An ashy septingentenarian: the Kaharoa tephra turns 700
(with notes on its volcanological, archaeological, and historical importance)

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Introduction

Most of us are aware of the basaltic Tarawera eruption on 10th June 1886: the high toll on life (~120 people), landscape devastation, and loss of the Pink and White Terraces. But this was not the first time that Mt Tarawera produced an eruption of importance both to volcanology and human history. This edition of the *GSNZ Newsletter* marks the 700th anniversary of the Kaharoa eruption – its septingentenary to be precise – which occurred at Mt Tarawera in the winter of 1314 AD (± 12 years) (Hogg et al. 2003) (Fig. 1). The importance of the Kaharoa eruption is at least threefold. (1) It is the most recent rhyolite eruption in New Zealand, and the largest New Zealand eruption volumetrically of the last millennium. (2) The Kaharoa tephra is an important marker horizon in late Holocene stratigraphy and geoarchaeology (Lowe et al. 1998, 2000), and in particular helps to constrain the timing of settlement of early Polynesians in North Island (Newnham et al. 1998; Hogg et al. 2003; Lowe 2011). (3) There is a link between the soils that developed on the Kaharoa tephra, the animal 'wasting' disease known as 'bush sickness', and the birth of a government soil survey group as an independent organisation (Tonkin 2012).

