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AQUA

Co-organised through the **Geological Society of New Zealand** (GSNZ) and the **Australasian Quaternary Association** (AQUA)

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2004 NZ-INTIMATE* Meeting

GNS-Rafter Laboratory, Wellington:
23rd & 24th August, 2004

Convener – Brent Alloway

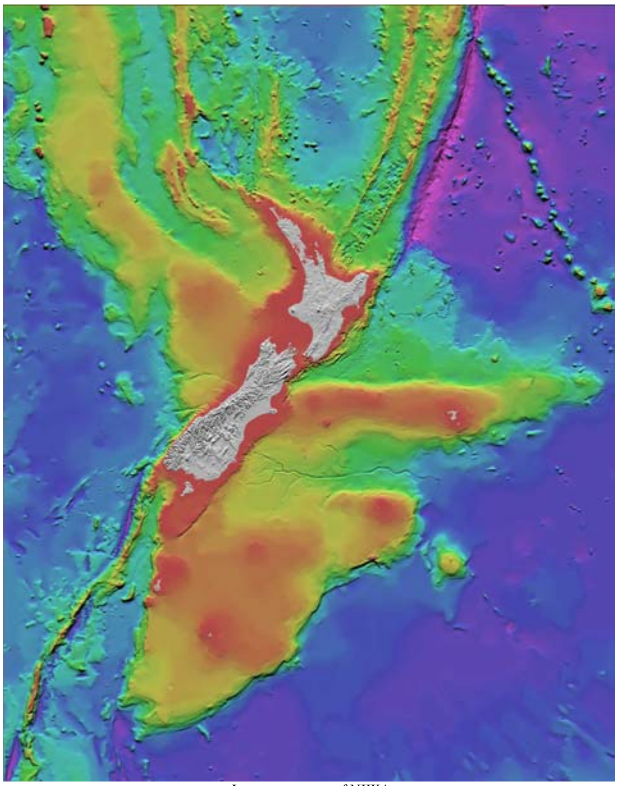

Image courtesy of NIWA

*** INTegration of Ice-cores, Marine and TErrestrial records**

PREFACE: TOWARDS AN INTIMATE EVENT STRATIGRAPHY FOR NEW ZEALAND

Jamie Shulmeister [1], Brent Alloway [2] and Rewi Newnham [3]

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"The hypothesis which we accept ought to explain phenomena which we have observed. But they ought to do more than this: our hypothesis ought to foretell phenomena which have not yet been observed" William Whewell (1794-1866)

Since 1997, INTIMATE (INTegration of Ice-core, Marine and TErrestrial records – a core programme of the INQUA (International Union for Quaternary Research) Paleoclimate Commission) project members have, through a series of international workshops, sought ways to improve procedures for establishing the precise ages of, and effecting high resolution correlations between, events of the Last Termination. There have been two major driving forces behind this. First was the publication of the GRIP and GISP2 ice-core records (Alley et al. 1993; Johnsen et al. 2001), which showed that environmental changes during the Last Termination were more abrupt and complex than had previously been realised. They demonstrated the need for methods that enabled the sequence of events during the Last Termination to be reconstructed at the decadal time–scale. The second was the growing realisation of the severity of the difficulties that affect radiocarbon dates, the method most widely used to date the Last Termination events. INTIMATE members have therefore proposed a number of ways by which clarity and precision might be improved, and these include an event stratigraphy basis for correlation (Bjorck et al. 1998; Walker et al. 1999; Lowe et al. 2001), improved protocols for radiocarbon dating (e.g. Wohlfarth, 1996; Lowe and Walker, 2000) and tephrochronology (Turney at al. 2004), correlation based on stratigraphical methods thought to reflect synchronous regional or global changes (e.g. oxygen isotope stratigraphy; Hoek and Bohncke, 2001) and more effective use of sites with annually laminated sediment sequences (e.g. Litt et al., 2001).

The 2004 NZ-INTIMATE workshop is specifically directed at the NZ paleoclimate community to:

(a) identify and prioritise New Zealand onshore and offshore reference records for MIS 2 and 2/1 transition with the ultimate goal of developing an event stratigraphy for the region, and
(b) promote ways to improve procedures for establishing the precise ages of, and effecting high resolution correlations between, these key onshore and offshore NZ records.

Outcomes of the workshop will be presented at the Australasian-INTIMATE meeting held in conjunction with the AQUA biennial meeting in Tasmania (Dec. 2004). They will also be reported to the 2004 North Atlantic Workshop in Germany in September.

