

Towards a climate-event stratigraphy for New Zealand for the past 30,000 years – an evaluation of the 2005 NZ-INTIMATE Meeting

David J. Lowe

Department of Earth Sciences, University of Waikato, Private Bag 3105,
Hamilton, New Zealand

Introduction

More than 30 geoscientists representing a range of disciplines met at the Institute of Geological and Nuclear Sciences (GNS) Rafter Laboratory in Lower Hutt in early July to present new developments in the quest to prepare a definitive climate-event stratigraphy for the New Zealand (NZ) region since 30 ka (all ages in calendar years unless noted otherwise). The meeting, ably convened by Brent Alloway (GNS) and Jamie Shulmeister (Canterbury University), was the second to be held by the NZ-INTIMATE (NZ-INT) palaeoclimate community (Fig. 1).

The first NZ-INT meeting, held in August 2004 (Alloway 2004), was successful in that one of the initial objectives, to publish a poster documenting a series of well-dated, high-resolution on-shore and off-shore proxy records from a variety of latitudes and elevations on a common calendar time scale, has now been achieved (Barrell et al. 2005). The poster depicts high-resolution records for the LGM and the Last Glacial-Interglacial transition (LGIT) from Auckland maars, Kaipo and Otamangakau wetlands (eastern and central North Island [NI]), marine core MD97-2121 (east of southern NI), speleothems (northwest South Island [SI]), Okarito wetland (southwestern SI), and ice-core records from Antarctica (EPICA Dome C) and Greenland (GISP2) for comparison. Fragmentary records comprising compilations of glacial sequences, fluvial sequences, loess and aeolian quartz accumulation are also included on the poster. A major advantage immediately evident is the way all the records, apart from the speleothems, are linked precisely by one or more rhyolitic tephra layers. A key marker is the very widespread Kawakawa Tephra (KKT) erupted from Taupo volcano ~26.5 ka (Fig. 2). Inset maps on the poster show NZ's oceanographic setting, principal currents and water masses, glacier extent, and the distribution of vegetation zones at ~22 ka and at modern times (derived from inferred vegetation distribution at *c.* 1250 AD, just before initial deforestation by Polynesian settlers). The accompanying text provides further information and references. Other outcomes from the 2004 meeting included construction of a palaeoclimate website at www.paleoclimate.org.nz and an e-discussion facility at <http://groups.yahoo.com/group/nz-paleoclimate-community> (Alloway & Shulmeister 2005).

Making progress

What progress was made at the 2005 meeting? Firstly, after an introductory overview by the convenors, 18 papers were presented. Some were updates on research reported in 2004, but in others work from new sites or new interpretations were presented. The main findings are evaluated below.

- (1) A review paper on Antarctic and Greenland ice cores concluded that the EPICA Dome C core currently provides the best Southern Hemisphere record for NZ-INT purposes because it has the highest resolution for the OIS 2/1 period and is the most

precisely dated (Naish & Bertler, presented by Alloway). The second EPICA core (from Dronning Maud Land, being drilled) is expected to provide an even better record.

