LAND AND LAKES

LAND AND SOIL IN THE MAKING
LAND AND SOIL MANAGEMENT FOR CLEANER WATER

GUIDEBOOK FOR
LAND AND LAKES FIELD TRIP
TUESDAY 28TH NOVEMBER, 2006

New Zealand Society of Soil Science
Biennial Conference, Rotorua
27-30th November, 2006

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NEW ZEALAND SOCIETY OF SOIL SCIENCE BIENNIAL CONFERENCE, ROTORUA 27-30TH NOVEMBER, 2006

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Note

Some material in this guide is unpublished and authors should be consulted for permission before citing it in any other publications.

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Introduction

Welcome to Rotorua. The trip today (28th November, 2006) has twin themes: "Land and soil in the making" and "Land and soil management for cleaner water". It offers an opportunity for participants to 'peep behind the scenes' at the wonderful volcanic landscapes, ash layers, soils, and waters of the Lake Rotorua–Lake Okaro–Lake Rerewhakaaitu areas in the Rotorua region. We hope the trip will be an informative, interesting and enjoyable day out with something for everyone.

We will look at the linkages between soils and water and show how science and society are working together to understand and reduce the impacts of municipal, farming and forestry activities on our environment. Multiple layers of tephras, clear examples of buried soil horizons, and three remarkable soil profiles will be seen. Soil and environmental scientists, foresters, tephrochronologists (volcanic ash specialists), and volcanologists will join forces with local farmers and others to give us their perspectives at various stops during the trip.

Schedule and route in brief

Depart Rydges Hotel 8.00 am, return ~5.00 pm. Lunch and teas provided (see notes below).
Morning: Four scientific stops. We begin on the eastern heights above Lake Rotorua and drive through the Whakarewarewa Forest and Waipa catchment, south to the Waimangu-Lake Okaro area, and then on to Rerewhakaaitu village hall for lunch.
Afternoon: Two scientific stops. We will circumnavigate Lake Rerewhakaaitu and view the ash layers, soils, farms and forests in this very picturesque landscape that includes the impressive bulk of Mt Tarawera and layered ignimbrite plateaux.

Safety and comfort

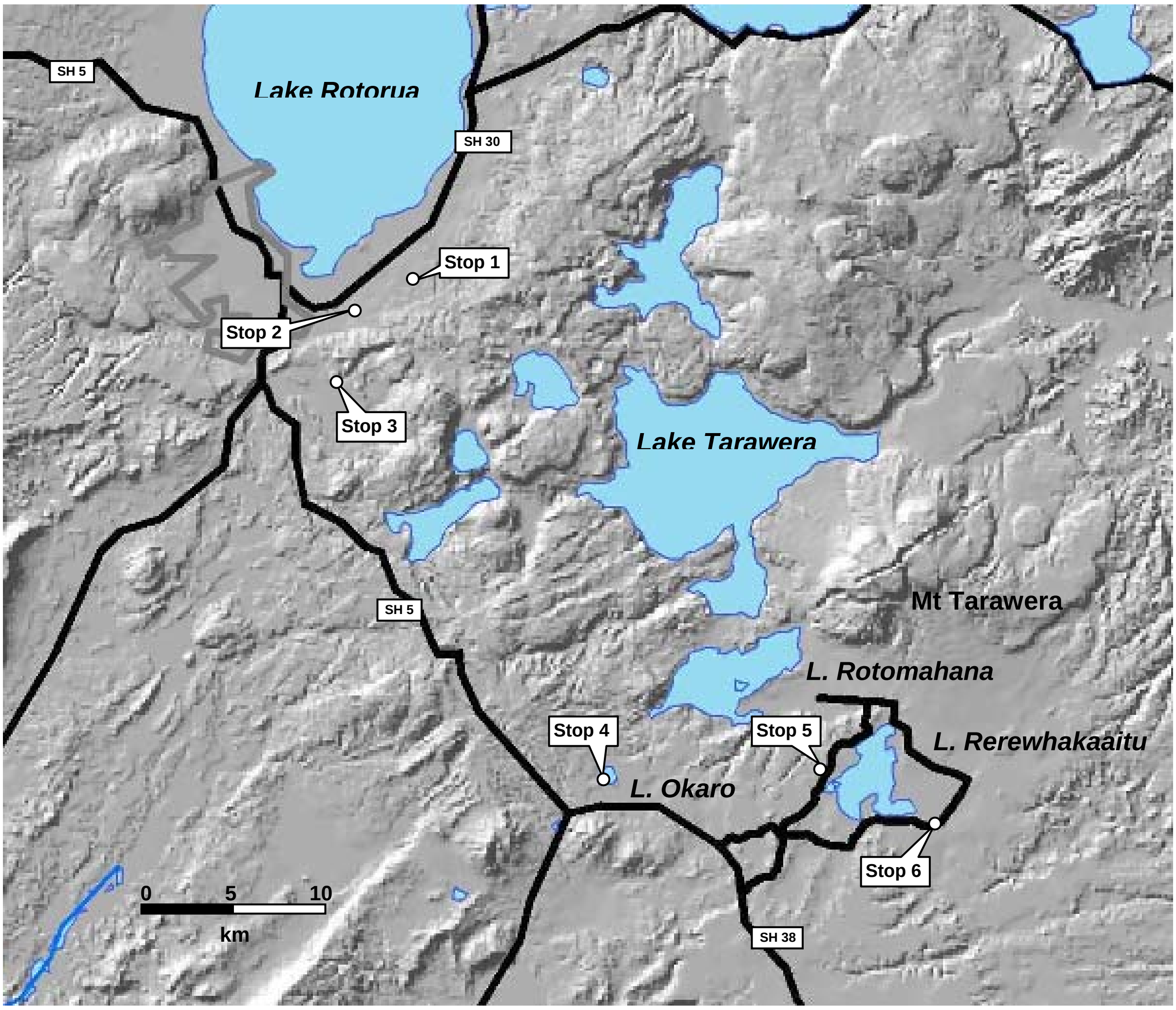
We have a very large number of participants in today's trip and will be running three buses (an unprecedented level of interest for a NZSSS field trip) together during the day. We have taken extra trouble to ensure that the day runs smoothly and safely for all participants. We ask for your special cooperation and consideration in various ways:

- We will be on the road at stop 5 (Brett Rd) and alongside/crossing the road at stop 6 (Ash Pit Rd) and so it is essential that all participants are very careful and responsive if traffic comes along the road. We will have traffic signs out and any approaching traffic will be flagged to slow down at stops 4, 5, and 6. Please respond quickly if asked to move off the road or away from the road edge at stops 5 or 6.
- Around 40 participants will be asked to wear orange Hi-Vis fluoro vests to add extra visibility to our group. Leaders will be wearing yellow Hi-Vis fluoro vests.
- We will have a sound system to enable leaders to address the group at the scientific stops but you will need to try to keep closely together so that most can see and hear what's going on. The soil profiles (freshly prepared) and tephra sections extend over a lateral distance of ~20 m and so there should be ample opportunities for all those interested to see various details. A few minutes will be set aside when we arrive for participants to photograph the sections before discussion and digging commence.
- We have allowed either 40 or 30 minutes, and an additional 10 mins for getting off/on the buses, for each stop. We need to stick closely to the schedule to complete the day by ~5 pm.
- If the day is sunny or even partially cloudy you will need hats and sunblock. Please note that we will be at around 450 m altitude most of the day and it can get quite cold around Lake Rerewhakaaitu if the weather deteriorates and the wind gets up – please bring a warm jumper and windproof coat/raincoat. Boots are recommended footware although we are not hiking any great distances (maximum walk ~ 80 m into forest; possibly slightly muddy on track to Ngakuru profile).

■ We will be providing tea/coffee and limited quantities of other drinks at scheduled breaks, and will carry potable water with us for topping up water bottles. We would advise that you bring your own water bottle and also snacks to supplement the packed lunches provided.

■ Toilets will be available at morning tea (Whakarewarewa Forest Visitors' Centre), stop 4 (Lake Okaro), lunch (Rerewhakaaitu hall), and final stop at Half-Moon Bay. However, the toilet facilities at several of these stops are rather limited.

Map of route and stops



Tour leaders, contributing authors, and other helpers

Numerous people have contributed in various ways to planning, supporting, and leading today's trip. Thanks are due to all of them and others.

Planning committee

Peter Singleton (Environment Waikato)
David Lowe (EOS, Univ. of Waikato)
Amy Taylor (Environment Bay of Plenty)
Haydon Jones (Ensis)
Loretta Garrett (Ensis)
Wim Rijkse (consultant)
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Additional leaders/helpers

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Penny MacCormick (Environment Bay of Plenty)
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Brent Green (Asarco Exploration, Perth)
Rick Vallance (Manager, Wharenui Station)
Shane Birchall (Farmer, Lake Okaro)
Tim Charleson (Red Stag Timber)
Dave Palmer, Scott Fraser, Annie Barker, Richard Smith, Roger Briggs, Geraldine Cook (Univ. of Waikato)

Itinerary at a glance

8.00 am Depart Rydges Hotel (departure point outside hotel – look for buses!)

8.20 am STOP 1 Wharenui Station: introduction
- Short overview landscape (Rotorua caldera, lake history)
- Short overview Rotorua soils
- Short overview land management and water quality issues
- Land/soil management from farming perspective

9.20 am Morning tea/coffee at Visitors' Centre, Long Mile Drive [toilets]

10.00 am STOP 2 Ngakuru sandy loam
- Ngakuru soil, tephras
- Plantation forestry

11.00 am STOP 3 Rotorua Land Treatment System, spray block 2
- Land treatment system, spray irrigation
- Waipa catchment wetlands, stream monitoring

12.00 noon STOP 4 Lake Okaro and wetlands [toilets]
- Landscape
- Lake water quality trials, wetlands, Rule 11
- Farming perspective

12.50 Lunch at Rerewhakaaitu Hall [toilets]
- Poster displays, maps

1.50 pm STOP 5 Rotomahana sandy loam, tephras/buried soil horizons, Brett Rd
- Landscape
- Rotomahana soil, tephras, buried soil horizons
- Project Rerewhakaaitu, farming perspective

3.00 pm STOP 6 Tephra section with buried soil horizons, Matahina gravel, Ash Pit Rd
- Tephra sequence, buried soil horizons, buried Podzol Soils
- Matahina soil

3.50 pm Half-Moon Bay, Lake Rerewhakaaitu [toilets]
- Lakeside refreshments and wrap-up

4.30 pm Depart Lake Rerewhakaaitu and return to Rydges Hotel by ~5.00 pm

For further detailed information on the links between (for example) land use and water quality, nutrient loads of Lake Rotorua, and ages of groundwater in the Rotorua region, go to Environment Bay of Plenty's website where numerous technical reports are available: http://www.ebop.govt.nz/Water/Lakes/Technical-Reports.asp.

A soils man, simple and pure
Was sent out to work in the sewer
And there, going to sea [or Lake Roto-i-ti]
He saw N, K and P
Left his job, and went selling manure (by Jock Churchman, 1973)

Introduction to North Island volcanoes and their products

David Lowe and Richard T. Smith
Department of Earth and Ocean Sciences, University of Waikato, Hamilton

Volcanoes are not only conical mountains, but span a very wide range of landforms. Simply, 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. The following notes are in part modified after the review of Smith et al. (2006).

Magma and types of eruptions

Magmas contain almost all of Earth's known chemical elements but typically they consist of just 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 (ca. 1100–1200 ^{0}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.
- *Rhyolite* magma is rich in Si, K and Na and erupts at temperatures between 700–850 ^{0}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 ca. 800–1000 ^{0}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 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 ^{0}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 deposit. The more explosive the eruption the more energetic this roaring stream of gas, and the higher the tephra and rock 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 direct 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. Auckand Volcanic Field); and
- caldera collapse craters (e.g. Taupo caldera, Okataina 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 today's trip, we will see mainly rhyolitic or dacitic deposits and landforms but some basaltic materials are also on show.

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.

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 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 ^{0}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.

Volcanism in North Island

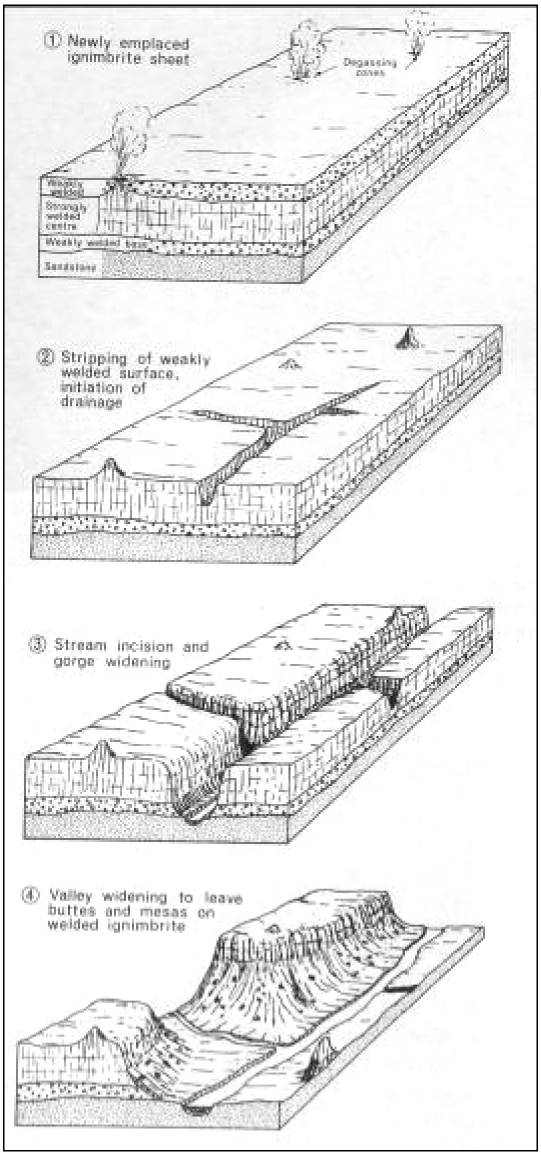
The highest concentration of volcanic activity in New Zealand occurs in the area known as the Taupo Volcanic Zone (TVZ). This narrow band of cone and caldera volcanoes extends from Ruapehu in the south, over 240 kilometres to Whakaari (White Island) in the north, with the Taupo, Okataina, Rotorua and 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 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).

Taupo Volcanic Zone

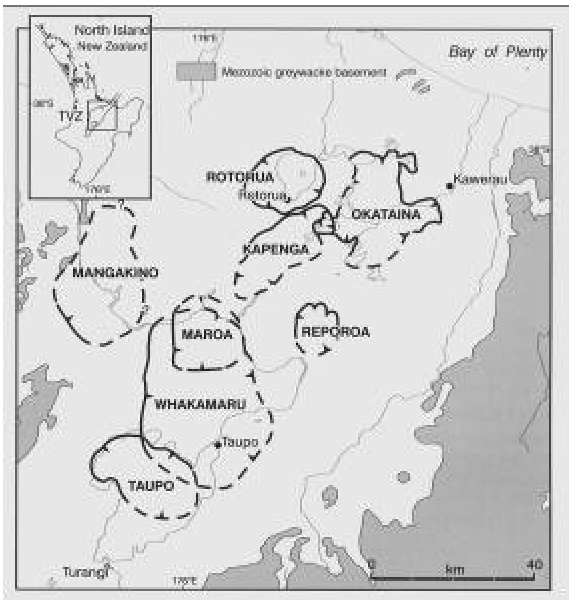
The TVZ can be thought of in three distinct parts. A southern part, dominated by andesite cones, includes the active Ruapehu and Tongariro volcanoes and the probably extinct Pihanga and Tihia-Kakaramea cones. A northern part, which is also dominated by andesite stratovolcanoes, includes the active Whakaari (White Is.) and the recently active Putauaki (Edgecumbe), and the much older, deeply eroded cones of Motuhora (Whale Is.) and Manawahe. These two stratovolcano clusters 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 at least six older calderas including Mangakino, Kapenga, Whakamaru, Reporoa, Rotorua and Maroa. 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 ca. 350,000 years ago are found under the seabed 1200 km east of Napier. 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 Rotorua, 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. Such distinctive landscapes attract and inspire New Zealanders and visitors.



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 (diagram designed by M.J. Selby, from Healy, 1992).



Locations of main rhyolitic volcanic centres active in the Taupo Volcanic Zone (TVZ) during the last million years (from Nairn, 2002).

What is '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 cars. 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 around 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. 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.

