Quaternary Science Reviews 74 (2013) 170–194

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Ages of 24 widespread tephras erupted since 30,000 years ago in New Zealand, with re-evaluation of the timing and palaeoclimatic implications of the Lateglacial cool episode recorded at Kaipo bog

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ARTICLE INFO

Article history:
Received 31 May 2012
Received in revised form
7 November 2012
Accepted 21 November 2012
Available online 19 February 2013

Keywords:
Tephras
Tephrochronology
Tephrostratigraphy
Isochron
Age modelling
Bayesian
Bacon
OxCal
Radiocarbon
NZ-INTIMATE
Lateglacial cool episode
Lateglacial reversal
Climate events
Termination 1
Kaipo bog
ACR
GS-1
YD
NZ-CES
NZce-3
Marine reservoir
Palaeoenvironmental reconstruction
Volcanic eruptions
New Zealand
Patagonia

ABSTRACT

Tephras are important for the NZ-INTIMATE project because they link all three records comprising the composite inter-regional stratotype developed for the New Zealand climate event stratigraphy (NZ-CES). Here we firstly report new calendar ages for 24 widespread marker tephras erupted since 30,000 calendar (cal.) years ago in New Zealand to help facilitate their use as chronostratigraphic dating tools for the NZ-CES and for other palaeoenvironmental and geological applications. The selected tephras comprise 12 rhyolitic tephras from Taupo, nine rhyolitic tephras from Okataina, one peralkaline rhyolitic tephra from Tuhua, and one andesitic tephra each from Tongariro and Egmont/Taranaki volcanic centres. Age models for the tephras were obtained using three methods: (i) ^{14}C-based wiggle-match dating of wood from trees killed by volcanic eruptions (these dates published previously); (ii) flexible depositional modelling of a high-resolution ^{14}C-dated age–depth sequence at Kaipo bog using two Bayesian-based modelling programs, Bacon and OxCal's *P_Sequence* function, and the IntCal09 data set (with SH offset correction −44 ± 17 yr); and (iii) calibration of ^{14}C ages using OxCal's *Tau_Boundary* function and the SHCal04 and IntCal09 data sets. Our preferred dates or calibrated ages for the 24 tephras are as follows (youngest to oldest, all mid-point or mean ages of 95% probability ranges): Kaharoa AD 1314 ± 12; Taupo (Unit Y) AD 232 ± 10; Mapara (Unit X) 2059 ± 118 cal. yr BP; Whakaipo (Unit V) 2800 ± 60 cal. yr BP; Waimihia (Unit S) 3401 ± 108 cal. yr BP; Stent (Unit Q) 4322 ± 112 cal. yr BP; Unit K 5111 ± 210 cal. yr BP; Whakatane 5526 ± 145 cal. yr BP; Tuhua 6577 ± 547 cal. yr BP; Mamaku 7940 ± 257 cal. yr BP; Rotoma 9423 ± 120 cal. yr BP; Opepe (Unit E) 9991 ± 160 cal. yr BP; Poronui (Unit C) 11,170 ± 115 cal. yr BP; Karapiti (Unit B) 11,460 ± 172 cal. yr BP; Okupata 11,767 ± 192 cal. yr BP; Konini (bed b) 11,880 ± 183 cal. yr BP; Waiohau 14,009 ± 155 cal. yr BP; Rotorua 15,635 ± 412 cal. yr BP; Rerewhakaaitu 17,496 ± 462 cal. yr BP; Okareka 21,858 ± 290 cal. yr BP; Te Rere 25,171 ± 964 cal. yr BP; Kawakawa/Oruanui 25,358 ± 162 cal. yr BP; Poihipi 28,446 ± 670 cal. yr BP; and Okaia 28,621 ± 1428 cal. yr BP.

