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A composite pollen-based stratotype for inter-regional evaluation of climatic events in New Zealand over the past 30,000 years (NZ-INTIMATE project)

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ABSTRACT

Our review of paleoclimate information for New Zealand pertaining to the past 30,000 years has identified a general sequence of climatic events, spanning the onset of cold conditions marking the final phase of the Last Glaciation, through to the emergence to full interglacial conditions in the early Holocene. In order to facilitate more detailed assessments of climate variability and any leads or lags in the timing of climate changes across the region, a composite stratotype is proposed for New Zealand. The stratotype is based on terrestrial stratigraphic records and is intended to provide a standard reference for the intercomparison and evaluation of climate proxy records. We nominate a specific stratigraphic type record for each climatic event, using either natural exposure or drill core stratigraphic sections. Type records were selected on the basis of having very good numerical age control and a clear proxy record. In all cases the main proxy of the type record is subfossil pollen. The type record for the period from ca 30 to ca 18 calendar kiloyears BP (cal. ka BP) is designated in lake-bed sediments from a small morainic kettle lake (Galway tarn) in western South Island. The Galway tarn type record spans a period of full glacial conditions (Last Glacial Coldest Period, LGCP) within the Otira Glaciation, and includes three cold stadials separated by two cool interstadials. The type record for the emergence from glacial conditions following the termination of the Last Glaciation (post-Termination amelioration) is in a core of lake sediments from a maar (Pukaki volcanic crater) in Auckland, northern North Island, and spans from ca 18 to 15.64 ± 0.41 cal. ka BP. The type record for the Lateglacial period is an exposure of interbedded peat and mud at montane Kaipo bog, eastern North Island. In this high-resolution type record, an initial mild period was succeeded at 13.74 ± 0.13 cal. ka BP by a cooler period, which after 12.55 ± 0.14 cal. ka BP gave way to a progressive ascent to full interglacial conditions that were achieved by 11.88 ± 0.18 cal. ka BP. Although a type section is not formally designated for the Holocene Interglacial (11.88 ± 0.18 cal. ka BP to the present day), the sedimentary record of Lake Maratoto on the Waikato lowlands, northwestern North Island, is identified as a prospective type section pending the integration and updating of existing stratigraphic and proxy datasets, and age models. The type records are interconnected by one or more dated tephra layers, the ages of which are derived from Bayesian depositional modelling and OxCal-based calibrations using the IntCal09 dataset. Along with the type sections and the Lake Maratoto record, important, well-dated terrestrial reference records are provided for each climate event. Climate proxies from these reference records include pollen flora, stable isotopes from speleothems, beetle and chironomid fauna, and glacier moraines. The regional composite stratotype provides a benchmark against which to compare other records and proxies. Based on the composite stratotype, we provide an updated climate event stratigraphic classification for the New Zealand region.

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[1] INTIMATE = INTegration of Ice core, MArine, and TErrestrial records.

[2] The following people attended the Australasian-INTIMATE meeting at Kaikoura, New Zealand, 29–30 November 2006, at which the climate event stratigraphy was first defined: Peter Almond, David Barrell, Tim Barrows, Martin Brook, Phil Burge, Michael Evans, David Fink, Olivia Hyatt, Darren King, Ed Rhodes, Jamie Shulmeister, Greg Skilbeck, Phil Tonkin, Marcus Vandergoes, Paul Williams and Craig Woodward. In addition, Brent Alloway, Maarten Blaauw and Alan Hogg have contributed to concept development or refinement of chronologies in support of the NZ-INTIMATE project.

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The stratotype and event classification are not intended to act as definitive statements of paleoclimate history for the New Zealand region, but rather provide a firm baseline against which to compare other records including those from the marine realm.

1. Introduction

Earth's climate system functions on several different scales. Over long time scales (10^5 to 10^4 yrs), cycling between glacial and interglacial conditions has dominated the globe during the latter part of the Quaternary Period (e.g. Hays et al., 1976). On intermediate scales (10^3 to 10^2 yrs) are climatic episodes of apparently limited global extent, such as Dansgaard-Oeschger events (Dansgaard et al., 1993), the Lateglacial Younger Dryas (YD) cold event in the North Atlantic region, Antarctic Cold Reversal (ACR) of the Southern Ocean (Broecker et al., 1990, 2010; Putnam et al., 2010a), and the late Holocene Medieval Warm Period/Little Ice Age (Denton and Broecker, 2008; Miller et al., 2012). At short time scales (10^1 to 10^0 yrs), there are patterns of variability such as the Interdecadal Pacific Oscillation, a decadal-scale modulation in the behaviour of the El Nino-Southern Oscillation cycle (Salinger et al., 2001). How these modes of behaviour interrelate, and the degrees to which they are global, regional, or are transmitted with leads or lags, are keys to understanding the mechanisms that drive natural climate change.

