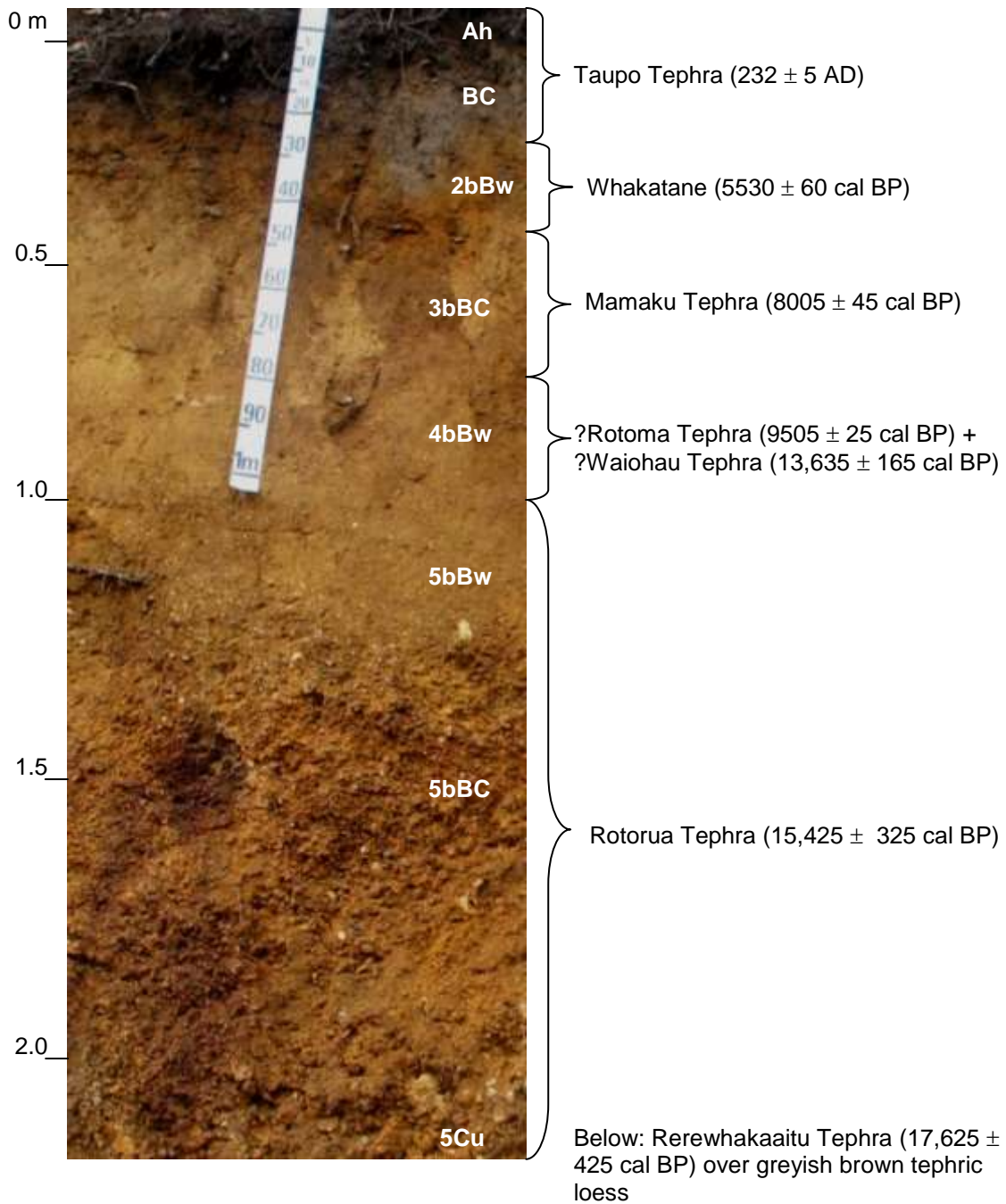
**STOP 1 – ROTORUA LAND TREATMENT SYSTEM,  
WHAKAREWAREWA SANDY LOAM, RADIO HUT RD**  
Location U16 961325, elevation 350 m asl, rainfall ~1600 mm pa



Tephros and Whakarewarewa soil on Radio Hut Rd (November 2006). *Photo:* David Lowe

## Whakarewarewa sandy loam

NZSC: Vitric Orthic Allophanic Soils; tephric, rhyolitic; loamy/sandy; rapid/moderate  
Soil Taxonomy: Medial, mesic Vitric Hapludand



Modern soil and buried soil horizons in tephra over Rotorua Tephra. *Photo, stratigraphy and horizonation*: Haydon Jones, Loretta Garrett, David Lowe, and Wim Rijkse

## Soil profile descriptions by Haydon Jones

*Scion, Rotorua*

Soil profile description data for the three soils to be seen on Day 2 are presented below. For each description, the reference data are given first, then information describing the nature of the site, and finally the soil morphological data are given (following Clayden and Hewitt, 1994; Milne et al., 1995). The land management practices of grazing and fertilization have been applied to both the Rotomahana and Matahina soils whereas the Whakarewarewa soil is under forestry and will have been subject to forest management practises. Note that as part of the geomorphic description, slope shape is given in the format of profile/contour (e.g. linear/convex) shape and that all aspects are given in degrees relative to magnetic north. Soil classifications are reported for both NZSC and *Soil Taxonomy*.

### Whakarewarewa reference data

- Soil name:
  - Series: Whakarewarewa
  - Type: sandy loam
- Soil classification:
  - NZSC: Vitric Orthic Allophanic Soils; tephric, rhyolitic; loamy/sandy; rapid/moderate
  - Soil Taxonomy: Medial, mesic Vitric Hapludand

### Site data

- Location:
  - Map reference: NZMS 260 U16 2796180 6332592
  - Word description: Road cutting about 55 m from corner of Radio Hut and Nursery Roads, Whakarewarewa forest, Rotorua
- Elevation: 350 m
- Geomorphic position: Profile on a 12° linear/convex slope with 323° aspect contained within the shoulder of a side slope in hill country
- Erosion/deposition: Nil
- Vegetation: Scrub, ferns, and *Pinus radiata*
- Parent material: Taupo Tephra with underlying buried soil horizons formed in various tephra deposits (Whakatane, Mamaku, ?Rotoma, ?Waiohau, Rotorua, and Rerewhakaaitu tephra on tephric loess; see photos for tephra ages) ( $\pm$  discontinuous Rotomahana Mud in A horizon?)
- Drainage class: Well drained

### Soil data

Ah

0-15 cm Very dark brown (10YR 2/2) very slightly gravelly sandy loam with fine sub-angular slightly weathered pumice gravels; slightly sticky; slightly plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; very weakly allophanic; indistinct wavy (occluded) boundary. [Taupo]

BC

15-35 cm Dark greyish brown to olive brown (2.5Y 4/2.5) slightly gravelly loamy sand with fine to medium sub-angular slightly weathered pumice gravels; slightly sticky; non plastic; soil very weak and very friable; apedal single grain; strongly allophanic; distinct irregular boundary. [Taupo]

2bBw	
35-47 cm	Brown to dark yellowish brown (10YR 4/3.5) sandy loam; slightly sticky; slightly plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; very strongly allophanic; distinct wavy boundary. [Whakatane]
3bBC	
47-68 cm	Dark yellowish brown to yellowish brown (10YR 4.5/4) sandy loam; slightly sticky; slightly plastic; soil weak and friable; apedal massive; strongly allophanic; indistinct convolute boundary. [Mamaku]
4bBw	
68-96 cm	Dark yellowish brown (10YR 4/4) sandy loam; slightly sticky; slightly plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; moderately allophanic; diffuse wavy boundary. [?Rotoma, ?Waiohau]
5bBw	
96-140 cm	Dark yellowish brown (10YR 4/4) very slightly gravelly sandy clay loam with fine sub-rounded slightly weathered pumice gravels; slightly sticky; slightly plastic; peds weak and very friable; apedal earthy; profuse very fine polyhedral peds; moderately allophanic; indistinct wavy boundary. [Rotorua]
5bBC	
140-245 cm	Strong brown (7.5YR 5/8) extremely gravelly and with fine to coarse sub-angular slightly weathered pumice gravels; non sticky; non plastic; apedal single grain; weakly allophanic; indistinct wavy boundary. [Rotorua]
5Cu	
245 cm –on	Yellow (10YR 7/6) extremely gravelly sand with fine to coarse sub-angular slightly weathered pumice gravels; non sticky; non plastic; apedal single grain; very weakly allophanic [Rotorua]

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Note: Source vents for Rotorua Tephra are only ~7-8 km to the south-east of this site (rhyolite dome complex between lakes Tikitapu and Okareka). Soils of the Whakarewarewa Forest area have been mapped and described (scale 1: 50,000) by Rijkse (1979). Analytical data for a Whakarewarewa/Ngakuru soil are available below (from Rijkse, 1992).

#### Note from Wim Rijkse

**Whakarewarewa sandy loam** is moderately leached (base saturations 40%, 22%, 4%) in the upper 44 cm) with low exchangeable cations (Ca, Mg, K and Na) (Vucetich and Wells, 1978). Available phosphorus in these soils tends to be low. Foresters in the Bay of Plenty have been concerned about assumed low boron levels, but where measured in several forests it always was adequate (available boron is regarded as adequate if between 1 to 5 mg/kg).

#### References

- Clayden, B., Hewitt, A.E. 1994. *Horizon Notation for New Zealand Soils*. Manaaki Whenua Press, Lincoln.
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- Milne, J.D.G., Clayden, B., Singleton, P.L., Wilson, A.D. 1995. *Soil Description Handbook*. Manaaki Whenua Press, Landcare Research Ltd, Lincoln.
- Rijkse, W.C. 1979. Soils of the Rotorua lakes district, North Island, New Zealand. *N.Z. Soil Survey Report 43*.
- Vucetich, C.G., Wells, N. 1978. Soils, agriculture, and forestry of Waiotapu region, central North Island, New Zealand. *New Zealand Soil Bureau Bulletin 31*. 100pp. + 5 maps.

Location: Larch Road, Whakarewarewa Forest

Grid reference: U16 975303

Slope: 0° Aspect: West Altitude: 356 m Rainfall: 1600 mm

Nature of slope: crest of easy rolling hill

Vegetation: Bracken fern, hard fern and blackberry

Profile description

<u>Field no.</u>	<u>Lab. no.</u>	<u>Depth (cm)</u>	<u>Description</u>
Wa2-1	87/43/2a	0-4	dark brown (10YR 3/3) sandy loam; friable; few firm Taupo lapilli; distinct irregular boundary,
2	b	4-34	dark yellowish brown (10YR 4/4) greasy sandy loam; friable; few medium lapilli; (Mamaku Ash),
3	c	34-64	brown (10YR 4/3) fine sandy loam; greasy; friable; (Rotoma Ash); distinct smooth boundary,
4	d	64-103	dark yellowish brown (10YR 4/6) gritty silt loam; slightly firm; many very fine lapilli; (Waiohau Ash); indistinct smooth boundary,
5	e	103-133	dark greyish brown (10YR 4/6) gritty sandy loam; friable; (Rotorua Ash paleosol); distinct smooth boundary,
6	f	133-175	yellowish brown to brownish yellow (10YR 5/5-10YR 6/6) pumice gravel (average size 2-15 mm, max. size 25 mm); loose; (Rotorua lapilli),
7	g	175-235	yellowish brown to brownish yellow (10YR 5/8-10YR 6/6) coarse pumice gravel (av. size 15-40 mm, max. size 70 mm); loose; (Rotorua lapilli) sharp smooth boundary,
8	h	235-265	yellowish brown (10YR 5/4) gritty silt loam; friable; (loess).

**Data on this and following page are for Whakarewarewa/Ngakuru soil and are from Rijske (1992)**

Site : Wa2

## PARTICLE SIZE DISTRIBUTION (mm, %)

Lab No : 87/43/2

Horizon Depth (cm)	Lab Letter	Sample Depth (cm)	FINE EARTH FRACTION					WHOLE SOIL		
			Coarse Sand 2-0.6	Medium Sand 0.6-0.2	Fine Sand 0.2-0.06	Silt 0.06- 0.002	Clay <.002	>19	19-2.0	<2.0
			(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
0-4	A	0-4	7	12	25	49	7	0	4	96
4-34	B	4-34	11	21	25	30	13	0	1	99
34-64	C	34-64	4	23	30	31	12	0	1	99
64-103	D	64-103	10	21	26	27	16	0	1	99
103-133	E	103-133	17	34	21	20	8	0	1	99
133-175	F	133-175	76	17	2	4	1	0	39	61
175-235	G	175-235						15	78	7
235-265	H	235-265	1	6	25	44	24			

## DENSITY, POROSITY AND WATER RETENTION MEASUREMENTS

Horizon Depth (cm)	PA Number	Sample Depth (cm)	Water Content (%)	Dry Bulk Density (t/m <sup>3</sup> )	Particle Density (t/m <sup>3</sup> )	Total Porosity (%)	Macro- porosity (%)	Water Content (% v/v) at Tensions (kPa)				Available Water (%)	Total Water (%)
								5	10	100	1500		
0-4	2582	1-4	49.2	0.58	2.33	75.3	39.6	35.7	30.3	17.8	12.4	12.5	17.9
4-34	2583A	15-18	63.4	0.77	2.37	67.7	16.2	51.5	47.3	38.8	23.9	8.5	23.4
	2583B	19-22	57.6	0.82									
34-64	2584A	45-48	48.4	0.92	2.40	61.8	16.3	45.5	42.6	36.4	23.6	6.2	19.0
	2584B	49-52	46.4	0.94									
64-103	2585A	80-83	60.2	0.87	2.48	65.1	11.6	53.5	51.0	44.6	32.2	6.4	18.8
	2585B	84-87	50.7	0.88									
103-133	2586A	114-117	49.8	0.95	2.44	61.3	13.8	47.5	45.0	36.6	23.6	8.4	21.4
	2586B	118-121	41.2	0.97									
133-175	2586C	133-175	35.8	0.72									
175-235	2586D	175-235	64.3	0.55									
235-265	2587A	246-249	56.5	0.94	2.51	62.3	4.4	57.9	55.1	40.8	21.8	14.3	33.3
	2587B	250-253	55.4	0.89									

Soil Name: WHAKAREMAREMA FOREST ?

Lab No: IS00258

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	Pyrophosphate- extractable (%)			Acid oxalate- extractable (%)			ODOE	Dithionite-citrate extractable (%)		Stones >2mm (%)	Moisture factor
				Fe	Al	C	Fe	Al	Si		Fe	Al		
				8B			8A				8C			
	0-4	a	0-4	0.27	0.48		0.45	1.1	0.30		0.50	0.57	n.d	1.034
	4-34	b	4-34	0.20	0.46		0.70	2.8	1.1		0.63	0.88	n.d	1.044
	34-64	c	34-64	0.03	0.26		0.34	2.3	1.2		0.41	0.47	n.d	1.057
	64-103	d	64-103	0.03	0.21		0.68	2.9	2.0		0.82	0.53	n.d	1.056
	103-133	e	103-133	0.03	0.17		0.36	2.0	1.3		0.41	0.26	n.d	1.029
	133-175	f	133-175	0.01	0.08		0.13	0.86	0.65		0.16	0.08	n.d	1.013
	175-235	g	175-235	0.01	0.05		0.13	0.78	0.46		0.12	0.07	n.d	1.013
	235-265	h	235-265	0.04	0.07		0.47	0.45	0.29		0.74	0.18	n.d	1.026

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	pH				Phosphorus fractions (mg %)				F retn (%)				
				H <sub>2</sub> O	1M KCl	1M NaF	CaCl <sub>2</sub>	H <sub>2</sub> O Moist	C (%)	W (%)	C/W		0.5 M H <sub>2</sub> SO <sub>4</sub>	Inorg.	Organic	Total
				2A	2C	2D	2B	3A	4A	5A	5D		5B	5F	5G	
	0-4	a	0-4	5.4				4.6						67		
	4-34	b	4-34	5.7				2.9						93		
	34-64	c	34-64	5.9				1.8						85		
	64-103	d	64-103	6.0				1.1						89		
	103-133	e	103-133	6.3				0.31						77		
	133-175	f	133-175											35		
	175-235	g	175-235											31		
	235-265	h	235-265											44		

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	Cation exchange								KCl Ex. Al (me. %)	Titratable acidity (me. %)	Reserve Mg <sup>+</sup> K <sup>+</sup> (me. %)	S Total (ug/g)	Phosphate ext. (ug/g)
				[NH <sub>4</sub> OAc @ pH 7 me %]				[NH <sub>4</sub> OAc @ pH 7 me %]								
				Ca	Mg	K	Na	Ca	Mg	K	Na					
	0-4	a	0-4	15.1	2.49	16	1.40	0.38	0.49	0.22	1.3					
	4-34	b	4-34	11.9	0.53	4	0.25	0.03	0.10	0.15	0.2					
	34-64	c	34-64	9.1	0.35	4	0.25	0.06	0.01	0.03	0.1					
	64-103	d	64-103	7.7	0.63	8	0.36	0.09	0.13	0.05	0.1					
	103-133	e	103-133	3.7	0.98	16	0.43	0.08	0.03	0.04	0.1					
	133-175	f	133-175													
	175-235	g	175-235													
	235-265	h	235-265													

Analysts: KMG LJG COM

Date: 31-Mar-1992

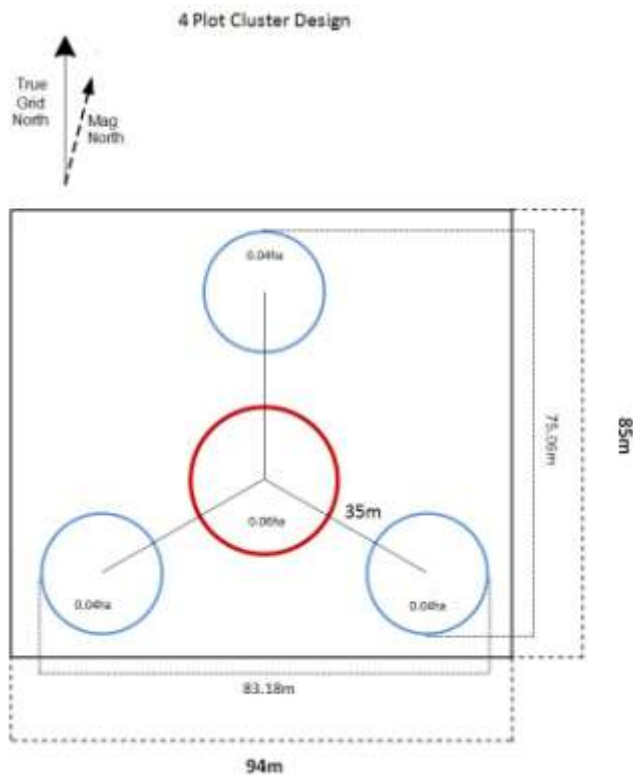
## Forest carbon inventory and modelling