Secondly, we have re-dated the start and end of the Lateglacial cool episode (climate event NZce-3 in the NZ-CES), previously referred to as the Lateglacial climate reversal, as defined at Kaipo bog in eastern North Island, New Zealand, using both Bacon and OxCal *P_Sequence* modelling with the IntCal09 data set. The ca 1200-yr-long cool episode, indicated by a lithostratigraphic change in the Kaipo peat sequence to grey mud with lowered carbon content, and a high-resolution pollen-derived cooling signal, began 13,739 ± 125 cal. yr BP and ended 12,550 ± 140 cal. yr BP (mid-point ages of the 95% highest posterior density regions, Bacon modelling). The OxCal modelling, generating almost identical ages, confirmed these ages. The Lateglacial cool episode (ca 13.8–12.6 cal. ka BP) thus overlaps a large part of the entire Antarctic Cold Reversal chronozone (ca 14.1–12.4 cal. ka BP or ca 14.6–12.8 cal. ka BP), and an early part of the Greenland Stadial-1 (Younger Dryas) chronozone (ca 12.9–11.7 cal. ka BP). The timing of the Lateglacial cool episode at Kaipo is broadly consistent with the latitudinal patterns in the Antarctic Cold Reversal signal suggested for the New Zealand archipelago from marine and terrestrial records, and with records from southern South America.

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http://dx.doi.org/10.1016/j.quascirev.2012.11.022

1. Introduction

Tephrochronology is the use of tephra layers as isochrons to correlate and synchronize sequences in different places by providing precise chronostratigraphic tie-points, and to transfer numerical ages to such sequences where the tephras have been dated by radiometric, incremental, or other methods (Lowe, 2011). The role of tephrochronology as a linking and dating tool in palaeoenvironmental reconstructions, including INTIMATE projects (**INT**egration of **I**ce-core, **MA**rine, and **TE**rrestrial records) centred in both hemispheres, is well established (e.g. Lowe et al., 2008a, 2008b; Moriwaki et al., 2011; Blockley et al., 2012; Davies et al., 2012). In New Zealand, the NZ-INTIMATE community developed an initial climate event stratigraphy based on identifying a series of well-dated, onshore and offshore proxy records from a variety of latitudes and elevations on a common calendar (cal.) timescale extending from 30,000 cal. yr BP to the present (Barrell et al., 2005; Alloway et al., 2007). A major advantage of these records (apart from those derived from speleothems) is that they are linked precisely by one or more tephra layers. Twenty-two tephras, derived from Taupo, Okataina, Tuhua, Tongariro, and Egmont/Taranaki volcanic centres (Fig. 1), were selected as marker beds for the NZ-INTIMATE project, and their stratigraphic relationships, distribution, composition, and ages were reported by Lowe et al. (2008a). The ages were developed via Bayesian-based modelling using both OxCal and Bpeat programs, and utilised IntCal04 for tephras <26,000 cal. yr BP and 'comparison curves' for those >26,000 cal. yr BP. The 22 tephras were originally chosen in part because of their widespread distribution, each occurring ~250 km or more from source. The close stratigraphic and temporal relationships of various tephra layers to signals of climatic or environmental change since 30,000 cal. yr BP were also documented (Alloway et al., 2007; Lowe et al., 2008a).

An important conclusion reached by the NZ-INTIMATE community is that no single climate record provides a definitive INTIMATE reference standard for the New Zealand region and, consequently, Alloway et al. (2007) used an array of proxy records from the New Zealand region to develop a composite stratigraphic framework of climatic events. The most recent initiative has been to formalise a New Zealand climate event stratigraphy (NZ-CES), tied to a composite inter-regional stratotype of three high-quality proxy records, that will facilitate enquiry into event regionality, and leads