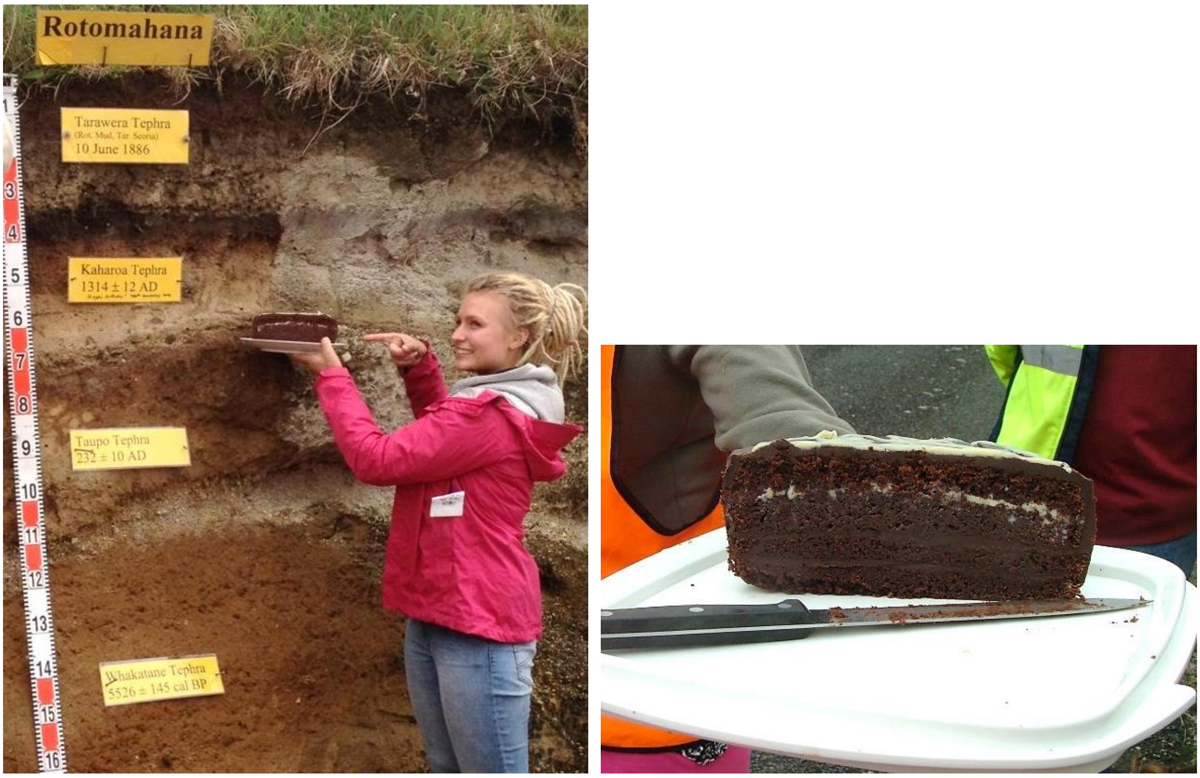


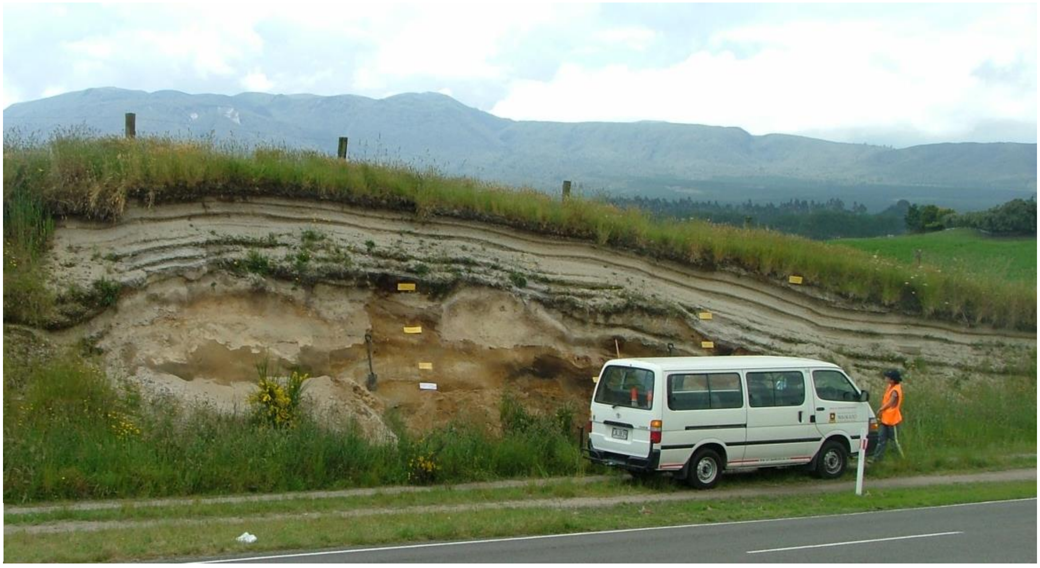
Fig. 1. The Kaharoa tephra, a distinctive rhyolitic marker bed posing with Waikato University Earth science student Anna Eames, who is holding the Kaharoa tephra birthday cake at a section on Brett Rd near Mt Tarawera. Close-up of cake (right) shows white chocolate layer representing Kaharoa tephra and two buried dark chocolate 'paleosols' beneath it. Photos: T.A. O'Neill and D.J. Lowe.

The eruption and its deposits

A sill-like rhyolite magma body, ≥ 11 km^3 in volume and located about 6–7 km beneath Mt Tarawera, had existed for some time prior to the c. 1314 AD eruption (Leonard et al. 2002; Nairn et al. 2004). Basalt magmas had repeatedly intruded the rhyolite body, until one of these finally triggered the eruption (Leonard et al. 2002). The Kaharoa eruption was staged at seven vents aligned along an 8-km-long zone and lava extrusion may have persisted for around 4–5 years, eventually erupting about 5 km^3 of the magma (Nairn et al. 2001, 2004). Early plinian eruptions from several vents (Fig. 2) dispersed swathes of tephra deposits along eastern North Island and beyond (Grange 1937; Vucetich and Pullar 1964; Pullar and Birrell 1973; Pullar et al. 1977; Lowe et al. 1998). As well as visible layers, the Kaharoa tephra has also been identified in the Hamilton and Auckland regions as a cryptotephra deposit (Gehrels et al. 2010; Shane et al. 2013).

Fig. 2. The c. 1314 AD plinian phase of the Kaharoa eruption. Wait! That's not possible! Actually, the top half of the image is the famous Mt Pinatubo eruption column of June 12, 1991 (D. Harlow, USGS, retrieved from vulcan.wr.usgs.gov). The bottom half shows Mt Tarawera, Lake Tarawera, and the white sandy beach comprising mainly reworked Kaharoa tephra at Stoney Point. Photo: D.J. Lowe.

The first plinian sequence erupted mainly from the central crater vent and lasted approximately 10 days, generating units A-H (Fig. 3) although unit C, and part of Unit H, relate to activity from separate vent/s at Ruawahia or Wananga (Nairn et al. 2001). A lava body, Green Lake plug, was extruded on the southwest slope of Mt Tarawera during this time. Plinian eruptions continued at Ruawahia and Wananga vents during the first month (units I-L, Nairn et al. 2001) and may have persisted at Ruawahia vent for several months (unit M, Nairn et al. 2001). Pyroclastic surges and flows also occurred during the plinian phases and some travelled more than 10 km from their source vents (units Cpdc, Hpdc, Nairn et al. 2001).



a

b

Fig. 3. Ash Pit Road section showing **(a)** Mt Tarawera in the background (with white cliffs of Kaharoa eruptives just visible), and **(b)** bedded units A-H of the initial plinian sequence (overlying a pale enleached soil horizon in uppermost Taupo ignimbrite, dated at 232 AD ± 10: Hogg et al. 2012). Tarawera eruptives of 1886 (Rotomahana Mud, with scoria) lie above the Kaharoa deposits. Photos: D.J. Lowe.