**Peter Beets and Thomas Paul**

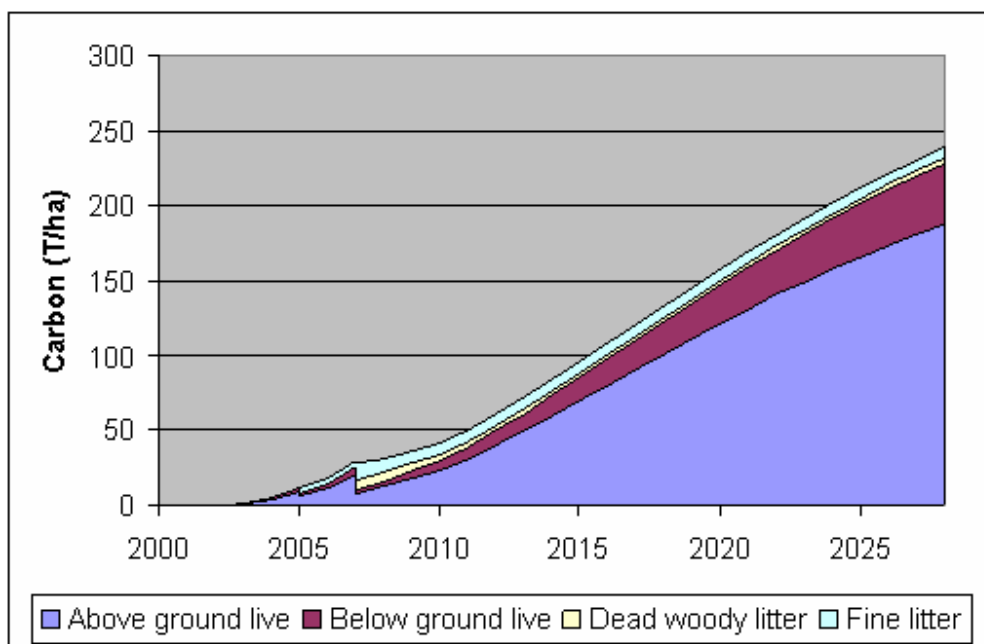
*Scion, Rotorua*

Now that the Kyoto Protocol is in effect, the NZ Government is obligated to report on carbon stocks and changes in forests and soils, and to account for carbon stock changes in post-1989 forests from 2008-2012

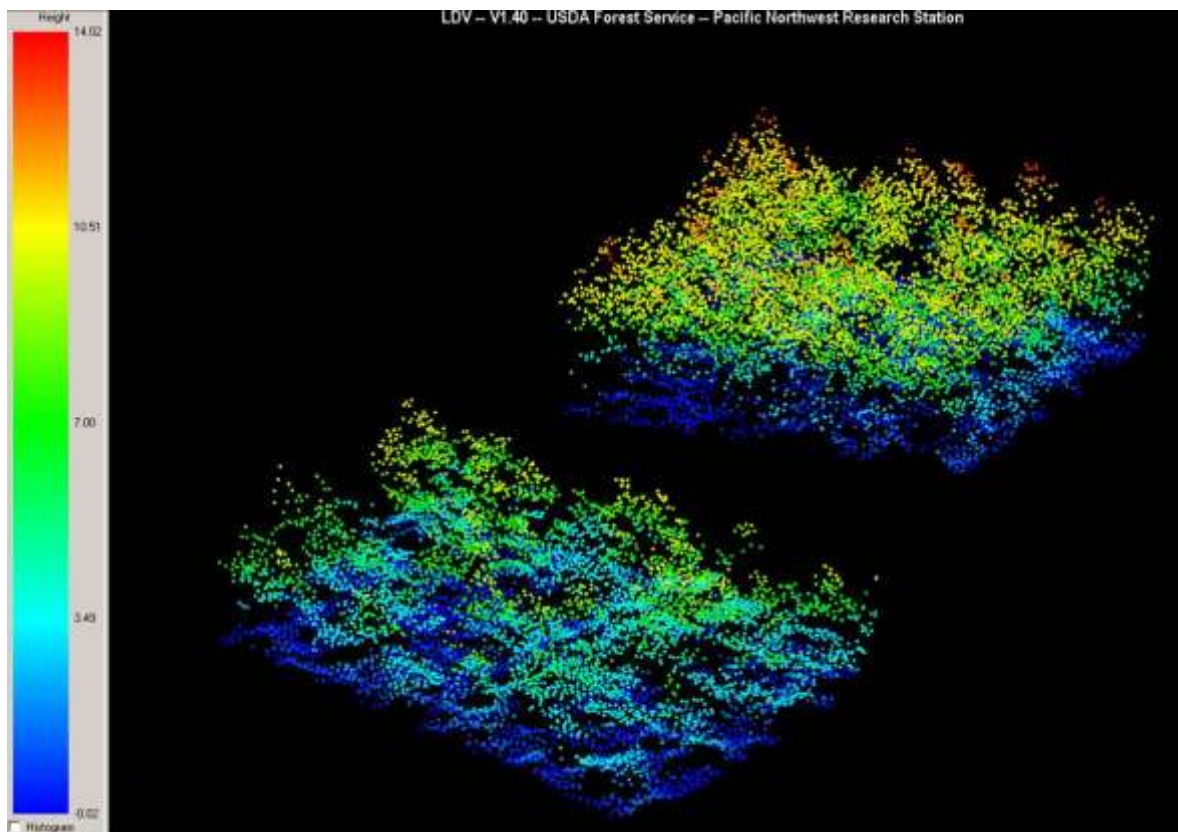
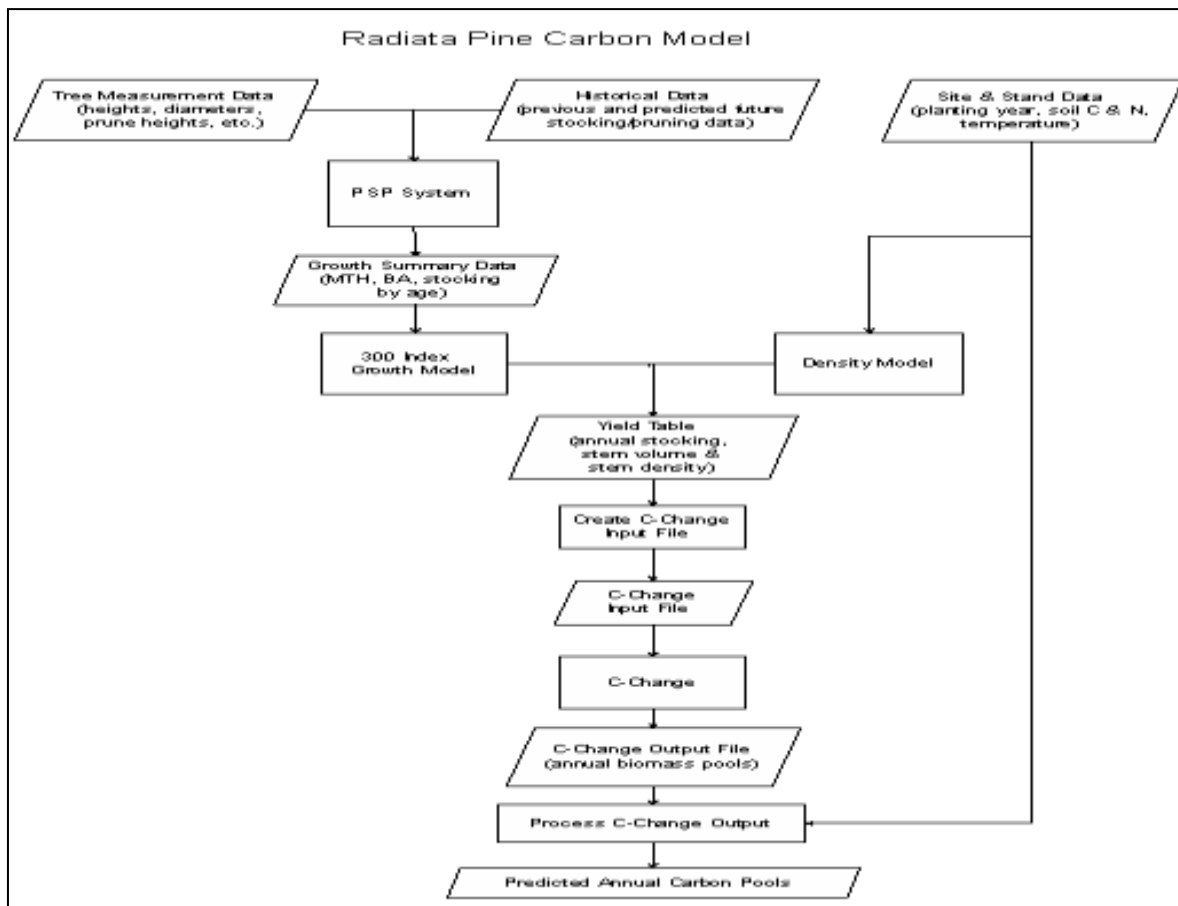
### Forest sampling includes ground and LiDAR plots



- Cluster plots on 4 km national grid
- Four plots per cluster
- Standard plot measurements (dbh, ht, crown height, stocking) of standing and felled trees
- Soil nitrogen fertility
- LiDAR data acquired



Modelled carbon stock estimates in a radiata pine stand



LiDAR point clouds – Puruki plots 5/5/11 & 5/3/3

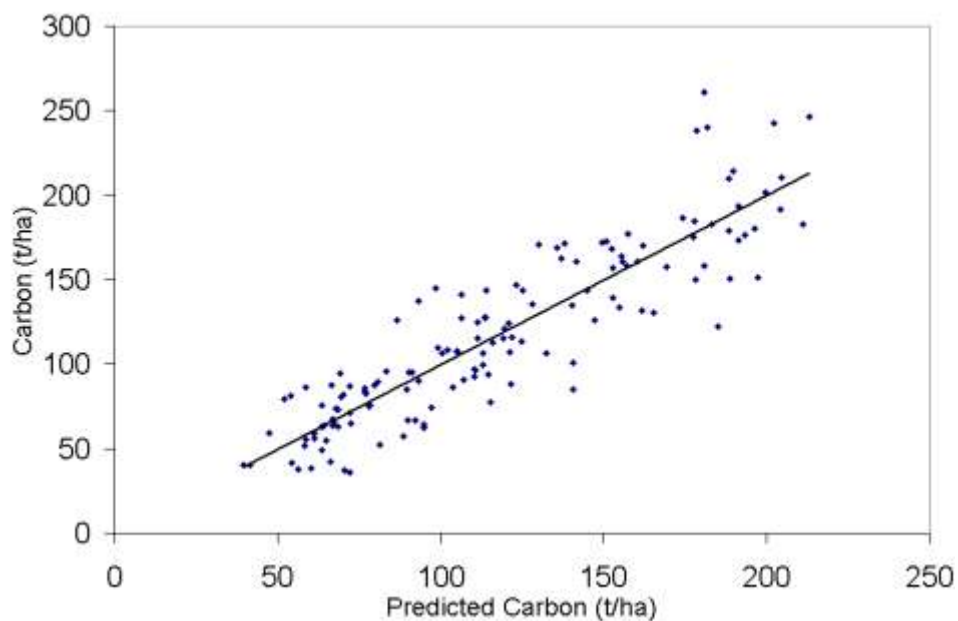
## Development of regression relationships



Scion's research programme is examining the effects of leaf area index, tree age, stocking, height, basal area, prune height, and understory on LiDAR metrics – to increase the precision of national carbon stock and changes estimates

### Summary

1. A national inventory of post-1989 planted forest plots was completed in November 2008
2. Data analysis and carbon stock and change estimates based on ground plot measurements will be completed early in 2009.
3. Development of LiDAR relationships and assessment of their impact on the precision of national carbon stock and change estimates is expected to be completed by mid-2009.



Relationship carbon estimates in ground plots and regression estimates based on LiDAR metrics

## Sample collection for soil carbon stock assessment in plantation forests

**Haydon Jones**

*Scion, Rotorua*

Two main types of forest floor material are commonly sampled: needle litter (L) and fermented and humic material (FH). Prior to mineral soil sampling, the L and FH materials are collected from within a 0.25 m<sup>2</sup> area centred on the sample point and demarcated using a metal quadrat. Each forest floor type is placed in a separate bag and the depths of L and FH material recorded. The L material is collected from the entire 0.25 m<sup>2</sup> area (Fig. 2a) whereas the FH material is collected from within a stainless steel soil sampling ring (of 98-mm internal diameter) placed in the centre of the 0.25 m<sup>2</sup> area after removal of the litter (Fig. 2b).



**Fig. 2** Litter sampling using the 0.25 m<sup>2</sup> quadrat (a) and FH sampling using the 98 mm diameter ring (b).

The mineral soil is sampled from three 0.1-m depth ranges (0-0.1, 0.1-0.2, and 0.2-0.3 m) using a 98-mm diameter ( $\times$  100 mm depth) soil sampling ring positioned in the centre of the 0.25 m<sup>2</sup> area immediately after the FH material has been collected. The soil samples are carefully excavated and extracted with regular depth checking to ensure that the correct depth range was sampled (Figs. 3 and 4). Volumetric sampling is favoured over sampling using a small-diameter tube sampler in gravely soils because it ensures that each 0.1 m increment is accurately collected and avoids the problems of sample column compression or gravel blockages.



**Fig. 3** Excavation of cores (a) and sample depth checking (b) during the collection of mineral soil samples.

The above approach was used in a study of the effects of different forest harvest residue management practices on the soil carbon stocks in Tarawera Forest in the Bay of Plenty (Jones, 2007). The young, coarse-textured soils at the site (Vitrandic Udorthents corresponding to Typic Tephric Recent Soils of the NZSC) were formed in basaltic scoria (Tarawera Scoria) that was erupted from the Tarawera Volcanic Complex on 10 June 1886 (Walker et al., 1984). A paper describing the results of the study was published by Jones et al. (2008) (see abstract below). The work was funded by the NZ Ministry for the Environment.

## References

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- 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.



**Fig. 4** Core extraction from pit using a flat trowel (a) and bagging the mineral soil samples (b)

## Impacts of Harvest Residue Management on Soil Carbon Stocks in a Plantation Forest

Haydon S. Jones<sup>\*</sup>, Loretta G. Garrett, Peter N. Beets, Mark O. Kimberley and Graeme R. Oliver  
Scion, Private Bag 3020, Rotorua, New Zealand

<sup>\*</sup> Corresponding author ([haydon.jones@scionresearch.com](mailto:haydon.jones@scionresearch.com)).

The impacts of plantation forest management on soil C stocks in New Zealand need to be better understood for the purposes of C accounting under the Kyoto Protocol. We investigated the impacts of three harvest residue management treatments on C and N stocks in a scoriaceous forest soil: whole-tree harvesting plus forest floor removal, whole-tree harvesting, and stem-only harvesting. Volumetric samples were collected from the forest floor and three mineral soil depth increments (0–0.1, 0.1–0.2, and 0.2–0.3 m) 16 to 17 yr after harvesting. Both fine (<2-mm) and coarse (>2-mm) fractions of the mineral soil were analyzed. No significant impacts on stocks of C and N were observed in the mineral soil fine fraction. Averaged across treatments, the 0- to 0.3-m mineral soil coarse fraction contained  $5.2 \pm 0.52 \text{ Mg C ha}^{-1}$ , representing 25% of total mineral soil C, with most derived from the fine-earth-coated scoria gravel. The inclusion of the coarse fraction stocks enabled the detection of significant treatment effects. Stem-only harvesting (residue retention) had significantly larger C stocks in the 0- to 0.1-m total mineral soil (fine + coarse fractions), forest floor, and total soil (forest floor + 0–0.3-m total mineral soil) pools than whole-tree harvesting (residue removal) plus forest floor removal. We recommend the retention of both harvest residues and forest floor materials for the maintenance of soil C stocks in plantation forests. Detection of residue management impacts on C stocks in soils with vesicular gravels may require analysis of the coarse fraction.

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## **STOP 2 – SPRAY BLOCK 2, RED TANK RD**

Location U16 972309, elevation 360 m asl, rainfall ~1500 mm pa

## **STOP 3 – WETLAND, LONG DRIVE**

Location U16 967294, elevation 340 m asl, rainfall ~1500 mm pa



Sprayers operating in Whakarewarewa Forest. *Photo: David Lowe*

## **Waipa Mill groundwater remediation: a success story**

### **Tim Charleson**

*Environmental Manager, Red Stag Timber Ltd, Waipa Mill, Rotorua*

Pentachlorophenol (PCP)-containing solutions were used at the Waipa Mill for the preservative treating of timber before being withdrawn in 1984. Poor handling practices resulted in PCP solutions contaminating soil. The volcanic soils are highly porous and the groundwater in the PCP handling areas was less than 3 m below ground level. As a consequence, significant PCP contamination of groundwater occurred. A 1991 study of PCP contamination at Waipa showed significant soil contamination but highlighted the groundwater contamination as the most immediate threat due to its mobility and the consequence on the wider environment. The total mass load of PCP entering the Waipa Stream was calculated as 575 kg/yr. A remediation system was designed to remove at least 80% of the total load entering Waipa Stream. There are three stages to the remediation system which was commissioned in 1994 and has run 24/7 until late 2005.