- (2) A benchmark speleothem compilation from both North and South islands defined seven climatic events, dated via >74 TIMS U-series ages, using $\delta^{18}\text{O}$ measurements to reconstruct temperatures: event-1, LGM; event-2, late-glacial warming ~18.2-14.8 ka; event-3, late-glacial optimum 14.8-13.2 ka; event-4, late-glacial reversal 13.5-11.6 ka; event-5, early Holocene optimum 11.6-10.8 ka; event-6, mid-Holocene variability; event-7, late Holocene warm interval 1-0.5 ka (including LIA cooling ~0.4 ka) (Williams, King, Neil & Zhao). The speleothem records also showed statistically significant periodicities at decadal-to-century and millennial scales, the strongest being at ~3600, ~150, and ~100 years.
- (3) The MD97-2121 marine record (Carter & Manighetti) and the montane (1000 m) Kaipo pollen record (Lowe, Hajdas & Newnham) both showed close correspondence in timing with speleothem event 4, the late-glacial climate reversal beginning ~13.6 ka during the ACR (evident in both records) and concluding at 12.6 ka (Kaipo) or ~12.0 ka (MD97-2121) during the first part of the YD chron. A prolonged still-stand of sea level (± 56 m) occurred at ~12.5 ka. At Kaipo the lowland podocarp: grasses (LPG) ratio, a surrogate for temperature (but see 4 below), indicated that conditions remained cool-but-warming from 12.6 to 11.9 ka. Both the MD97-2121 and Kaipo records contain the same suite of tephra markers and so can be reliably correlated. The Kaipo record was dated using wiggle matching of around 50 independent age points against INTCAL04 via OxCal. Radiolarian-based estimates of sea-surface temperatures (SSTs) in the MD97-2121 record showed steady, progressive warming during the LGIT (Hollis, Luer, Scott, Neil & Manighetti).
- (4) At Otamangakau (600 m) and Durham Rd (260 m), pollen records showed a possible climate reversal, or slow-down in rising winter temperatures, between 15 and 13.5 ka, and warming by 12 ka (McGlone, Turney & Wilmshurst). The impact of tephra fall was evident at Otamangakau where late-glacial vegetation was constantly disturbed for short periods by fallout. A major advance was the presentation of a newly-derived pollen-based transfer function ($r^2 = 0.82$) for mean annual temperature (MAT), presented appropriately enough by MATT McGlone. MATs were within approximately 3°C of the present by 17 ka and within 2°C by 14 ka.
- (5) The long pollen record at Okarito is important because it spans the full last glacial-interglacial cycle (it also extends into MOIS 6) and it recorded high-resolution climatic changes including a mid-LGM warming and minor late-glacial reversal (Hendy, Vandergoes & Newnham). Because it lies close to Westland glaciers, Okarito provides direct correlation with deposits associated with their advance and retreat. It is linked via KKT to the MD97-2121 record and on-land NI sites including the Auckland maar records >800 km to the north. Dating with ^{14}C has not been straightforward but >80 ^{14}C dates have been obtained (plus OSL dates).
- (6) A new record for subantarctic Campbell Is. (52°S) is an essential high-resolution reference sites for NZ-INT: it represents the lowest tree line in the region (~100 m), hence is very sensitive to fluctuations in summer temperature; the island is covered with blanketing peat and so long, high-resolution records can be obtained virtually anywhere; and there are restricted pollen and spore flora and close correlation of

these with local vegetation cover (McGlone, Wilmshurst & Turney). MATs were at least 3° C lower than now from 17.0 ka, with moderate warming from 16.0 ka. Dating is currently underway to confirm the timing of an ACR-like interval of cooler climates between ~15.4 and 14.3 ka. Warming between 14.3 and 11.5 ka eventually attained MATs within 0.7-0.9° C of the present.

- (7) The Auckland maar records provide potentially the best palaeoclimate records for Australasia (Augustinus, Shulmeister, Shane, Newnham & Alloway). Cores from Onepoto and Pukaki contain high-resolution records spanning 30-8 ka and those from Pupuke provide the Holocene component. All three cores were linked using tephra layers, and these, together with AMS ¹⁴C dates, provide a tight chronology. The age control may be further improved using counts of laminae in parts of the cores to provide sub-decadal to possibly annual resolution. Pollen analysis and other proxies including magnetic susceptibility, grain size, elemental composition, δ¹³C and δ¹⁵N, C/N ratios, and total OM were reported. Warming following the LGM began ~17.7 ka when podocarp forests expanded at the expense of beech forest, shrub and grassland. The pre-human Holocene record showed little change (i.e. stability). Palaeolimnological records from lakes in the Waikato region (e.g. Newnham et al. 1999), dating back to ~20 ka, may complement the Auckland records but at lesser resolution.
- (8) Loess and associated fluvial records from both SI (Almond, Hughes, Tonkin, Shulmeister, Barrell & Rieser) and NI (Litchfield & Palmer) were reported. Potential for deriving a novel palaeoprecipitation record using δ¹³C measurements of pedogenic carbonate from loess near Banks Peninsula requires resolution of conflicting ages based on cryptic KKT and OSL and ¹⁴C dating. In southern NI, loess accumulation was most extensive during the LGM but continued until 11.6 ka (from OSL dating). Tephra aided correlation and provided ages for fluvial terraces and loess deposits, the number of terraces being controlled partly by rates of tectonic uplift: areas with low rates (comparatively more stable) have more complete loess records (e.g. Wairarapa), those with high rates have more extensive fluvial records (e.g. Gisborne). An aeolian quartz flux record for the andesitic Taranaki region provided a proxy for palaeowind strength across the continental shelf off southwestern NI (Alloway). A quartz peak at 27 ka preceded deposition of KKT – marked by a drop in quartz flux – and a second occurred at 20-21 ka. The quartz flux dropped rapidly to 14.7 ka and then declined to the present. Sampling at finer intervals and measuring smaller (dust-sized) particles derived possibly from Australia offer potential for further study. On the basis of ~15-bar water contents (field moist *vs* air dry) and Al/Si atomic ratios of allophanes within upbuilding andic soil materials, the LGM was dry but the early to mid-Holocene was wet.
- (9) The extent of glaciers in NZ since ~30 ka, based on moraines and outwash surfaces and associated deposits, was reviewed (Barrell, Suggate, Almond & Rother). Glaciers were widespread in mountainous regions during the LGM but many areas became ice-free during the LGIT. Key events were: (i) advance to near full-LGM extent before KKT deposition (~26.5 ka); (ii) unknown amount of retreat; (iii) formation of multiple moraines at or inside the full LGM extent between ~23.5-19.0 ka; (iv) rapid retreat, glacier areas reduced by ~60-100%; (v) locally extensive ‘late-glacial’ advances in some high altitude catchments (HACs) ~14-11.4 ka; (vi) persistent glacier presence in HACs with multiple advances and retreats of uncertain extent after ~5.5 ka; (vii) rapid retreat since late 19th C. Based on a