Four rhyolite domes (Crater, Tarawera, Wahanga, and Ruawahia domes) were emplaced after the explosive phase, characterising most of the 4–5-year eruptive episode and forming the modern steep-sided topography of Mt Tarawera (Fig. 2; Cole, 1970a; Nairn et al. 2001, 2004). Repeated collapse mainly of the Wahanga and Ruawahia domes generated block-and-ash flows, which travelled up to 8 km away (Fig. 4). More than 6 km^3 of magma, which was not erupted, remained at depth and probably drove the Rotomahana geothermal system (Nairn et al. 2004).

Fig. 4. Crater Road section about 4 km south of Mt Tarawera showing the top of the well-bedded initial plinian sequence (units A-G), cross-stratified pyroclastic flow and surge deposits (unit Hpdc), and overlying poorly sorted block-and-ash flow deposit derived from collapse of the Ruawahia dome. Carbonised logs from unit Hpdc, used for carbon-14 and associated wiggle-match dating using dendrochronology, are also evident. Photo: D.J. Lowe.

A 'break-out' flood event from Lake Tarawera took place shortly after the eruption (Hodgson and Nairn 2005).

Composition and pre-eruption temperature

The lithology and petrography of proximal Kaharoa deposits have been described in detail by Cole (1970b) and Nairn et al. (2004). Glass and mineral phases, like those of some other Okataina-derived eruptives, are the product of two magmas that can be distinguished on the basis of glass major-element compositions, one high (>4 wt%) and the other low in K_2O, and by two different compositions of biotite and melt inclusions (Shane et al. 2003, 2008; Nairn et al. 2004; Smith et al. 2005; Lowe et al. 2008a; Johnson et al. 2013). The eruptives are dominated by plagioclase, quartz, and biotite, with subordinate amounts of hornblende, cummingtonite and clinopyroxene in the ferromagnesian mineral assemblages, a notable exception being in Kopouatai bog where biotite (the key 'marker mineral' for Kaharoa tephra) has been rapidly dissolved under very acid conditions (Hodder et al. 1991). The pre-eruption Kaharoa magma temperature was estimated at 731 ± 10 °C (Smith et al. 2005).

Timing of Polynesian settlement in New Zealand and dating the Kaharoa eruption

The timing of the earliest Polynesian settlement of the New Zealand archipelago, the last substantial land mass in the world (outside polar regions) to be colonized by humans, has been controversial, partly because it has been so recent (Lowe 2011). Radiocarbon age data, potentially open to question because of likely contamination in lake sediments by inwashing of old carbon as a result of Polynesian deforestation activities, inbuilt age, or dietary effects, effectively resulted in two contradictory models of settlement: 'early' settlement about 1500–2000 years ago (Sutton 1987) versus 'late' settlement about 700 years ago (Anderson 1991). The Kaharoa tephra, distributed widely over much of eastern and northern North Island, and easily recognised by the distinctive major element compositions of its glasses (Stokes et al. 1992; Lowe et al. 2008a) and marked biotite content, provides a 'settlement datum' to help determine which model was more likely to be correct by linking and dating palynological evidence of initial human impact (derived from analyses of cores from peat bogs and lakes) (Fig. 5) with archaeological and artefactual evidence (Fig. 6) (Newnham et al. 1998; Lowe et al. 2000, 2002; Lowe, 2011).

No cultural remains are known to occur beneath the Kaharoa tephra – apart from one rat-nibbled seed at Te Rerenga, on the northeast coast of the Coromandel Peninsula (Wilmshurst and Higham 2004) – and palynological evidence for earliest human-induced impact (a sustained deforestation signal comprising a decline in tall trees and a concomitant rise in bracken spores) occurs stratigraphically just before its deposition in five pollen profiles out of around two dozen documented sites (e.g. Newnham et al. 1998; Giles et al. 1999; Horrocks et al. 2001; Lowe et al. 2002). Thus the earliest settlement was inferred by Lowe et al. (2000) from the pollen records to have occurred a few decades before deposition of the Kaharoa tephra and 'no earlier than *c.* 1280 AD'. The accurate determination of the date of eruption of Kaharoa tephra therefore became a priority to help constrain the timing of Polynesian settlement (at least in North Island), as well as for volcanological purposes.