### 1. Groundwater interception

Strategically located shallow interception trenches were laid to intercept the majority of contaminated groundwater flow. In total about 700 m of trenches using impervious plastic sheeting and slotted PVC pipe was laid. An important aspect of the interception project was to minimise contaminated groundwater infiltration into stormwater drains which drain into the Waipa Stream.

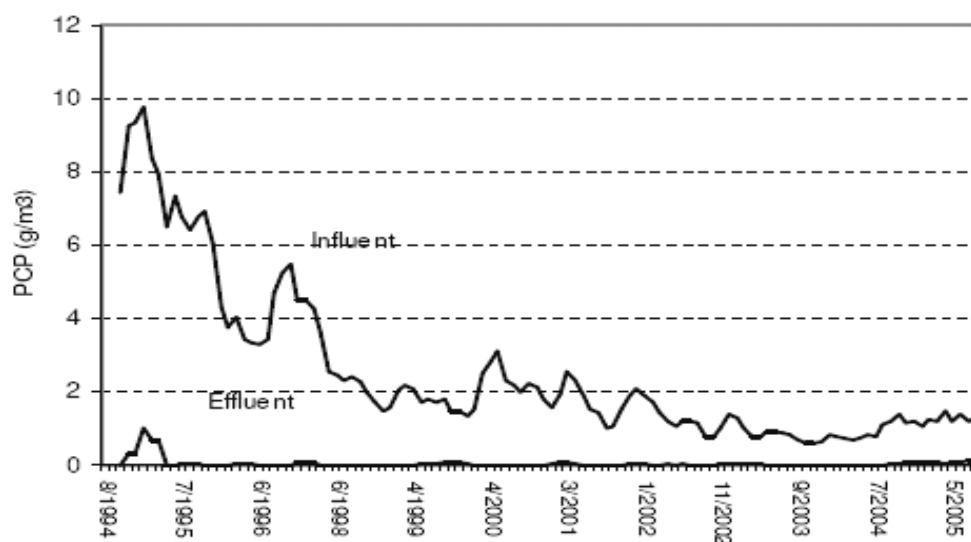
### 2. Groundwater treatment

Chemical treatment of the intercepted groundwater using the Rayox® process was chosen for this step. Hydrogen peroxide in the presence of ultraviolet light destroys the PCP in a series of chemical reactions.

### 3. Discharge via the wastewater system

The treated groundwater is discharged to the existing oxidation pond sewage treatment system where it is ultimately discharged to the adjacent forest, land disposal system.

Eleven years after it first began, the Rayox plant had typically achieved in excess of 99.8% destruction of PCP in the in-coming groundwater (influent) (see figure below). The treated groundwater (effluent) PCP concentration had typically been significantly less than 10 ppb. A steady decline in the influent PCP concentration demonstrates that groundwater contamination from the site is diminishing and has been successfully remediated.



**Rayox plant influent and effluent PCP concentrations**

The Rayox plant was decommissioned in 2005 as a consequence of the successful remediation of the groundwater. The remaining low concentration PCP groundwater (typically <math>< 0.2 \text{ g/m}^3</math>) is now successfully treated in the site's wastewater oxidation ponds using natural solar photo-oxidation.

## **STOP 4 – LAKE OKARO AND WETLANDS, OKARO RD**

Location U16 177171, elevation 420 m asl, rainfall ~1500 mm pa

### **Lake Okaro and its restoration**

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#### **Geology and soils in Lake Okaro area**

Lake Okaro was formed c. 700 years ago, probably during the Kaharoa eruption ( $1314 \pm 12$  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  $0.28 \text{ km}^2$  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

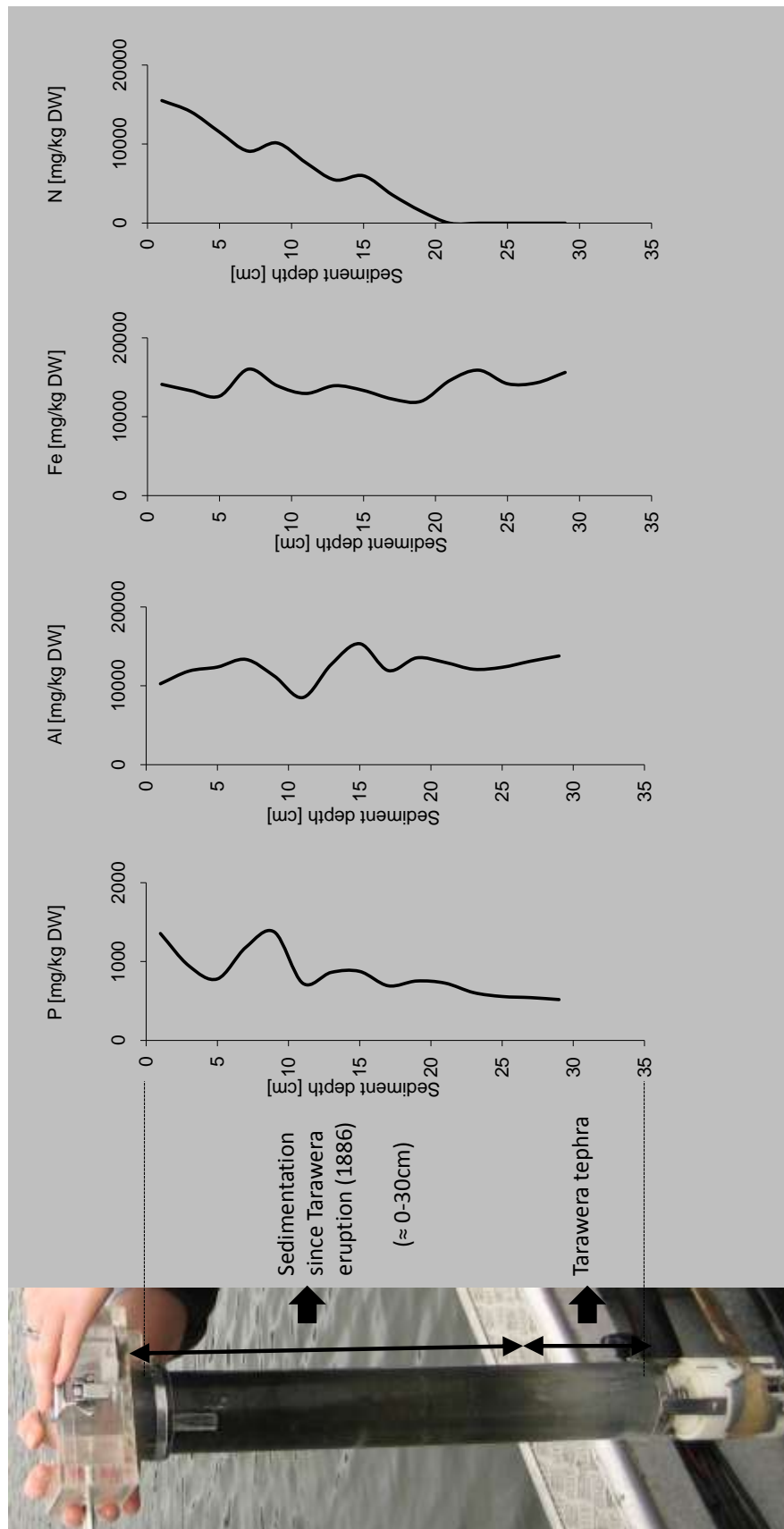
Period	Chloro <i>a</i> [mg m <sup>-3</sup> ]	SD [m]	Total P [mg m <sup>-3</sup> ]	Total N [mg m <sup>-3</sup> ]	TLI	TN:TP ratio
Jul 1991 - Jun 1992	24.44	1.18	115.78	1289.67	5.66	11.14
Jul 1992 - Jun 1993	27.75	1.73	91.67	1015.67	5.45	11.08
Jul 1993 - Jun 1994	12.35	1.60	101.10	1259.33	5.35	12.46
Jul 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

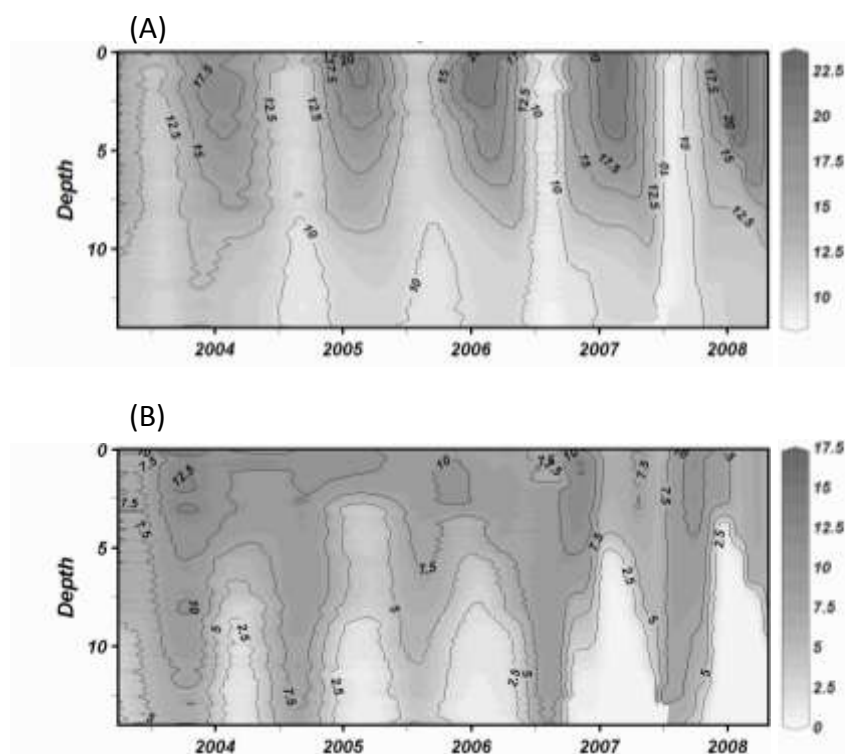
Nitrogen (N) and phosphorus (P) are the key drivers of water quality in Lake Okaro. The catchment area (3.89 km<sup>2</sup>) has been almost entirely cleared of native vegetation and is now used as pasture, mostly for dairy production, resulting in increased nutrient runoff both indirectly and through 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<sub>4</sub>-N) and P in the form of orthophosphate (PO<sub>4</sub><sup>3-</sup>). 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<sup>3</sup> of alum on 16 and 17 December, 2003. Alum was applied as aluminium sulphate and achieved a concentration of 0.6 g Al m<sup>-3</sup> 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).



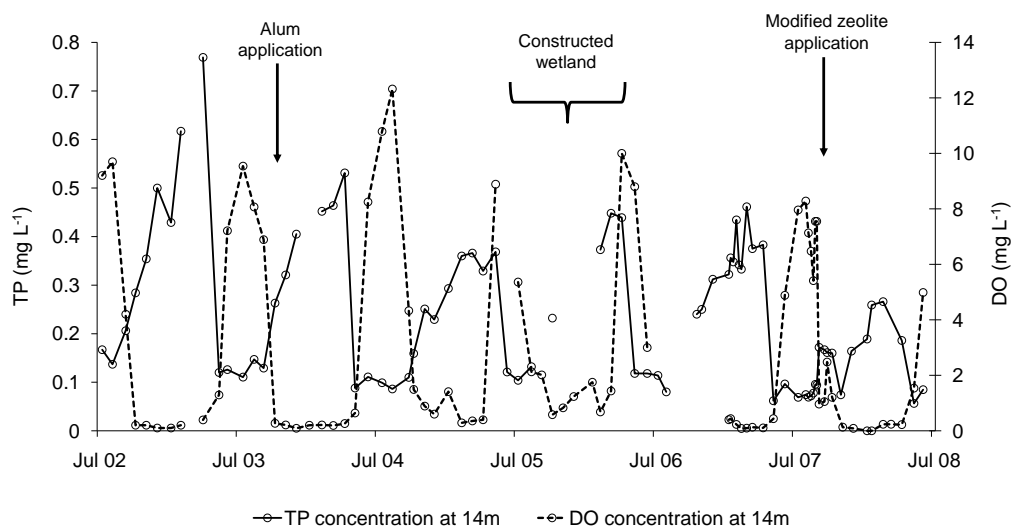
**Fig. 1** Sediment core from Lake Okaro and vertical profiles of phosphorus (P) ( $\text{mg kg DW}^{-1}$ ), aluminium (Al) ( $\text{mg kg DW}^{-1}$ ), iron (Fe) ( $\text{mg kg DW}^{-1}$ ), and nitrogen (N) ( $\text{mg kg}^{-1} \text{DW}$ ) (N profile courtesy of Dennis Trolle, University of Waikato)



**Fig. 2** Temperatures ( $^{\circ}\text{C}$ ) in Lake Okaro (A), and dissolved oxygen concentrations ( $\text{mg L}^{-1}$ ) 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% ( $165\text{-}210 \text{ kg yr}^{-1}$ ) and 10-15% ( $5\text{-}6 \text{ kg yr}^{-1}$ ), 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  $350 \text{ g m}^{-2}$ , 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 ( $\text{mg L}^{-1}$ ) and dissolved oxygen (DO) concentrations ( $\text{mg L}^{-1}$ ) for Lake Okaro at 14 m depth for period July 2002 until June 2008

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. Further research to investigate the individual effects of the successive restoration programme is underway with the focus on internal P cycle. We are currently studying 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.

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## **Military activities in the Rerewhakaaitu area**

Military activities around Rerewhakaaitu, documented by Mossop (1993), began with annual camps by New Zealand field artillery units in the 1920s-1930s. With the onset of World War II, the artillery units became established along the eastern shores of Lake Rerewhakaaitu and near Mt Tarawera. Batteries fired from escarpments along Northern Boundary Road into the lower slopes of Mt Tarawera. The New Zealand Tank Brigade (~1000 men and ~300 vehicles) trained there from May 1943.

Three infantry divisions of the US Army (the 25<sup>th</sup>, 37<sup>th</sup>, and 43<sup>rd</sup>), comprising about 15,000 men in total, camped and trained in the area from 1942 to July 1944. The main units were the 43<sup>rd</sup> 'Winged Victory Division' and to a lesser extent the 25<sup>th</sup> 'Tropic Lightning Division'. The 25<sup>th</sup> Division was from Hawaii. It left New Zealand in February 1944. The 43<sup>rd</sup> Division was raised from Vermont, Connecticut, and Maine. It began training at Rerewhakaaitu on April 1944, and left New Zealand by the end of July. Winter in 1944 was very cold and snowfalls were recorded.

The main training area comprised land to the northeast of Lake Rerewhakaaitu bounded by Mt Tarawera in the north and the edge of the Kaingaroa forest in the south. The only other people living in the district were on Brett Rd, west of the lake, according to Mossop (1993). The main line of fire was towards the east, the so-called 'impact area' bounded today by eastern Ash Pit Rd. The camps were entirely tent-based with no wooden buildings. After the war ended, engineers from the New Zealand Army began the job of disposing of unexploded shells etc, completed by about 1950.

From the 1950s, the area on the northern shores of the lake was used as a camp for compulsory military training by the New Zealand Army (Steve Gilbert pers. comm., 2006). Gilbert also recorded that the road to the top of Mt Tarawera had been constructed by the US Army and lookouts posted there permanently during the war. Today, reminders of the US presence in the area include Yankee Rd, Republican Rd, and Democrat Rd, although the last has been re-named Rerewhakaaitu Rd on the latest topographic maps. A trig point near the intersection of Ngamotu Rd and Okahu Rd is recorded as 'America NL' (506 m).

### **Reference**

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# 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  $1314 \pm 12$  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 are noted in a short article below (Lowe and McDaniel, this volume).

