Far-flown Markers

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Tephras are fragmentary materials that are blasted explosively into the air during volcanic eruptions. Distributed throughout Zealandia, tephras provide useful markers for connecting and dating land surfaces, sedimentary deposits and archaeological sites.

▲A plume of andesitic tephra, carried by the wind, drifts northeastward from Ruapehu volcano during the June 1996 eruption. Fallen tephra has dusted the snow, turning it grey.

From the Greek for ashes, the word 'tephra' was used originally by Aristotle to describe material erupted near Sicily c. 350 BC, and was resurrected in 1944 by Icelander Sigurdur Thorarinsson. Tephra, in its modern usage, includes both fall deposits and loose material originating from ground-hugging pyroclastic flows or surges. It thus ranges in size from fine dust to sofa-sized blocks. Tephras are used widely to correlate and date sedimentary sequences — a technique known as tephrochronology — and to determine the eruptive history of volcanoes, and thus assess the types of hazards they pose.

Tephras have two unique features. First, they are erupted over short time periods, usually hours or days, and second, they can spread widely over land and sea to form a thin blanket that, unless reworked, has the same age wherever it occurs. Once it is identified from its physical and chemical properties, a tephra layer provides a marker for an instant in time — the date of the volcanic eruption producing the layer.

Tephra layers result from explosive eruptions that blast volcanic particles into the atmosphere. Particles and gases are carried upward as an eruption column, driven by expanding hot gases. The column rises until its density matches that of the surrounding atmosphere. It then expands to form an umbrella-shaped cloud that can be blown by winds, forming plumes [see p.169]. The final distribution of tephra is governed mainly by the column height and the strength and direction of the wind.

Ashen Skies

North Island volcanoes, especially the rhyolitic calderas in central Taupo Volcanic Zone, have blasted huge volumes of tephra into the atmosphere, depositing it over northern New Zealand and in some cases more than 1000 km out to sea. The thickest tephras occur downwind of the Taupo Volcanic Zone, but much of central North Island has a mantle of tephra many metres thick just beneath the land surface.

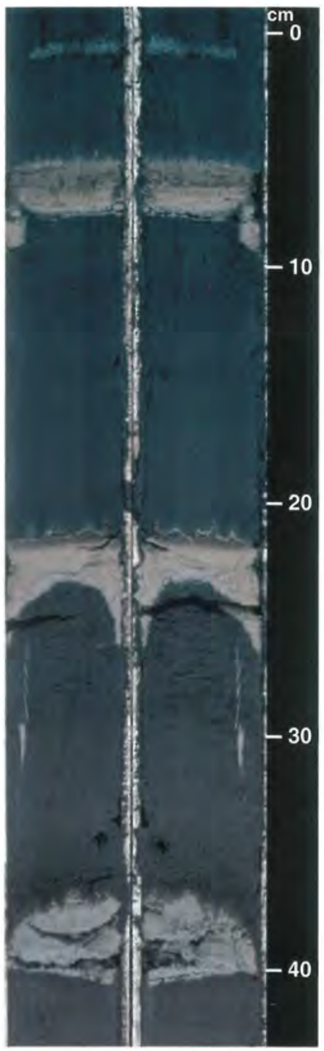
Some of the best tephra sequences are found in lakes and bogs where layers only a few millimetres thick are preserved. Sediment cores from lakes near Hamilton, for example, reveal c. 50 tephra layers, some up to 12 cm thick, originating from Taupo and Okataina volcanic centres, and from Tuhua, Egmont, Ruapehu, and Ngauruhoe volcanoes, over the past 20,000 years. Studies of lakes in the Auckland region show that numerous thin tephras from the same sources, including at least 43 from Egmont volcano, have rained out over the area in the past 70,000 years.

The longest, most complete tephra records have been obtained from deep-sea drilling. More than 130 tephra layers, one of which is nearly 1 m thick, have been identified in Ocean Drilling Program cores from up to 800 km to the east of the North Island [see p.271]. The layers record