With reference to the two general objectives for the meeting, we suggest that the NZ Workshop should make progress with several issues identified at our previous meetings.

A major target of this workshop should be the reconciliation of marine and terrestrial records at the LGM (~25-18 ka, Houghton et al. 2001). For example - extrapolation of climate from sea-surface temperature (SST) reconstructions suggest that very harsh conditions should have existed over much of New Zealand. This is inconsistent with the persistence of woody vegetation in the far south of South Island. Similarly, the elimination of continuous lowland forest to the south of ca. 38 ^{O}S, when more extensive forest persisted to the north, also requires reconciliation with SST reconstructions.

(1) The NZ 'LGM', currently defined (by Pillans et al., 1993) as ~25 – 15 ka, requires close examination both in terms of timing of onset and termination and in the spatio-temporal patterns of climate change exhibited (and leaving aside the question of whether 'LGM' is indeed a suitable label) Of particular interest are observations of relatively mild climate at times within this overall cold period. Clearly, deciphering the LGM record in a much greater level of detail is a key objective.

(2) In the last few years there has been good progress in our understanding of the NZ deglaciation (~18 to 10 ka) and there is now much international as well as local interest in records from our region. Nevertheless we must expect complexity during this interval. A major challenge for our group is to establish robust spatio-temporal patterns of climate change depicted in the NZ record and to identify any apparent differences between records that may be attributed to limitations in the data.

In order for this group to successfully establish regional patterns of climate change, we need to get our chronology right. The primary issues appear to be as follows:

(a) The adoption of a standard calibration for radiocarbon ages and rigid adherence to the standard once we agree on it. This should include an agreed protocol for calibrating ^{14}C ages beyond 20 ka.
(b) Tephrochronology offers unrivalled opportunity for high precision dating and correlation in our region but we must be careful to establish, and work within, the error margins of age constraints for each tephra as well as identify important issues of uncertainty. For example, some ^{14}C and many luminescence ages on samples bracketing the Kawakawa Tephra are consistently younger than the 'established' age by 1-3 ka. An outcome from this workshop would be a resolution to write a review paper on the NZ tephrochronostratigraphic framework for our interval of interest headed by the tephra specialists within the group but under the auspices of Australasian INTIMATE.
(c) We should also recognize that the eventual identification and geochemical characterisation of *cryptotephra* dispersed in distal terrestrial and marine sediments should enable us to extend the tephrochronologic framework to areas where no visible tephra records are available, and perhaps ultimately into the ice core domain.

Finally, we would like to re-emphasise the need to highlight gaps in our records and deficiencies in our understanding so that we can target a limited number of new records to develop or, alternatively, enhancement of existing records. This effort needs to be carefully prioritized as in our funding environment it may be difficult to establish new records within the lifetime of the current project. It is nevertheless worthwhile.

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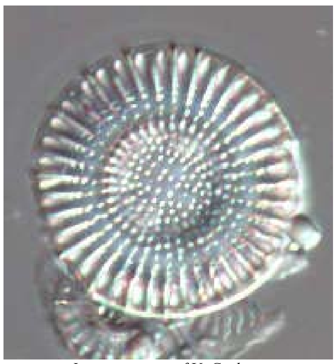
Image courtesy of H. Rother



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GUIDE TO TERMINOLOGY USED IN PALEOCLIMATE STUDIES OF THE LAST 150,000 YEARS

Houghton et al., IPCC (2001) Scientific Basis - Chapter 2, page 137

"Event"	**Stage Estimated age (calendar years)**
Holocene	~10 ky BP to present
Holocene maximum warming (also referred to as "climatic optimum")	Variable? ~4.5 to 6 ky BP (Europe) 10 to 6 ky BP (SH)
Last deglaciation	~18 to 10 ky BP
Termination 1	~14 ky BP
Younger Dryas (YD)	~12.7 to 11.5 ky BP
Antarctic cold reversal (ACR)	14 to 13 ky BP
Bölling-Alleröd warm period	14.5 to 13 ky BP (Europe)
Last glacial	~74 to 14 ky BP
LGM (last glacial maximum)	~25 to 18 ky BP
Last interglacial peak	~124 ky BP
Termination 2	~130 ky BP
Eemian/MIS stage 5e	~128 to 118 ky BP
Heinrich events	Peaks of ice-rafted detritus in marine sediments, ~7 to 10 ky time-scale.
Dansgaard-Oeschger events	Warm-cold oscillations determined from ice cores with duration ~2 to 3 ky (now ~1500 yr).
Bond cycles	A quasi-cycle during the last Ice Age whose period is equal to the time between successive Heinrich events.
Terminations	Periods of rapid deglaciation.

