Role of Tephra in Dating Polynesian Settlement and Impact, New Zealand

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Introduction: Heated Debate

Tephrochronology in its original sense is the use of tephra layers as time-stratigraphic marker beds to establish numerical or relative ages (Lowe and Hunt, 2001). Tephra layers have been described and studied in New Zealand for more than 160 years (the German naturalist and surgeon Ernst Dieffenbach described 'recognizable' tephra sections in his 1843 book *Travel in New Zealand*), and the first isopach map, showing fallout from the deadly plinian basaltic eruption of Mt Tarawera on 10 June 1886, was published in 1888 (Lowe, 1990; Lowe et al., 2002). More recently, a wide range of tephra-related paleoenvironmental research has been undertaken (e.g., Lowe and Newnham, 1999; Newnham and Lowe, 1999; Newnham et al., 1999, 2004; Shane, 2000), including new advances in the role of tephra in linking and dating sites containing evidence for abrupt climatic change (e.g., Newnham and Lowe, 2000; Newnham et al., 2003). Here we focus on the use of tephrochronology in dating the arrival and impact of the first humans in New Zealand, a difficult problem for which this technique has proven to be of critical importance.

The timing of initial settlement of New Zealand has been the subject of heated debate. An early but transient contact AD 50 to 150, based on Pacific rat-bone (*Rattus exulans*) dates obtained from natural sites, was proposed by Holdaway (1996) on the premise that the rats, an introduced predator to New Zealand, accompanied the early Polynesians as a food source or as stowaways (Matisoo-Smith, 2002; Matisoo-Smith and Robins, 2004). This proposal seemingly supported Sutton (1987, 1994), who first suggested on the basis of small-scale but short-lived disturbance evident in pollen records that 'archeologically invisible' Polynesian sailors might have reached New Zealand around this time. However, the reliability of the early rat-bone dates has been disputed, especially as aberrant rat-bone dates were reported from several archeological sites (Anderson, 1996, 2000, 2004; Higham and Petchey, 2000; Higham *et al.*, 2004), and dates on rat-nibbled land snail shells (*Placostylus ambagiosus*) and rat-nibbled seeds both suggested instead that the Pacific rat became established after AD 1250 (Brook, 2000; Wilmshurst and Higham, 2004). Moreover, the early rat-bone dates at one of Holdaway's (1996) sites in the South Island have not been duplicated (Holdaway et al., 2002; Anderson and Higham, 2004).

Fig.1: Human footprint in basaltic Rangitoto Tephra, erupted c. AD 1400, Auckland, northern North Island (Nichol, 1982). The age of the eruption is derived from multiple radiocarbon, paleomagnetic, thermoluminescence, and obsidian hydration dates (Lowe et al., 2000). Photo courtesy of Reg Nichol.

Using Tephra Layers to Date Archeological and Paleoenvironmental Sites

Because tephras provide essentially instantaneous chronostratigraphic marker horizons, or *isochrons*, that can be correlated between sites independently of radiometric dating, they provide a way of circumventing the various interpretative difficulties associated with radiocarbon dating very recent (last millennia) archeological and paleoenvironmental (natural) sites. Because tephra deposits are found in both archeological and natural sites, they have the capacity for linking such sites in an unambiguous manner unparalleled by other dating or correlative techniques (Lowe et al., 2000).

Direct links between early Polynesians and their descendants (Maori) and tephras in New Zealand are associated with three different eruptive centers on North Island (Lowe et al., 2002).

(1) Human footprints and other artifacts are buried beneath and within basaltic ash erupted from Rangitoto Island volcano, near Auckland, at AD 1400 (Fig. 1).

(2) The remains of Maori cooking stones (*umu*) aged AD 1450 to 1500 lie sandwiched between tephras on the slopes of the andesitic stratovolcano of Taranaki (Mt Egmont) in western North Island (Fig. 2).

(3) The key event for dating Polynesian settlement in New Zealand was the eruption of Kaharoa Tephra, a geochemically distinctive, rhyolitic tephra layer originating from Mt Tarawera volcano in central North Island near Rotorua

Fig. 2: Early Maori cooking stones (umu) sandwiched between andesitic tephra layers on Taranaki volcano, western North Island. At this site, the stones are overlain directly by Burrell Ash and underlain by Waiweranui Lapilli, dating the umu to c. AD 1500 or a little before (Alloway et al., 1990; Lowe et al., 2000). First recognized by Oliver (1931), the oldest umu on Taranaki is dated at c. AD 1450. Photo courtesy of Brent Alloway.