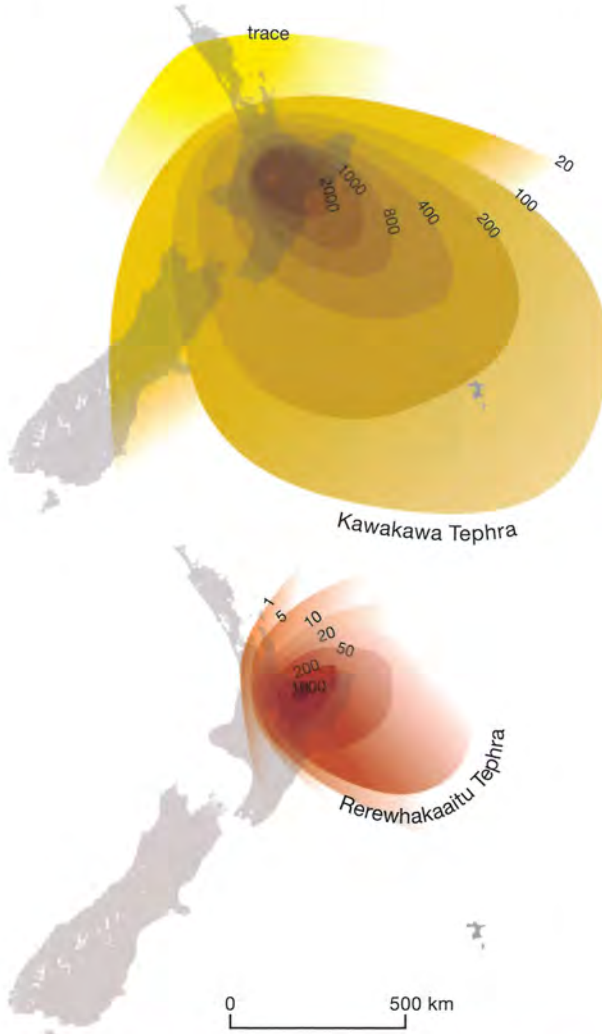
Size Does Matter

'Volcanic ash' is not a burnt residue, but refers to particles erupted from a volcano that are less than 2 mm in size and composed of pumice and rock fragments, mineral grains (crystals), and shards of volcanic glass. Larger particles, 2–64 mm in size, are 'lapilli' (literally 'little stones'), and particles greater than 64 mm in size are 'blocks' if they are dense and angular, or 'bombs' if they are full of gas bubbles, and partly rounded.

▲ **A road cutting near Putaruru, southeast of Hamilton, shows the Kawakawa Tephra (Kk) as a pinkish marker bed c. 50 cm thick, overlying loess and buried soils. Lower in the sequence is the 50,000 year old rhyolitic Rotoehu Ash (Re) overlying another buried soil.**



repeated large explosive eruptions from the Coromandel Volcanic Zone between 12 and 2 million years ago and from the Taupo Volcanic Zone since c. 2 million years ago.



▲ **Thickness maps of the c. 25,400 year old Kawakawa Tephra and the c. 17,600 year old Rerewhakaaitu Tephra show their widespread distribution (thicknesses are in millimetres). These tephras are key marker beds for studies of climate change during the most recent (Otira) glaciation.**

◀ **Rhyolitic tephra layers are prominent in this sediment core from Lake Rotongata in southern Waikato. The lowest tephra is from Taupo caldera, erupted c. 10,100 years ago, the middle two tephras are from Okataina caldera, erupted c. 9500 and c. 8000 years ago, and the top, thin, tephra is from Tuhua volcano (Mayor Island) in the Bay of Plenty, erupted c. 7000 years ago.**

Only a few tephra layers have been recognised in the South Island. The most widespread by far is the voluminous rhyolitic Kawakawa Tephra (also known as Oruanui Tephra), which was erupted c. 25,400 years ago from Taupo volcanic centre. It is also found on the Chatham Islands.

In the Field

Tephra fall deposits tend to mantle pre-existing topography. During periods of repose between major eruptions, when there is little or no fallout, tephras on the land surface are modified by weathering and other soil-forming processes. The soils are then buried by new layers of tephra, forming 'paleosols'.

Tephra deposits from a single eruption may be tens of metres thick near the source of the eruption, but thin quickly away from that source, until at a distance of about 100 km they may be only a few centimetres or millimetres thick. Individual tephra components are largest near the source but become smaller with increasing distance away, because smaller grains are transported further by the wind. One hundred kilometres or more from the source, the particles are mainly ash-size, less than 2 mm across. At great distances from the source, ash grains may be only sparsely scattered within deposits such as peat or loess, and are invisible in the field. These 'hidden' tephra deposits are known as 'cryptotephras'. High-precision methods have been developed for detecting them, allowing tephras to be traced over much larger areas than was previously known and hence making it possible to produce more accurate maps of tephra distribution.