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

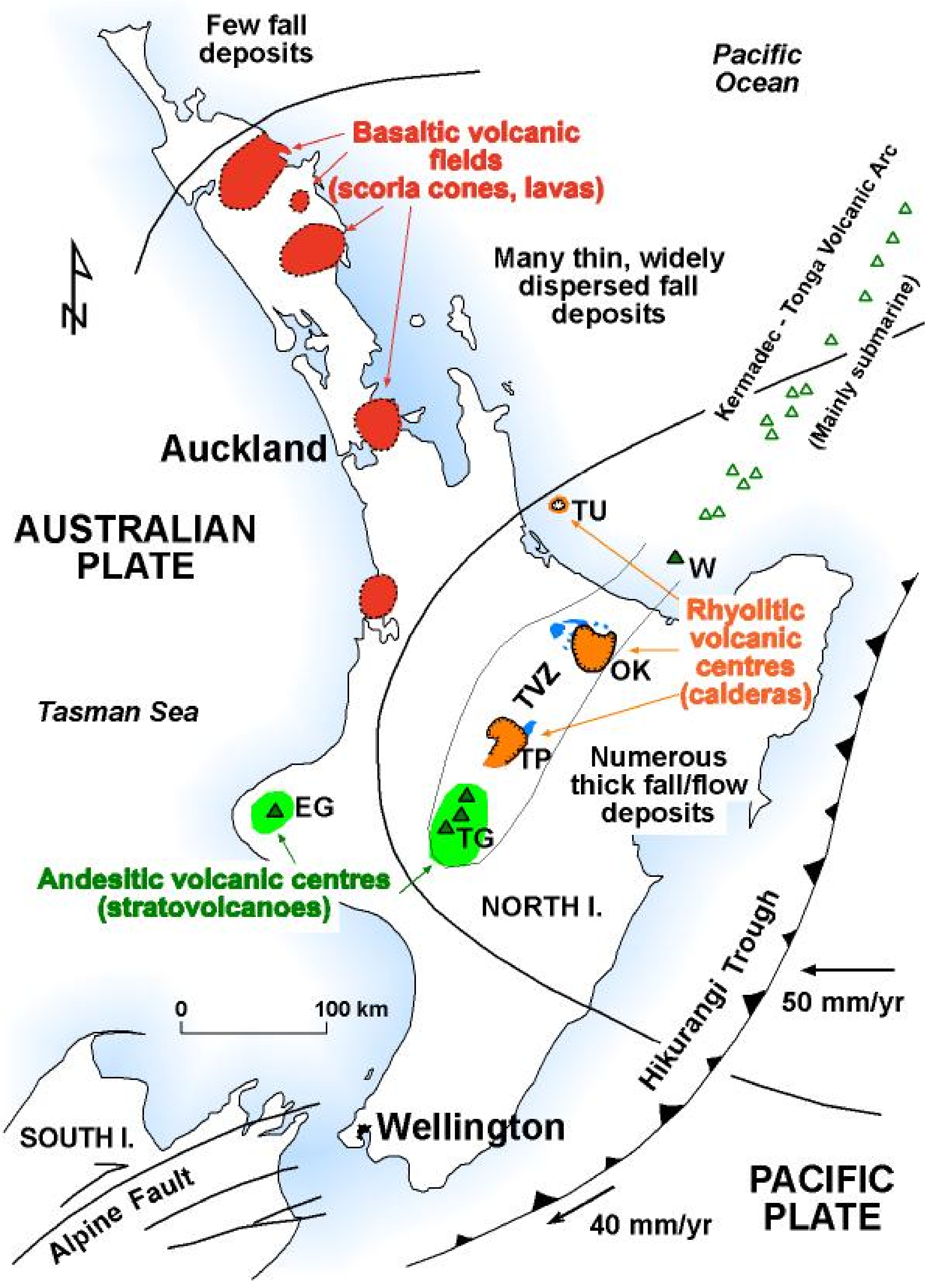
The thickest tephra sequences occur downwind of the TVZ in the Rotorua-Taupo area, Bay of Plenty, East Coast-Poverty Bay, and Hawke's Bay. Moderately thick deposits are found in Wanganui-Taranaki, King Country-Waikato-Coromandel and Auckland regions. Fewer tephra layers occur in other parts of the North Island. Only a handful of tephras has been recognised so far in the South Island. They include Rangitawa Tephra, erupted ca. 350,000 years ago from Whakamaru volcano, and Kawakawa Tephra, erupted ca. 27,100 yr ago from Taupo volcano.

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 (ca. 233 AD) is usually cream-coloured and relatively easy to crush between fingernails whereas pumice from the Kaharoa eruption (ca. 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.) ca. 7000 years ago, for example, contains very unusual minerals that allow it to be identified instantly with a microscope, even if just a few grains are present. But 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).

Tephra as a unique dating tool

Tephra-fallout layers have two special features: (1) they are erupted over very short time periods, geologically speaking, usually a matter of only hours or days to a few 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, that instant being the date of the eruption that produced the layer. In New Zealand and elsewhere many studies have used tephra layers 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 pp. 50-51).



General map showing plate tectonic setting, the main volcanic centres that have erupted soil-forming tephras, 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.

Volcanic topdressing

The frequent but usually localised eruptions from the volcanoes of Tongariro Volcanic Centre and also Taranaki but less often, have added small but markedly beneficial amounts of many nutrients to soils downwind from the volcano. For example, the 1995–1996 eruptions of Mt Ruapehu added 30–1500 kg ha^{-1} of sulphur and small quantities of other useful elements (including cobalt) to large areas of land in central and eastern North Island. By coring lakes and bogs in Waikato and Auckland regions and identifying many thin tephras preserved within them 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 $m^2\ g^{-1}$) 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).

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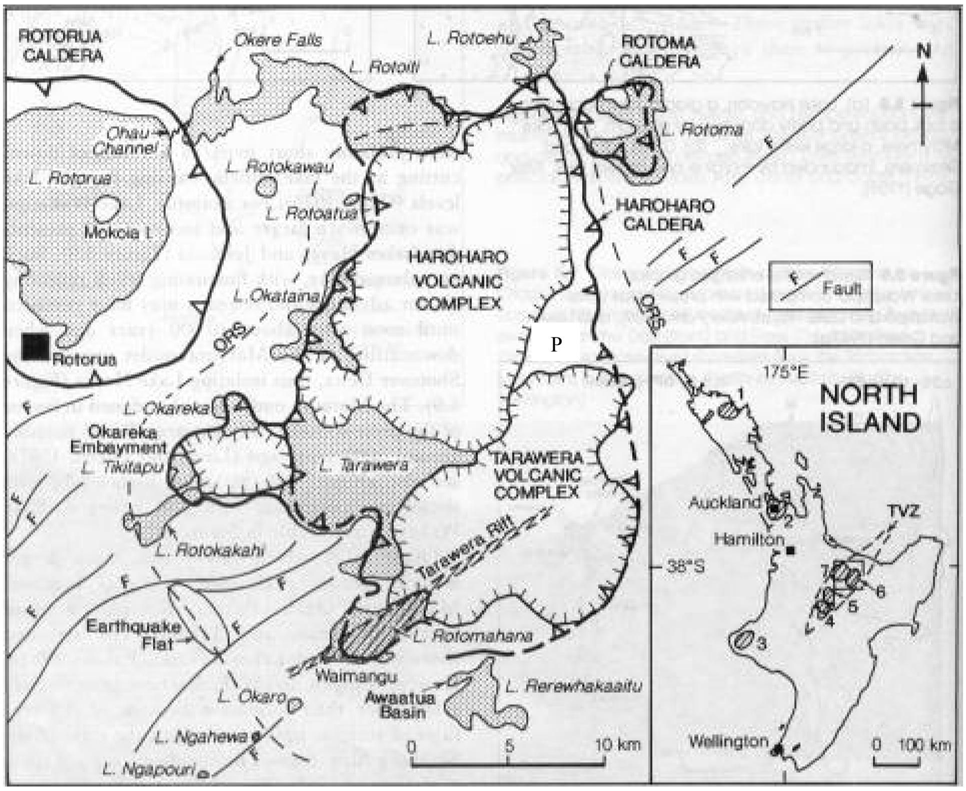

Volcanic lakes in the Rotorua area and simplified structural and volcanic features associated with the Rotorua and Haroharo calderas. Haroharo caldera comprises two main volcanic complexes, Haroharo and Tarawera, and lies within the Okataina Volcanic Centre (dashed line marked ORS) (from Lowe and Green, 1992). P, Puhipuhi Basin. Far more faults are present than shown.

Introduction to tephra-derived soils of the Rotorua region

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The relatively young landscapes of the Bay of Plenty region, like those of the central North Island, 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, 1993).

A distinctive feature of many of the volcanic-derived soils in the region 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 over the last 20,000 thousand years or so. 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) – i.e. soil processes alter the underlying material in a downward-moving front, forming generally well-developed subsoil horizons. Where the tephra deposited by a subsequent eruption was of sufficient thickness to bury the existing soil below the range of soil forming processes (known as retardant upbuilding), 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.

Where successive tephra deposits are thin and accumulate relatively frequently (e.g. at locations distal from source), however, the material from each eruption will become incorporated into the existing soil via soil mixing and other process through *upbuilding pedogenesis*. During such periods when tephras are accumulating incrementally, 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 upbuilding pedogenesis, subsurface horizons are weakly expressed. The terms developmental upbuilding and retardant upbuilding were used by Johnson and Watson-Stegner (1987) as part of their dynamic-rate model whereby soils evolve by 'ebb and flow' through time (see also Johnson et al., 1990; Schaetzl and Anderson, 2005).

A complication is that loess (wind-blown dust) 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) 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 (ca. 17,600 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 where deposition was enhanced by turbulence and the slowest was less than 0.01 mm per year. Accretion rates for tephric loess in the Waikato region, 0.03–0.08 millimetres per year, are similar to those for loess in south Westland, 0.04–0.12 mm per year.

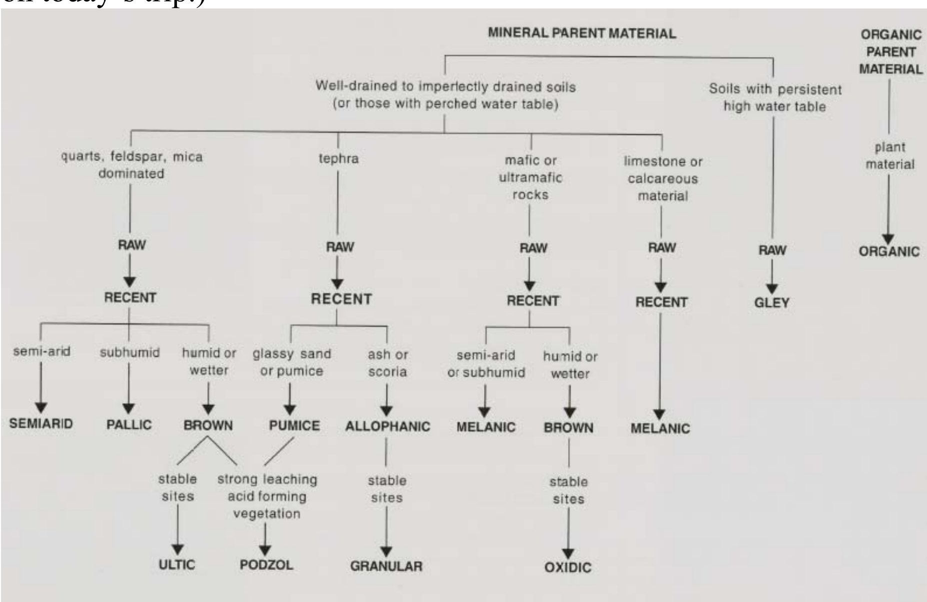
Ages and rates of soil formation can be assessed for the tephra-derived soils through tephrochronology, the use of tephra layers to link and date sequences. The main soil-forming tephras and marker beds in the Rotorua area, and their ages, are listed in the table below.

Tephra-derived soils and land use

Although many of the tephra-derived soils are of supreme quality, some are not. In the early part of the 20th century – at a time when large tracks of land were being prepared for pastoral agriculture – many of the soils on the central plateau were found to be deficient in trace elements crucial for animal health (i.e. cobalt, copper, and selenium), causing the so-called 'bush sickness" problem. Early surveys of soils and tephra deposits ("soil-forming ash-showers") showed a link between Kaharoa and Taupo deposits and the occurrence of bush sickness, but it was not recorded on Tarawera eruptives. The worst bush-sick area was on Kaharoa Tephra and the soils were regarded (even into the 1950s) as 'despised soils' (Vucetich and Wells, 1978). 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, 1993). 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.

Classification of tephra-derived soils

Soils formed from tephra deposits are represented by four 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%) (Hewitt, 1998; Lowe and Palmer, 2005). (Examples of the first three will be seen on today's trip.)



Major taxonomic development paths of New Zealand soils (from Allan Hewitt in Molloy and Christie, 1993, p.235).

Tephric Recent Soils

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 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

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 (ca. 233 AD) and Kaharoa eruptions (ca. 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 tephras buried beneath them.

Allophanic Soils

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 $m^2 g^{-1}$) (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, 1993). These features and their distribution on smooth, easily manageable tephra-mantled landscapes make them ideal for pasture production and grazing in our humid climates. In fact, 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).

Granular soils

These sticky and clayey but well-structured and productive soils have formed on older, strongly weathered tephra layers erupted from central TVZ between about 80,000 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. (These soils will not be seen on the field tour today.)

Summary of main rhyolitic tephras deposited in the Rotorua region during the last ca. 27,000 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 also has been dusted regularly with andesitic tephra fallout from numerous eruptions at Tongariro Volcanic Centre and Egmont Volcano.

Name (source)*	Date or age (cal yr BP)¶	Description
Tarawera Tephra (Tarawera)	10 June 1886	Comprises basaltic scoria (Tarawera Scoria) with occasional rhyolite clasts and/or fine greyish brown 'muddy' ash (Rotomahana Mud). Mud was dispersed more widely.
Kaharoa Tephra (Tarawera)	1314 ± 12 AD (636 ± 12 cal BP)	Fine to coarse white to grey ash, with occasional dense pumice, rhyolite, obsidian and basalt lapilli. Contains abundant biotite.
Taupo Tephra (Taupo)	233 ± 13 AD (1717 ± 13 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.
Waiohau Tephra (Tarawera)	13,635 ± 165 cal BP	Grey fine and coarse shower-bedded ash. Distinctive v. fine ash layer at the base. Usually has a well developed yellowish-brown upper soil horizon reflecting pedogenesis before burial.
Rotorua Tephra (Okareka embayment)	15,425 ± 325 cal BP	Shower-bedded pumiceous yellowish lapilli or blocks (gravel). Occasional rhyolitic lithics.
Rerewhakaaitu Tephra (Tarawera)	17,625 ± 425 cal BP	Yellowish-brown ash grading down into tephric loess. Contains abundant biotite. Marks transition from Last Glacial to Post Glacial conditions; reafforestation occurred soon after deposition.
Okareka Tephra (Tarawera)	21,800 ± 500 cal BP	Yellowish brown ash contains abundant biotite. Marks coldest part of Last Glacial (typically encased in yellowish to olive brown tephric loess).
Te Rere Tephra (Haroharo/Okareka)	25,271 ± 779 cal BP	Yellowish-brown ash (typically encased in yellowish to olive brown tephric loess).
Kawakawa Tephra (also known as Oruanui) (Taupo)	27,097 ± 957 cal BP	Olive brown to pale yellowish brown ash (typically encased in yellowish to olive brown tephric loess).

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

¶Most ages are given in calibrated or calendar (cal) years (95% probability range) before present (BP), 'present' being 1950 in the ^{14}C timescale (from Lowe et al., 2008a). 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).

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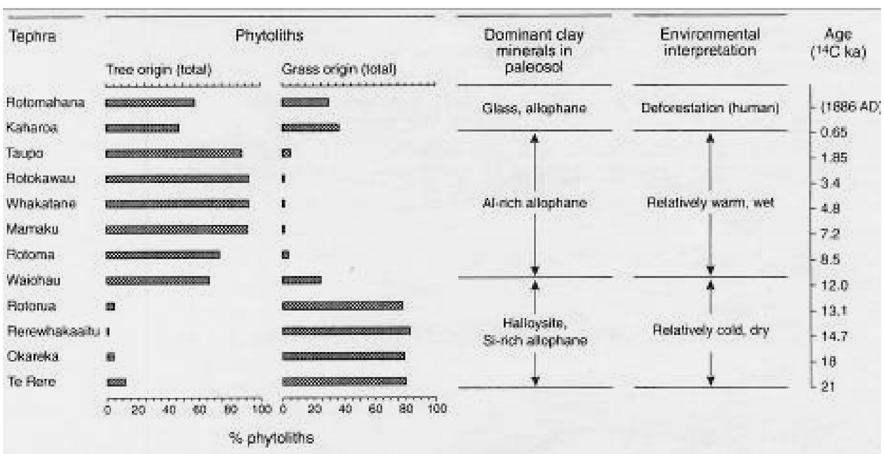


Evidence of environmental change since ca. 24,000 cal. yr ago based on phytolith and clay mineral data from analysis of buried soil horizons on rhyolitic tephras at Te Ngae, Rotorua (from Newnham et al., 1999 — after Sase et al., 1988; Sase and Hosono, 1996; Hodder et al., 1990).