Fig. 5. White Kaharoa tephra layer, ~3–5 cm thick, in peat at Waihi Beach, Bay of Plenty. Taupo tephra (232 AD ± 10) occurs below it. Pollen analyses from a nearby site were reported by Newnham et al. (1995). Note blackened charcoal-rich peat above Kaharoa tephra, which probably reflects Polynesian firing in the area. Cutting tool ~30 cm long. Photo: D.J. Lowe.

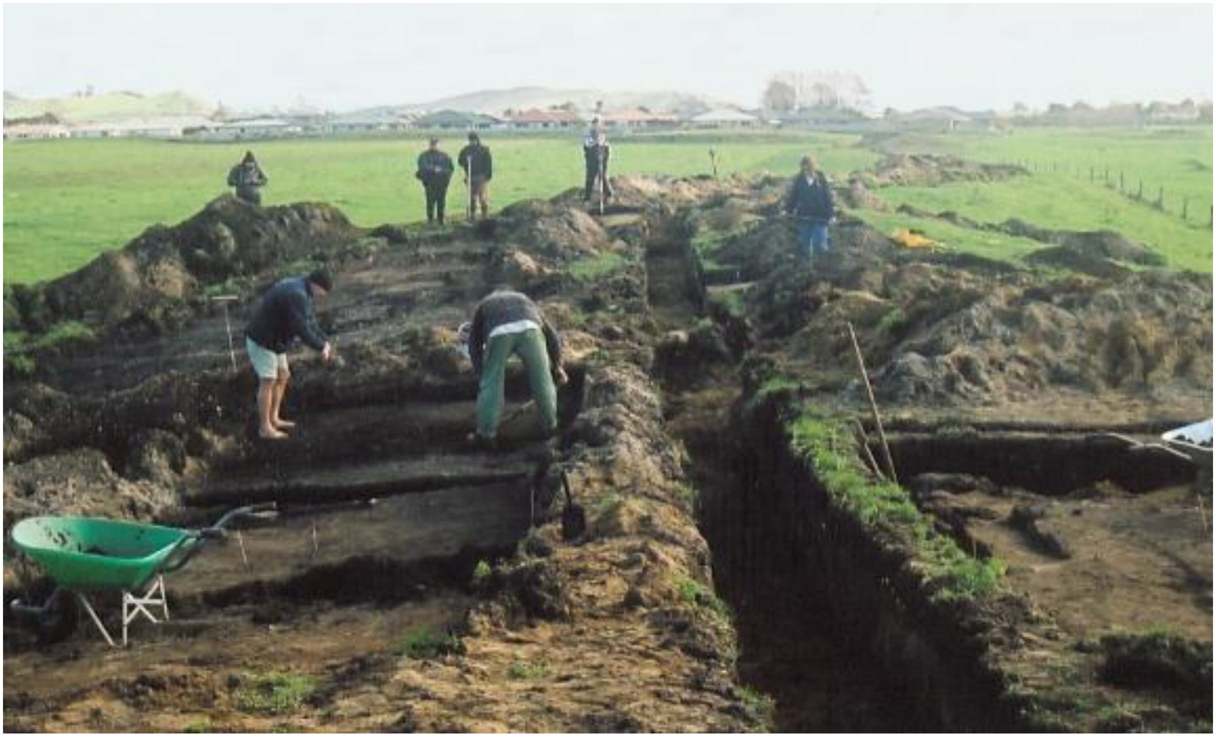


Fig. 6. Kaharoa tephra layer marking the 'white floor' of an ancient Maori village on a sand dune near Papamoa Beach, Bay of Plenty. After Lowe et al. (2008b, p. 172).

The calendrical date of c. 1314 AD for the explosive phases of the Kaharoa eruption was obtained using a technique known as 'wiggle matching' whereby a sequence of radiocarbon dates is matched with a radiocarbon calibration curve. Samples taken from a known sequence, such as a tree-ring series, are radiocarbon dated and the results fitted to published calibration curves using statistical methods of best fit or Bayesian-based modelling (Hogg et al. 2003). Although Lowe et al. (1998) had determined a mean radiocarbon age for the deposition of the Kaharoa tephra of 665 ± 15 ^{14}C years BP, this age corresponded to a wide range of calendar dates because of marked fluctuations (wiggles) of calibration curves in the 14th Century, and hence the Kaharoa eruption could have occurred at any time between c. 1290 AD and c. 1400 AD using just the mean age alone for calibration. Moreover, Buck et al. (2003) criticised some of the methods used to derive the mean age.