Enquiry into the fine detail of natural climate variations faces many challenges. Some natural archives of paleoclimate information are of very high resolution, such as tree rings or ice-sheets with annual accumulation layers. Other archives, such as ocean floor sediments, lake sediments, or peat deposits usually, but not always (e.g. Nakagawa et al., 2012), lack annual layering, and extracting their paleoclimate information depends on age control derived from geochronometric methods, such as radiocarbon dating, with attendant age uncertainties of the order of decades to centuries. Nonetheless, the compilation of natural archive records of past climate from around the world provides a means of testing the roles of different factors in effecting climate change at varying time scales. Here we present a composite stratotype that represents the general sequence of climate events over the past 30,000 years in the New Zealand region. This work builds on previous syntheses from the NZ-INTIMATE [New Zealand INTegration of Ice core, MArine, and TErrestrial records) project (Barrell et al., 2005; Alloway et al., 2007).

2. INTIMATE

An important aim of the INTIMATE projects is to improve knowledge of the nature, timing and regional-to-global extent of climatic and environmental changes. The INTIMATE initiative began in the North Atlantic region, focusing on climate changes associated with the termination of the Last Glaciation, between ca 22 and 11.5 k calendar years before present (cal. ka) (Björck et al., 1998), with particular emphasis on testing for delays in the registration of climate changes across wide regions, and between different parts of the environment, such as between terrestrial and marine ecosystems. An Australasian (Australia plus New Zealand) project commenced in 2003 (Barrows et al., 2013a), with the Australasian INTIMATE group (AUS-INTIMATE) operating as two parallel research collectives, one focused on Australia (OZ-INTIMATE – Turney et al., 2006) and the other focused on New Zealand (NZ-INTIMATE – Alloway et al., 2007).

A goal of each INTIMATE project is to erect climatic event stratigraphies for each region to aid inter-comparison of different climate records and proxies in order, for instance, to identify time-transgressive climate changes. The North Atlantic INTIMATE project adopted the NGRIP Greenland ice core record as the regional stratotype for climatic events because of its high resolution and precise chronology (Lowe et al., 2008a; Blockley et al., 2012). The North Atlantic project benefits from close regional connectivity afforded by the Atlantic's meridional circulation. In contrast, the AUS-INTIMATE group was cautious about using Antarctic ice cores for a regional climate baseline because of the potential for some disconnection between Australasia and Antarctica due to the strongly zonal flows of the Southern Hemisphere westerlies and the Antarctic Circumpolar Current. The wide mid-latitudinal spread of Australasia places it within the zone of interaction between tropical and polar climatic influences and further complicates comparison with Antarctic ice core records. The identification of more 'events' in the New Zealand record than could be recognised in Antarctic ice cores (Barrell et al., 2005; Alloway et al., 2007) reinforced these concerns, as did differences between Antarctic ice cores from coastal versus inland sites, including differences in snow accumulation rates and thus chronological resolution. Although tephrochronology is an immensely valuable chronostratigraphic tool for inter-regional comparison in the North Atlantic region, including the Greenland stratotype which contains tephra isochrons (Davies et al., 2012), New Zealand-derived tephra, or associated acidity fingerprints, have not yet been identified unequivocally in Antarctic ice, preventing tephrochronological linkage between New Zealand and Antarctica paleoclimate records (Lowe et al., 2008b). These difficulties were recognised at a meeting of the AUS-INTMATE group at Auckland, New Zealand, in February 2006, where participants did not reach agreement on which, if any, Antarctic ice core records should be used as stratotypes for the AUS-INTIMATE project.

Befitting Australasian cultural linguistic traditions, the AUS-INTIMATE group has instead relied upon its 'MATES' (MArine and TErrestrial recordS) to develop regional climate event stratigraphies. The New Zealand climate event stratigraphy was configured for the period 30–8 cal. ka, in accord with the wider Australasian project, although the NZ-INTIMATE collective maintained a window of interest extending to the present day (Alloway et al., 2007). As New Zealand was first colonised by humans only ca AD 1280 (Hogg et al., 2003; Wilmshurst et al., 2008), its Holocene terrestrial climate proxy records are unencumbered by anthropogenic influences that may have affected terrestrial environments in Australia and in the North Atlantic region during much of the Holocene.

3. Development of the NZ-INTIMATE climate event stratigraphy

During 2004–2005, the NZ-INTIMATE research collective agreed upon a compilation of representative continuous and fragmentary records across New Zealand and the surrounding ocean (Alloway, 2004; Alloway and Shulmeister, 2005; Lowe, 2005), which were brought together in poster form by Barrell et al. (2005) and described in detail by Alloway et al. (2007). The compilation highlighted climatic episodes that appeared to have had a general coherence across New Zealand. These regionally-widespread climatic phases formed the basis of a climatic classification (Fig. 1) proposed by Alloway et al. (2007). However, also evident were differences in the occurrence, timing or expression of some aspects of these phases from record to record. It seems likely that a variety of factors may have contributed to these differences, such as geographic or microclimatic settings of the record sites, proxy type,