STOP 1 – WHARENUI STATION, WHARENUI RD

Location U16 005350, elevation 350 m asl, soil underfoot Wharenui sandy loam (Kennedy, 1981), rainfall ~1600 mm pa

Note: Lake Rotorua has an area of ca. 80 km^2 (11th largest lake in New Zealand by area, the third largest in North Island after Taupo and Wairarapa) and a maximum depth of 45 m. A large-scale map (scale 1: 15,000) of the soils of Rotorua City was prepared by Kennedy (1981) but the accompanying bulletin remains in draft form.

An introduction to Rotorua Basin (an iconoclastic view)

Will Esler

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

Basin formation

For forty years the Rotorua Basin has been regarded as a caldera formed by the eruption of the Mamaku Ignimbrite 140,000, then 220,000, now 240,000 years ago. Recently it has become clear that there was a large hole in the ground well before then, i.e. an older caldera. Mamaku Ignimbrite is a thin veneer (~120 m only) draped over the antecedent topography, with with some collapse occurring in the east and south of the Basin. The volume of magma involved in the Mamaku Ignimbrite eruption was >140 km^3. Gravity data show that much less than half of this could have come from the Rotorua Basin. The rest came from the ‘real’ caldera probably near the Horohoro Bluffs (just south of Rotorua). The Mamaku Ignimbrite was one part of a quickfire fissure eruption on the western boundary of the Taupo Volcanic Zone (TVZ), although there may have been a late-stage vent within the Rotorua Basin.

The Ngongotaha rhyolite massif erupted well after the Mamaku Ignimbrite from a distantly related glassy magma. Much of the ‘caldera’ collapse in the city area came after the rhyolite extrusion. Mokoia Island and two small lava domes south of the airport are much older than previously thought. All pre-date the Rotoiti Ignimbrite of ca. 50,000 years ago. The soft top of the Mamaku Ignimbrite was severely eroded by frost, rain and wind during the Last Glacial, and in earlier cold periods. A recently recognized set of sinuous ridges of ‘M’ cross-section has joined the famous family of isolated tors of the Mamaku plateau. Localised fumerolic hardening has never been adequately proven.

Local geological history

The large hole on the upwind margin of the TVZ has proved the best place to find evidence of the history of the past 250,000 years in the central North Island. Rotorua city now has the most detailed local history in New Zealand. Lake Rotorua is the oldest lake in the North Island, and perhaps New Zealand. The default condition is diatomite accumulation. Within the sediments are more than 40 recognised tephras preserved in exquisite detail, and many more eagerly awaiting a core barrel. Electron microprobe analysis of glass to obtain major element chemistry is the most useful tephra identification technique, along with identification of mineral assemblages. Tephras from Okataina, Taupo, Taranaki, Tongariro, Mayor Island, and probably Maroa volcanic centres have been identified.

Ernst Dieffenbach made a flying start on local history with the 1841 observation that the same tephra sequence was recognizable in different parts of the Rotorua Basin. Les Grange put local stratigraphy on a rational, objective basis with chemical and mineralogical description of tephras in the 1920s-1930s. A great milestone was the classic, though geologically naïve, paper by Neill Kennedy, ‘Alan’ Pullar, and Colin Pain in 1978: *Late Quaternary land* *surfaces and geomorphic changes in the Rotorua Basin, North Island, New Zealand* (N.Z. Journal of Science 21, 249-264). 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. In the Okataina Volcanic Centre, Ian Nairn successfully united both approaches from the late 1970s.

Lake level

Lake level history has proved to be far more complex than Kennedy and Pullar suggested. There have been at least seven periods of very high lake level, up to 120 m above present level (Lake Rotorua is currently at 280 m asl), and the lake has drained completely at least twice. Lake Rotorua has once or twice been part of a huge lake extending to Atiamuri or beyond. Lake level has responded to whatever geological events were on offer. The usual condition has been the seepage of lake water to the thick pumice aquifer beneath the Mamaku Ignimbrite rather than surface discharge. The upper part of this aquifer supplies most Rotorua's water. In places it is enriched with agricultural nutrients moving steadily towards the lake. The northwestern rim of the Basin was first breached at about 55,000-50,000 years ago during a local collapse event in the Tikitere Graben that may have also formed the 'caldera' fault at Hamurana. Rotoiti Ignimbrite impounded the lake for about 20,000 years to its highest proven altitude (ca. 400 m), with two internal drainage episodes. The lake then extended well beyond the Rotorua Basin. The shallow arm south of Hemo Gorge was larger than the present Lake Rotoiti. The last highstand, from 33,000 to 30,000 years ago, was at ca. 380 m. The prominent high terrace around the Rotorua Basin dates from this time.

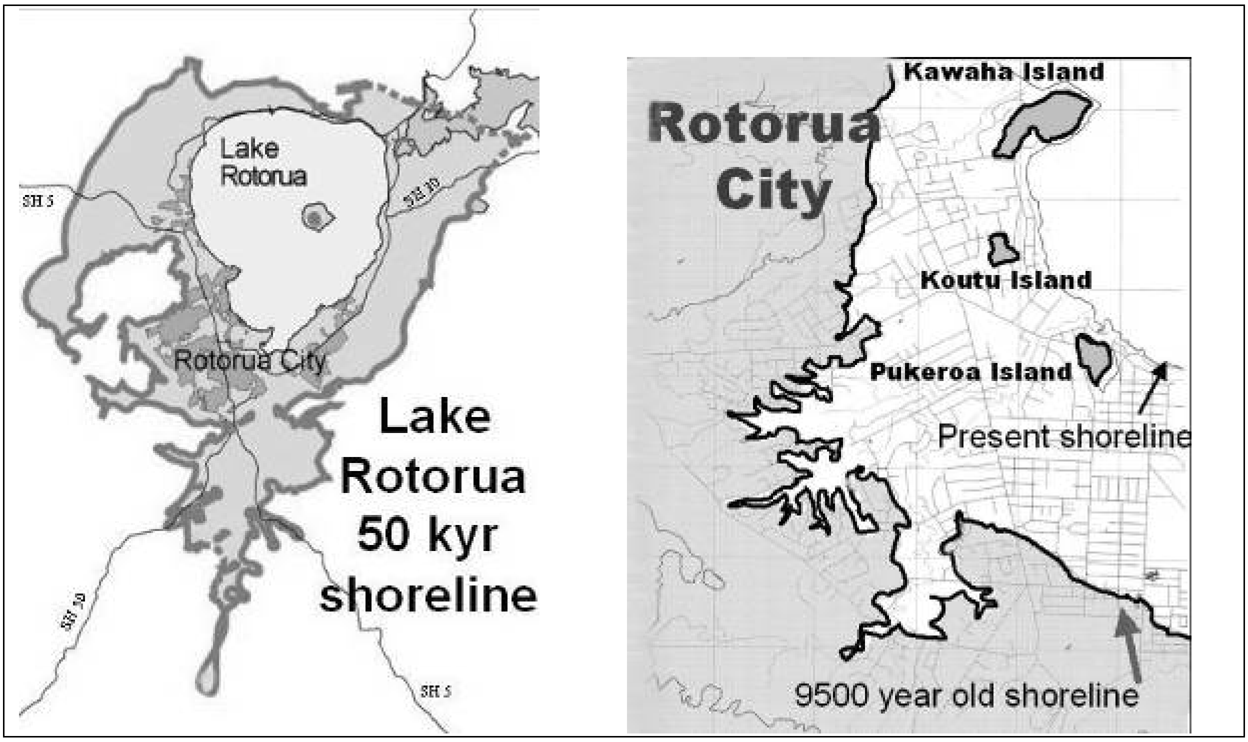
The present surface discharge from the Rotorua Basin is an anomaly dating from about 30,000 years ago. Southerly drainage through the Hemo Gorge is a cherished myth dating from the 1920s. A more recent fiction is the notion of a 'caldera break-out flood' from the present Rotorua Basin. There is now a composite fairy tale in circulation.

Lava dams of the Rotoma eruptive period (9505 ± 25 cal. yr BP) caused a minor high stand and united Late Rotoiti with Lake Rotorua 15 m above the present lake level. Faulting in the Tikitere Graben has controlled lake level since then.

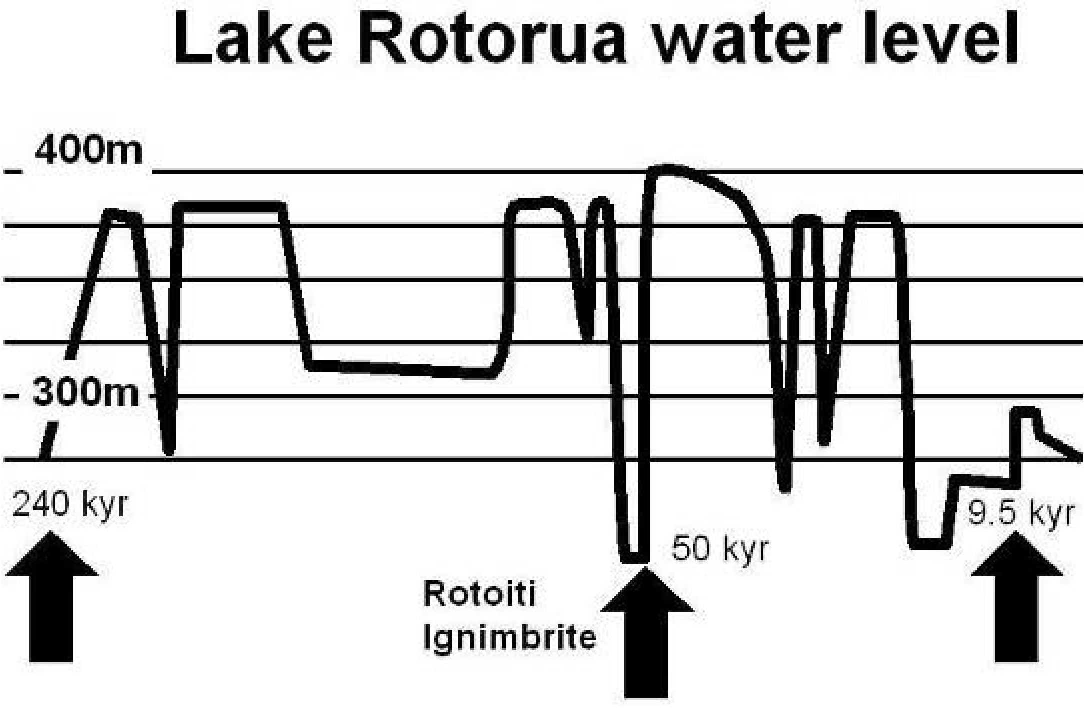
Faulting probably accompanies most Okataina eruptions. Contemporaneous Okataina-generated pumice rafts drifted across Lake Rotorua to the Ohau Channel, lingered, saturated, and sank. This secondary impoundment of the lake blurs the faulting record. Lake level apparently fell by nearly eight metres around the time of the Whakatane Tephra eruption (5530 ± 60 cal. yr BP). Pumice rafting would have been irrelevant on that occasion. On present trends, Lake Rotorua will have again drained completely in 6000 years. Te Arawa iwi has recently resumed ownership of the lake bed, and can expect a real-estate bonanza a few minutes after the next earthquake in the Tikitere Graben. Properties will suffer downstream of Lake Rotorua.

Other hazards

Much of Rotorua city has been built on a sandy tephra pad <1m thick over soft lake silts that will inevitably liquefy in some places during a moderate earthquake. Building has recently accelerated on land clearly identified as unsuitable for housing by Soil Bureau a generation ago. The 1886 lahar paths have been overlooked. Toxic hydrogen sulphide adds a distinctive flavour to geothermal hazards in the city. More deaths have been caused by various geothermal mishaps than by the 1886 Tarawera eruption. Many of the casualties were Maori in pre-European times. The dramatic lake level changes in the past ca. 55,000 years have often caused hydrothermal explosions. Some abandoned geothermal wells are now in a brittle condition. Clearly, citizens in some parts of Rotorua are exposed to multiple hazards.



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



Changing levels of Lake Rotorua since ca. 240,000 years ago. Present level is ca. 280 m asl. (W.R. Esler, unpubl. data)

Land use impacts on lake water quality

Amy Taylor
Environment Bay of Plenty, Whakatane
Peter Singleton
Environment 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.

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 has a natural source. However, the pressures on the Rotorua lakes are mostly from the intensification of agriculture and growth in lakeside communities.

Steps to improve water quality
Some of the contributing factors and steps to improve water quality are listed below.

Lake	Water quality problems	Steps to improve water quality
Okareka	Moderate risk of cyanobacterial blooms.	Action plan operational. Sewerage reticulation. Lake edge wetlands. Treatment of hypolimnetic water with flocculants to remove phosphorus. Environmental programmes for landowners. Land use change for lower nutrient export.
Okaro	Severe cyanobacterial blooms (alternates between blue-green and green algal). Previous scientific reports dating back to 1966 describe Lake Okaro a having ‘clear water’ with a pH of 7. Today the lake has a very low clarity and a surface water pH in excess of 8.	Action plan operational. Chemical flocculant trials, constructed wetland and riparian retirement. Environmental programmes for landowners.

Lake	Water quality problems	Steps to improve water quality
Okataina	None - low risk of cyanobacterial blooms. Possible water quality degradation that could come from lake level changes or other natural fluctuations.	Action plan process beginning to investigate the causes of lake quality decline. Environmental programmes for landowners.
Rerewhakaaitu	Risk of cyanobacterial blooms during summer where lake is shallow and calm. Water quality fluctuations noted in the past.	Local projects undertaken in catchment with landowners. Trials of treatment boxes to remove nitrogen from streams. Phosphorus-absorbing socks in the Mangakino Stream. Environmental programmes for landowners.
Rotoehu	Severe cyanobacterial blooms (have been more persistent since an increase in nutrients in 1993). 2003/04 summer had no cyanobacterial blooms, but a large bloom returned in the 2004/05 summer along with a large hornwort infestation.	Action plan process underway. Riparian retirement programme. Constructed wetlands. Treatment box to remove stream nitrate. Hornwort harvesting trial to remove nutrients
Rotoiti	Severe cyanobacterial blooms in Okawa Bay (have become more persistent in past few years). Isolated blooms in eastern lake area. Receives nutrient rich water from Lake Rotorua (~72% nutrients are from Rotorua). Massive algal bloom in early 2003.	Action plan process underway. Riparian retirement. Sewage reticulation for lakeside settlements. Diversion of inflow from Ohau Channel down the Kaituna River.
Rotokakahi (Green Lake)	Moderate risk of cyanobacterial blooms. Water quality is lower than in the 1950s, but there has been no discernible change since 1970/71.	Actions to improve lake water quality to be negotiated with lake owners.
Rotoma	None. Low risk of cyanobacterial blooms.	Action plan process beginning. Sewage reticulation and nutrient management for farmland. Environmental programmes for landowners.
Rotomahana	Occasional cyanobacterial blooms.	No action at this time, until July 2008. Environmental programmes for landowners.
Rotorua	Experience water quality decline between 1978 and 1983. Foam (associated with kirchneriella algae species). Isolated blooms of nuisance algae. Moderate risk of cyanobacterial blooms.	Action plan process underway. Rotorua District Council diversion of treated sewage to land disposal in 1991, and further improvements in progress. Riparian retirement since 1970 as part of Kaituna Catchment Control Scheme. Diversion of nutrient rich spring flows investigated. Flocculant dosing of nutrient-rich streams. Stormwater upgrades. Environmental programmes for landowners.
Tarawera	Occasional cyanobacterial blooms. Bacterial issues from septic tanks around some lakeshore areas.	Action plan process beginning. Land use change to lower nitrogen and phosphorus export encouraged. Planning for future sewage reticulation. Environmental programmes for landowners.
Tikitapu (Blue Lake)	Probable lake water decline from septic tanks from camping ground and public amenities. Low risk of cyanobacterial blooms.	Sewerage reticulation as part of the Lake Okareka scheme. Action plan process beginning.

Rule 11

Rule 11 is a commonly used term for a collection of rules in the proposed Regional Water and Land Plan that will restrict landowners in catchments of some of the Rotorua lakes from increasing the amount of N and P leaving their property. The 'Rule 11' regulations are part of a wide-ranging programme of action called the Rotorua Lakes Protection and Restoration Action Programme. This is a joint project by Environment Bay of Plenty, Rotorua District Council, and Te Arawa Maori Trust Board. These rules have important implications for land use, development and management in certain lake catchments. Rule 11 has a single goal: to protect lake water quality. Nutrient benchmarks must be set for all properties larger than 4,000 m^2 in five lake catchments. They are 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. 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 must review Rule 11 for each affected lake catchment. A plan variation for each catchment must be notified by 31 December 2007.