(Lowe et al., 2000). Widely dispersed over > 30,000 km² of northern and eastern North Island, Kaharoa Tephra provides a unique 'settlement layer' (*landnámslag*) (Wastegard et al., 2003; Sveinbjornsdottir et al., 2004) in northern New Zealand. Difficult to date accurately by radiocarbon alone because of wiggles in the calibration curves (Lowe et al., 1998), we derived a wiggle-match date of AD 1314±12 for the Kaharoa Tephra eruption—the main plinian, tephra-fall-producing phase of which occurred in the austral winter (Hogg et al., 2003)—using a carbonized log of *Phyllocladus* spp. We used the Southern Hemisphere calibration curves of Hogg et al. (2002), thus avoiding the interhemispheric offset problem, and confirmed our date's likelihood using Bayesian statistics (Buck et al., 2003).

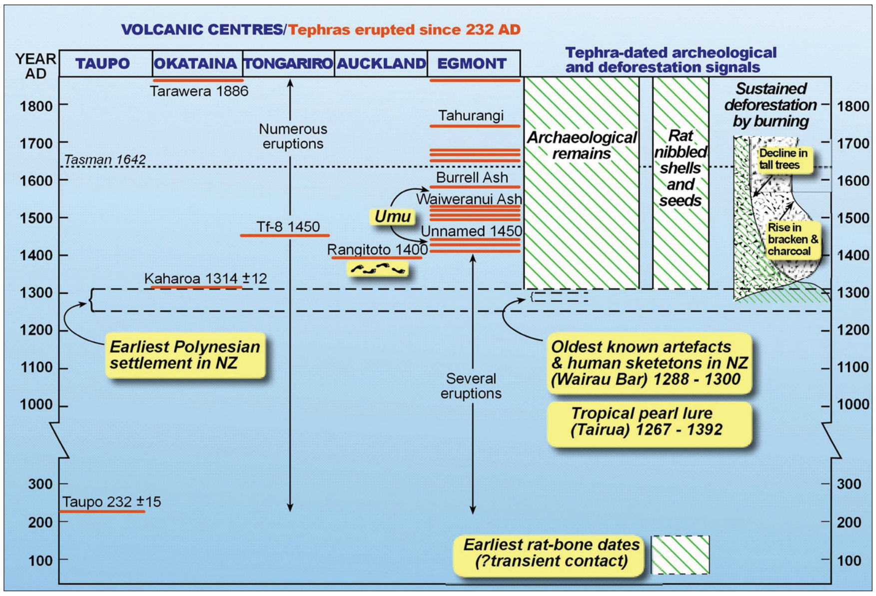

Fig. 4: Summary of stratigraphy and ages of tephras, erupted from five volcanic centers since c. AD 232 (left side of diagram), and their relationship with archeological and deforestation signals in northern and eastern North Island (right) (after Lowe et al., 2000, 2002). The Kaharoa Tephra provides a settlement datum, or landnámslag, for inferred human-induced burning and deforestation in much of northern and eastern North Island (e.g., Newnham et al., 1998; Horrocks et al., 2001). It matches the earliest settlement dates of c. AD 1250–1300 from many sites containing archeological remains (e.g., Anderson, 1991; Higham and Hogg, 1997; McFadgen, 2003; Higham et al., 2004), including the ancient Wairau Bar artifacts and skeletons (Higham et al., 1999) and the tropical pearl lure at Tairua (Schmidt and Higham, 1998) (2 sigma error ranges), the oldest known rat-nibbled snail shells and seeds (Brook, 2000; Wilmshurst and Higham, 2004), and the earliest reliable dates for sustained deforestation elsewhere in the New Zealand archipelago (Ogden et al., 1998; McGlone and Wilmshurst, 1999). The zone depicting possible early transient human contact is based on Holdaway (1996, 1999). Dutchman, Abel Tasman, was probably the first European to visit New Zealand (AD 1642).

Numerous archeological sites in eastern and northern North Island contain the Kaharoa Tephra datum (Fig. 3; Lowe et al., 2000; see also supplementary material), and the absence of artifacts or cultural remains reported beneath it thus far indicates that these sites must be younger than AD 1314. In the same

Fig.3: Distal rhyolitic Kaharoa Tephra showing up as a prominent, 5-cm-thick marker layer in shallow peat deposits at Waihi Beach, western Bay of Plenty, eastern North Island. Taupo Tephra (erupted c. AD 232; Sparks et al. 1995; Lowe and de Lange, 2000) occurs also in the section, faintly visible as fine lapilli on the 'corner' in the middle of the photo, a few centimeters above the pale muds near the water table. The peat above Kaharoa datum is darker than below because it contains abundant charcoal from Polynesian burning, which is documented by pollen analysis in this area (Newnham et al., 1995). Cutting tool handle is ~30 cm long. Photo: David Lowe.