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

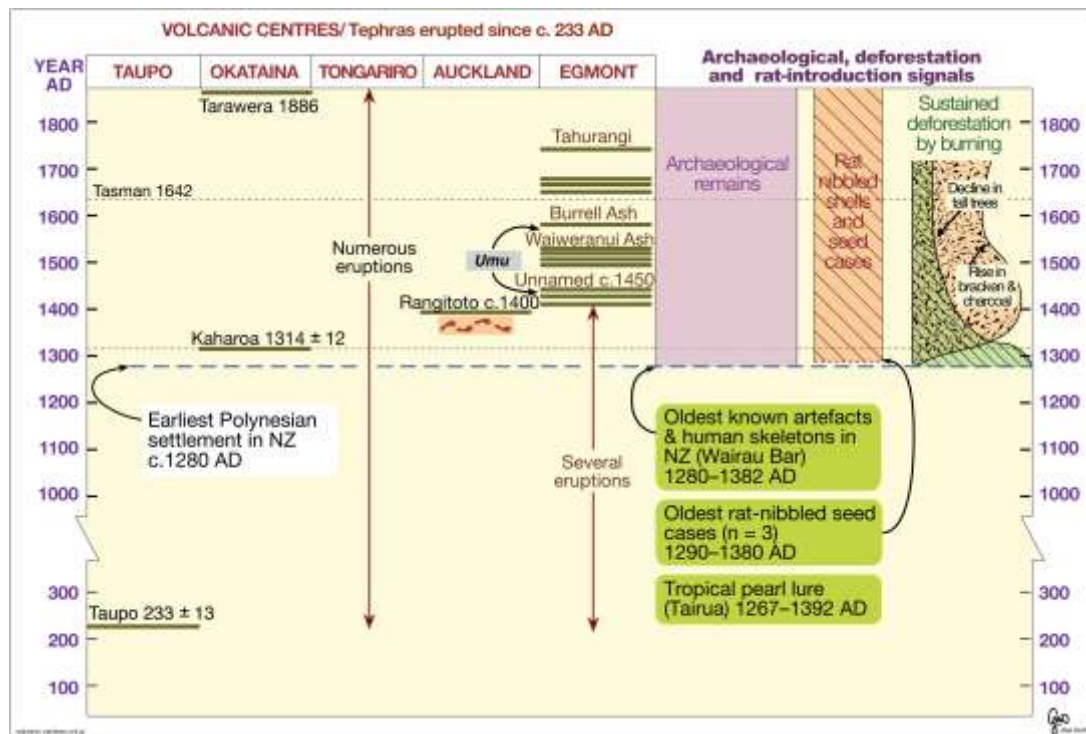
bone dating. This was done by obtaining AMS (accelerator-based) radiocarbon ages on unequivocally rat-gnawed woody seed cases preserved in sediments. Wilmshurst and Higham dated numerous seeds at three sites, one on Coromandel Peninsula and two in Taranaki (i.e. opposite sides of North Island). The results were extremely clear: all rat-gnawed seeds were younger than about  $780 \pm 70$  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  $702 \pm 32$  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  $232 \pm 5$  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

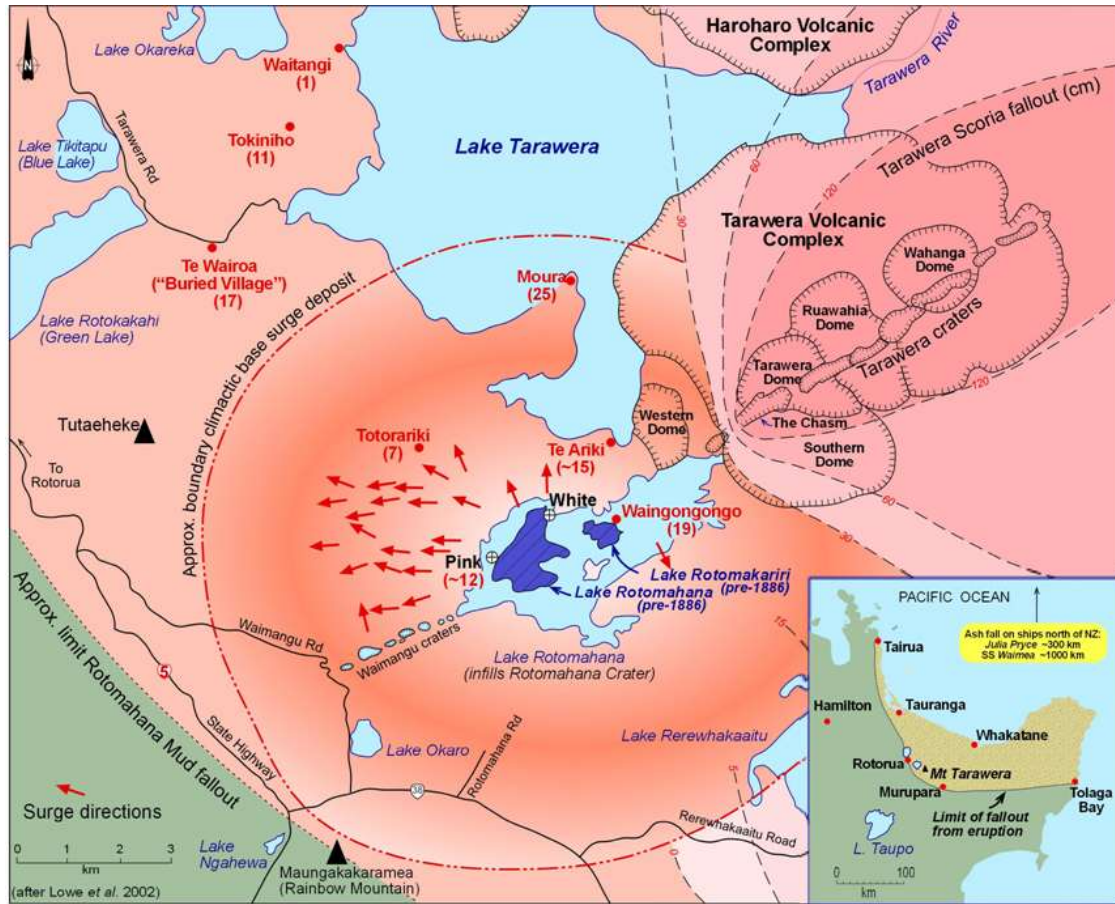
The Tarawera eruption of 10 June, 1886, was the biggest and most destructive eruption in New Zealand during the historical (European) period. It was a basaltic rather than rhyolitic event, but was nevertheless very explosive: the resulting scoria fall ('Tarawera Scoria') has a dispersal similar in extent 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, associated 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<sup>3</sup> (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<sup>3</sup> 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 *Hinemihī*, 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) (there was an additional death at an unknown locality). Fatalities were all Maori apart from six Europeans at Te Wairoa and one European and three (part) Maori at Waingongongo. On the night of the eruption nearly half of Te Aniki's 27 residents were camped at Pink Terrace (Otukupuarangi). Inset shows eastern North Island and documented limits of tephra fallout from the eruption (based on maps by A.P.W. 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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## STOP 5 – ROTOMAHANA SILT LOAM, BRETT RD

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  $1314 \pm 12$  AD. It has an area of  $7.4 \text{ km}^2$  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?). *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*

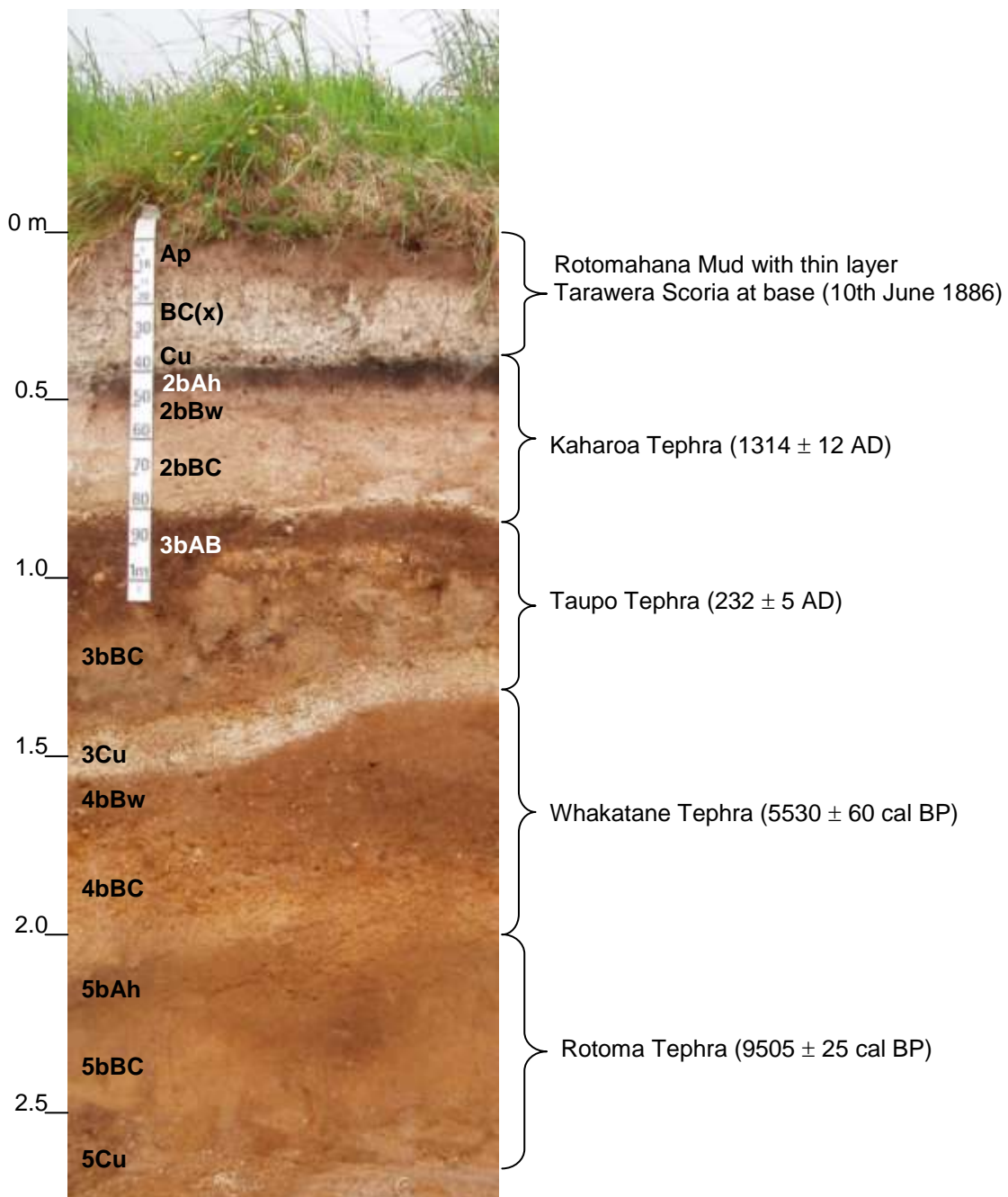
When it rains and the soil is sodden the pasture can turn to mud very quickly. To overcome this we have built a feed pad to feed cows and stand them on in particularly wet conditions. But we do drain very well and once it stops raining we can go back on the pasture within 24 hours with care. ‘Mud’ is 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



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

## 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 tephra) (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]

BC(x)

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.

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Soils and land use in the Waiotapu region (covering five districts including Rerewhakaaitu) 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  
 Aspect: West near top of ridge Altitude (m): 400 Rainfall (mm): 125 Slope: 2° Landform: Ridge Grid ref: N85/848863  
 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	Depth (cm)	PROFILE DESCRIPTION	Profile	Depth (cm)	PROFILE DESCRIPTION
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,	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.
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,			

CLASSIFICATION - N.Z. Genetic: Recent soil (ash)

Taxonomy: Typic Udorthent, fine loamy, mixed, mesic

## CHEMISTRY ROTOMAHANA LOAM

Sample No. SB	Depth (cm)	Hor.	pH				Exchangeable cations (meq/100 g)				Estr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	BCBC	CEC (meq/100 g)		Base saturation (%)		
			H <sub>2</sub> O	KCl	ΔpH	NaF	Ca	Mg	K	Na				NH <sub>4</sub> OAc (pH 7)	Σ Cations (pH 8.2)	Σ bases CEC NH <sub>4</sub> OAc	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	51.5	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	11.5	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	8.3	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	0.32	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)			P Retention (%)	Dithion. cit. (%)		Yann ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)
					H <sub>2</sub> SO <sub>4</sub> (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K <sub>c</sub>	Mg <sub>r</sub>	
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	0.64	0.45	0.81	0.34	0.33	0.34	0.08	0.7	4

**Data on this and following pages are from Parfitt et al. (1981)**

Hosono, M., Oba, Y., Sase, T., Utsugawa, T., Aoki, K. 1991. Holocene volcanic ash soils at Waimangu Road tephra section, North Island, New Zealand - soil formation-vegetation relationship. *The Quaternary Research (Japan)* 30, 91-101.

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Vucetich C.G., Wells N. 1978. Soils, agriculture, and forestry of Waiotapu region, central North Island, New Zealand. *New Zealand Soil Bureau Bulletin* 31. 100pp. + 5 maps.



## 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 Vitrandis 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

Location	Rhizome biomass		FronD biomass	
	Mean (kg m <sup>-2</sup> )	Range	Mean (kg m <sup>-2</sup> )	Range
Nelson, New Zealand <sup>1</sup>	--	7.08 (max.)	--	1.41 (max.)
New Zealand (23 stands) <sup>2</sup>	2.92	0.91-5.19	--	--
Idaho, USA (9 stands) <sup>3</sup>	1.96	1.14-2.54	0.52	0.27-0.89

<sup>1</sup>Bray (1991)

<sup>2</sup>Unpublished data of D. Whitehead, Landcare Research, Lincoln, NZ, cited by McGlone et al. (2005)

<sup>3</sup>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’, *Miscanthus 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. 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  $\leq 2$  (dark) throughout
  - Melanic index  $\leq 1.70$  throughout
  - $\geq 6\%$  organic C as weighted average
  - Andic soil properties
  - $\geq 30$  cm thick
- 

\* 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  $\delta^{13}\text{C}$  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 tussock grassland and most contain A-type humic acids ( $\pm$  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.

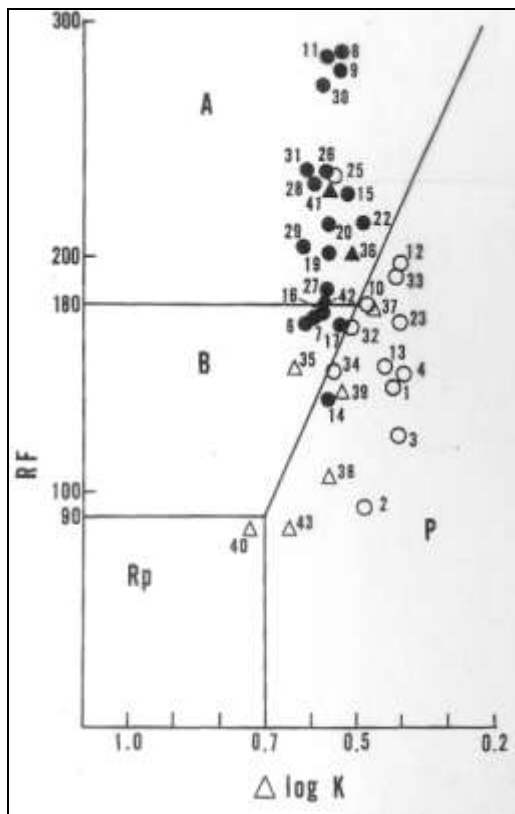
## Chemical and Mineralogical Conversion of Andisols following Invasion by Bracken Fern

J. L. Johnson-Maynard,\* P. A. McDaniel, D. E. Ferguson, and A. L. Falen

### ABSTRACT

Andisols support  $\approx 200\,000$  ha of mid-elevation grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.) forests in the Pacific Northwest region that are characterized by little or no natural conifer regeneration following removal of the forest canopy. Previous work suggests that the properties of these Andisols have been altered as a result of the establishment of successional communities dominated by bracken fern (*Pteridium aquilinum* [L.] Kuhn) in deforested areas. In this study, we compared soil properties in a 30-yr-old bracken fern site (clear-cut in 1965), a natural bracken fern site that is estimated to be centuries old, and an adjacent undisturbed forest in the Clearwater National Forest of northern Idaho. Results indicate that changes in chemical properties have accompanied establishment of successional communities. Mean weighted pH within the ash cap of the 30-yr-old bracken fern site (4.6) is significantly lower than that of the undisturbed forest (5.2). Mean values for Al saturation range from 27% in the undisturbed forest to 52% in the 30-yr-old bracken fern site; organic C is also lower in the undisturbed forest (37 g/kg) than in the 30-yr-old bracken fern site (54 g/kg). The dominant secondary mineralogical component of soils of the undisturbed forest is inorganic, short-range-order Al-Fe minerals, while metal-humus complexes are dominant in the bracken-fern-influenced soils. Data indicate that bracken fern successional communities are responsible for a shift from allophanic to nonallophanic properties in these soils, probably due to increased levels of soil organic C associated with bracken fern and a subsequent increase in formation of Al-humus complexes. Furthermore, such a mineralogical shift may contribute to the observed problems with conifer regeneration.

From *Soil Science Society of America Journal* (1997) 61, 549-555.



Comparison of humic acids from volcanic ash-derived soils in Japan and New Zealand (from Watanabe and Sakagami, 1999)

RF, relative colour intensity

$\Delta \log K$ , colour coefficient

Type A = grassland, fernland (melanic)

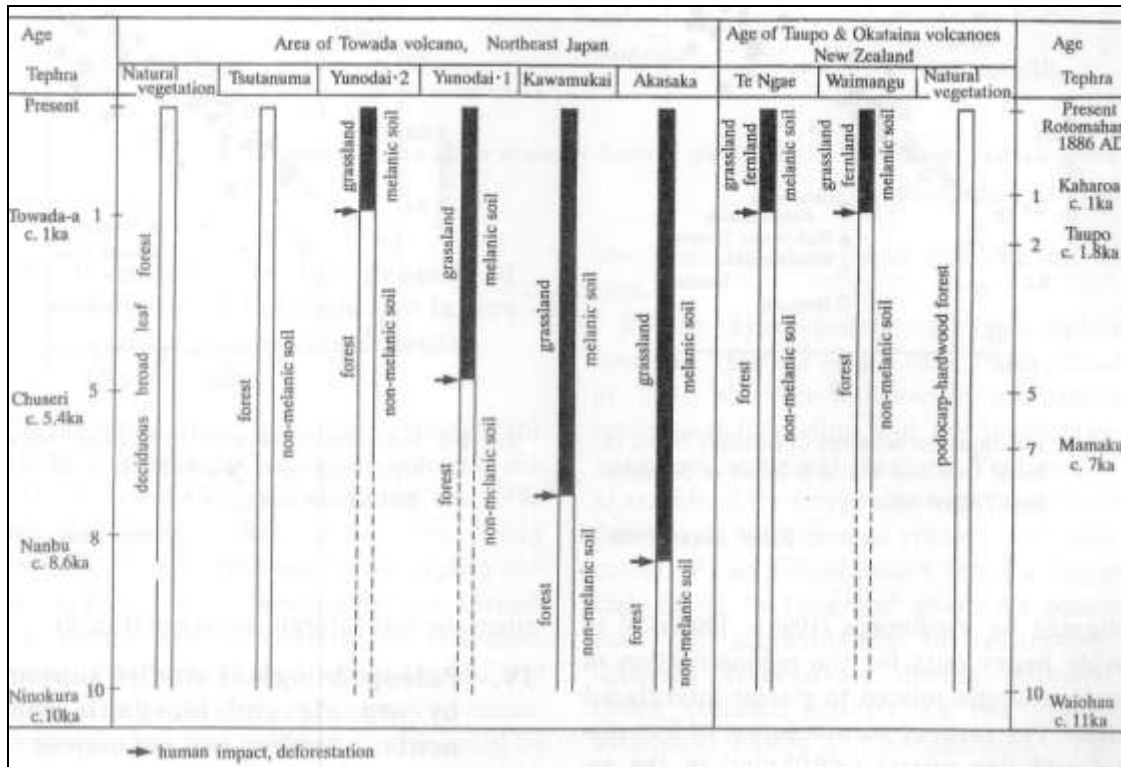
Types B, Rp, P = forest

● Melanic soil, Japan

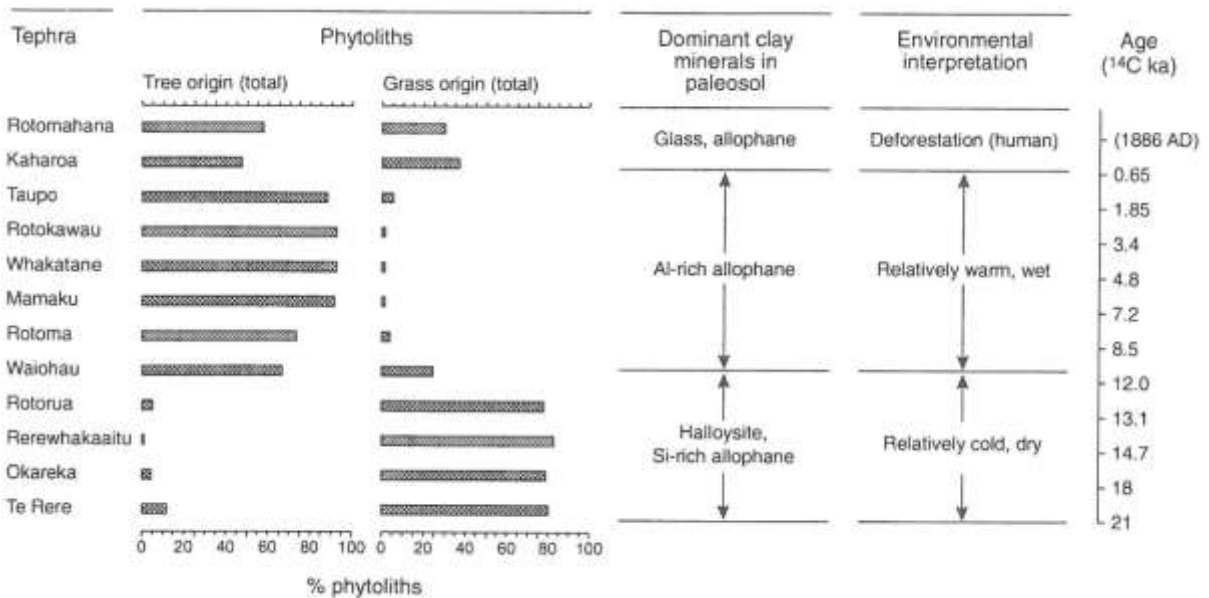
○ Non-melanic soil, Japan

▲ Melanic-like soil, New Zealand

△ Non-melanic soil, New Zealand



Relationship between vegetation, tephra age (in <sup>14</sup>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.