Ohau Channel diversion

Environment Bay of Plenty has been granted resource consent to build a wall structure in Lake Rotoiti. The structure is designed to stop water flowing from Lake Rotorua into the main body of Lake Rotoiti via the Ohau Channel. The wall is expected to cost up to $14 million to build. This is being funded by Environment Bay of Plenty and central Government.

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.

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 10 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.

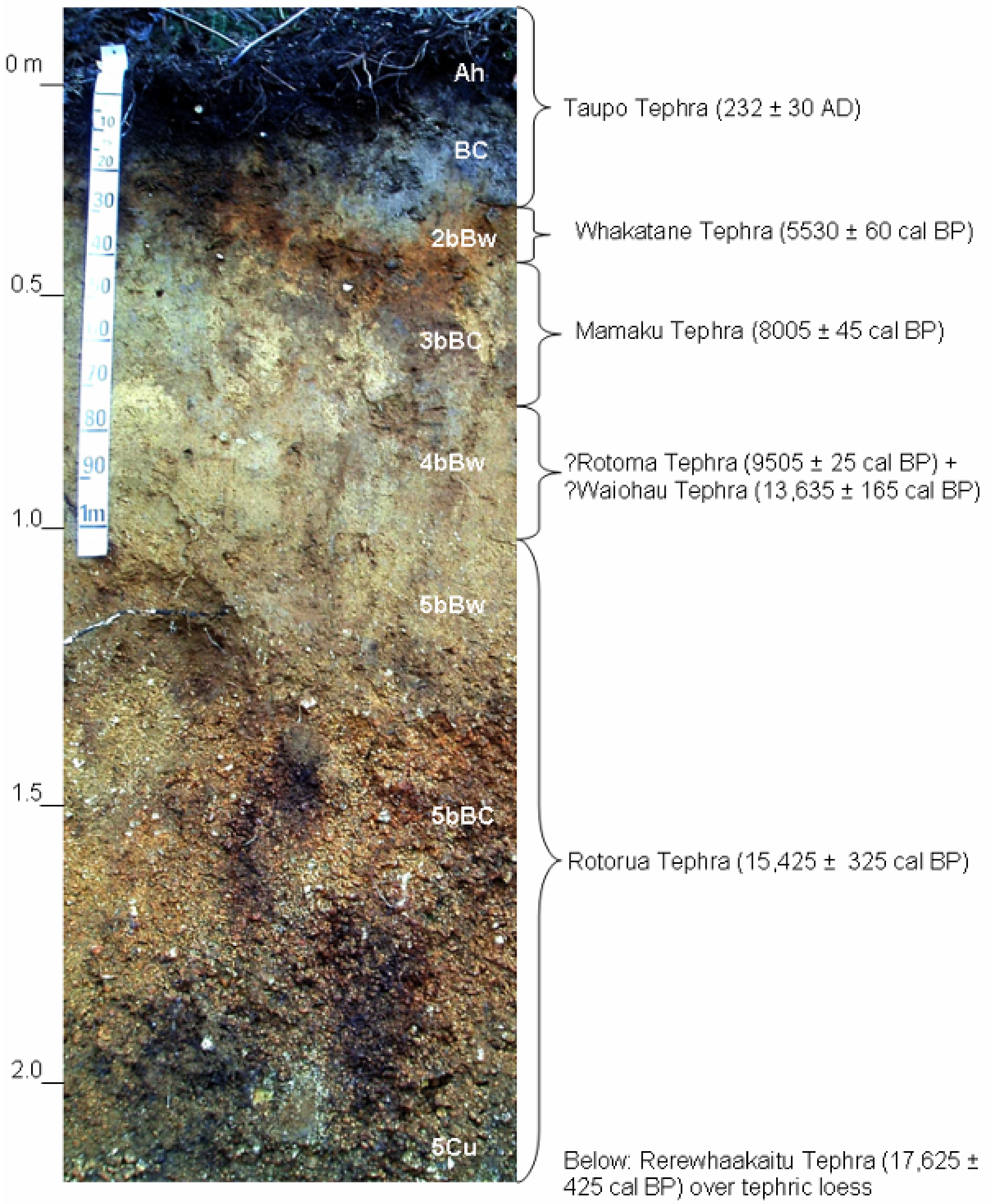
STOP 2 – NGAKURU SANDY LOAM, RADIO HUT RD

Location U16 961325, elevation 387 m asl, soil underfoot Ngakuru sandy loam (Rijkse, 1979), rainfall ~1600 mm pa

Ngakuru sandy loam

NZSC: Vitric Orthic Allophanic Soils; tephric, rhyolitic; loamy/sandy; rapid/mod.

Soil Taxonomy: Vitric Hapludands



Modern soil and buried soil horizons in tephras over Rotorua Tephra (*photo, stratigraphy and horizonation*: Haydon Jones, Loretta Garrett, David Lowe, and Wim Rijkse)

Soil profile descriptions by Haydon Jones

Ensis (Forests and Environment), Rotorua

Soil profile description data for the three soils being examined today 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 Ngakuru 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. The soil classifications follow Hewitt (1998), Clayden and Webb (1994), and Soil Survey Staff (1999, 2003).

Ngakuru reference data

- Soil name:
    - Series: Ngakuru
    - Type: sandy loam
- Soil classification:
    - NZSC: Vitric Orthic Allophanic Soils; tephric, rhyolitic; loamy/sandy; rapid/moderate
    - Soil Taxonomy: 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: 387 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 tephras on tephric loess) (see photo for tephra ages)
- 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.

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]

Note: Source vents for Rotorua Tephra are only ca. 7-8 km to the south-east of this site (rhyolite dome complex between lakes Tikitapu and Okareka). Soils of the Whakarewarewa area have been mapped and described (scale 1: 63,360) by Rijkse (1979) (see short review below p. 33). Analytical data for a Whakarewarewa soil (very similar to the Ngakuru soil) are available below (from Rijkse, 1992).

Note from Wim Rijkse

Ngakuru 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).

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Location: Larch Road, Whakarewarewa Forest

Grid reference: U16 975303 (August 1964)

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

Field no.	Lab. no.	Depth (cm)	Description
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).

Site : Wa2 PARTICLE SIZE DISTRIBUTION (mm , %) Lab No : 87/43/2

Horizon Depth (cm)	Lab Letter	Sample Depth (cm)	FINE EARTH FRACTION: Coarse Sand 2-0.6	Medium Sand 0.6-0.2	Fine Sand 0.2-.06	Silt 0.06-0.002	Clay <.002	WHOLE SOIL: >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			
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/m3)	Particle Density (t/m3)	Total Porosity (%)	Macro-porosity (%)	Water Content (%, v/v) at Tensions (kPa) 5	10	100	1500	Available Water (%) Readily 10-100	Total 10-1500
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									

WHAKAREWAREWA FOREST 7 Lab No: I800258

Horizon depth (cm)	Lab letter	Sample depth (cm)	Pyrophosphate-extractable (%) Fe	Al	C	Acid oxalate-extractable (%) Fe	Al	Si	Mn	ODOE	Dithionite-citrate extractable (%) Fe	Al	Stones >2mm (%)	Moisture factor
			8B			8A					8C			1
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 depth (cm)	Lab letter	Sample depth (cm)	pH H2O	1M KCl	1M NaF	CaCl2	H2O Moist	C (%)	N (%)	C/N	Truog P (ug/g)	Phosphorus fractions (mg %) 0.5 M H2SO4	Inorg.	Organic	Total	P retn (%)
			2A	2C	2D	2B		3A	4A		5A	5D		5E	5F2	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 depth (cm)	Lab letter	Sample depth (cm)	Cation exchange (NH4OAc @ pH7 me %) CEC	Sum bases	%BS	Ca	Mg	K	Na	KCl Ex. Al (me. %)	Titratable acidity (me. %)	Reserve Mgr (me. %)	Kc	S Total (ug/g)	Phosphate ext. (ug/g) S	SO4
			6A4	6A3	6A5	6A2				6B1	6C1	7B	7A		11A1	11A3
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	0.58	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														

Data on this and previous page are from

Rijkse, W.C., 1992. Notes for field days of 1992 conference of NZSSS. *New Zealand Society of Soil Science*. 35 pp + 6 pp.

Overview of soils of Whakarewarewa Forest area, Rotorua

David Lowe
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Haydon Jones
Ensis (Forests and Environment), Rotorua

Rijske (1979) mapped the soils in the Rotorua Lakes area at a scale of 1:63 360. 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 the balance between upbuilding and topdown 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 on p. 20 (note that usually not all tephras are present at any one locality, and in most profiles there are likely to be thin deposits of andesitic and other tephras 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

	Soil series		
Feature	**Haparangi**	**Whakarewarewa**	**Ngakuru**
Rotomahana Mud	Absent	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 found in the Whakarewarewa soils where it is evident as pale grey 'blobs' (2-8 cm thick) in the topsoil. Subsoils (beneath Taupo) are typically yellowish-brown Bw or BC or Cu 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.

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Rijkse, W.C., 1992. Notes for field days of 1992 conference of NZSSS. *New Zealand Society of Soil Science*. 35 pp + 6 pp.

Geothermal fields and the 'bore war'

David Lowe

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

Geothermal fields in the TVZ, and also in Northland at Ngawha, provided a hot-water supply for cooking, bathing, and medical treatment for early Maori. In 1914 the New Zealand Government published a book by A.S. 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. The Wairakei geothermal power station began providing energy on completion in 1958, and a second geothermal power station was finished at Ohaaki in 1989. Together Wairakei and Okaaki provide about 5% of New Zealand's energy needs. Geothermal fields at Waimangu and Waiotapu, and within the Rotorua caldera, attract many tourists to New Zealand.

Before 1886, around 130 geysers were regularly active in five major fields in the Rotorua-Taupo area but the Tarawera eruption, a dam at Orakeikorako, and the geothermal power projects reduced geysers to barely a dozen. As well, natural heat flows in Rotorua between 1967 and 1985 dropped by 30% because of increased drawoff by commercial and domestic users. To preserve the last geysers at Whakarewarewa in Rotorua, the New Zealand Government, acting primarily on the advice of geoscientists Ron Keam and Ted Lloyd – vilified at the time but years later awarded medals for their foresight and courage – launched the 'Bore War' in 1987 by closing down many private bores despite 'heated' opposition from Rotorua's citizens. Within three years, fewer than 150 wells were operating compared with 430 previously, and the geysers were saved.

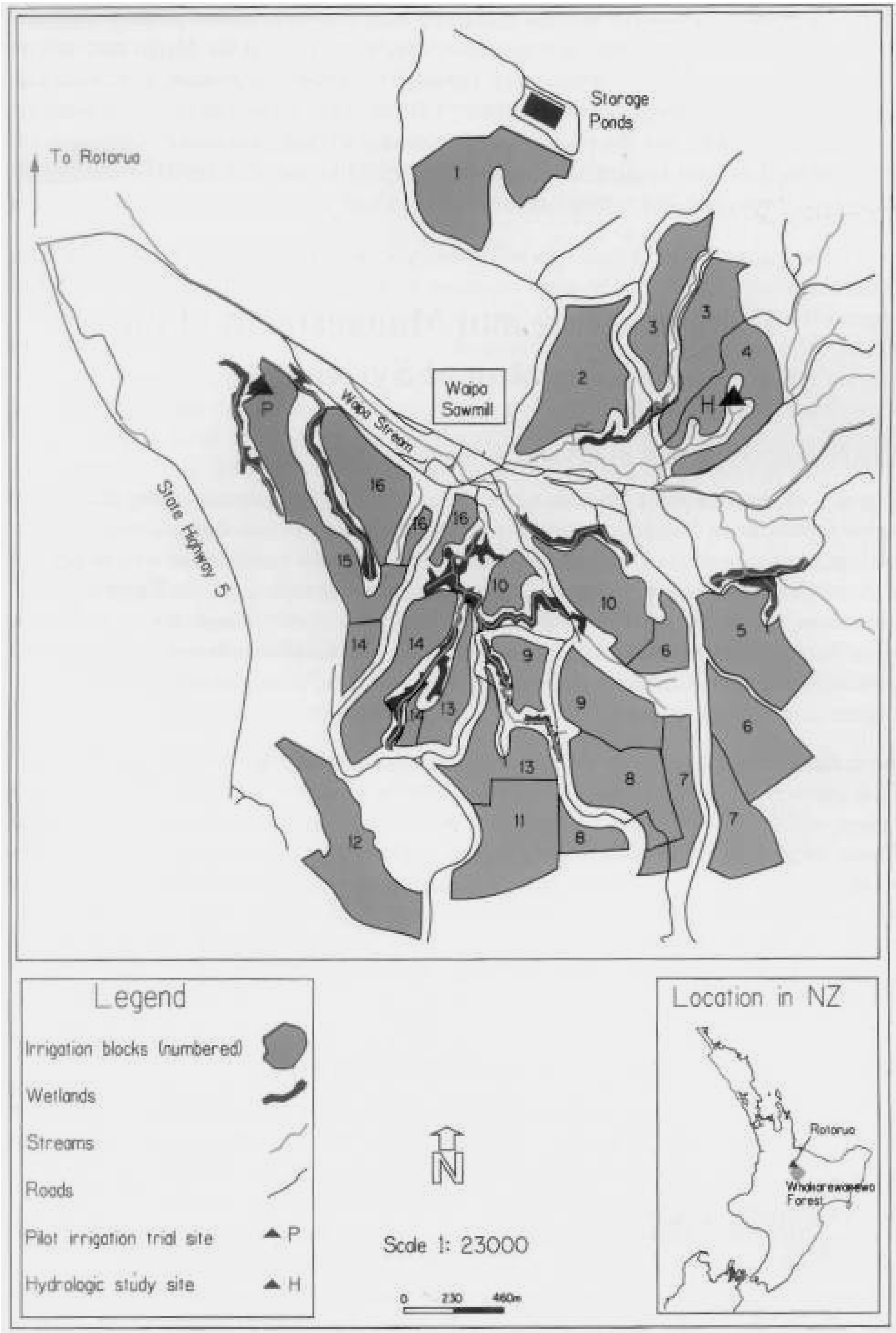
STOP 3 – ROTORUA LAND TREATMENT SYSTEM, SPRAY BLOCK 2, RED TANK RD

Location U16 972309, elevation 350 m asl, soil underfoot Ngakuru sandy loam (Rijkse, 1979), rainfall ~1600 mm pa

Rotorua sewage effluent irrigation scheme

Gerty Gielen

Scion, Rotorua



Spray irrigation areas and wetlands and Waipa Stream. Waipa Mill location also shown.