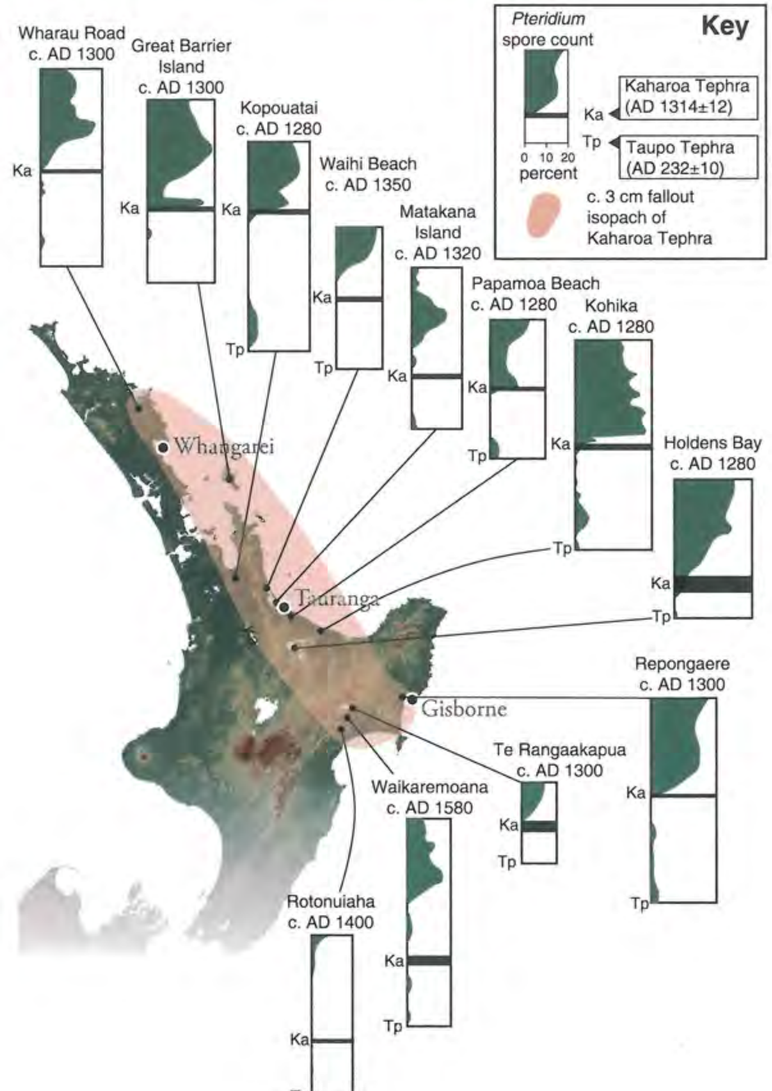
▲ **The andesitic Manganui Tephra, erupted c. 3300 years ago from Fanthams Peak on Egmont volcano, mantles the pre-existing topography like a blanket. The underlying dark reddish-brown horizons are paleosols formed on earlier erupted material.**

Fingerprinting

Some types of minerals found in tephras allow them to be matched to the volcanoes from which they originated. For example, tephras erupted from Tuhua volcano contain minerals unlike those from Taupo Volcanic Zone volcanoes, providing a sure-bet identification. However, the usual way of identifying the source is by chemical analysis of individual glass shards in tephra layers using an electron probe micro-analyser. The 'microprobe' can be used also to analyse iron–magnesium silicate minerals such as biotite to assist in identifying the source. Using advanced analytical techniques involving laser ablation and inductively-coupled plasma mass-spectrometry (ICP-MS), the abundances of trace elements such as rubidium can be determined, which may improve the odds for correctly matching, and therefore correlating, tephras. Statistical analysis of the chemical compositions of volcanic glass or the iron–titanium oxide minerals magnetite and ilmenite is now used to help identify and match tephras. The latest research has shown that some tephras vary more in composition than previously thought, making the process of tephra 'fingerprinting' more complex. This variability is caused by the mingling of separate batches of magma that were tapped simultaneously or sequentially as eruptions proceeded.

▲ An archaeological dig of an early Māori village on sand dunes near Papamoa Beach exposes a white 'floor' of Kaharoa Tephra. So far, no artefacts have been found beneath this tephra at any archaeological site in the North Island, apart from rat-nibbled seed on Coromandel Peninsula, implying that almost all sites were not occupied until after the eruption of Kaharoa Tephra in c. AD 1314.