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 Newnham et al., 1999 – after Green, 1987; Hodder et al., 1990; Sase et al., 1988; Kondo et al., 1994)

## Potential impacts of ash fall on dairy farms – Rerewhakaaitu case study by Wilson and Cole (2007)

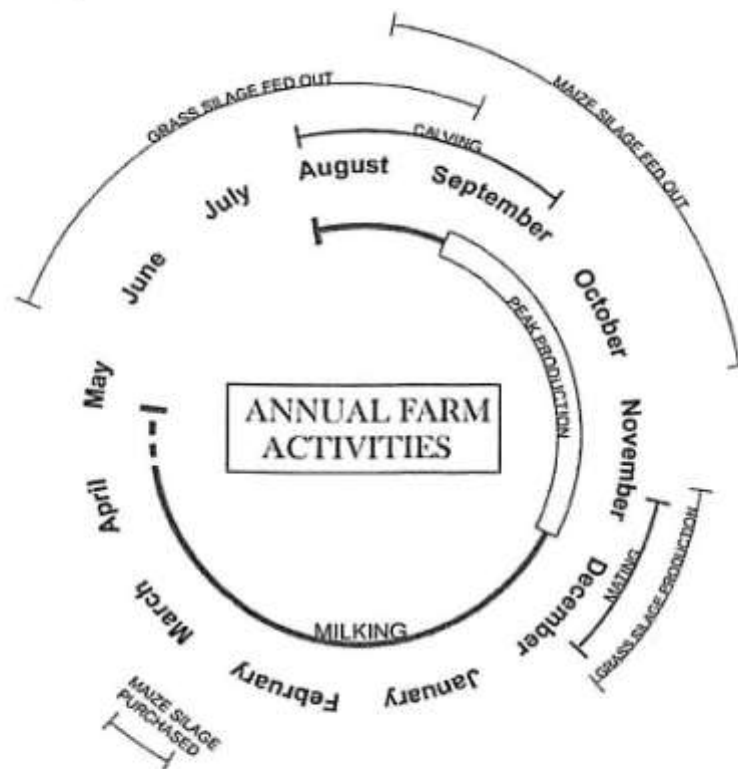
Nat Hazards (2007) 43:103–128  
DOI 10.1007/s11069-007-9111-8

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

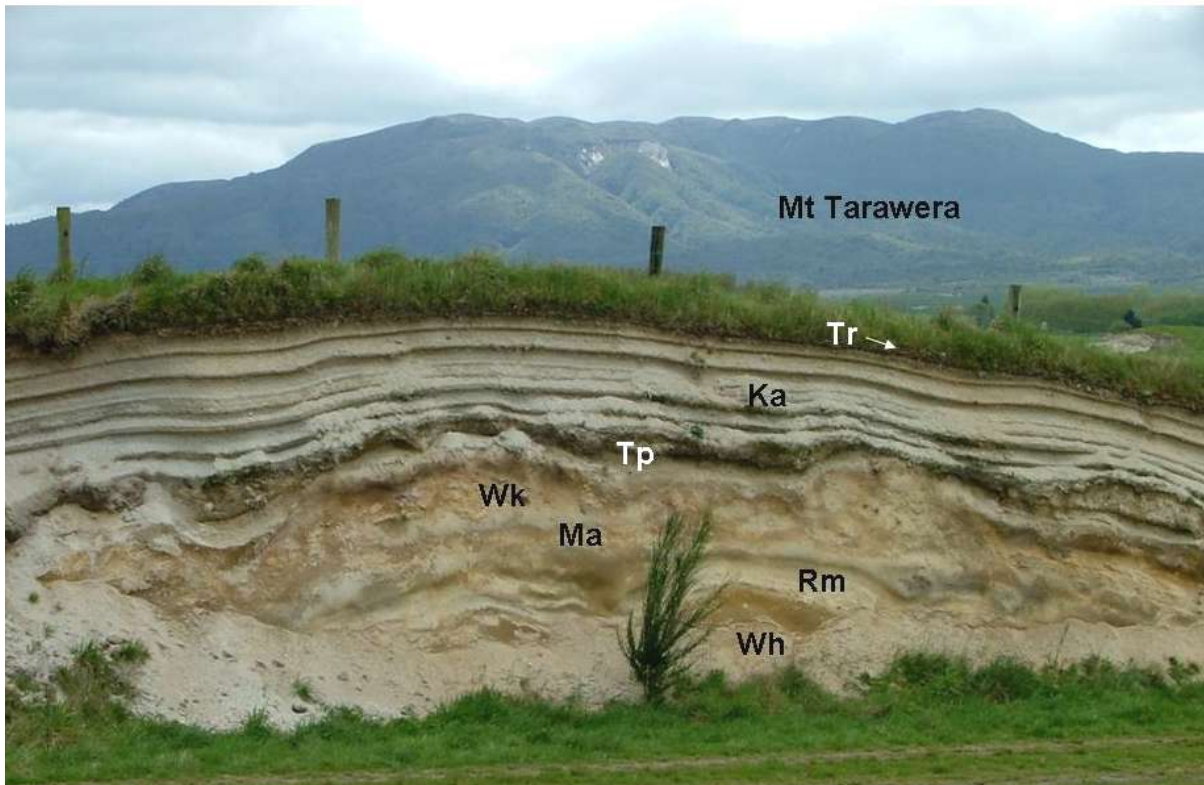
The effect of ash fall will depend on the magnitude, style of eruption, location of active vent zone, vent positions within the active vent zone, local topographic controls and wind directions. It is extremely hard to predict any of these factors for the next eruption, given the variety of styles of 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:

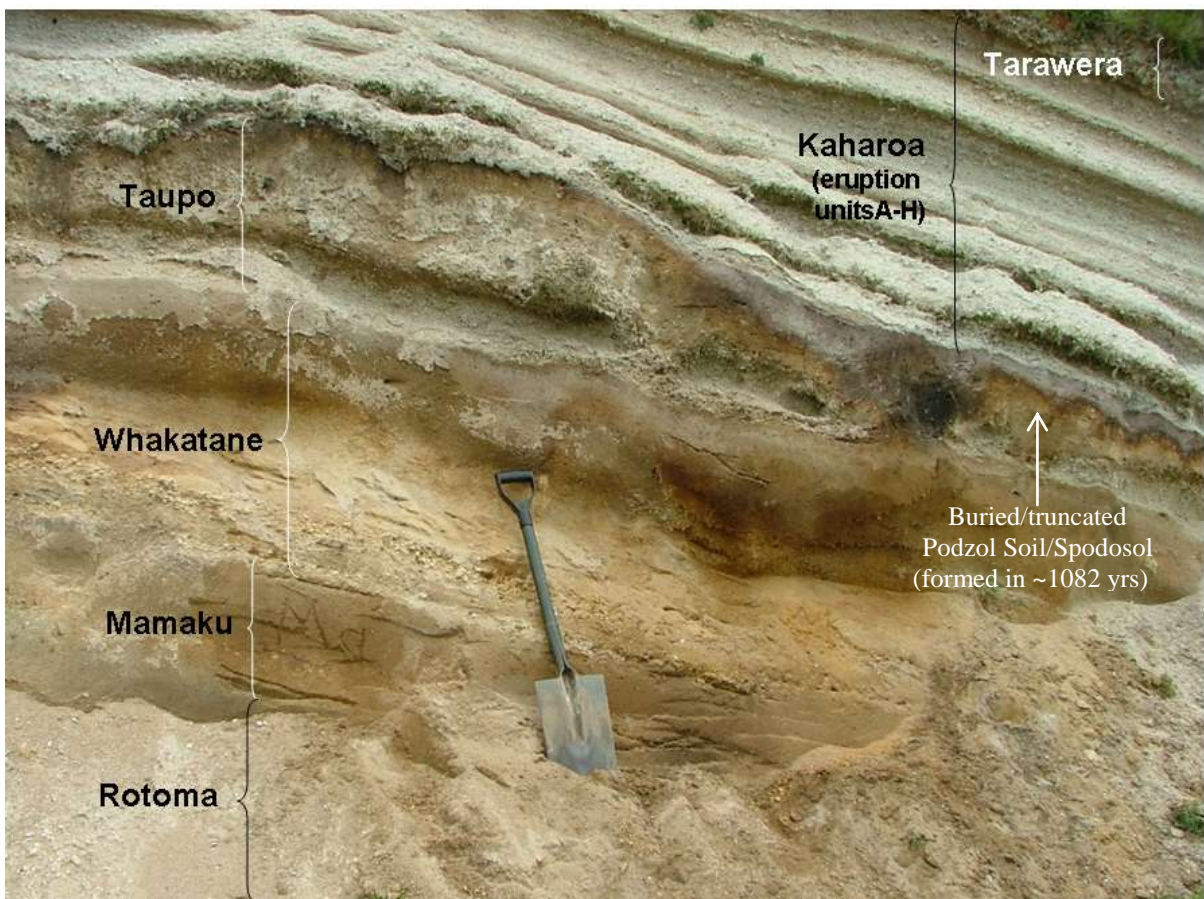
- (1) Long term planning (*periods of quiescence*)
  - Maintain power supply lines so they are in good order.
  - Develop a water supply with large tank storage capacity.
  - Develop a 'feed pad' that is easily cleared of ash for distributing supplementary feed.
  - Ensure roof pitches are greater than 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).

## STOP 6 – TEPHRAS AND BURIED SOIL SEQUENCE, 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*



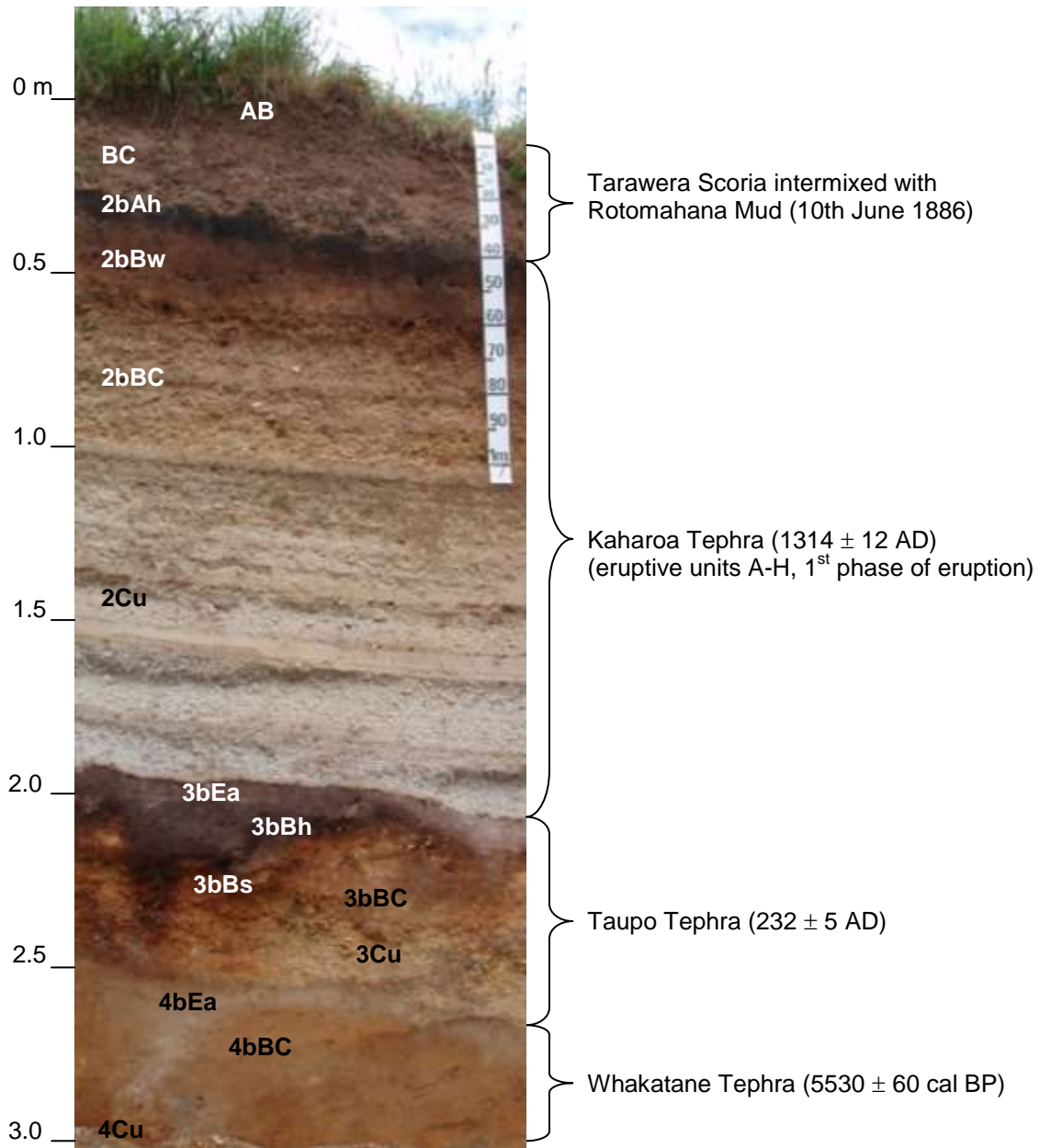


Tephra names and ages	
Tr,	Tarawera (10 June 1886)
Ka,	Kaharoa (1314 ± 12 AD)
Tp,	Taupo (Y) (232 ± 5 AD)
Wk,	Whakatane (5530 ± 60 cal. BP)
Ma,	Mamaku (8005 ± 45 cal. BP)
Rm,	Rotoma (9505 ± 25 cal. BP)
Op,	Opepe (E) (10,075 ± 155 cal. BP)
Wh,	Waiohau (13,635 ± 165 cal. BP)



## 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

## Soil profile description by Haydon Jones

Scion, Rotorua

### Matahina reference data

- Soil name:
  - Series: Matahina
  - Type: gravel
- Soil classification:
  - NZSC: Allophanic Orthic Pumice Soils; tephric, basaltic/rhyolitic; loamy/cindery; rapid
  - Soil Taxonomy: Ashy-skeletal/pumiceous, mixed/glassy, subactive (?), mesic Vitrandic Udorthents

### Site data

- Location:
  - Map reference: NZMS 260 V16 2818852 6315448
  - Word description: road cutting on Ash Pit Road (southeastern side of Lake Rerewhakaaitu) about 600 m south from corner of Ash Pit and Gavin roads
- Elevation: 440 m
- Geomorphic position: Profile on a 10° convex/convex slope with 320° aspect contained within the side slope of a knoll in rolling land
- Erosion/deposition: Nil
- Vegetation: Pasture; grasses
- Parent material: Intermixed Tarawera Scoria and Rotomahana Mud with buried soil horizons formed in various underlying tephra deposits (Kaharoa, Taupo, and Whakatane tephra) (see photos for tephra ages)
- Drainage class: Well drained

### Soil data

AB

0-12 cm Very dark grey to very dark greyish brown (2.5Y 3/1.5) moderately gravelly sandy loam with fine to medium sub-angular slightly weathered scoria gravels; slightly sticky; non plastic; peds very weak and very friable; apedal earthy; profuse very fine polyhedral peds; very weakly allophanic; indistinct smooth boundary. [Tarawera/Rotomahana]

BC

12-38 cm Very dark greyish brown (2.5Y 3/2) very gravelly loamy sand with fine to medium sub-angular slightly weathered scoria gravels; non sticky; non plastic; soil very weak and very friable; apedal single grain; moderately allophanic; abrupt smooth to wavy boundary. [Tarawera/Rotomahana]

2bAh

38-49 cm Black (2.5Y 2.5/1) loamy sand; slightly sticky; non plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; strongly allophanic; distinct smooth (occluded) boundary. [Kaharoa]

2bBw

49-63 cm Very dark greyish brown (10YR 3/2) loamy sand; slightly sticky; non plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; strongly allophanic; indistinct smooth boundary. [Kaharoa]

2bBC

63-110 cm Brown (10YR 4.5/3) extremely gravelly sand with fine to medium sub-angular slightly weathered pumice gravels; non sticky; non plastic; apedal single grain; moderately allophanic; *interlayered with* light olive brown (2.5Y 5/3.5) slightly

gravelly loamy sand with fine to medium sub-angular slightly weathered pumice gravels; non sticky; non plastic; soil very weak and very friable; apedal single grain; strongly allophanic; abrupt smooth boundary. [Kaharoa]

2Cu

110-203 cm Light yellowish brown (2.5Y 6/3) extremely gravelly sand with fine to medium sub-angular slightly weathered pumice gravels; non sticky; non plastic; apedal single grain; weakly allophanic; *interlayered with* light brownish grey (2.5Y 6/2) very slightly gravelly loamy sand with fine to medium sub-angular slightly weathered pumice gravels; very few extremely fine distinct yellowish brown (10YR 5/6) mottles; non sticky; non plastic; soil very weak and very friable; apedal single grain; moderately allophanic; abrupt wavy boundary. [Kaharoa]

3bEa

203-220 cm Dark grey (5Y 4/1) very slightly gravelly loamy sand with fine sub-angular slightly weathered pumice gravels; slightly sticky; non plastic; soil very weak and very friable; apedal massive; very weakly allophanic; distinct irregular boundary. [Taupo]

3bBh

220-222 cm Black (7.5YR 2.5/1) very slightly gravelly sandy loam with fine sub-angular slightly weathered pumice gravels; slightly sticky; non plastic; peds weak and friable; apedal earthy; profuse very fine polyhedral peds; strongly allophanic; distinct irregular boundary. [Taupo]

3bBs

222-227 cm No data.