regional climate model embedded within an atmospheric GCM, and coupled to SSTs and sea-ice models, the extent and thickness of ice caps in NZ for the LGM were determined and climatic parameters simulated (Drost). Mean annual cooling was 4.5-5.0° C over NZ but influenced markedly by strong cooling over the Southern Alps. Removal of that component resulted in temperatures 2.5-4.0° C cooler than today's during the LGM, with maximum cooling in winter and in the SI. Precipitation was reduced everywhere during the LGM except eastern SI (always dry). The main zone of precipitation shifted westward along western SI because glacial ice expanded laterally and vertically. Changes in wind patterns influenced both temperature and precipitation, enhancing geographic differences and seasonality during the LGM. Westerlies increased over NI but reduced in eastern SI. An increase in southerlies (both frequency and strength) affected temperatures in the SI especially.

- (10) The advantage of using tephra layers as isochrons to link and date most of the high-resolution palaeoenvironmental sequences in the NZ region was emphasised, but their ages needed 'sharpening' to meet the accuracy demanded for NZ-INT (Lowe, Hajdas, Newnham, Alloway & Hogg). Approaches include using Bayesian statistics (which allow the inclusion mathematically of stratigraphic information) and wiggle matching long stratigraphic sequences of ¹⁴C ages. New ages (reported as 2σ ranges) were determined for late-glacial and early Holocene tephras using wiggle-match dating of the Kaipo sequence via Bayesian-based OxCal. The age of late-Holocene Kaharoa Tephra was determined via wiggle matching and dendrochronology (1314 ± 12 AD) and evaluated using Bayesian analysis. KKT, erupted during the LGM, is currently dated at 22.6 ¹⁴C ka. However, attempts to reproduce this have been frustrated by a paucity of datable material preserved in chemically-stable sites, and in any event it is unable to be calibrated via INTCAL04. Other approaches include high-precision dating on appropriate material from carefully selected sites or new radiometric techniques (e.g. U-Th/He dating), or from the identification of tephras in ice cores or laminated sediments for which reliable calendar-age models have been constructed. Improved discrimination of tephras with ambiguous fingerprints requires new analyses of glass via microprobe or LA-ICPMS or of mineral phases (where available). Extending the known distribution of tephras into the SI or subantarctic islands by cryptic tephra analysis might add more tie-points between the records and hence allow climatic 'leads' or 'lags' to be determined. The distribution and stratigraphic relationships of tephras east of NZ were revealed by new piston cores obtained by Scripps' ship *Roger Revelle* (Shane, Sikes, Guilderson & others). A high-resolution record of interfingering rhyolitic, andesitic and peralkaline tephras was derived from 31 sites in Bay of Plenty, Hawke Bay, and Chatham Rise. The longest cores extended to ~50-70 ka. The tephras recorded activity from Taupo Volcanic Zone, White Is. and Mayor Is. Within the NZ-INT time period they included KKT and four derived from Mayor Is. (~20, 14, 8, & 7 ka) with distinctive peralkaline compositions.