Sewage effluent concentrations, loadings for major nutrients and irrigation details

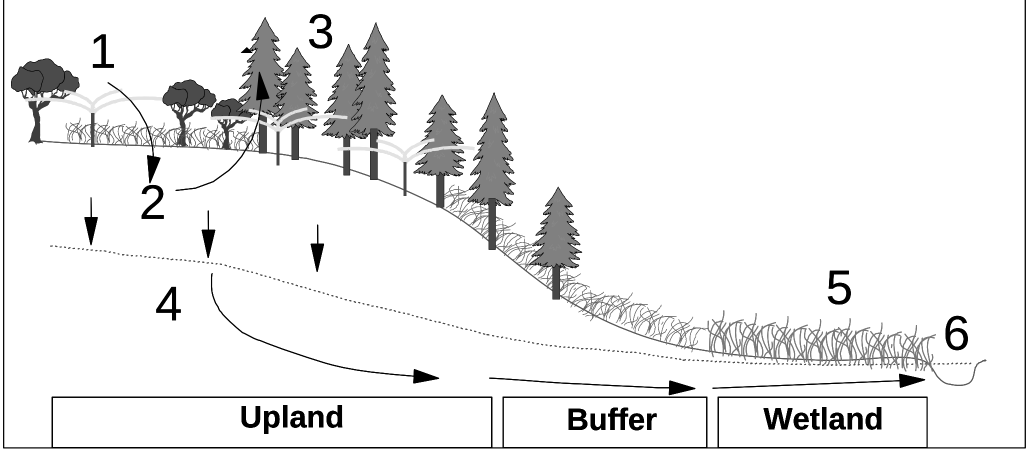
Constituent	**Mean concentration** (standard deviation) (g/m³)	**Mean area loading** (kg/ha.year)
pH	7.3 (0.2)	NA
Total nitrogen	10.6 (2.5)	395
Oxidised nitrogen	6.5 (2.4)	236
Kjehldahl nitrogen	4.2 (2.7)	155
Ammonium nitrogen	2.6 (2.8)	96
Total phosphorus	3.6 (1.7)	130
Dissolved reactive phosphorus	3.3 (1.7)	121
Total organic carbon	7.1 (3.0)	263

Average daily volume	19,000 m³/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

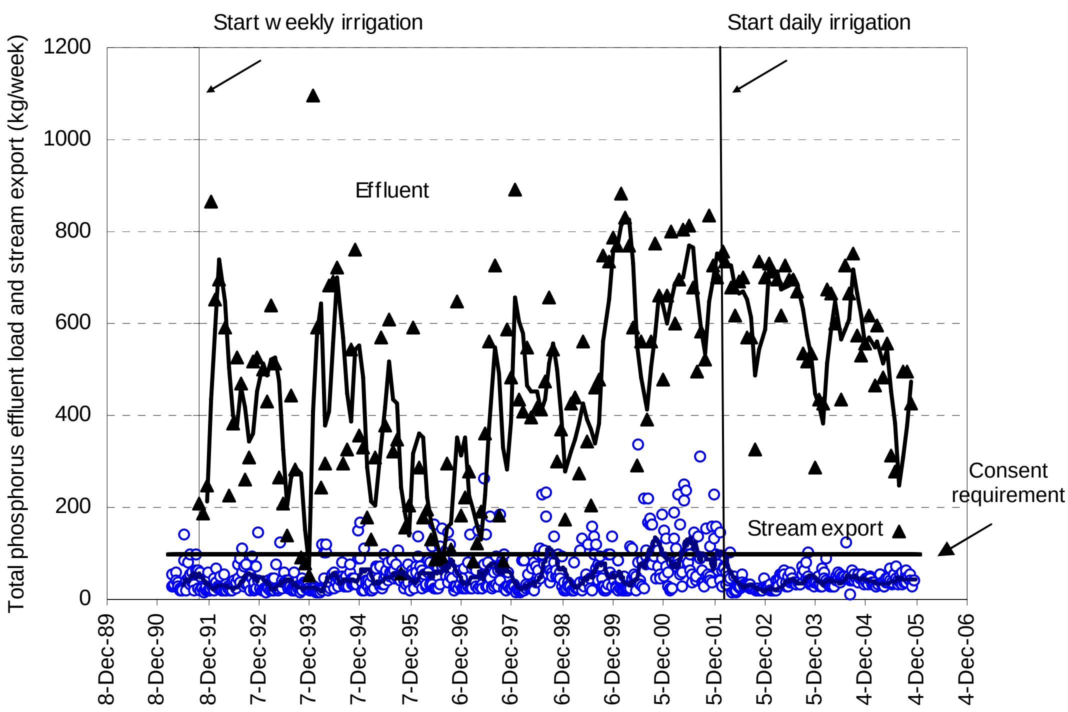
Current consent conditions N stream export 30,000 kg/year
P export 3,000 kg/year

Component:	**Functional importance:**
1. Irrigation	Uniform water distribution
2. Soils	Hydraulic acceptance, nutrient adsorption
3. Plants	Uptake of nutrients & water
4. Ground water	Transport to wetlands
5. Wetlands	Denitrification
6. Stream flow	Export

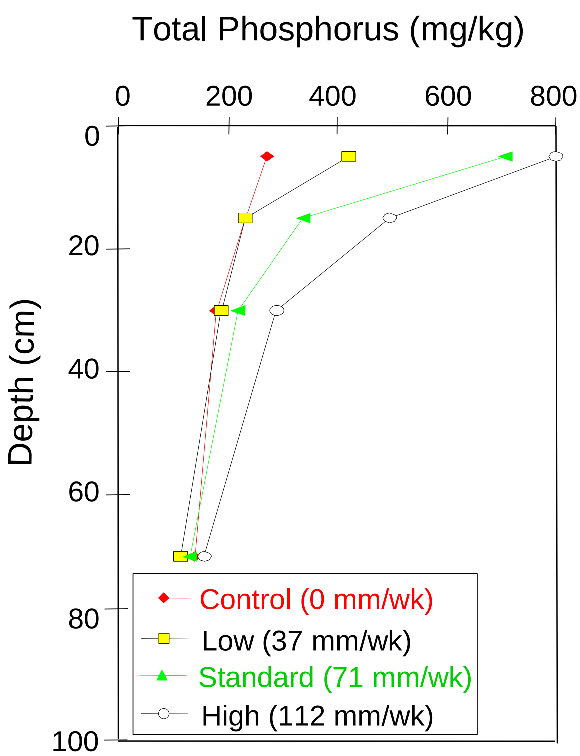


Schematic cross section of a land-based system for wastewater treatment employing upland and wetland components of landscape design

Total phosphorus effluent loading and stream export
Including 3 month moving average trend line (RDC, 2006).



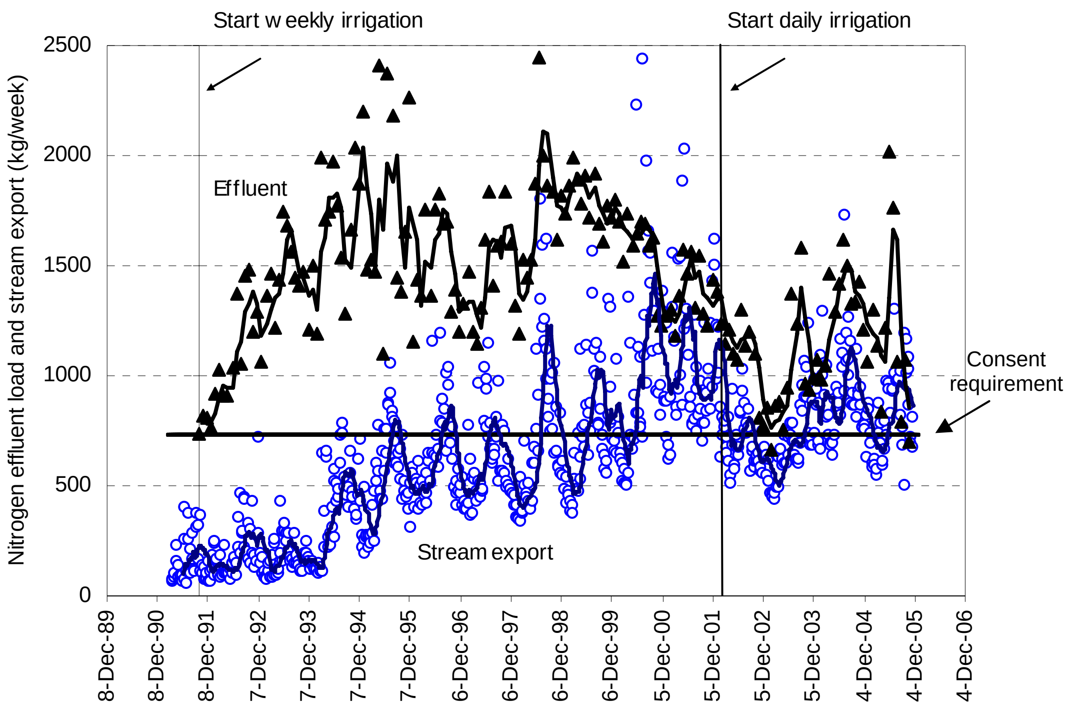
Soil phosphorus content after 4 years of irrigation
(K. Hopkins, MSc project)



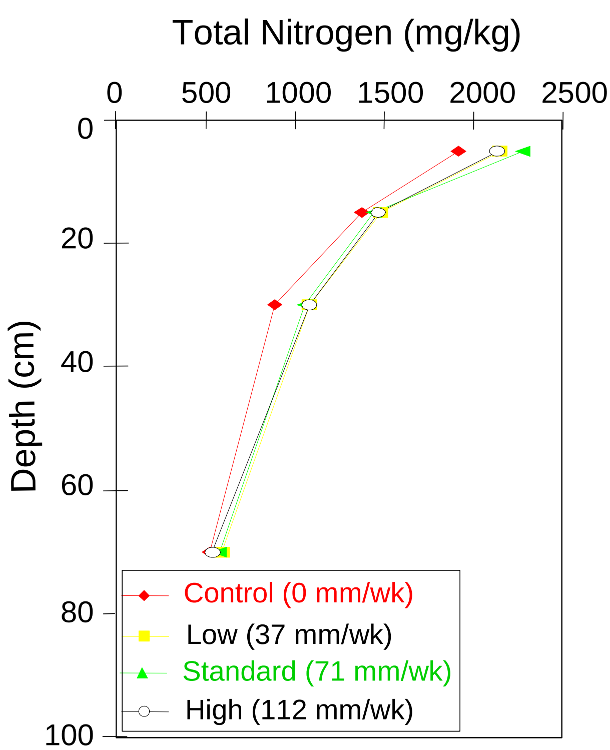
Significance groupings

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, 2006).



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

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

References

Barton L., McLay, C.D.A., Schipper, L.A., Smith, C.D. 2000. Denitrification rates in a wastewater-irrigated forest soil. *Journal of Environmental Quality* 28, 2008-2014.

Gielen, G.J.H.P., Smith, C.T., Oliver, G.R. 2000. Seasonal pattern of soil solution chemistry in an effluent-irrigated *Pinus radiata* plantation in New Zealand. *In*: Symposium Proceedings, *The Forest Alternative: Principles and Practice of Residuals Use*. 14-16 July 1997, Seattle, WA, USA, pp.163 -169.

McLay, C.D.A., Tomer, M.D., Hopkins, K., Thorn, A.J., Smith, C.T. 2000. Chemical changes in a volcanic forest soil after four years of effluent irrigation. *In*: Symposium Proceedings, *The Forest Alternative: Principles and Practice of Residuals Use*. 14-16 July 1997, Seattle, WA, USA.

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Tozer, W.C., Wilkins, K.J., Wang, H., van den Heuvel, M., Charleson, T., Silvester, W.B. 2005. Using N-15 to determine a budget for effluent-derived nitrogen applied to forest. *Isotopes in Environmental and Health Studies* 41, 13-30.

Waipa Mill groundwater remediation: a success story

Tim Charleson

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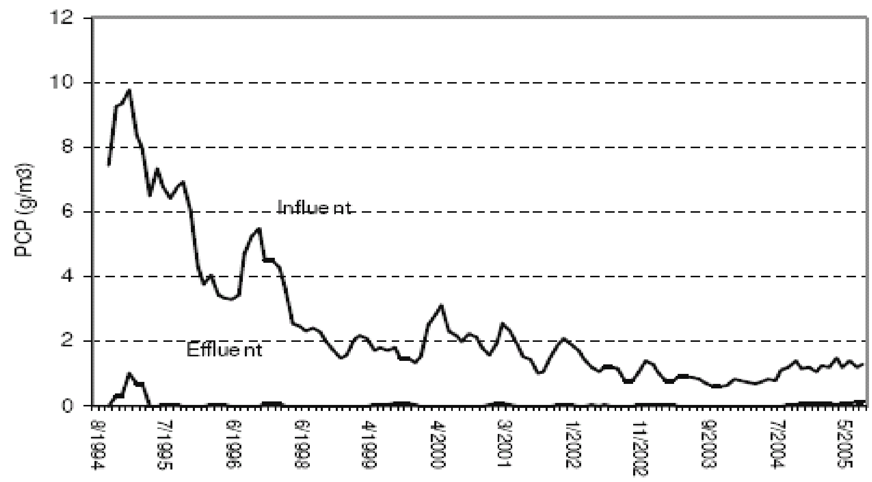
Pentachlorophenol (PCP)-containing solutions were used at the Waipa Mill for treating timber before being withdrawn in 1984. Poor handling practices resulted in PCP solution contaminating soil. The volcanic soils are highly porous and the groundwater in the PCP handling areas was less than 3 m below 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 mobility and as a 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 since then.

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

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 has 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 has typically been significantly less than 10 ppb. A steady decline in the influent PCP concentration indicates that groundwater contamination from the site is diminishing and is being successfully remediated.



Rayox plant influent and effluent PCP concentrations

STOP 4 – LAKE OKARO AND WETLANDS, OKARO RD

Location U16 177171, elevation 420 m asl, soil underfoot Rotomahana silt loam, mottled phase (Cross, 1972), rainfall ~1500 mm pa

Note: Lake Okaro has an area of 0.28 km^2 and maximum depth of 18 m. It was formed ca. 700 years ago, probably during the Kaharoa eruption (1314 ± 12 AD), by a phreatic (steam) eruption. The geology and soils of the Lake Okaro area were described by Cross (1963), and soil units were recorded on the Rerewhakaaitu sheet (scale 1: 31,680) by Cross (1972) in Vucetich and Wells (1978). Studies into 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 ca. 1-m thick mantle of Rotomahana Mud deposited in the area on 10 June, 1886. The rill formation was rapid, and began within days of the eruption and stopped within a few years. Why 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 U.S.A., rills are described as small, runoff channels that can be obliterated by conventional tillage (cf. gullies) (USDA National Soil Survey Center field book for describing and sampling soils).

Cross, D. J. 1963. Soils and geology and some hydrothermal eruptions in the Waiotapu district. *New Zealand Journal of Geology and Geophysics* 6, 70-87.
Hardy, L. 2005. Lake Okaro: explosions and erosion. Unpublished BSc (Hons) thesis, University of Otago. 66pp.
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.

Lake Okaro action plan

Amy Taylor
Environment Bay of Plenty, Whakatane

Popular with water skiers, this small lake has hosted algal blooms every summer for many years. The small catchment hosts beef, sheep and deer farms. Landowners have worked closely with the Lakes programme partners to develop the action plan. The two main actions are to:

- absorb the release of phosphorus (and some nitrogen) from the Okaro lake-bed sediments
- reduce the long-term inflows of nitrogen and phosphorus entering Lake Okaro.

The first attempt at removing dissolved phosphorus in-lake was in 2003, an application of a chemical called alum10. Alum binds to phosphorus in the water column, forms microscopic flocs and settles on the lake bed. The alum lowered P concentrations by 20% compared to past July levels, as measured in July 2004 after an annual lake cycle. Since the 2003 alum application, flocculants such as alum, treated zeolite, melter slag, and Phosloc have been trialled using mesocosms. The mesocosms are made from impermeable PVC plastic, two metres in diameter, with the entrance buoyed by a pontoon at the surface and extend some ten metres to the lake bed. The mesocosm results have helped make decisions about the best flocculant product to use in Lake Okaro.

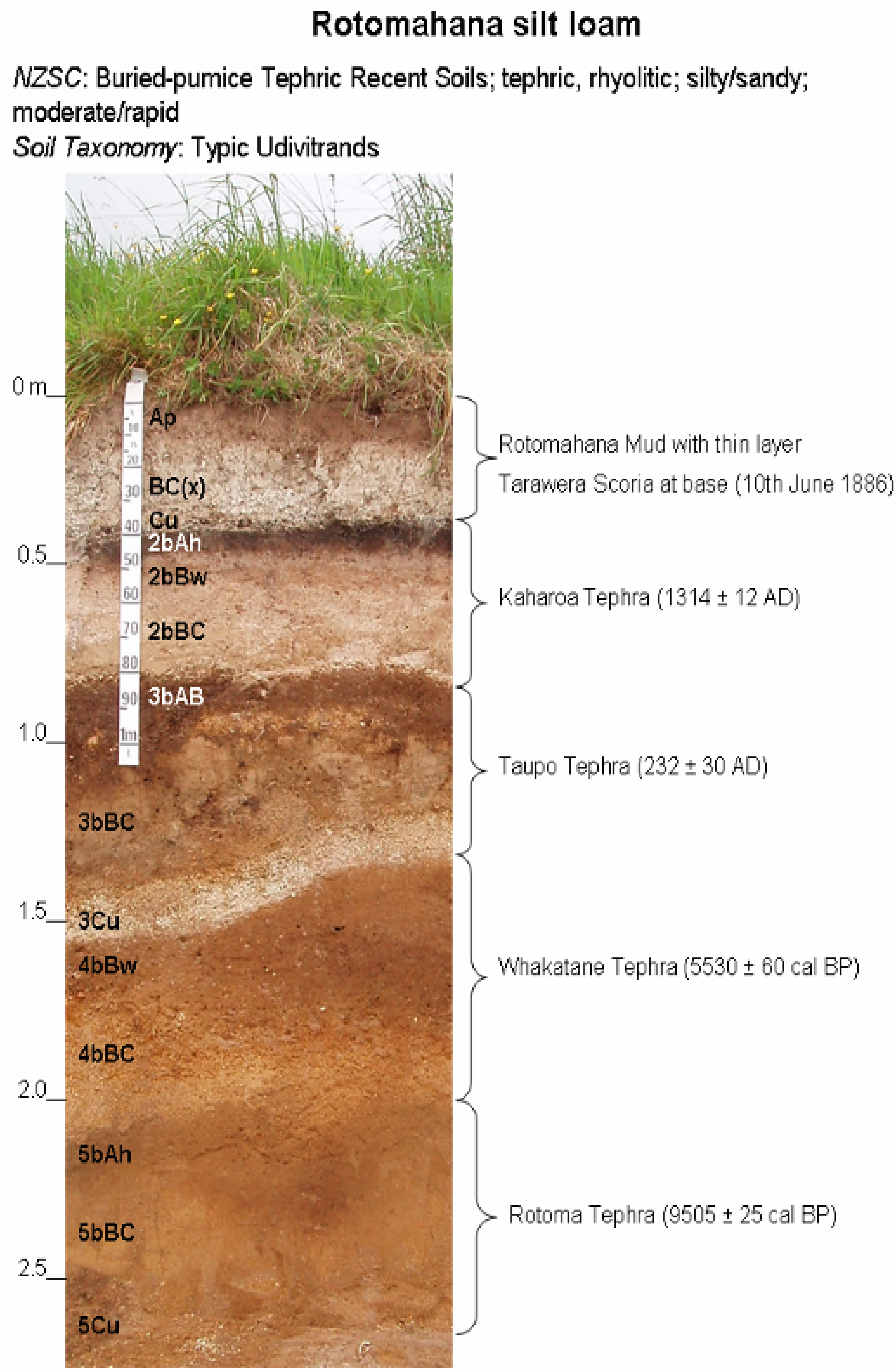
The Lake Okaro wetland covers 2.3 ha and encompasses both private land (Waionehu Farm) owned by farmers Shane and June Birchall, and Rotorua District Council reserve. It was built by Environment Bay of Plenty for the purpose of removing a substantial amount of dissolved nitrogen from water flows. The wetlands will be an average of about 300 mm deep, which will allow emergent wetland plants to cover most of their area. There will be some small areas of deeper water to provide some open water. Both wetlands will have a number of earth bunds which will act as baffles to ensure that the water flows through the entire wetland area, maximizing treatment effectiveness. Environment Bay of Plenty has added an extra carbon source (sawdust) to boost bacterial activity and optimise wetland de-nitrification.