3bBC

227-233 cm Olive brown (2.5Y 4/3.5) very slightly gravelly loamy sand with fine sub-angular slightly weathered pumice gravels; slightly sticky; non plastic; soil very weak and very friable; apedal massive; strongly allophanic; distinct smooth wavy boundary. [Taupo]

3Cu

233-250 cm Yellowish brown (10YR 5/6) extremely gravelly sand with fine to medium sub-angular slightly weathered pumice gravels; non sticky; non plastic; apedal single grain; very weakly allophanic; abrupt smooth wavy boundary. [Taupo]

4bEa

250-263 cm Greyish brown to light olive brown (2.5Y 5/2.5) very slightly gravelly sand with fine sub-angular slightly weathered pumice gravels; non sticky; non plastic; soil very weak and very friable; apedal massive; moderately allophanic; distinct irregular boundary. [Whakatane]

4bBC

263 cm -on Olive brown (2.5Y 4/3) very slightly gravelly sand; non sticky; non plastic; soil very weak and very friable; apedal massive; moderately allophanic. [Whakatane]

### 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.

Vucetich, C.G., Leamy, M.L., Popplewell, M.A. Ure, J., Taylor, C.R., Will, G.M., Sutton J.A., Blakemore, L.C. 1960. Soils, forestry and agriculture of the northern part, Kaingaroa State Forest and the Galatea Basin. *New Zealand Soil Bureau Bulletin* 18. 51pp. + map

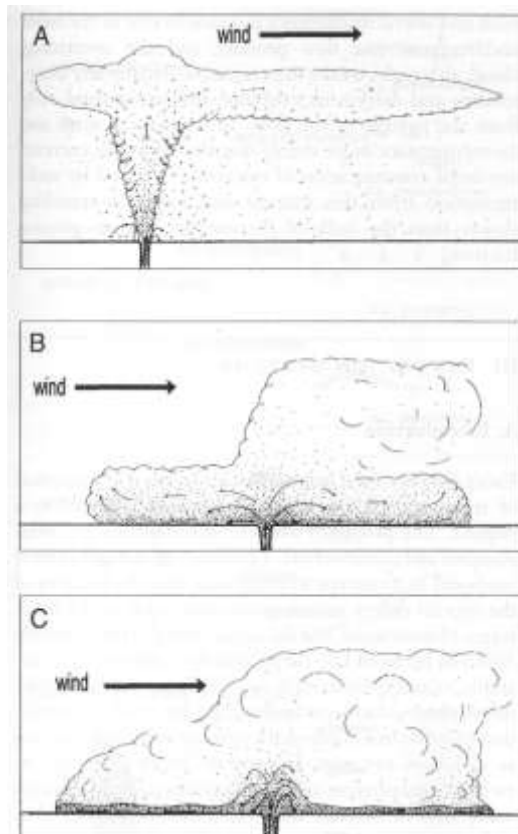


FIGURE 1 Schematic diagram to illustrate the three main end-member transport systems for the emplacement of pyroclastic deposits. (A) Fall: high buoyant plume carrying all except coarsest particles to heights of kilometers to tens of kilometers above the surface; particles sedimented from plume to form 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.

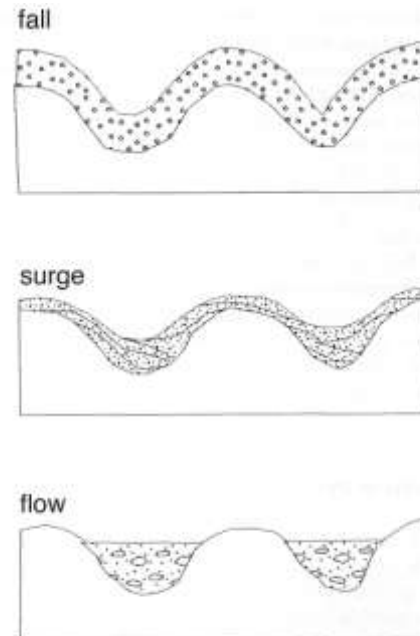


FIGURE 5 Schematic diagram of the archetypal characteristics of the three main pyroclastic deposit types. Fall—mantle bedding, with plane parallel beds and no internal erosion, good sorting (except where water is present; see Section III.E), juvenile clasts with angular to ragged shapes. Surge—nonmantling 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.

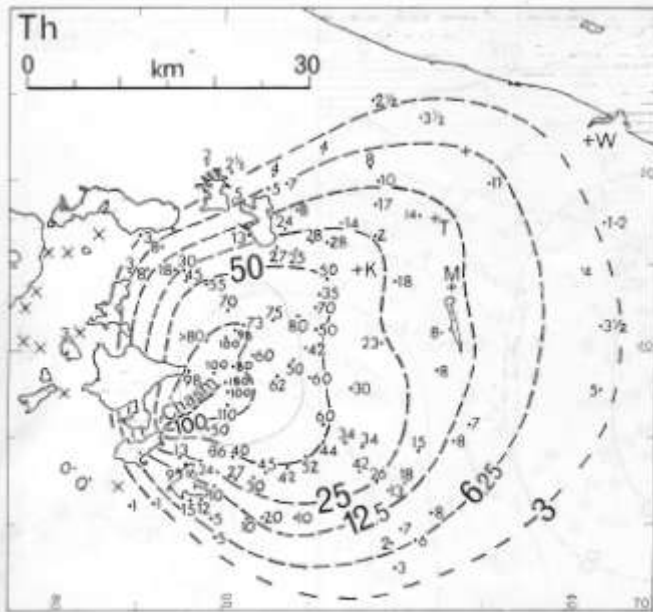
Above: From Wilson, C.J.N., Houghton, B.F. 2000. Pyroclastic transport and deposition. *In*: Sigurdsson, H. (ed-in-chief), *Encyclopaedia of Volcanoes*. Academic Press, pp. 545-554.

Below: From Nairn, I. A., Shane, P., Cole, J.W., Leonard, G.J., Self, S., Pearson, N. 2004. Rhyolite magma processes of the ~AD 1315 Kaharoa eruption episode, Tarawera volcano, New Zealand. *Journal of Volcanology and Geothermal Research* 131, 265-294. **Units A-H are evident at Stop 6.**

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 <sup>3</sup> DRE)	VDR* ( $10^3$ m <sup>3</sup> /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 <sup>4</sup>

\*VDR is DRE volumetric discharge rate.



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.

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. X = locations where basaltic scoria occurs admixed with Rotomahana Mud, but does not form a discrete layer.

Weight % allophane in buried soil horizons (whole soil basis) in Rotorua region (Te Ngae, Democrat Rd [now Rerewhakaaitu Rd]) (from Green, 1987)

Tephra & Horizon	Sample Number	wt % Al <sub>(ox)</sub>	wt % Al <sub>(py)</sub>	wt % Al <sub>(ox)</sub> -Al <sub>(py)</sub>	wt % Si <sub>(ox)</sub>	Al:Si Ratio	Si Factor	wt % Allophane
Te Ngae site 1	TN							
Rotomahana	A 1	0.67	0.20	0.47	0.33	1.36	17.0	2.0
Kaharoa	A 3	0.83	0.18	0.65	0.45	1.44	16.5	2.7
	B 4	0.79	0.11	0.68	0.39	1.74	15.0	2.6*
	C 5	0.08	neg	0.08	0.15	0.60	20.0	0.8
Rotokawau	B 7	3.19	0.25	2.94	2.33	1.26	17.3	13.5
	C 8	2.42	0.13	2.29	1.33	1.72	15.0	8.9
Whakatane	B 12	1.49	0.08	1.41	1.09	1.29	17.0	6.4*
	BC 13	1.10	neg	1.10	0.68	1.62	15.0	4.5
	C 14	0.53	neg	0.53	0.44	1.20	17.5	2.5
Manaku	B 15	1.48	0.04	1.44	1.15	1.25	17.3	6.7*
	BC 18	1.32	neg	1.32	0.83	1.59	15.0	5.5
	C <sub>1</sub> 20	0.46	neg	0.46	0.33	1.39	17.0	1.9
	C <sub>2</sub> 22	1.13	neg	1.13	0.81	1.40	18.5	4.9
	C <sub>3</sub> 23	0.29	neg	0.29	0.29	1.00	18.5	1.6
Rotoma	C <sub>4</sub> 24	0.79	neg	0.79	0.75	1.05	18.5	4.1
	(B) 27	0.67	neg	0.67	0.59	1.14	18.0	3.3
	C <sub>1</sub> 29	1.33	neg	1.33	0.91	1.46	16.5	5.5
	C <sub>2</sub> 31	0.42	neg	0.42	0.37	1.14	18.0	2.1
Waiohau	B 34	1.77	0.02	1.77	1.70	1.04	18.5	9.2*
	BC 36	1.68	neg	1.68	1.35	1.34	17.0	7.4
	C 38	1.11	neg	1.11	0.92	1.21	17.5	5.3
Rotorua	B 39	1.20	neg	1.20	1.14	1.05	18.5	6.2*
	BC 41	1.13	neg	1.13	0.99	1.04	18.0	5.5
	C <sub>1</sub> 44	0.73	neg	0.73	0.66	1.11	18.0	3.7
	C <sub>2</sub> 45	1.07	neg	1.07	0.51	2.10	15.5	3.3
	C <sub>3</sub> 47	0.59	neg	0.59	0.81	0.73	20.0	4.1
Rerewhakaaitu	B 49	0.34	neg	0.34	0.19	1.79	14.5	1.3*
	BC 51	0.33	neg	0.33	0.28	1.18	17.5	1.6
	C 53	0.26	neg	0.26	0.15	1.73	15.0	1.0
Okareka	BC 56	0.24	neg	0.24	0.27	0.90	19.0	1.4
Democrat Rd site 2	DR							
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) in Rotorua region (Te Ngae, Democrat Rd [now Rerewhakaaitu Rd]) (from Green, 1987)

Tephra & Horizon	Sample Number	wt % Fe <sub>(ox)</sub>	wt % Fe <sub>(py)</sub>	wt % Fe <sub>(ox)</sub> -Fe <sub>(py)</sub>	wt % Ferrihydrite (x 1.7)
Te Ngae site 1		TN			
Rotomahana	A 1	0.96	0.31	0.65	1.3
Kaharoa	A 3	0.82	0.13	0.69	1.3
	B 4	0.80	0.06	0.74	1.4*
	C 5	neg	0.23	neg	neg
Rotokawau	B 7	2.53	0.04	2.30	4.4
	C 8	1.96	0.01	1.92	3.7
Whakatane	B 12	0.94	neg	0.93	1.8*
	BC 13	0.58	neg	0.58	1.1
	C 14	0.12	neg	0.12	0.2
Mamaku	B 15	0.62	neg	0.69	1.3*
	BC 18	0.14	neg	0.14	0.3
	C 20	0.02	neg	0.02	neg
Rotoma	B 27	0.12	neg	0.12	0.2
	C <sub>1</sub> 29	0.09	neg	0.09	0.2
	C <sub>2</sub> 31	0.02	neg	0.02	neg
Waiohau	B 34	0.52	neg	0.52	1.0*
	BC 36	0.06	neg	0.06	0.1
	C 38	0.02	neg	0.02	neg
Rotorua	B 39	0.11	neg	0.11	0.2*
	BC 41	0.03	neg	0.03	0.1
	C 44	0.01	neg	0.01	neg
Rerewhakaaitu	B 49	0.38	neg	0.38	0.7*
	BC 51	0.26	neg	0.26	0.5
	C 53	0.02	neg	0.02	neg
Okeraka	BC 56	0.07	neg	0.07	0.1
Democrat Rd site 2		DR			
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*

Clay mineral assemblages of clay fractions in buried soil horizons in Rotorua region (Te Ngae, Democrat Rd [now Rerewhakaaitu Rd]) (from Lowe and Percival, 1993 – after Green, 1987)

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 Tikitere <sup>T</sup>
Ka	GL ≥ Al- & Si-ALL > OM >> H, Q, +	
Tp		Al-ALL > GL > OM >> H, +
Wk	Al-ALL > Si-ALL ≥ GL > OM > H, +	<sup>T</sup> 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).

DEMOCRAT RD - Site 2		
<b>Taupo Paleosol</b>		
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	
<b>Rotoma Paleosol</b>		
7.5 % Clay	25.0 % organic matter <sup>2</sup> 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	
<b>Waiohau Paleosol</b>		
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 tephra at Democrat Road (now Rerewhakaaitu Rd), about 5 km west of Stop 6, from Green (1987), Hodder et al. (1990), and Lowe and Green (1991). The Democrat Rd site (V16 141150) is the type locality for Rotoma, Waiohau, and Rerewhakaaitu tephra (Vucetich and Pullar, 1964; Froggatt and Lowe, 1990; Lowe et al., 2008).

## References

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- Lowe, D.J., Shane, P., Alloway, B.V., Newnham, R.M. 2008. Fingerprints and age models for widespread New Zealand tephra marker beds erupted since 30,000 years ago: a framework for NZ-INTIMATE. *Quaternary Science Reviews* 27, 95-126.
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Tephra & Horizon	Sample Number	Organic Carbon (wt %)
Democrat Rd site 2		
	DR	
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 <sup>-3</sup> )
Democrat Rd site 2		
	DR	
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

## Day 3: Rotorua–Palmerston North

### Outline for Day 3 (Sunday 30<sup>th</sup> November)

**8.00 am** Depart Ventura Inn, Rotorua

**8.45-10.10 am STOP 1 Achilles Farm, Wairakei Estate, SH 5: modern dairy farm (previously pine plantation)**

- View cows being milked in 60-bail rotary cowshed
- View computer control room ('Milkhub' software): Aaron Karaka (Achilles Farm Manager)
- Converting plantation forestry to dairy farming
  - Context and practicalities: Alan Bullick (Supervising Dairy Farm Manager, Landcorp Pastoral)
  - Issues: Dr Chris McLay (Environment Waikato)
- Taupo sand (Typic Udivitransol) in pit in adjacent paddock

**10.25-10.45 am** Morning tea/coffee and toilets, Achilles Farm

**11.00-11.30 am STOP 2 View Rd near Wairakei: tephras, buried soils, loess, Taupo soil**

- Stratigraphy of lower part of sequence (~18 cal ka and younger)  
(plus Taupo sand, Typic Udivitransol – already seen at Stop 1)

**11.35 am-12.05 pm LUNCH** adjacent to car park and lake at Aratiatia Rapids, Waikato River (Aratiatia Rd)

- Lake Taupo and catchment: water quality and land-use issues: Dr Chris McLay (Environment Waikato)
- View opening of Lake Aratiatia dam (gates)

**12.30-1.00 pm** Huka Falls, Waikato River (Huka Falls Rd)

**1.10-1.30 pm STOP 3 Taupo lookout, Huka Falls Rd, Taupo**

- Rhyolitic vs andesitic volcanoes and volcanic landscapes

**1.30-2.00 pm BREAK** Story Place: Taupo gardens, harbour and waterfront

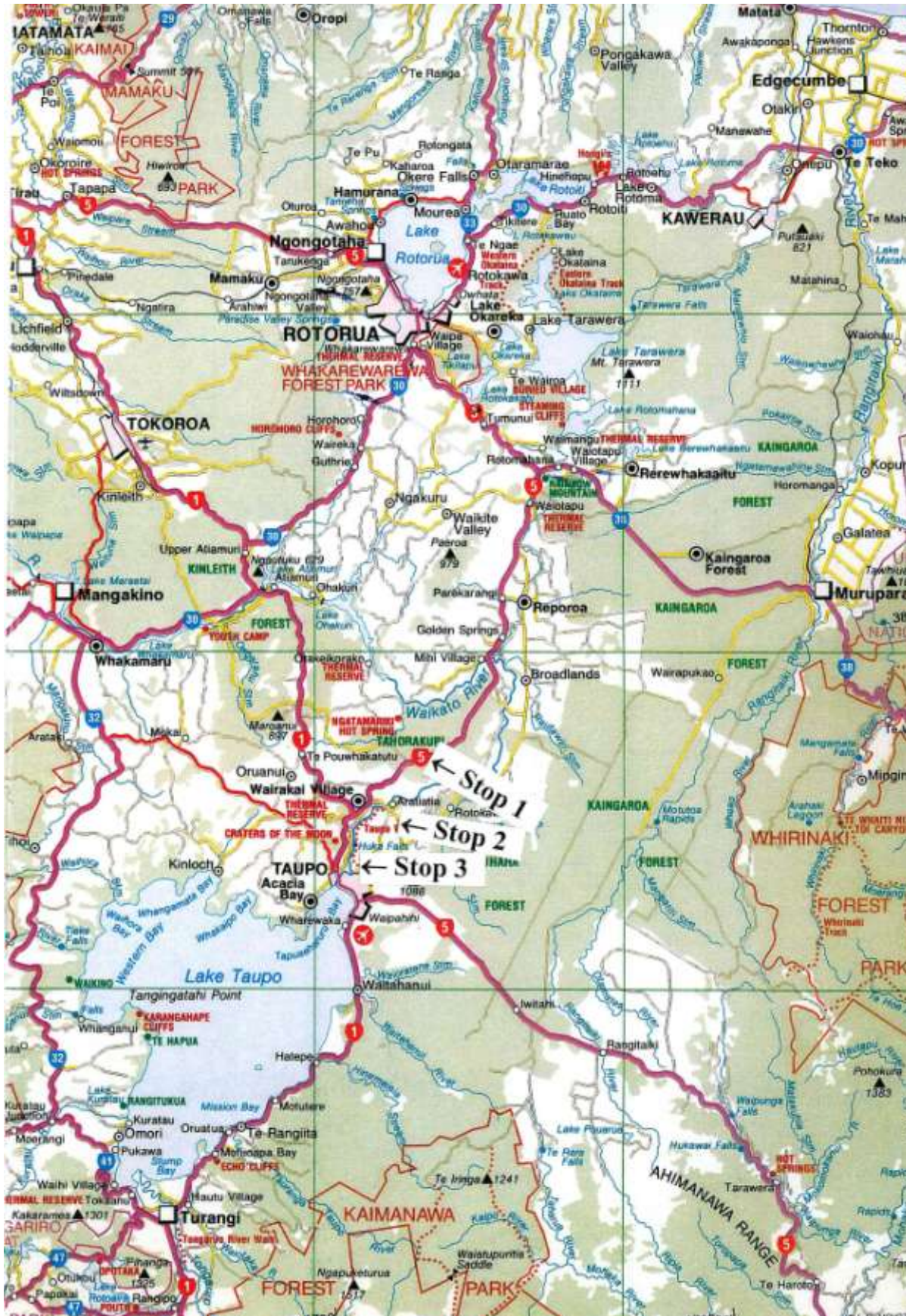
Stop to view Ruapehu and Ngaruahoe volcanoes (Desert Rd, SH 1)