region, nearly 20 pollen profiles obtained from peat or lake deposits contain both Kaharoa Tephra and palynological indicators for the onset of significant deforestation, in the form of both marked and sustained rises in bracken (*Pteridium*) spores and charcoal, and a concomitant decline in tall forest trees (Newnham et al., 1998; Horrocks et al., 2001, 2004; McGlone and Jones, 2004). Unprecedented in the Holocene record, these palynological changes are inferred to be the result of initial and repeated firing by early Maori (Ogden et al., 1998; McGlone and Wilmshurst, 1999; Flenley and Todd, 2001). In a few profiles, the sustained rises in bracken and charcoal occur well after the Kaharoa Tephra datum but in the others, they occur close to the time of its deposition. In four pollen profiles, the earliest sustained rises are recorded in sediments just a few centimeters below the Kaharoa Tephra layer, probably ≤ 50 years before the eruption of AD 1314 (Lowe et al., in press). A similar pattern is evident from independent opal phytolith data in tephra-soil sequences in the Bay of Plenty (Kondo et al., 1994; Sase and Hosono, 1996). Thus, it is likely that the Kaharoa eruption was witnessed by a small number of very early Maori (an argument supported by oral tradition) and that archeological sites containing artifacts just beneath the Kaharoa Tephra may yet be found.

Conclusions

Taken together, both the archeological and palynological evidence, constrained by the AD 1314 Kaharoa Tephra datum, suggests that the earliest environmental impacts associated with initial Polynesian settlement in northern New Zealand (North Island) occurred between AD 1250 and 1300. This is coincident with the earliest-known settlement dates from archeological remains on both North and South Islands, with dates obtained from rat-nibbled snail shells and seeds, and with reliably dated deforestation signals (Fig. 4). The fact that the maximum date for the onset of deforestation is similar to dates obtained from the oldest-known archeological sites (e.g., Wairau Bar), implies that the onset of forest burning was more-or-less contemporaneous with initial settlement (Lowe et al., in press). It remains feasible that earlier settlement sites still await discovery beyond the fall-out zone of macroscopic Kaharoa Tephra and that there might have been an earlier transient contact. If such transient contact occurred, it currently remains invisible in the archeological record and is indistinguishable from natural background events in the palynological record (Lowe et al., in press).

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Fig. 5: Archeological excavation of an early Maori village (kainga) site on dunes at Papamoa, coastal Bay of Plenty, eastern North Island, with the Kaharoa Tephra (dated at AD 1314±12 by Hogg et al., 2003) forming a prominent white marker layer in peat. Photo: David Lowe.

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Onshore-Offshore Correlation of Pleistocene Rhyolitic Eruptions from New Zealand: Implications for TVZ Eruptive History and Paleoenvironmental Construction

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Taupo Volcanic Zone (TVZ), in the North Island, New Zealand, is arguably the most active Quaternary rhyolitic system in the world. Numerous and widespread rhyolitic tephra layers, sourced from the TVZ, form valuable chronostratigraphic markers in onshore and offshore sedimentary sequences. In deep-sea cores from Ocean Drilling Program (ODP) Leg 181 Sites 1125, 1124, 1123 and 1122, located east of New Zealand (McCave & Carter, 1997; Hall et al., 2001; Fig. 1), 100 tephra beds have been recognized, post-dating the Plio-Pleistocene boundary at 1.81 Ma. These tephras have been dated by a combination of magnetostratigraphy, orbitally tuned stable-isotope data and isothermal plateau fission track ages. The widespread occurrence of ash offshore to the east of New Zealand is brought about by the small size of New Zealand, the explosivity of the mainly plinian and ignimbritic eruptions and the prevailing westerly wind field (Carter et al., 2003).

Although some tephras can be directly attributed to known TVZ eruptions, there are many more tephras represented within ODP cores that have yet to be recognized in near-source on-land sequences. This is due to proximal source area erosion and/or deep burial, as well as the adverse effect of vapor phase alteration and devitrification within near-source welded ignimbrites. Despite these difficulties, a number of key deep-sea tephras can be reliably correlated to equivalent-aged tephra exposed in uplifted marine back-arc successions of Wanganui Basin (Fig. 1), where an excellent chronology has been developed based on magnetostratigraphy, orbitally calibrated sedimentary cycles and isothermal plateau fission track ages. Significant Pleistocene tephra markers include: the Kawakawa, Omataroa, Rangitawa/Onepuhi, Kaukatea, Kidnappers-B, Potaka, Unit D/Ahuroa, Ongatiti, Rewa, Sub-Rewa, Pakihikura, Ototoka and Table Flat Tephras. Six other tephra layers are correlated between ODP-core sites but have yet to be recognized within onshore records.

The occurrence of fewer than expected equivalent marker beds that can be correlated between Wanganui Basin and the ODP cores is problematic and might be attributed to one or more factors. There is the possibility of narrow and highly directed tephra plumes that restrict the spatial distribution of fallout so that key tephra marker beds might be preserved in one or two cores but not necessarily in cores ideally located downwind from the TVZ and further eastward. Another explanation for the lack of tephras associated with voluminous and widespread eruptive events (e.g., Ongatiti eruption,