It is likely that reduced nutrient levels in the stream should be achieved within 12 months of the planting of wetland plants, and nutrient reductions should increase over time as the wetland plants and organic matter become established. Improvements to the lake's water quality may take many years, as the existing nutrients bound up in the lake bed will be depleted only very gradually.

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 ± 12 AD. It has an area of 7.4 km^2 and a maximum depth of 15 m. Awaatua basin is a small explosion crater ca. 10,000 years old (Nairn, 2002).



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

Ensis (Forests and Environment), 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: Typic Udivitrands

Site data

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

Soils, agriculture and forestry in the general Waiotapu region (covering five districts including Rerewhakaatiu) were described by Vucetich and Wells (1978). The area covering Rerewhakaaitu district (scale 1: 31,680) was surveyed by Derek Cross. Analytical data are available for Rotomahana soils from the tour guide for the 'Soils With Variable Charge' conference (Parfitt et al., 1981) (pp.110-114) and from 'Soils of New Zealand' (1968) part 3 (pp.122-123). The site sampled was ~400 m west of the Waimangu Tearooms. Data from Parfitt et al. (1981) are given below.

Note from Wim Rijkse

Rotomahana coarse sandy loam (as sampled near the Waimangu Tearooms) is moderately to slightly acid and weakly leached (base saturations 71%, 65%, 94%). Exchangeable cations (Ca, Mg, K and Na) are of medium to high levels. Reserve potassium and magnesium of the Rotomahana Mud are of medium to high value. Extractable phosphorus is low.

ROTOMAHANA LOAM

Location: Waimangu Road, 400 m west along from tearoom, east side of road reserve

Grid ref: N85/845863

Aspect: West near top of ridge Altitude (m): 400 Rainfall (mm): 125 Slope: 2° Landform: Ridge

Vegetation: Bracken fern with mahoe, coprosma, kamahi, lupin

Drainage class: Moderately well drained

Land use: Dairying and semi-intensive sheep farming

Parent material: Rotomahana Mud, hydrothermally altered rhyolitic ejecta from Lake Rotomahana (erupted in 1886)

PROFILE DESCRIPTION

Profile	Depth (cm)	
Ah	0- 7	very dark brown (10YR 2/2) loam; slightly sticky non plastic; slightly greasy; friable; moderately developed fine nut structure; many fine and medium roots; distinct smooth boundary,
C1	7-50	light olive grey (5Y 6/2) silt loam; friable; sticky slightly plastic; weakly developed medium block structure breaking to crumb structure; few fine roots; indistinct irregular boundary,
C2	50-67	light olive grey (5Y 6/2) silt loam; slightly firm; slightly sticky non plastic; weakly developed medium block structure breaking to crumb structure; few fine grey (10YR 6/1) basaltic lapilli; few dark brown root channels; distinct regular boundary,
Cg	67-78	pale olive (5Y 6/3) sandy loam; slightly firm; weakly developed medium block breaking to crumb structure; many indistinct yellowish brown and dark yellowish brown (10YR 5/6 & 4/6) fine and medium mottles; few medium dark brown (7.5YR 3/2) root channels; sharp smooth boundary,
2Ah	78-87	black (7.5YR 2/0) sandy loam; friable; weakly developed medium nut structure; few roots; distinct smooth boundary,
2Bw	87-96	dark brown (10YR 3/3) sandy loam; friable; weakly developed fine nut and crumb structure; few medium (2-6 mm) lapilli; locally a 4 cm pale brown (10YR 6/3) gritty sandy loam layer (E hor.) overlies this horizon; distinct irregular boundary,
2Bs	96-105	strong brown (7.5YR 4/6) pumice gravel; loose; single grain; lapilli 2-10 cm; sharp smooth boundary,
3Ah	105+	on yellowish brown (10YR 5/4) sandy loam; friable; weakly developed nut and crumb structure; many fine (2-4 mm) lapilli; few fine roots.

CLASSIFICATION - N.Z. Genetic: Recent soil (ash) Taxonomy: Typic Udorthent, fine loamy, mixed, mesic

CHEMISTRY ROTOMAHANA LOAM

Sample No. SB	Depth (cm)	Hor.	pH H_2O	pH KCl	pH ΔpH	pH NaF	Exch. cations (meq/100 g) Ca	Mg	K	Na	H (KCl)	Al (KCl)	Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g) NH_4OAc (pH 7)	CEC Σ Cations (pH 8.2)	Base saturation (%) Σ bases / CEC NH_4OAc	Σ bases / Σ Cations
9581 A	0-7	Ah	5.7	4.7	-1.0	7.8	14.7	4.6	2.03	0.33		0.22	29.6	29.4	21.8	28.2	51.3	77	42
B	7-25	C1	6.0	4.5	-1.5	8.8	5.9	2.76	1.81	0.49		0.14	7.5	7.4	11.3	12.3	18.5	89	50
C	25-50	C1	6.7	4.8	-1.9	8.5	8.3	3.11	1.31	1.23		0.08	5.5	5.4	14.1	13.7	19.5	(100)	72
D	50-67	C2	6.9	5.0	-1.9	8.5	8.2	3.05	0.97	1.56		0.08	4.4	4.3	14.0	13.7	18.2	(100)	76
E	67-78	Cg	6.9	5.2	-1.7	8.5	10.2	3.6	1.40	2.13		0.10	5.6	5.5	17.4	17.2	22.9	(100)	76
F	78-87	2Ah	6.5	5.5	-1.0	8.8	37	6.6	0.40	0.42		0.31	27.8	27.5	44.7	46.2	72.2	96	61
G	87-96	2Bw	6.5	5.5	-1.0	10.2	11.0	2.11	0.21	0.24		0.49	16.4	15.9	13.8	15.1	30.0	90	46
H	96-105	2Bs	6.4	5.3	-1.1	10.6	7.3	1.24	0.25	0.52		0.81	17.9	17.1	9.3	12.2	27.2	76	34

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g) H_2SO_4 (0.5 M)	Inorg.	Org.	P Retention (%)	Dithion. cit. (%) Fe	Al	Tamm ox. (%) Fe	Al	Si	Pyrophos. (%) Fe	Al	Reserves (meq/100 g) K_c	Mg_T	Extractable S (ppm)
9581 A	0-7	Ah	7.1	0.17	16	21	31	24	0.76	0.19	0.46	0.22	0.06	0.19	0.09	0.64	17	14
B	7-25	C1	0.6	0.12	17	23	6	17	0.77	0.19	0.34	0.14	0.10	0.05	0.01	0.73	26	3
C	25-50	C1	0.2	0.06	18	23	2	11	0.71	0.07	0.30	0.08	0.10	0.01	0.00	0.74	24	3
D	50-67	C2	0.2	0.05	18	24	1	10	0.72	0.07	0.27	0.08	0.09	0.01	0.00	0.81	22	2
E	67-78	Cg	0.3	0.06	18	24	2	13	0.99	0.14	0.35	0.10	0.09	0.03	0.00	0.72	19	7
F	78-87	2Ah	9.5	0.80	4	8	38	42	0.56	0.33	0.29	0.31	0.07	0.18	0.23	0.16	2.0	2
G	87-96	2Bw	3.7	0.41	4	11	26	45	0.58	0.37	0.32	0.49	0.04	0.25	0.31	0.12	1.1	4
H	96-105	2Bs	2.7	0.31	7	12	21	60	0.72	0.84	0.45	0.81	0.34	0.33	0.34	0.08	0.7	4

Data on this and following page are from

Parfitt, R.L., Pollok, J., Furkert, R.J. 1981. Guide book for tour 1, North Island. *International 'Soils With Variable Charge' conference*, Palmerston North, Feb 1981.

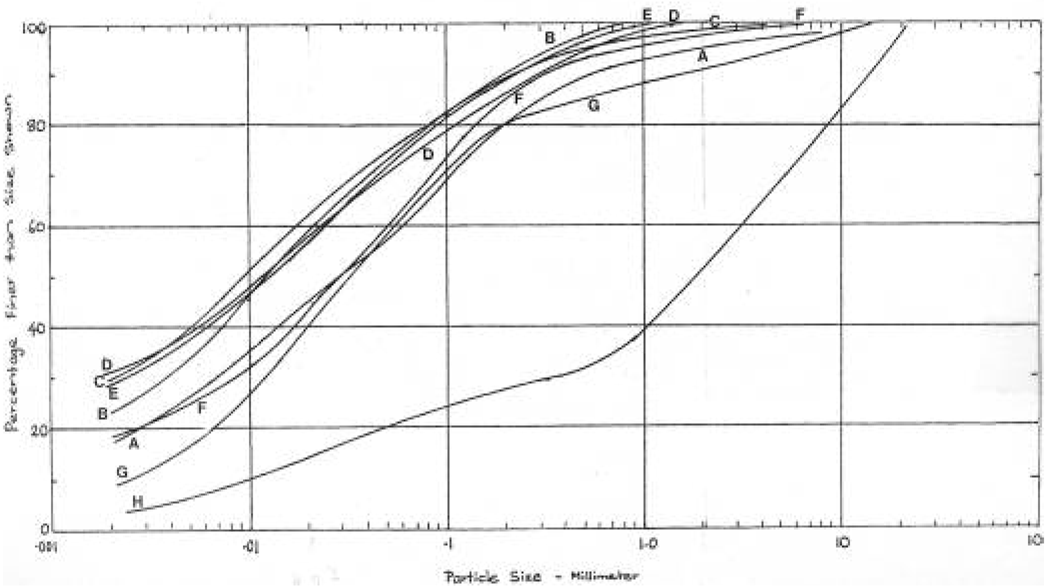
PARTICLE SIZE DISTRIBUTION (<2 mm) Rotomahana Loam

Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9581A	0-7	Ah	27	11	43	19			(4)
B	7-25	C1	18	10	48	24			(<1)
C	25-50	C1	16	8	46	30			(1)
D	50-67	C2	22	8	41	29			(<1)
E	67-78	Cg	18	11	42	29			
F	78-87	2Ah	25	14	45	16			2
G	87-96	2Bw	22	13	57	8			9
H	96-105	2Bs	50	11	34	5			50

PHYSICS

Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	15 bar water Air Dry (%)
0-7	Ah	25.0	16.7
7-25	C1	14.0	12.1
25-50	C1	14.3	12.4
50-67	C2	14.0	12.3
67-78	Cg	15.0	12.8
78-87	2Ah	21.2	16.0
87-96	2Bw	15.5	7.3
96-105	2Bs	12.4	7.4

Core Depth (cm)	Dry bulk density (T/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)



Mineralogy Rotomahana

Sample No. SB	Depth (cm)	Hor.	Clay Fraction (%) Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass
9581A	0-7	Ah			41	10		28	10			1		10			
B	7-25	C1			40	6		26	17					11			
C	25-50	C1			40	6		38	14					12			
D	50-67	C2			41	4		24	16					15			
E	67-78	Cg			56	4		14	11					10			
F	78-87	2Ah			20				27					14			32
G	87-96	2Bw			17				26					28			42
H	96-105	2Bs							10								61

Sample No. SB	Sand Fraction (%) Quartz	Feldspar (acid)	Andesine	Glass	Muscovite	Biotite	Hornblende	Augite	Hypersthene	Epidote	Zoisite	Apatite	Magnetite	Plant opal
9581A														
B														
C														
D														
E														
F														
G														
H														

Impacts of deforestation and burning on properties of buried soil horizons

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PEDOLOGICAL, CHEMICAL, AND PHYSICAL PROPERTIES OF ORGANIC HORIZONS OF PALEOSOLS UNDERLYING THE TARAWERA FORMATION

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(*Received for publication, 22 October 1970*)

Summary

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.

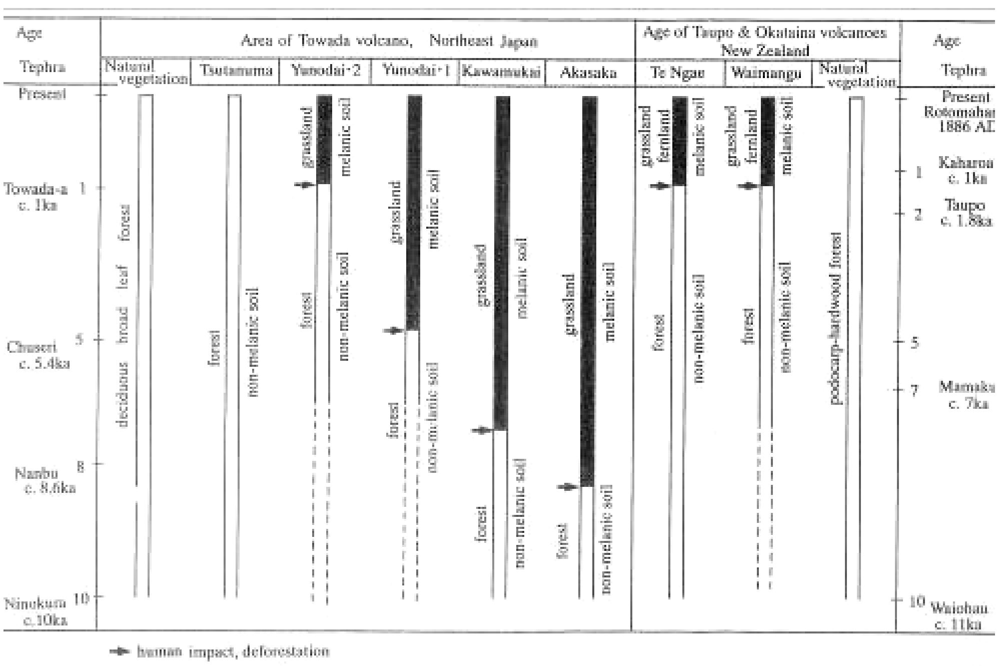

Fig. 6 Relationship among vegetation, characteristics of volcanic ash soils and human impact

From Sase and Hosono (1996).

Diagram above from Watanabe, M., Sakagami, K. 1999. Recent pedological approach to reconstruction of the Quaternary environment in Japan and east Asia. *The Quaternary Research* 38, 244-252.