What next?

A short discussion after the presentations concluded that two publications were now needed. Paper 1 is to critically evaluate the tephra framework for the NZ-INT timespan, led by David Lowe (Waikato University) with Phil Shane (Auckland University) and

Brent Alloway. Paper 2 is to synthesise and evaluate the high-precision OIS 2/1 records into a provisional event stratigraphy. This paper is being coordinated by Brent Alloway and Jamie Shulmeister, and the groups involved with each proxy record. Ultimately, all NZ-INT members will be co-authors. A new project, strongly endorsed by the NZ-INT group, was the proposal by Helen Neil (NIWA) to obtain a marine core from the Tasman Sea not far off-shore from the west coast of SI – possibly in 2006 or 2007. A potential coring site has been identified by exploratory mapping and shallow coring. Such a core would help to link more directly the glacial records of the SI and the various proxy records from elsewhere. NZ-INT members plan to informally review progress at the Geological Society of NZ annual conference in Kaikoura from 28 Nov-1 Dec 2005. The next Australasian INTIMATE meeting is scheduled for the Taipa Bay Resort, Northland, on 11 Feb 2006 (see http://www.sges.auckland.ac.nz/anzgg_2006/).

Summary of key points

- (1) Speleothem records from both North and South islands provide a high-precision palaeotemperature record divided into seven climatic events. The record is exceptional because it has been dated by >70 TIMS dates that circumvent the calibration problems inherent in ^{14}C dating, and thus provides a benchmark to which other records can be compared.
- (2) High-resolution pollen records at Kaipo, Okarito, and Campbell Is., well spaced latitudinally and altitudinally, are able to be enhanced through the development of a novel pollen-based temperature transfer function.
- (3) Long lake records from the Auckland region offer very high resolution and potentially sub-decadal chronologies or better and have the advantage of providing a wide range of proxies that enable palaeoenvironments to be reconstructed in detail.
- (4) Core MD97-2121 provides an exceptional high-resolution record of ocean change during the LGIT period that generally corresponds well with the Kaipo bog and speleothem records in timing.
- (5) Apart from the speleothem and Campbell Is. records, tephra layers link all the records. The NI records, including MD97-2121, contain multiple tie points and isochrons. Cryptotephrochronology could provide more. However, the precision of the ages on some of the tephras, especially during the LGM and LGIT periods, needs improving. KKT is a critical target because it is so widespread, and tephras marking boundaries of climate events (e.g. Rerewhakaaitu ~17.7 ka, Waiohau ~14.0 ka) are also targets.
- (6) Currently the EPICA (Dome C) core provides the optimum ice-core record for correlation for NZ-INT.
- (7) Records of glacial and associated deposits, loess, and aeolian quartz, although fragmentary, provide essential data and with improved dating potentially offer further insight into regional climate variations including 'leads' and lags'.
- (8) Modelling of climates is important to provide an integrated overview.
- (9) A new core from the Tasman Sea near Westland, if it can be funded, is urgent.

References

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Fig. 1. NZ-INTIMATE members at the Rafter Research Centre, Lower Hutt, 5 July 2005.

Back row (L-R): James Crampton, Jeremy Cole-Baker, Phil Burge, David Lowe, Phil Shane, Martin Crundwell, Matt McGlone, David Barrell, and Chris Hendy

Middle row (L-R): Lionel Carter, Christine Prior, John Carter, Paul Augustinus, Jamie Shulmeister, Helen Neil, Pat Suggate, Fred Knox, Frank Drost, Paul Williams, Dallas Mildenhall and Darren King

Front row (L-R): Margaret Harper, Chris Hollis, Matthew Hughes, David Kennedy, Peter (Freddy) Almond, Liz Kennedy, Caell Waikari and Yanbin Deng

Kneeling: Brent Alloway

Absent: Maureen Marra, Nancy Bertler, Tim Naish, Ian Graham, Ursula Cochran, Erica Crouch, Percy Strong, Andrew Mackintosh, Albert Zondervan, Nicola Lichfield and Robert Langridge