**4.15-4.30 pm** Afternoon tea/coffee and toilet stop, Taihape (BP Connect)

**6.00 pm** Arrive 'Wharerata', Massey University, Palmerston North

- Ice-breaker meal, drinks at Wharerata
- Drop off at accommodation as required from ~7.15 pm (bus)

### Day 3 – route and scientific stops



## **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 2.96 cows per hectare in 2004 – resulting in an additional 16 cows per 100 hectare farmed and another 1.6 tonnes of nitrogen leached for an average farm. In the Waikato, much of this intensification has occurred in the upper Waikato catchment, around Reporoa and Whakamaru. Another process of agricultural intensification is land-use change from plantation forests to pastoral agriculture.

### **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 involved is not known, but we estimate between 5,000 and 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.
- 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 minimising 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 the hearing committee is currently deliberating on submissions.

### **Flood management**

Large scale changes in land use will alter the flood hydrology of the Waikato River system. A working group is currently assessing the impacts of land use conversions on flood hydrology and is due to report back later in the year. Meanwhile, Taylor et al. (2008) showed that infiltration rates under grazed pasture was an order of magnitude less than that under pine forest for a range of soils in the upper Waikato catchment (mainly as a result of low macroporosity). They concluded that converting forest to agricultural land is likely to result in increased flooding and flood intensity.

### **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**

Impacts on water quality in particular will conflict with iwi expectations for river and catchment management (refer negotiations between Tainui and the Crown in regard to Waikato River).

### **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, 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 currently being negotiated by the Crown with Waikato-Tainui. Waikato-Tainui has indicated a desire to see the river maintained, at least in its current condition, if not improved.

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>

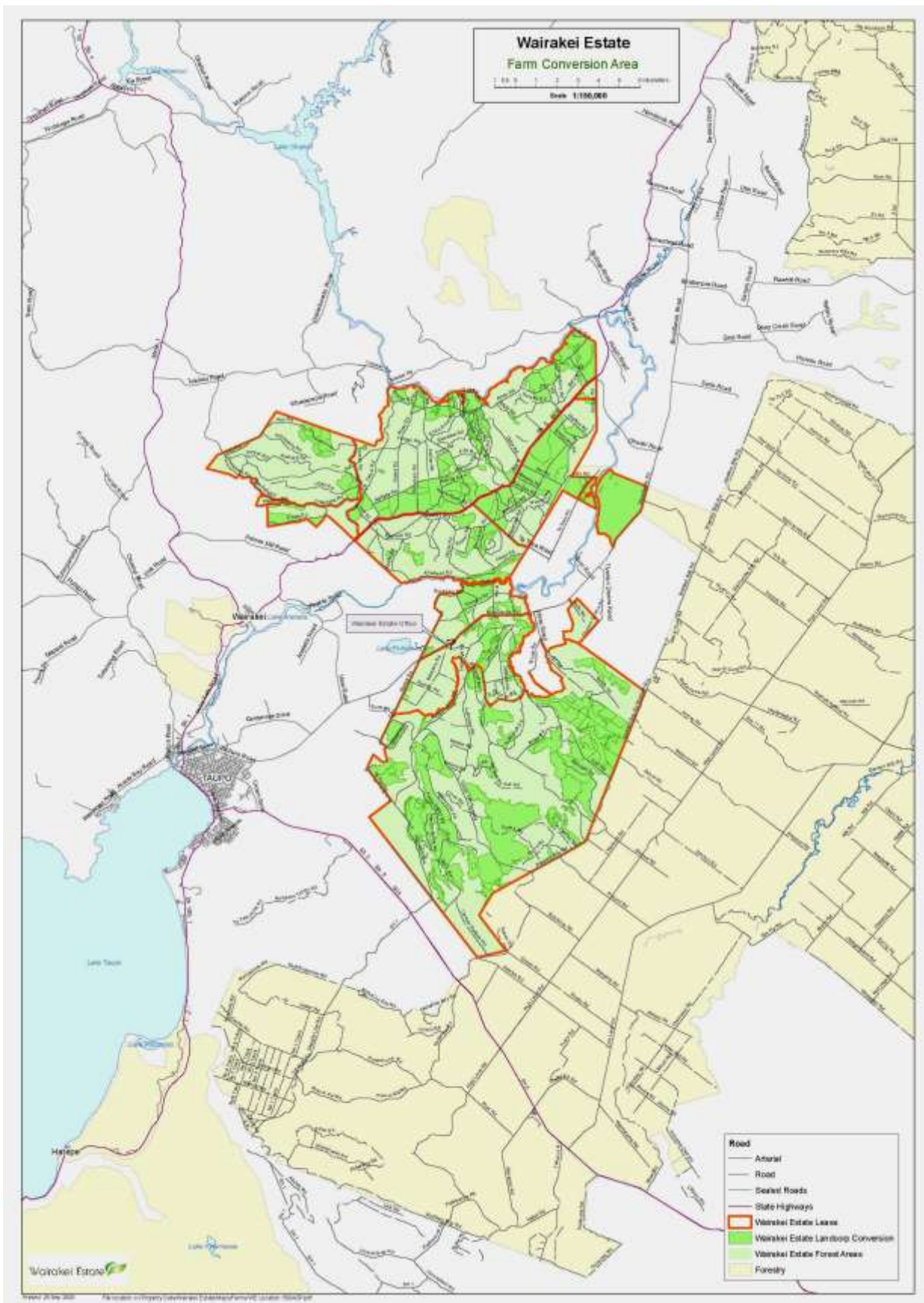
Taylor, M., Mulholland, M., Thornburrow, D. 2008. Infiltration of water into soil under forestry and agriculture in the upper Waikato catchment. *New Zealand Soil News* 56, 6-8.



# STOP 1 – ACHILLES FARM, WAIRAKEI ESTATE, SH 5

Location U17 895876, elevation ~330 m asl, rainfall ~1100 mm pa





Wairakei Estate showing land conversions from plantation forestry to pastoral farming (maps provided courtesy of Alan Bullick, Landcorp Pastoral)

## Introduction to Taupo volcano

**David J. Lowe**

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

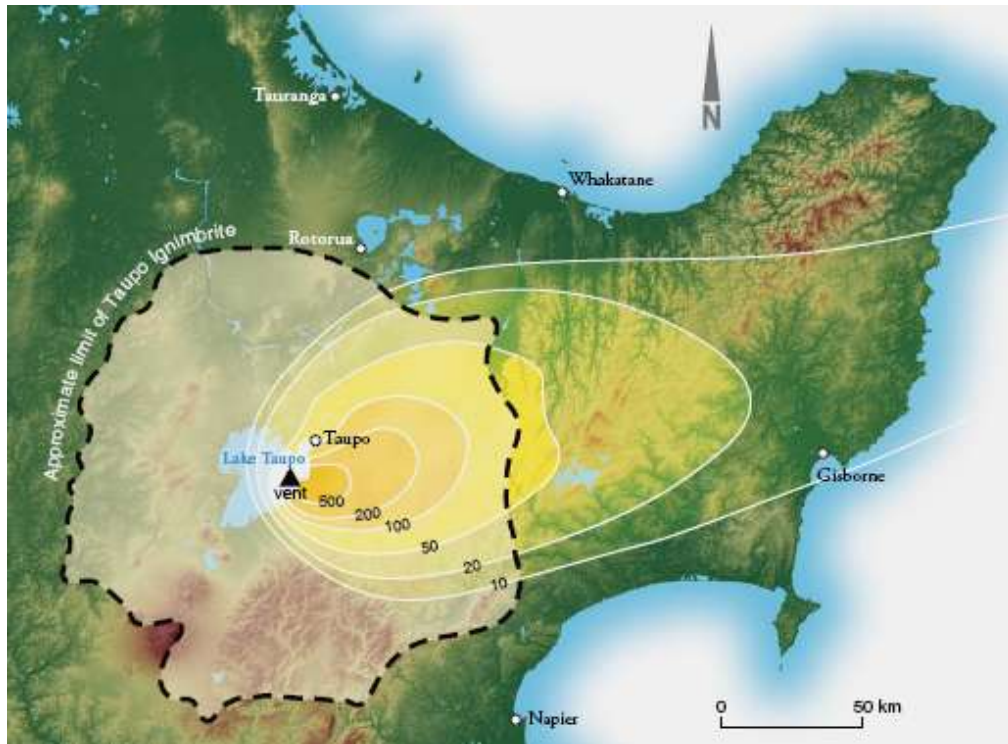
Taupo volcano is the most frequently active and productive rhyolite volcano on Earth. Activity began after the eruption of the widespread and voluminous c. 340 ka Whakamaru group ignimbrites, including a correlative Rangitawa Tephra (seen on Day 1 at Stop 2), from Whakamaru caldera. Several groupings 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<sup>3</sup> (equivalent to nearly 1200 km<sup>3</sup> 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). Caldera collapse associated with this eruption generated much 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 (e.g. Manville and Wilson, 2004; see also Rosenberg and Kilgour, 2004).

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  $\psi$  (the oldest) followed by  $\Omega$ , 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) <sup>14</sup> C time scale	Adopted age (years BP) calibrated timescale	Bulk volume in km <sup>3</sup> as used by Wilson (1993)	Other volume estimates, in km <sup>3</sup>	Eruptive activity 'dry' fall	'wet' fall	Pyroclastic flow(s)	Lava extrusion
(not defined)	Eruption Z	-	1740	0.28	-	-	-	-	yes
Taupo Tephra	Unit Y	1850	1770	44.75	65, 105	yes	yes	yes	-
Magara 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)
(not recorded)	Unit U	(2750)	2850	0.2	-	-	yes	-	-
(not recorded)	Unit T	(3000)	3200	0.08	-	-	yes	-	(possible)
Wairimbia Tephra	Unit S	3300	3550	16.9	15, 17, 19, 29	yes	-	yes	-
Hinemaiaia Tephra	Unit R	3950	4450	0.05	-	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	(3)	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)
Motutere Tephra	Unit J	(4620)	5370	0.015	-	-	yes	-	(possible)
	Unit I	(5200)	5950	0.02	-	-	yes	-	(possible)
	Unit H	(5300)	6050	0.2	(0.5, 1)	yes	yes	-	(possible)
(not recorded)	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
(not recorded)	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 Q	(c. 15 600)	(c. 18 800)	0.1	-	yes	yes	-	-
(not recorded)	Unit P	(c. 17 200)	(c. 20 500)	(0.05)	-	yes	yes	-	(possible)
Kawakawa Tephra	Oruanui ignimbrite	22 600	24 000-	300	-	-	-	yes	-
	Oruanui fall deposit		26 500	c. 500	-	-	yes	-	-

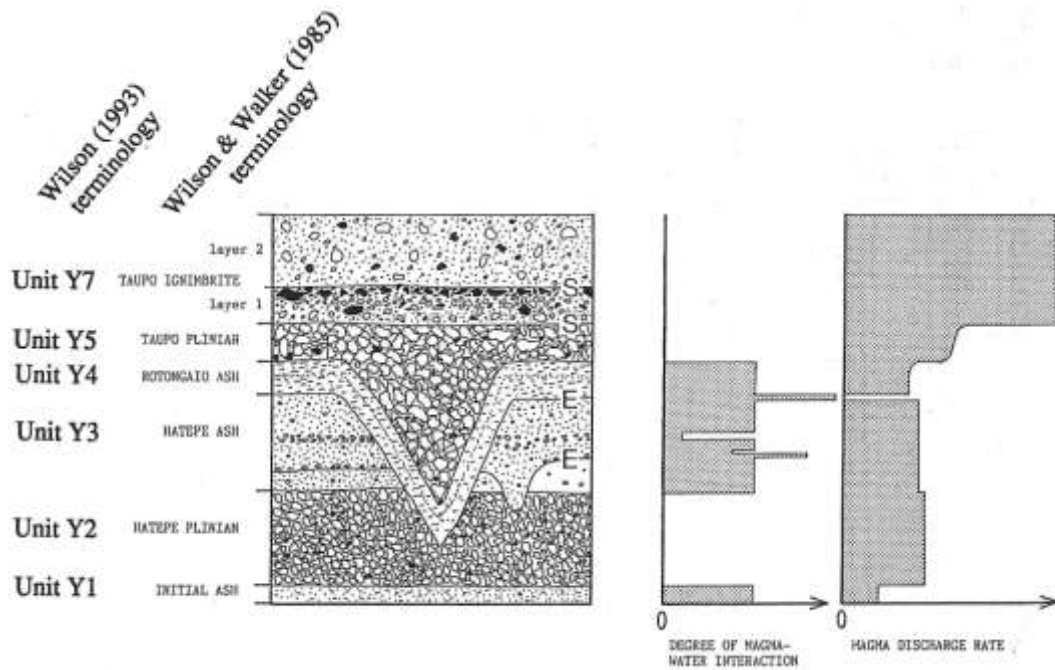
The so-called Taupo eruption (eruption Y) took place in late summer to early autumn (typically late March to early April) on the basis of fruit and seeds preserved in a buried forest at Puroera and the lack of an outer latewood ring (Clarkson et al., 1988; Palmer et al., 1988). The eruption year was  $232 \pm 5$  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  $\sim 105 \text{ km}^3$  ( $\sim 30 \text{ km}^3$  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<sup>2</sup> 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-veener deposits (IVD) are generally 0.5 to 1 m-thick and drape topographic highs; valley-pond ignimbrites (VPI) infill valleys and depressions to depths of 5 to 60 m (Manville, 2001).

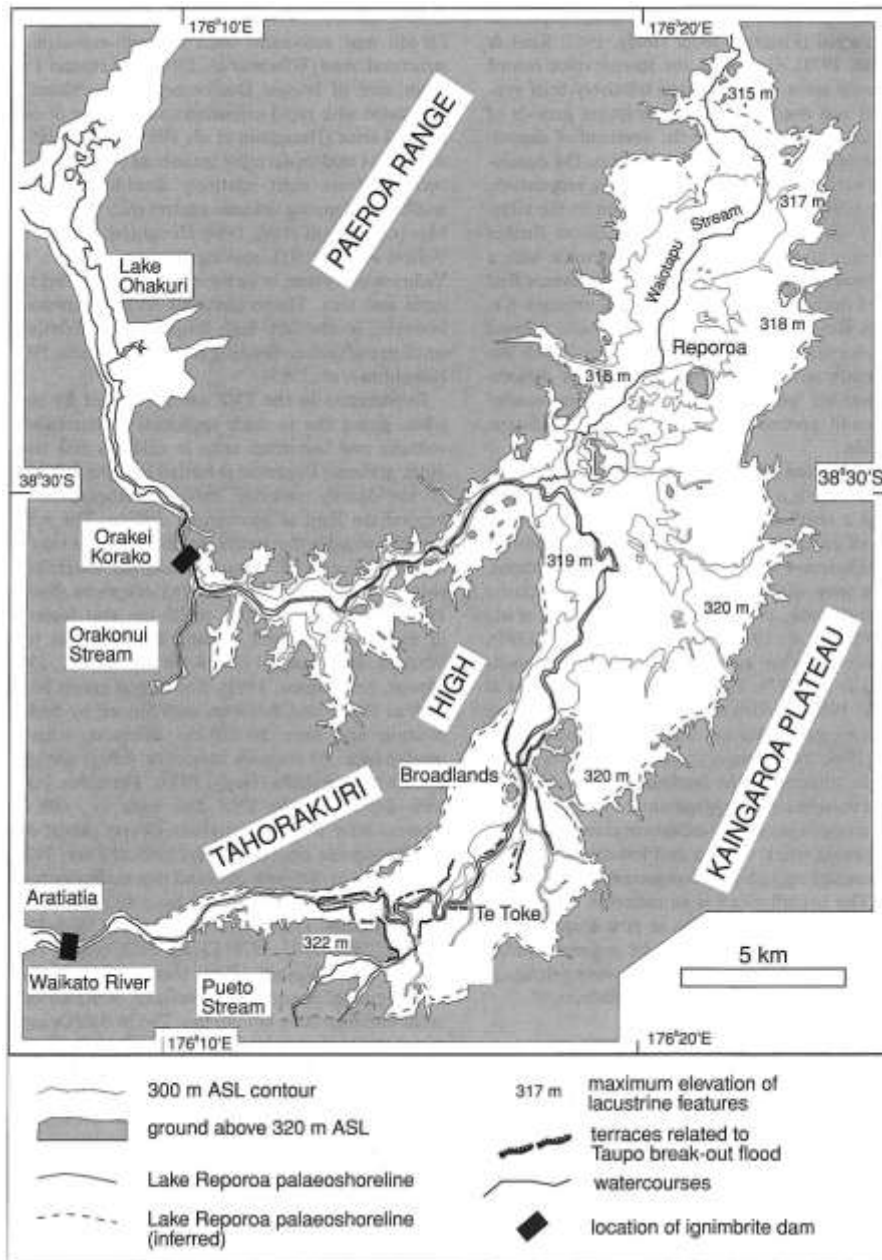
Because of its extreme violence and energy release ( $\geq 150 \pm 50$  megatons explosive yield), and by analogy with the 1883 Krakatau event, it is likely that the ignimbrite-emplacement phase generated a volcano-meteorological tsunami that may have reached coastal areas worldwide (Lowe and de Lange, 2000). The emplacement of the ignimbrite destroyed all forests in its path, and the 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).