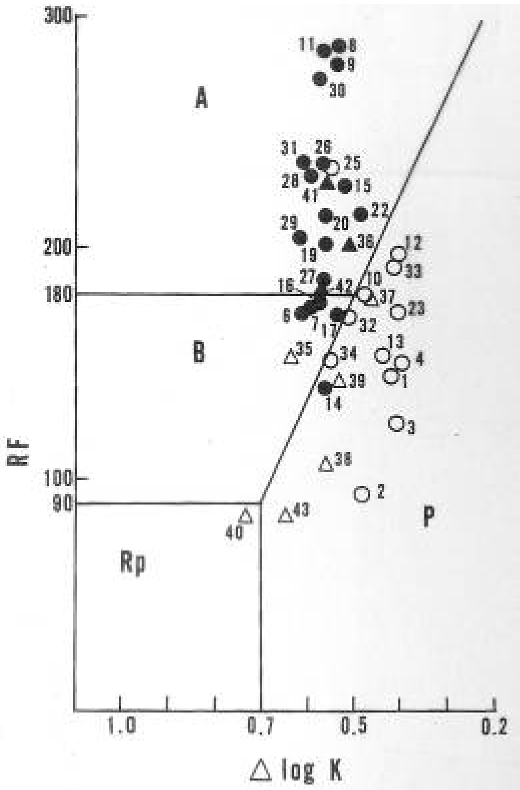

Fig. 7. Distribution of humic acids from volcanic ash soils. RF: relative color intensity, Δlog K: color coefficient compiled from Hosono et al. (1991), Hosono et al. (1992), Sase et al. (1992), Sase et al. (1993) and Hosono et al. (1994). Nos. are identical with those in Table 1. ●: melanic soil, Japan; ○: non-melanic soil, Japan; ▲: melanic soil, New Zealand; △: non-melanic soil, New Zealand.

Grass filters and grazing trials, Rerewhakaaitu area

Amy Taylor
Environment Bay of Plenty, Whakatane

Two grass filter trials are measuring the silt-trapping ability of Phalaris as a grass filter strip. These trials are being established and part funded through NIWA and will use runoff collectors to measure sediment trapping ability of Phalaris and the current pasture (control). The aim of the trial is to determine:

- How effective are contour landscape grass filter strips under field conditions?
- Are *Phalaris aquatica* or similar species of grass filter strips more effective at improving surface runoff ?

The grass filter and grazing trials are located at:
- Mac Pacey's property, Rerewhakaaitu: Rotomahana sandy loam (Typic Tephric Recent soil)
- Barry Russell's property, Rotorua: Oropi sand (Buried-allophanic Orthic Pumice soil)

The grazing trial will evaluate the performance under grazing of less-palatable grass species which may be suitable for use in grass filter strips. Species persistence and growth will be measured and compared to existing pasture (the control).

Polynesian settlement and impacts of volcanism on early Maori society

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Timing of Polynesian settlement

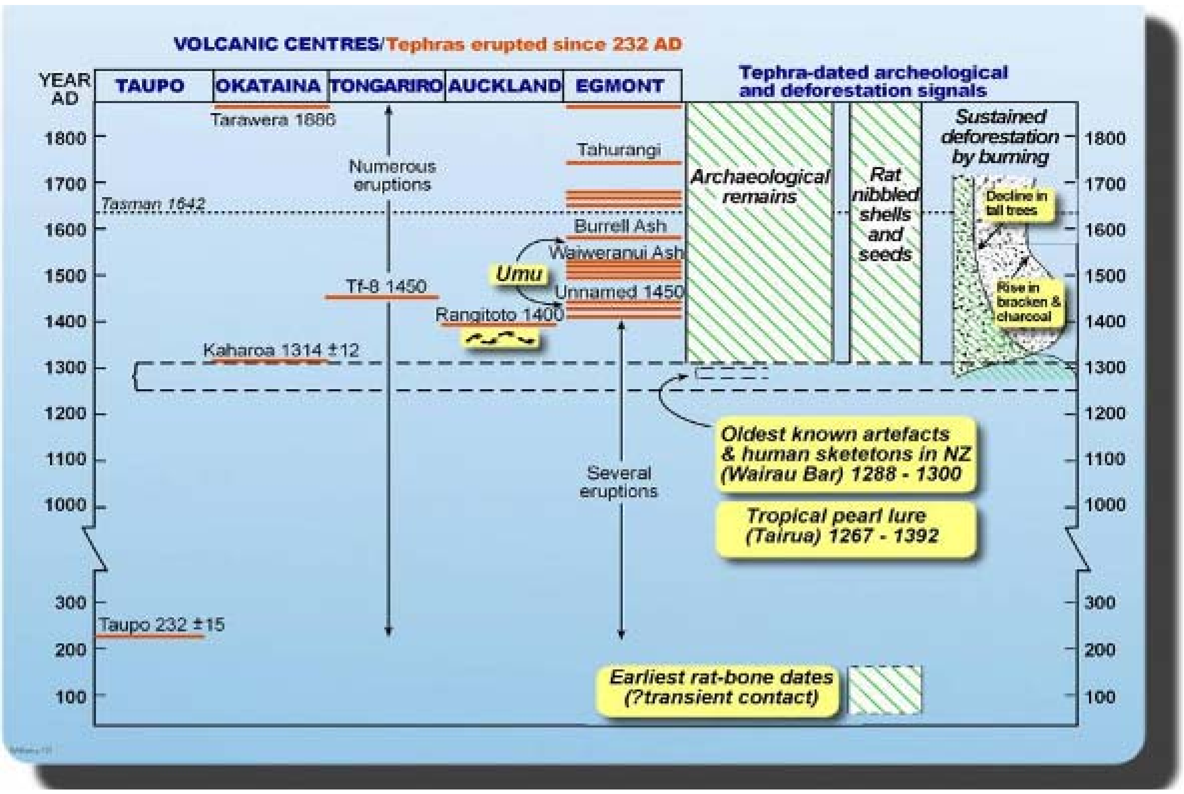
Various lines of evidence indicate that the 'homeland', or *Hawaiiki*, of the early Polynesian settlers of Aotearoa was eastern Polynesia (e.g. see Sutton, 1994; Howe, 2003). Establishing the timing of settlement has been problematic, however. The most recent and reliable evidence, both from archaeological and natural sites, points consistently to initial settlement between ca. 1250–1300 AD (called the late settlement model). The application of tephrochronology to the issue is well established (Newnham et al., 1998; Lowe et al., 2000). The Kaharoa Tephra was erupted from Mt Tarawera in winter of 1314 ± 12 AD, as determined from the wiggle-match dating of a log of celery pine (tanekaha, *Phyllocladus* spp.) killed in the eruption (Hogg et al., 2003). It provides a key marker enabling both archaeological and palaeoenvironmental sites – which record the earliest forest clearances accompanying settlement – to be dated.

An earlier, transient contact at ca. 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 (around 1250 AD). Holdaway has gone on to develop models involving the rapid spread of the rats over both islands and also attributes the decline (possibly extinction) in some birds and other animals to predation by rampant rats well before ca. 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 (easily accounted for by natural factors such as lightning or volcanic eruptions 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.

So, 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 750 years old (Wilmshurst and Higham, 2004). The results at the Coromandel sites were confirmed by the unequivocal identification of Kaharoa Tephra there − no rat-gnawed seeds were found beneath the Kaharoa layer, but plenty above it which had given the young ages. The conclusion from this work was that rats arrived after ca. 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. His results were the same: no snail shells had been nibbled before 1250−1300 AD. 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 ca. 1250−1300 AD, but plenty after that date.

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 have been published by Anderson and Higham (2004) − that site was called 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, Higham, Anderson and Trevor Worthy have collected rat-bone and bird-bone samples from other avian predator sites in the South Island, including Holdaway's original sites. The results, as for the new seed dating, are in the process of being written up (Lowe, 2006).



Summary of stratigraphy and ages of tephras, erupted from five volcanic centres since ca. 233 AD (left side of diagram), and their relationship with archaeological, nibbled seed/shell data, and deforestation signals in northern and eastern North Island (right) (after Lowe et al., 2000, 2002). 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 ca. 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, and the earliest reliable dates for sustained deforestation elsewhere in the New Zealand archipelago (McGlone and Wilmshurst, 1999).

Impacts of volcanism on early Maori society

Early Maori in northern New Zealand witnessed probably only one rhyolitic eruption (Kaharoa), two basaltic eruptions (Rangitoto, ca. 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. 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.

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).

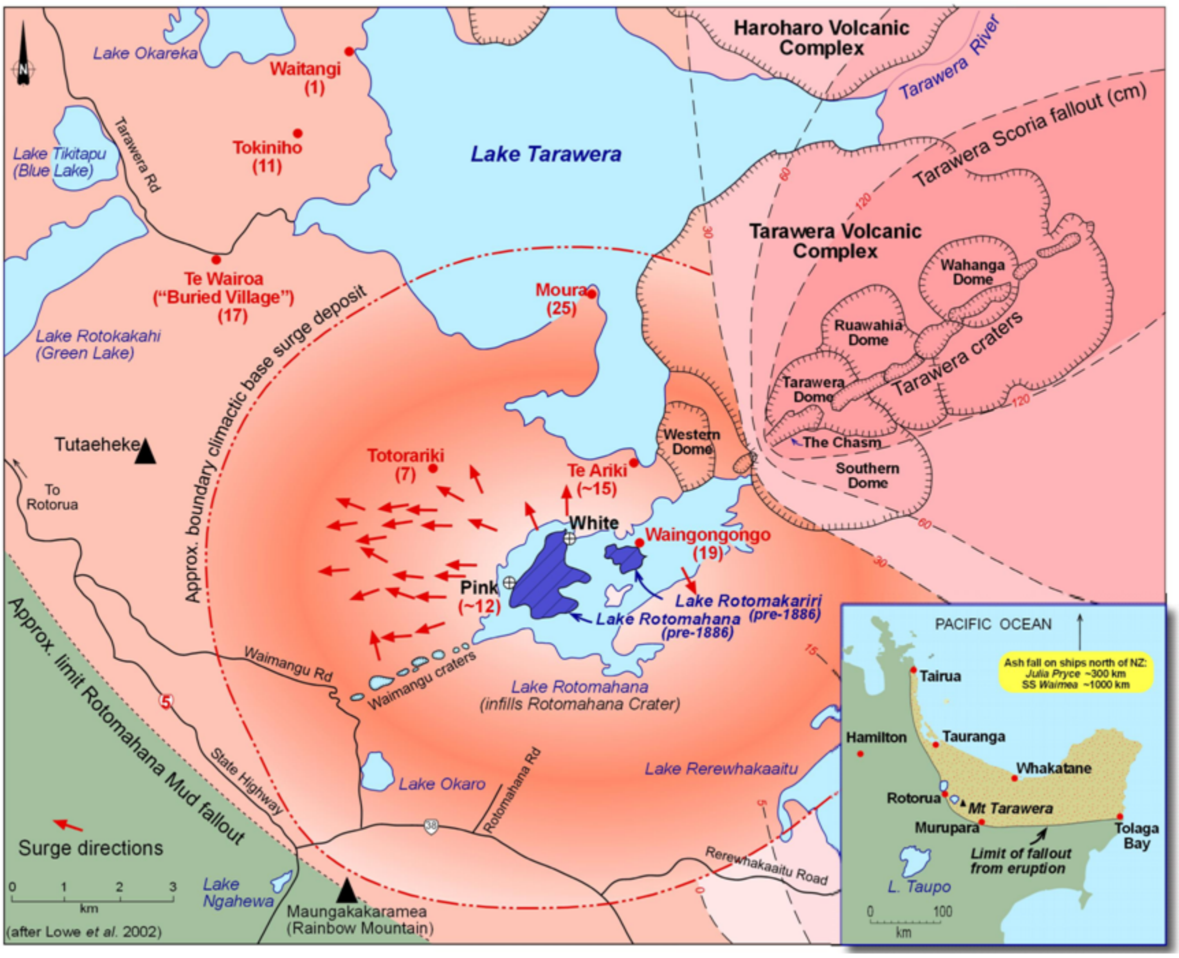
Tarawera eruption and catastrophic impacts

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). The eruption cored out a series of craters in a 7-km-long fissure through the antecedent rhyolite domes (including those emplaced during the Kaharoa event) of Mt Tarawera, and then generated more craters along an 8-km-long southwest extension of the fissure across the Rotomahana basin (which contained two shallow lakes and large silica sinter aprons, the 'Pink' and the 'White' terraces, asssociated with extensive hydrothermal activity) to Waimangu. Narratives (summarized authoritatively by Keam, 1988) indicate that after a series of precursory earthquakes from ~12.30 am, the eruption began at Ruawahia Dome at about 2.00 am on 10 June, 1886, and then gradually extended both northeastward and southwestward. At ~2.10 am the eruption intensified with the ascent of a tephra plume from the vicinity of Ruawahia Dome up to ~9.5 km. By 2.30 am craters along the whole length of the fissure were erupting, with the Rotomahana extension beginning to erupt possibly at ~3.20 am. By 3.30 am, craters along the entire 17 km-length of the fissure from Wahanga to Waimangu were in eruption. This paroxysmal stage of the eruption was over by 6.00 am when most activity ceased.

The erupted products were exclusively pyroclastic (no lava flows were generated, although basalt dikes were emplaced). The total volume (as deposited) of Tarawera Scoria is ~2 km^3 (Walker et al., 1984). The eruption along the Rotomahana and Waimangu extension was mainly phreatomagmatic (the result of interaction between basalt magma and hydrothermal water) and phreatic. The explosive expansion of superheated water fragmented the country rock containing the hydrothermal system, plus subordinate lake sediment, to produce surge beds and fall deposits ('Rotomahana Mud') that rained out over much of the Bay of Plenty and beyond (~0.5 km^3 as deposited). Near Rotomahana, the surge beds were emplaced violently by hot and fast-moving turbulent pyroclastic surges or density currents up to ~6 km from source (Nairn, 1979). Lightning during the eruption set fire to a house in Te Wairoa and to the forest on the north shore of Lake Tarawera; strong winds flattened many trees at Lake Tikitapu; and suffocating gases and falling mud and ash made breathing difficult at Te Wairoa, where most buildings were buried or collapsed under the weight of ~1 m of mudfall. A notable exception was *Hinemihi*, a large meeting house where most survivors were sheltered, because wooden forms for seating guests during Maori performances were used to prop up the roof.

All but seven of the 108 known fatalities arising from the Tarawera eruption were Maori (the true number of deaths may have been ~120, but the oft-cited 150 is erroneous). The majority of deaths were the result of the Rotomahana explosions, especially the lethal, scorching pyroclastic surges and blasts. Clearly the event had a profound impact on Maori (and others) in the Te Wairoa and Rotomahana area especially, but trauma was felt throughout the extensive fallout zone in the Bay of Plenty and eastern North Island (Keam, 1988). For example, some groups of Maori in the region of the Rangitaiki and Tarawera rivers, north of Tarawera, became refugees at Matata. Although they had escaped with their lives and without serious injury, their possessions were buried by ~15–30 cm of tephra (some were retrievable by excavation), many potato pits were lost and those with livestock had no feed for them and so many starved (Keam 1988; Lowe et al., 2002). These people were eventually resettled in 1903–1905.

The plight of these and other Maori seem minor in comparison with the difficulties of those from Te Wairoa-Rotomahana: apart from the lives lost, all possessions had been buried and many crushed. Among livestock, most smaller animals were killed, but dogs, pigs, cattle and horses that survived wandered loose and starving. The main livelihood of the region, tourism, had been destroyed, literally overnight. (Whilst Maori continued to participate in the tourist trade, its control effectively moved into European hands from 1894 with the opening of the railway line to Rotorua.) But 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 Ariki's 27 residents were camped at Pink Terrace (Otukapuarangi). Inset shows eastern North Island and documented limits of tephra fallout from the eruption (based on maps by A.P.W. Thomas, 1888). Ash fell on several ships at sea, the farthest being *Julia Pryce* (ca. 300 km) and S.S. *Waimea* (ca. 1000 km) north of North Island (Keam, 1988).