An expedition to Mt Tarawera to obtain suitable wood to undertake a wiggle-match date proved fruitless, almost all preserved logs found being totara which is not suitable for dendrochronology. However, one of us (DJL), when subsequently filming with Greenstone Pictures for a TVNZ documentary, by chance discovered a carbonised log of *Phyllocladus* spp., generally known as celery pine (tanekaha), and usually well suited to dendrochronology (Fig. 7). The log was found within the pyroclastic flow and surge deposits (unit Hpdc) exposed at the Crater Rd section (Fig. 4). These deposits encapsulating the log were emplaced early in the Kaharoa eruption episode. The duration of all the explosive eruption phases, which generated the distal tephra fall deposits (Kaharoa tephra), is estimated at 'days to weeks' (Nairn et al. 2001).

Fig. 7. Partly carbonized *Phyllocladus* spp. log (celery pine), about 15 cm in diameter and with intact bark, in place within pyroclastic flow deposits at the Crater Road section (June, 1999). This log was used to derive the wiggle-match date for the Kaharoa eruption (Hogg et al. 2003).

Five contiguous ten-ring (i.e. decadal) blocks of carbonized wood were removed for high-precision radiocarbon dating. The first sample was the youngest, spanning ten annual rings obtained from the outside of the log, but excluding the bark. Subsequent samples were extracted contiguously towards the older, central part of the log. The sequence of five dates, in their known order of age, were statistically matched to the wiggles of the newly-developed high-precision Southern Hemisphere radiocarbon calibration curve (Hogg et al. 2003).

The calendar date determined for the eruption of Kaharoa tephra using this method is 1314 ± 12 AD (2σ). Hogg et al. (2003) additionally used an alternative Bayesian program, OxCal, and produced a near-identical result for the death of the tree of 1305–1325 AD (2σ). The outermost ring of the *Phyllocladus* log seemed completely formed, having both early wood and late wood. This feature suggests that the tree was killed during the period from late autumn to early spring (i.e. between growth cessation because of the onset of winter but before the start of spring growth). The exact month of the eruption within this period is impossible to determine, but experience from contemporary tree-ring studies of the same species suggested that the period from May to September is likely (Hogg et al. 2003).

In summary, the use of the Kaharoa tephra isochron, together with a wide range of evidence including lake- and bog-derived pollen records, bones of the commensal Pacific rat *Rattus exulans*, rat-nibbled seed cases and snail-shells, fire records, ancient DNA, and archaeological and (reliable) radiocarbon data, support the 'late' settlement model (e.g. Higham and Hogg 1997; Ogden et al. 1998; Schmidt and Higham 1998; Higham et al. 1999; McGlone and Wilmshurst 1999; Brook 2000; Anderson 2002, 2005, 2013; Wilmshurst et al. 2008, 2011, 2014; Lowe 2011; Perry et al. 2012). Earliest Polynesian settlement of New Zealand is now dated at c. 1280 AD (Wilmshurst et al. 2008), or slightly later, c. 1320 to 1350 AD, according to Jacomb et al. (2014). However, the presence of the rat-nibbled seed beneath Kaharoa tephra at Te Rerenga, and the sustained rise in bracken spores starting just below the tephra in pollen profiles, are consistent with earliest settlement occurring just prior to the eruption of Kaharoa, not just after. Earlier transient contact remains a possibility but currently lacks evidence.

'Bush sickness' and the establishment of Soil Survey Branch, DSIR

The Pumice Soils (Hewitt 2010) that developed in the Kaharoa tephra in the Bay of Plenty were, like those on Taupo tephra, deficient in metals including cobalt and thus stock on them suffered 'bush sickness' until the remedy was discovered in the mid-1930s (Lowe and Palmer 2005; McDaniel et al. 2012). Once identified, the problem was readily cured by adding tiny amounts of cobalt to fertiliser, and abandoned farms could become productive (Tonkin 2012). It was L.I. Grange who made the connection between the occurrence of bush sickness and the soils formed in Kaharoa (and Taupo) tephras after he and N.H. Taylor had begun mapping the tephras and soils from 1926 (Taylor 1930; Grange 1931; Grange and Taylor 1932). That insight resulted in soil survey becoming a separate, independent branch of the Department of Scientific and Industrial Research (DSIR) in 1936 rather than effectively an 'add-on' to the Geological Survey Branch as it had been (Lowe 1990; Tonkin 2012). Grange was the first director of Soil Survey (and later a director of Geological Survey); it was renamed Soil Bureau in 1945 until morphing into Landcare Research in July, 1992.

Conclusion

Happy 700th birthday, Kaharoa tephra!

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