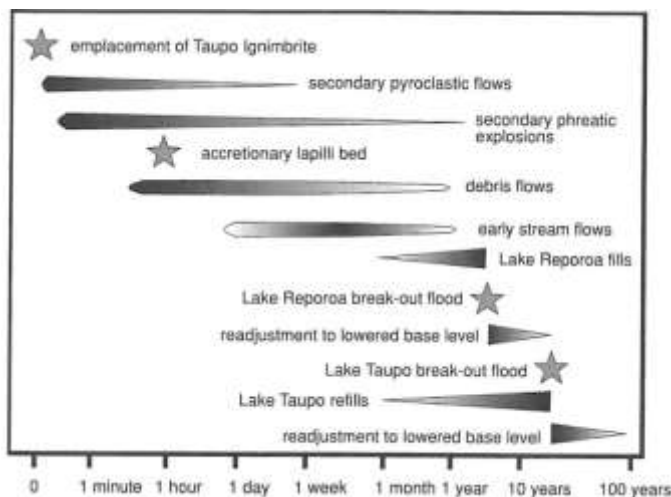
Summary of the stratigraphy of pyroclastic deposits of the Taupo eruption (eruption Y of Wilson, 1993). Graphs at right indicate qualitative changes in the inferred degree of magma-water interaction and the magma discharge rate during the eruption. E = erosion horizons formed by running water; S = erosion 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). 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 reestablishment of the Waikato River and the release of ~20 km<sup>3</sup> of water in a single phase, the peak discharge being 20,000–40,000 m<sup>3</sup>/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<sup>2</sup> and a volume of ~2.5 km<sup>3</sup> (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<sup>3</sup>/sec which contrasts with the Waikato River flow rate through the area today of ~130 km<sup>3</sup>/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, 2001)



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 chronostratigraphic markers) (from Manville, 2001)

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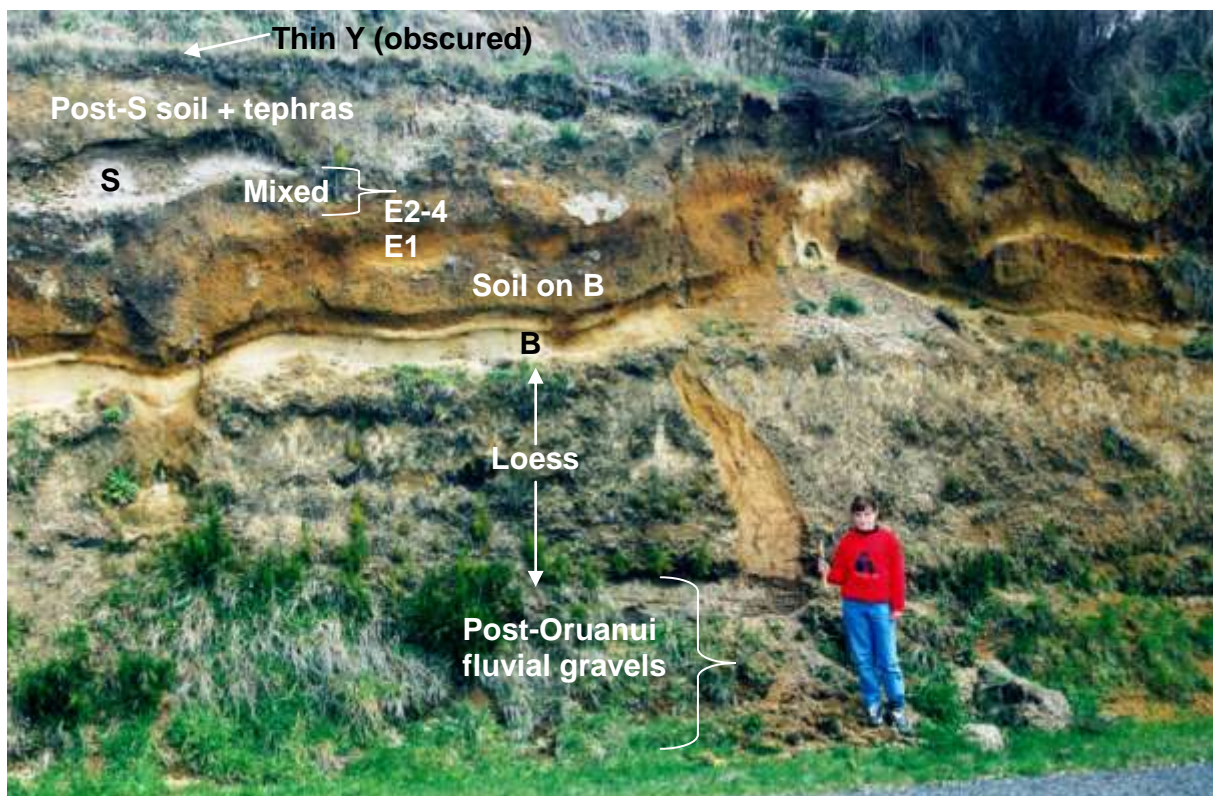
Pine plantations in the process of being converted to pastoral landuse (SH1 near Orakeikorako junction, between Wairakei and Atiamuri), 10 October 2008. *Photo*: David Lowe

## STOP 2 – TEPHRAS, LOESS AND BURIED SOIL SEQUENCE, TAUPO SAND, VIEW RD

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 ( $11,410 \pm 190$  cal yr BP); E, Opepe ( $10,075 \pm 155$  cal yr BP); mixed c. 6000-4000 cal yr BP; S, Waimihia ( $3410 \pm 40$  cal yr BP); Y, Taupo ( $1718 \pm 5$  cal yr BP or  $232 \pm 5$  AD: Hogg et al., 2009). Lydia provides the scale.

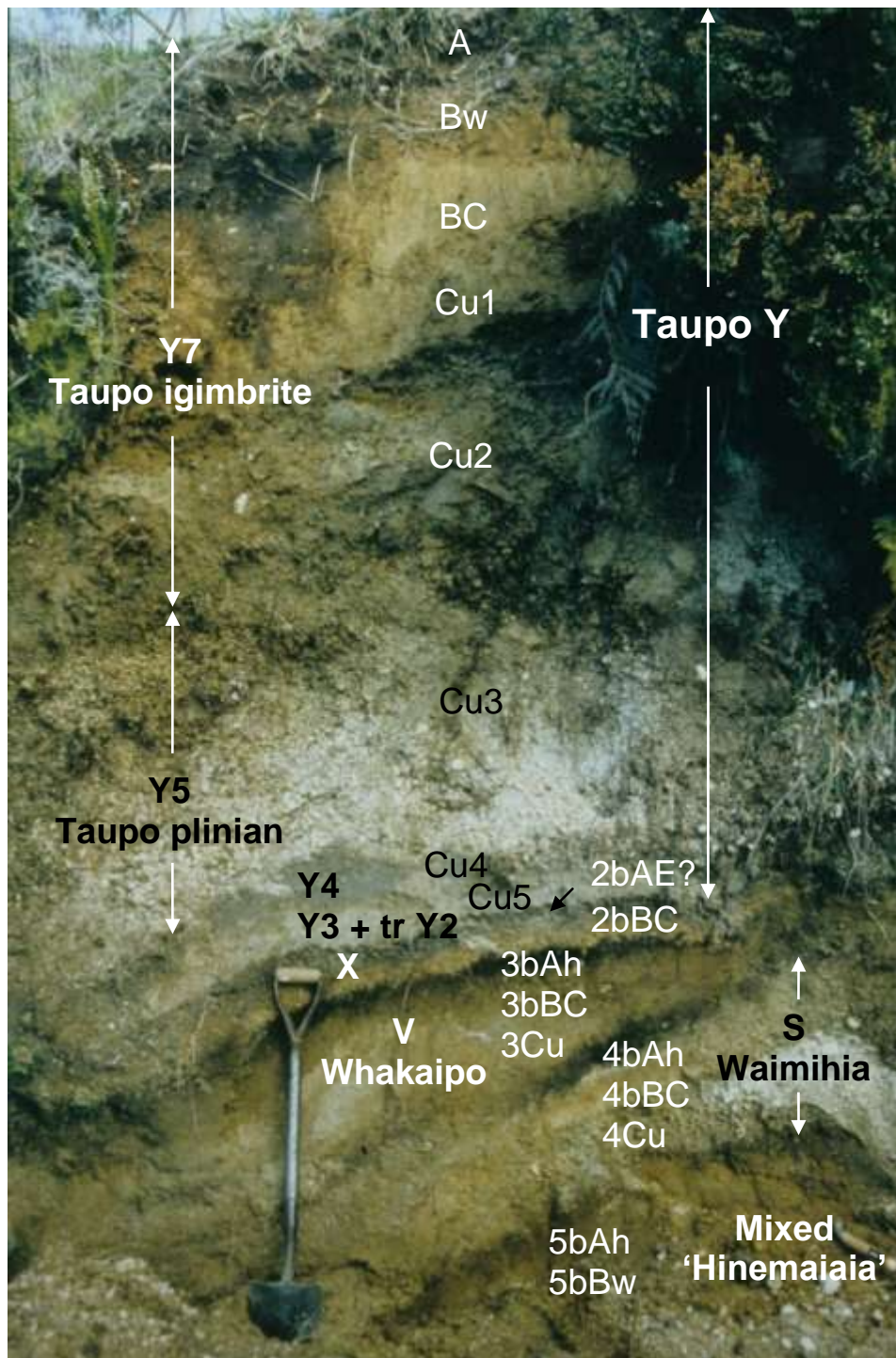


Stratigraphy of upper part of View Rd section. Tephra names and ages: Unit X, Mapara ( $2075 \pm 85$  cal yr BP); Y, Taupo ( $1718 \pm 5$  cal yr BP or  $232 \pm 5$  AD); Y2, Hatepe plinian; Y3, Hatepe ash; Y4, Rotongaio ash; Y5, Taupo plinian, Y7, Taupo ignimbrite. Spade  $\sim 1.1$  m long

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 <sub>o</sub> %	Al <sub>p</sub> %	Al/Si ratio	Si <sub>o</sub> %	Fe <sub>o</sub> %	Fe <sub>p</sub> %	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 ( $3410 \pm 40$  cal yr BP); V, Whakaipo ( $2865 \pm 145$  cal yr BP); X, Mapara ( $2075 \pm 85$  cal yr BP); Y, Taupo ( $1718 \pm 5$  cal yr BP or  $232 \pm 5$  AD): Y2, Hatepe plinian; Y3, Hatepe ash; Y4, Rotongaio ash; Y5, Taupo plinian, Y7, Taupo ignimbrite. Spade ~1.1 m long. Colin Wilson (Univ. of Auckland) is thanked for his assistance 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/pumiceous, 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)	Description	Stratigraphy
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,	Y5 (Taupo plin)
C1	34-64	very dark grey (10YR 5/1) 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,	Y4 (Rotongaio)
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)	
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				Stones (%)	PHYSICS				
		2-0.1 mm (%)	0.1-0.05 mm (%)	0.05-0.002 mm (%)	<0.002 mm (%)		Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	Air Dry (%)	Dry bulk density (T/m <sup>3</sup> )
0-9	Ap	40	18	38	4	(7)	0-9	Ap	12.9	10.3	0.75
9-24	Bw	30	19	48	3	(10)	9-24	Bw	7.8	4.6	0.82
24-34	BC	41	14	41	4	(12)	24-34	BC	4.6	2.5	0.90
34-64	C1	98	2	0	0	(52)	34-64	C1	2.6	2.0	0.94
64-95	C2	82	3	15	0	(66)	64-95	C2	6.0	1.6	0.84
95-102	C3	35	21	43	1	(4)	95-102	C3	4.6	2.4	1.30

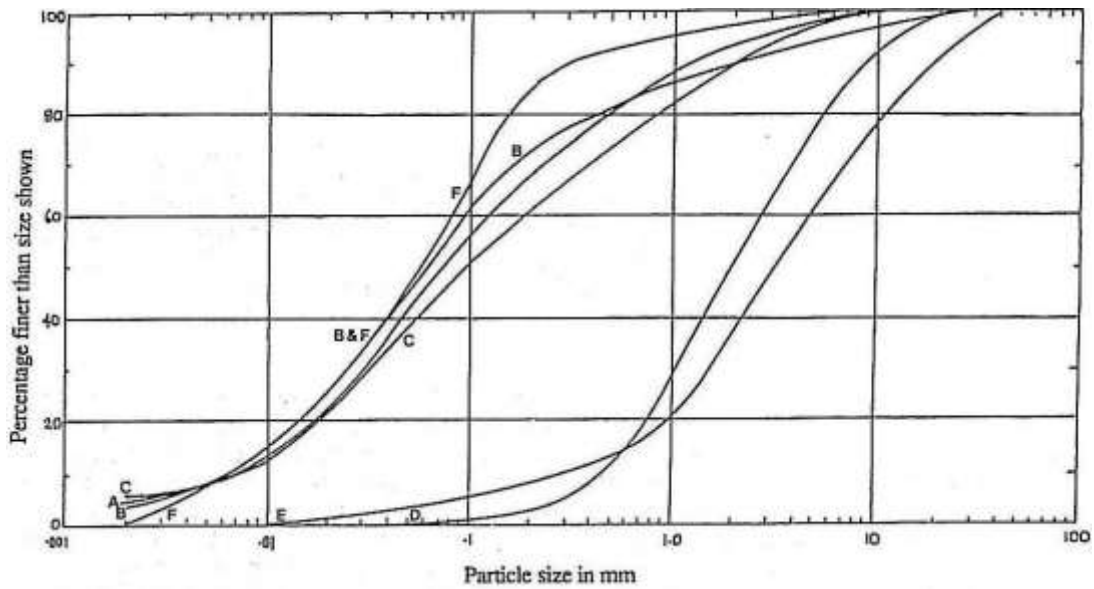


Fig. 6.12 Size grading curves for Taupo sand, Wairakei. A, 0-9 cm; B, 9-24 cm; C, 24-34 cm; D, 34-64 cm; E, 64-95 cm; F, 95-102 cm (from Parfitt et al. 1981).

**Chemistry and mineralogy of Taupo sand**

Depth (cm)	Hor.	H <sub>2</sub> O	pH			Exchangeable cations (meq/100 g)					Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	CEC (meq/100 g)	Base saturation (%)				
			KCl	Aph	NaF	Ca	Mg	K	Na	H (KCl)				Al (KCl)	CEC NH <sub>4</sub> OAc (pH 7)	I Cations (pH 8.2)	I bases CEC NH <sub>4</sub> OAc	I bases I Cations
0-9	Ap	5.0	4.2	-0.8	10.0	5.2	0.29	0.65	0.05		1.9	31.1	29.2	6.1	17.5	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. (%)		Yamox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)
				H <sub>2</sub> SO <sub>4</sub> (0.5 N)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K <sub>c</sub>	Mg <sub>r</sub>	
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	5
24-34	Bc	0.4	0.03	34	32	11	29	0.20	0.14	0.15	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	13	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 Hydrated Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Chlorite	Allophane	Feldspar	Glass	Hematite	Quartz	Feldspar (acid)	Andesite	Glass	Muscovite	Biotite	Hornblende	Augite	Hypersthene	Epidote	Quartz Ag	Apatite	Magnetite
0-9	Ap																S	c	A		tr	tr	tr	S				tr	R
9-24	Bw																S	A						S					R
24-34	Bc																S	A					tr	S					R
34-64	C1																S	C	A				R	tr	c		R	R	
64-95	C2																R	c	A					R	R			tr	R
95-102	C3																S	A						S					S

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Lowe, D.J., Percival, H.J. 1993. Clay mineralogy of tephra 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.

## **STOP 3 – TAUPO LOOKOUT, HUKA FALLS RD**

Location U18 773767, elevation ~410 m asl

Lake Taupo, with an area of ~ 620 km<sup>2</sup>, is the largest freshwater lake in Australasia. It has a volume of ~60 km<sup>3</sup> 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 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’), 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<sup>3</sup>) exceeds the combined volumes of all the andesitic edifices visible at the south end of the lake.

## **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 approach 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 organisation 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.

## 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 by intensive farming.

The move came at yesterday's Waikato Agriculture Summit in Hamilton, attended by about 90 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.

Buckley said it was working in 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 consent 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 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 our part to protect the environment," Mr Buckley said this morning.

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

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

EW told those attending the summit, which was aimed at 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 linked by an extensive environmental monitoring network to ensure that the policies were working.

"There was broad agreement that more focused, detailed thinking was required before we could arrive at the best solutions."

"There was also a general recognition that more based, 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 as that our partnership approach in addressing the issues is strengthened. We are willing to work with anyone on getting things right for the Waikato."

**There was broad agreement that we all needed to do more to manage farming's environmental impact in the Waikato.**

— Peter Buckley  
EW chairman

From the  
Waikato  
Times 13  
Nov, 2008

# 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.

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 5 per cent, and forestry, gorse and broom the remaining 2 per cent.



**LACHLAN MCKENZIE:**  
Rights turned over.



**PETER BUCKLEY:**  
Decision a good outcome.