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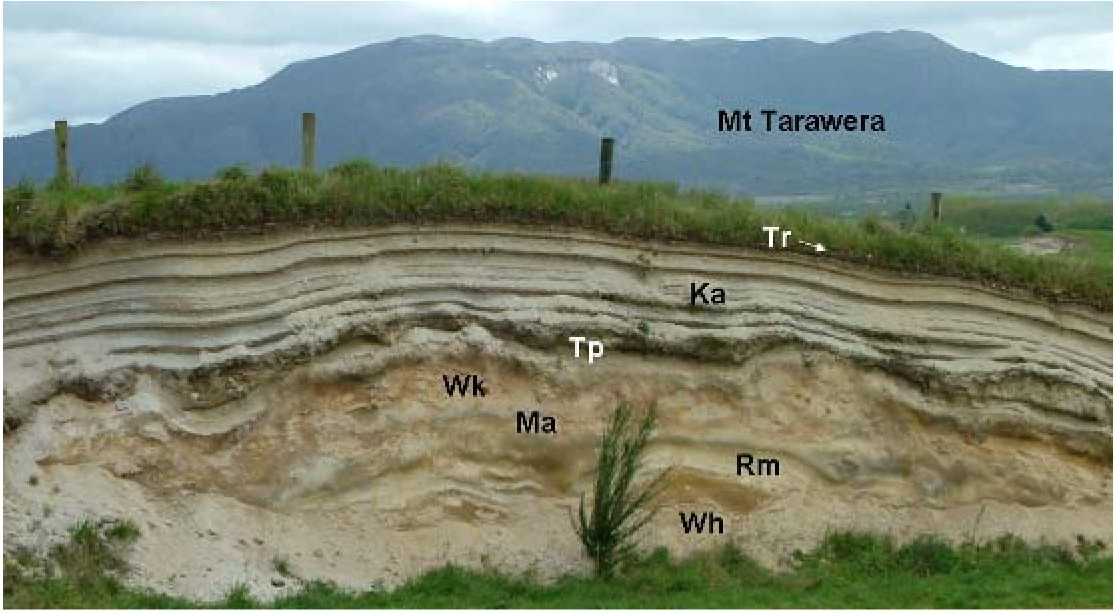
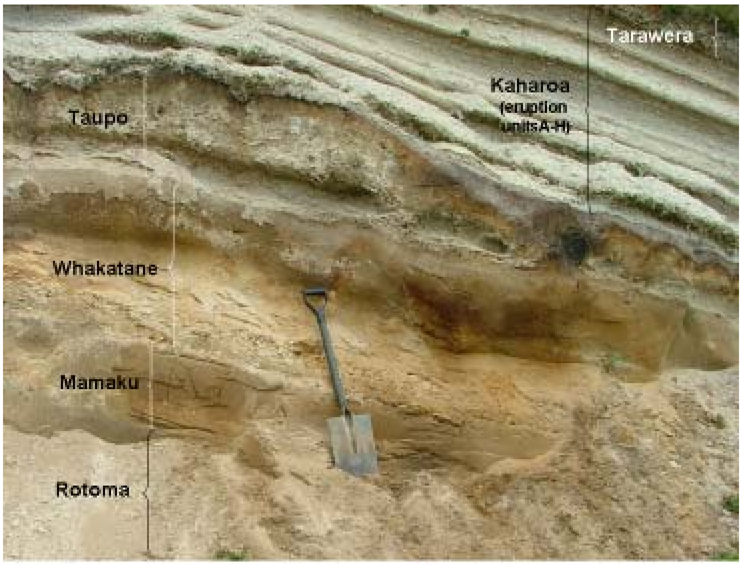
STOP 6 – TEPHRAS AND BURIED SOIL SEQUENCE, MATAHINA GRAVEL, ASH PIT RD

Location V16 188155, elevation 440 m asl, rainfall ~1500 mm pa





Section on Ash Pit Road (approx. 4 m high).

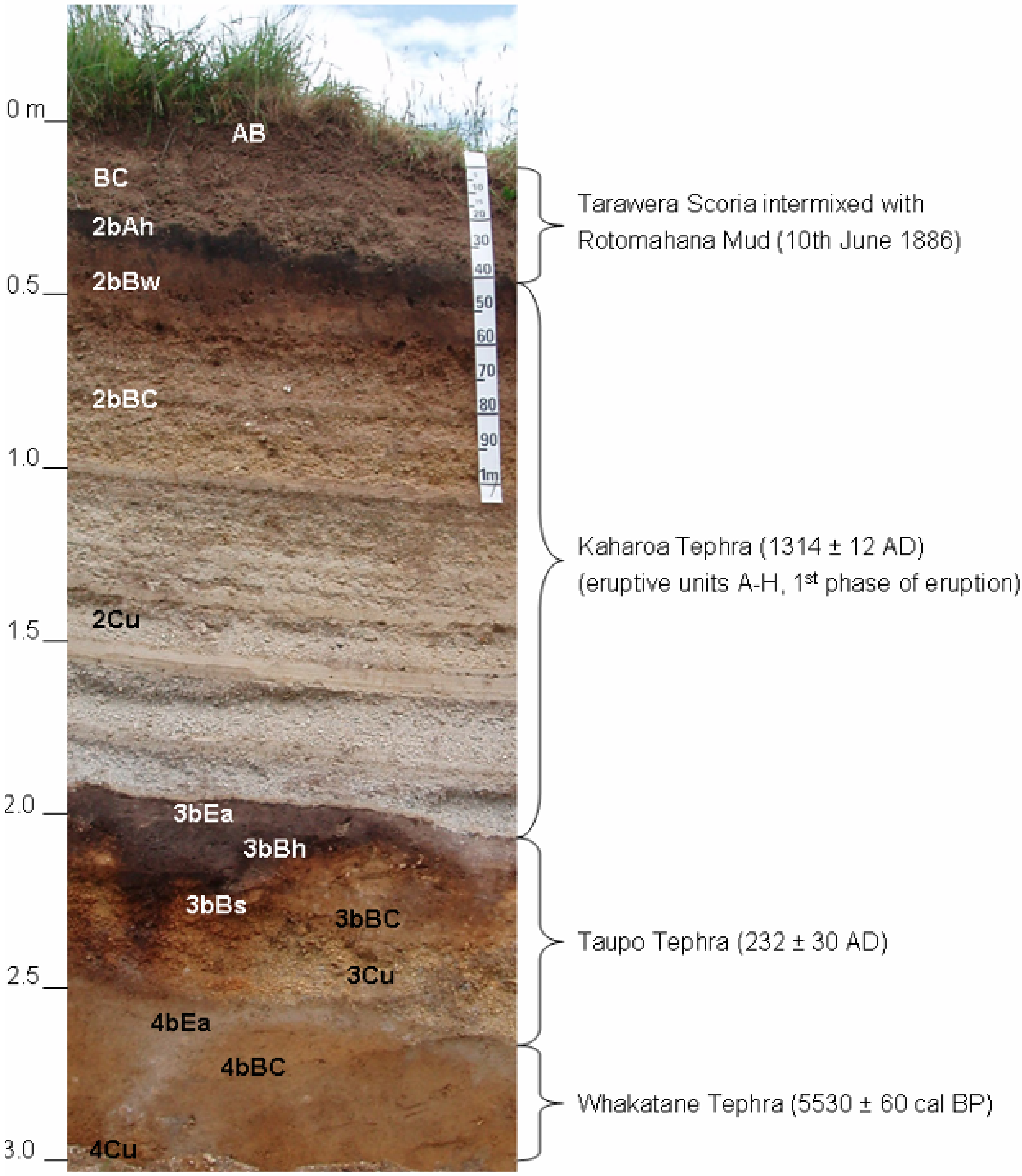
Tr, Tarawera (10 June 1886)
Ka, Kaharoa (1314 ± 12 AD)
Tp, Taupo (233 ± 13 AD)
Wk, Whakatane (5530 ± 60 cal. BP)
Ma, Mamaku (8005 ± 45 cal. BP)
Rm, Rotoma (9505 ± 25 cal. BP)
Wh, Waiohau (13,635 ± 165 cal. BP)

Photos: David Lowe

Matahina gravel

NZSC: Allophanic Orthic Pumice Soils; tephric, basaltic/rhyolitic; loamy/cindery; rapid

Soil Taxonomy: 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

Ensis (Forests and Environment), 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: Vitrandic Udorthent

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 tephras) (see photo 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; *inter-layered 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; *inter-layered 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]

Soils, agriculture and forestry in the general Waiotapu region (covering five districts including Rerewhakaatiu) were described by Vucetich and Wells (1978). The area covering Rerewhakaaitu district (scale 1: 31,680) was surveyed by Derek Cross.

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

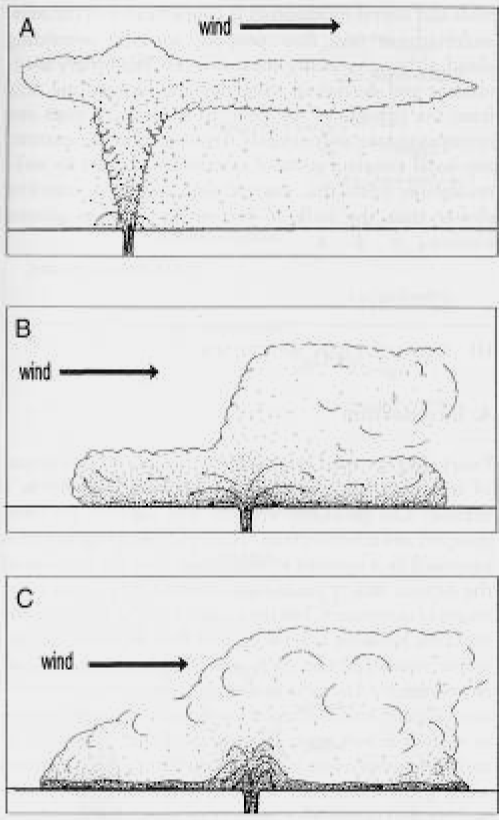


FIGURE 1 Schematic diagram to illustrate the three main end-member transport systems for the emplacement of pyroclastic deposits. (A) Fall: high buoyant plume carrying all except coarsest particles to heights of kilometers to tens of kilometers above the surface; particles sedimented from plume to form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

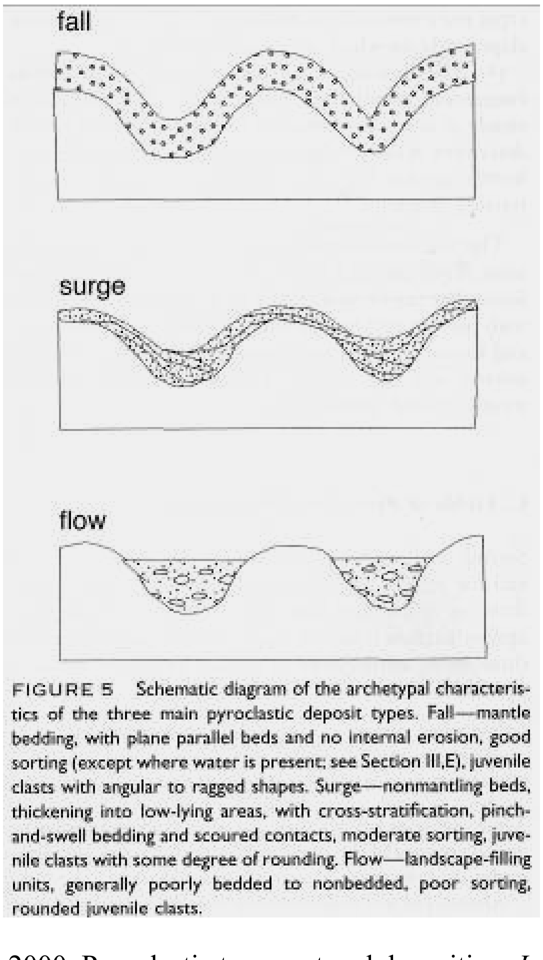


FIGURE 5 Schematic diagram of the archetypal characteristics of the three main pyroclastic deposit types. Fall—mantle bedding, with plane parallel beds and no internal erosion, good sorting (except where water is present; see Section III,E), juvenile clasts with angular to ragged shapes. Surge—nonmantling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

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

*VDR is DRE volumetric discharge rate.

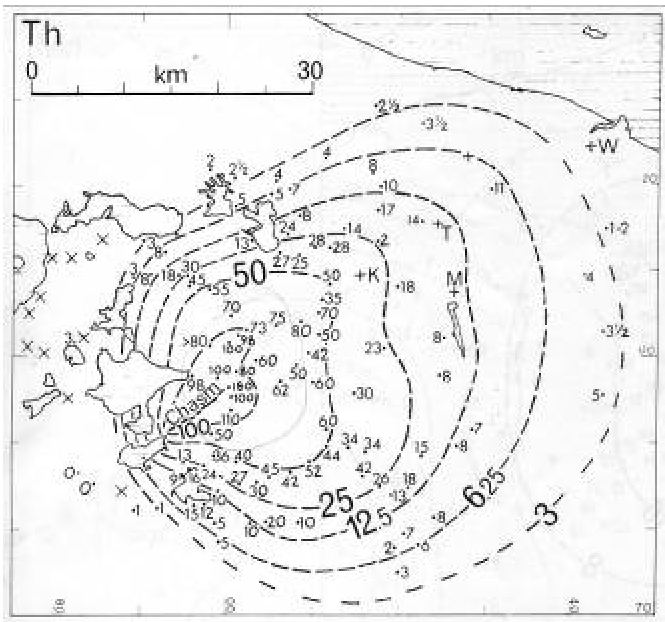


Fig. 3. Isopach map of the Tarawera 1886 basaltic scoria-fall deposit. Thickness values are in centimetres. *K* = Kawerau; *M* = Te Mahoe; *T* = Te Teko; *W* = Whakatane. Bars along margins relate to the New Zealand Survey 1000-yard grid. × = locations where basaltic scoria occurs admixed with Rotomahana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

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

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

Tephra & Horizon		Sample Number	wt % $Al_{(ox)}$	wt % $Al_{(py)}$	wt % $Al_{(ox)}-Al_{(py)}$	wt % $Si_{(ox)}$	Al:Si Ratio	Si Factor	wt % Allophane
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
Mamaku	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_1	20	0.46	neg	0.46	0.33	1.39	17.0	1.9
	C_2	22	1.13	neg	1.13	0.81	1.40	18.5	4.9
	C_3	23	0.29	neg	0.29	0.29	1.00	18.5	1.6
	C_4	24	0.79	neg	0.79	0.75	1.05	18.5	4.1
Rotoma	(B)	27	0.67	neg	0.67	0.59	1.14	18.0	3.3
	C_1	29	1.33	neg	1.33	0.91	1.46	16.5	5.5
	C_2	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_1	44	0.73	neg	0.73	0.66	1.11	18.0	3.7
	C_2	45	1.07	neg	1.07	0.51	2.10	15.5	3.3
	C_3	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 [now Rerewhakaaitu] Rd) (from Green, 1987)

Tephra & Horizon		Sample Number	wt % $Fe_{(ox)}$	wt % $Fe_{(py)}$	wt % $Fe_{(ox)}$- $Fe_{(py)}$	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_1	29	0.09	neg	0.09	0.2
	C_2	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 [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[T]
Ka	GL ≥Al- & Si-ALL >OM >>H, Q, +	
Tp		Al-ALL >GL > OM >>H, +
Wk	Al-ALL >Si-ALL ≥GL >OM > H, +	[T]Al-ALL >Si-ALL >GL >OM, H, Q, +
Ma	Al-ALL >Si-ALL >GL >OM, FE, H, +	
Rm		Al-ALL >GL > OM >Si-ALL >H, +
Wh	H ≥Si-ALL >GL >>OM, Al-ALL, +	Al-ALL >Si-ALL ≥GL >H >Q, +
Rr	Si-ALL >Al-ALL ≥GL ≥H >>OM, +	H >GL >Si-ALL > OM, +
Rk	H >GL >Si-ALL >OM, Al-ALL, +	

GL, glass; Al- and Si-ALL, Al-rich and Si-rich allophane; H, halloysite; OM, organic matter; FE, iron oxide mineral (e.g. ferrihydrite); Q, quartz; +, other Al and Si phase minerals (e.g. quartz, cristobalite, gibbsite).

DEMOCRAT RD - Site 2

Taupo Paleosol

4.4 % Clay
- 36.0 % allophane
- 3.2 % ferrihydrite
- 60.8 % glass

23.0 Silt
- 4.0 % allophane
- 0.5 % ferrihydrite
- 32.0 % crystals
- 63.5 % glass

72.6 % Sand
- 0.1 % ferrihydrite
- 20.3 % crystals
- 79.6 % glass

Rotoma Paleosol

7.5 % Clay
- 25.0 % organic matter [2]
- 48.1 % allophane
- 3.8 % ferrihydrite
- 23.1 % glass

22.3 % Silt
- 6.5 % allophane
- 0.4 % ferrihydrite
- 41.0 % crystals
- 52.1 % glass

70.2 % Sand
- 0.4 % allophane } x $\frac{95.57}{100}$
- 16.8 % crystals
- 82.8 % glass

Waiohau Paleosol

13.2 % Clay
- 14.4 % organic matter
- 51.0 % allophane
- 0.8 % ferrihydrite
- 6.8 % halloysite
- 27.0 % glass

22.1 % Silt
- 8.2 % allophane
- 0.7 % ferrihydrite
- 1.0 % halloysite
- 46.0 % crystals
- 44.1 % glass

64.7 % Sand
- 1.1 % allophane }1.2 x $\frac{90.58}{100}$
- 0.1 % ferrihydrite}
- 20.3 % crystals
- 78.5 % glass

Data for buried soil horizons on tephras at Democrat Road (now Rerewhakaaitu Rd) about 5 km west of stop 6 (from Green, 1987). The Democrat Rd site (V16 141150) was the type locality for Rotoma, Waiohau, and Rerewhakaaitu tephras (Vucetich and Pullar, 1964; Froggatt and Lowe, 1990)

References

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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 ($g\ cm^{-3}$)
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