The Kaharoa Tephra (Ka), erupted from Tarawera volcano in c. AD 1314, provides a benchmark for dating deforestation, and thus settlement by early Māori in the North Island. The profiles show changes in *Pteridium* bracken spores (green) in sediment cores. In most profiles, an increase in bracken and charcoal and decline of tall trees, indicating deforestation, occurs at or after the Kaharoa Tephra was deposited. In four profiles, Kopouatai, Holdens Bay, Papamoa Beach, and Kohika, deforestation occurred a few decades earlier. Dates at the top of each profile are estimates (± 30 years) for the start of deforestation, based on the position of the Kaharoa Tephra. Most profiles also contain Taupo Tephra (Tp), a layer deposited about 1000 years before Polynesian settlement.



▲Colin Vucetich displays a stack of named and dated tephra layers with paleosols on each near Murupara, northeast of Lake Taupo.

◄Alan Pullar stands by a soil profile near Tirau (Waikato), formed on many thin, intermixed tephra layers modified continually by soil-forming processes as they accumulated over the past c. 25,000 years. The tephras at Murupara are in effect blended into the upper part of the Tirau soil profile.

Time Markers

The age of individual tephras can be determined using a range of techniques, including radiocarbon, argon-40 — argon-39, (U-Th)/He, paleomagnetism, and dendrochronology (tree-ring counting) [see p.51]. The chosen method depends mainly on the composition and age of the tephra. An important advance has been the development of 'isothermal-plateau' fission-track dating [see p.71], which has enabled reliable glass ages to be obtained on tephras far from their source [see p.271].

Tephras have been employed to provide markers of known age for a diverse range of geological, landscape, and archaeological features across Zealandia. They have been used, for example, to help reconstruct ancient environments, to trace the development and uplift history of sedimentary sequences such as those in the Wanganui Basin [see p.281], to date past earthquakes in central and southern North Island, and to date Polynesian settlement and its impact in the North Island.

Tephras have also helped in determining volcanic hazards by establishing the frequency of volcanic eruptions and distribution patterns of tephra fallout. For example, probability models have been developed for estimating the likely thickness of tephra fallout in the Auckland region from eruptions at distant volcanoes in western and central North Island. These models are constructed in part using long drill-core records from ancient crater lakes in Auckland city such as Pukaki Lagoon, Onepoto Crater, and Lake Pupuke. The core sediments contain numerous tephras from distant volcanoes, as well as local basaltic tephras erupted from the Auckland volcanic field. One research project used tephras to precisely link marine and terrestrial records to test theories about abrupt climate change over the past c. 30,000 years. Key tephras–including Kawakawa, Okareka, Rerewhakaaitu, Waiohau, and Konini–were used to help date the climatic transition from the Otira Glaciation to the Holocene.

Payback

Although eruptions of New Zealand's volcanoes can be destructive, they have also provided enormous benefits through the formation of productive, versatile soils on tephra layers accumulated over thousands of years. The deep, friable ash-derived allophanic soils in the Taranaki, King Country, Waikato, and Bay of Plenty regions are unsurpassed for food and fibre production and for water storage and purification. The high productivity of these regions is due mainly to the physical properties of the soils, together with a favourable climate and careful management. The allophanic soils, and coarse-grained, glassy pumice soils, have a low natural fertility, however; they require regular topping-up with nutrients, such as phosphate and potassium, along with trace elements such as cobalt and selenium, to maintain high productivity and good animal health.

Tephra Pioneers

In 1888, Algernon Thomas (the University of Auckland) published the first isopach map in New Zealand, showing thicknesses of tephra from the 1886 Tarawera eruption. In 1928, medical superintendent Allan Berry was the first to suggest that widespread tephra layers could be used as time markers to assist in the study of ancient environments. Three years later archaeologist WRB Oliver used a tree-ring-dated tephra to determine the age of a Māori earth-oven on Egmont volcano, and thus a minimum age for Polynesian settlement — the first application of tephrochronology in New Zealand. From mid-1926 New Zealand Geological Survey geoscientists Leslie Grange and Norman Taylor began mapping soil-forming tephras to help solve animal health problems in central North Island. Grange also mapped tephras in the Taupo and Bay of Plenty regions to better assess volcanic hazard. Techniques for mapping and correlating tephras — tephrostratigraphy — were advanced in the 1960s by Colin Vucetich (Victoria University of Wellington) and Alan Pullar (New Zealand Soil Bureau), who used 'hand-over-hand' methods to trace tephras from cutting to cutting. Remarkably, much of this research was done in their own time because it had not been sanctioned by their employers.

Citation:

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