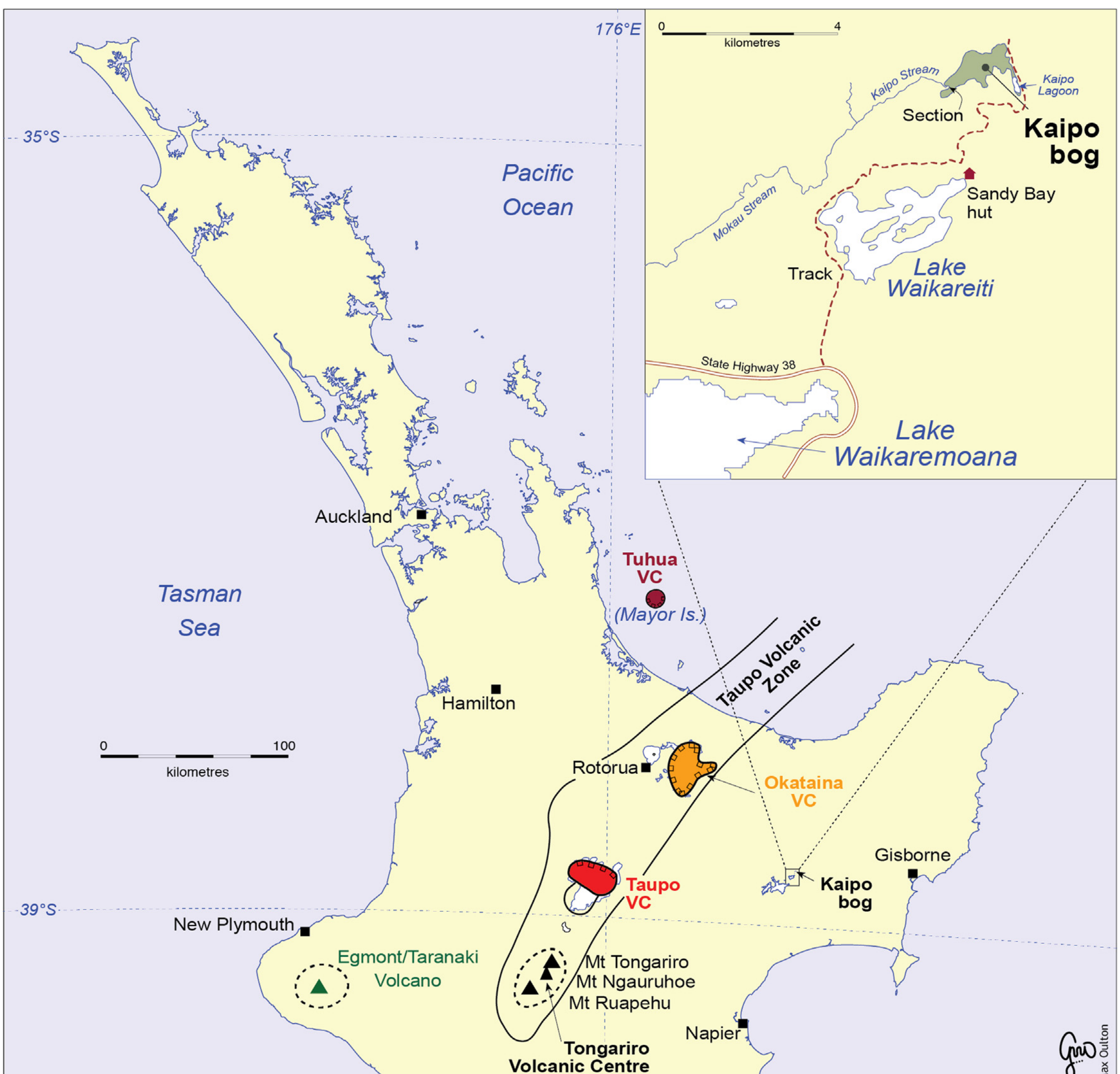

Fig. 1. Map of central and northern North Island, New Zealand, showing source volcanoes of the 24 tephras dated in this paper (after Froggatt and Lowe, 1990). VC, Volcanic Centre. Inset shows locations of Kaipo bog and the tephra-peat section.