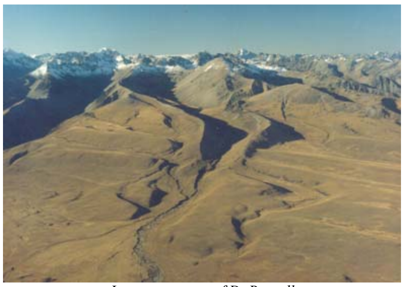

Image courtesy of D. Barrell

Image courtesy of GNS

WORKSHOP CONTRIBUTIONS:

Image courtesy of H. Rother

PROGRAMME:

MONDAY 23RD, AUGUST

8.30-9.00 am **INTRODUCTION**

Towards an INTIMATE event stratigraphy for New Zealand
Jamie Shulmeister, Brent Alloway and Rewi Newnham

09.00-10.00 am **PALYNOSTRAT. RECORDS**

Palynology of the termination of the Last Glaciation in New Zealand
Matt McGlone

Improved chronology for late-glacial climate reversal recorded at Kaipo Bog tephropalynological sequence, New Zealand
David J. Lowe, Rewi M. Newnham and Irka Hajdas

10.00-10.30 am Morning Tea

10.30-12.30 noon **NZ & ANTARCTIC GLACIAL RECORDS**

The Westland glacial sequence: its relevance to "global" boxes with time boundaries ?
R. Patrick Suggate and Peter C. Almond

Mountain glaciations in the Southern Alps of Canterbury between 30 – 8 ka: A review of the glacial records from the Rangitata, Rakaia, Waimakariri and Waiau valleys
Henrik Rother

Glacier-climate studies in New Zealand: present day measurements and modeling of Quaternary ice extent
Andrew Mackintosh, Brian Anderson, and Julian Thomson

The late-glacial climate of New Zealand: Evidence from numerical modelling of the Franz Josef Glacier
Brian Anderson and Andrew Mackintosh

Late Cenozoic glacial history of the Rennick Glacier, Northern Victoria Land, Antarctica
Paul Augustinus, David Fink, John Hellstrom, and Derek Fabel

12.30-1.30 pm LUNCH - IRL Café

1.30-2.00 pm **LOESS RECORDS**

Late last glacial loess in the North Island of New Zealand: An overview
Alan Palmer

OIS 2/1 transition and OIS 2 loess in South Island
Philip Tonkin, Peter Almond, David Barrell, and James Shulmeister

2.30-3.30 pm **MAAR/LAKE RECORDS**

Maar lake records and climate event stratigraphy for New Zealand from 30-8 ka
James Shulmeister and Paul C. Augustinus

A 6500 (^{14}C) year storm record from lake sediments, Hawke's Bay, New Zealand
Mike Page, Noel Trustrum, Lionel Carter, Alan Palmer, Hannah Brackley, and Lisa Northcote

The potential for retrieving a high-resolution southern mid-latitude record of LGM to post-glacial climate change from beneath Lake Pukaki, South Island, New Zealand
Brent Alloway, David J.A. Barrell and Dan Barker

3.30-4.00 pm Afternoon Tea

4.00-4.30 pm **SPELEOTHEM RECORDS**

Late Pleistocene to Holocene speleothem ^{18}O and ^{13}C records from South Island, New Zealand, and their palaeo-environmental interpretation
Paul W. Williams, Darren N.T. King, Jian-xin Zhao, and Kenneth D. Collerson

4.30-5.00 pm **DAY-1 DISCUSSION**

TUESDAY 24TH, AUGUST

8.30-10.00 am **MARINE RECORDS**

Sediment flux to the New Zealand ocean – responding to climatic, sea-level, oceanic and tectonic drivers
Lionel Carter and Barbara Manighetti

Refined microfossil-based paleoclimate records from late Quaternary marine cores, offshore eastern New Zealand
Chris Hollis, George Scott, Chris Prior, Helen Neil, Barbara Manighetti, Martin Crundwell, Erica Crouch, and Ursula Cochran

The INTIMATE detail of marine climate change: A high resolution record
Barbara Manighetti

10.00-10.30 am Morning Tea

10.30-11.00 noon **MARINE RECORDS con't**

Sedimentation during the LGM and OIS 3 in the Tasman Sea: Preliminary deep-water coring evidence from off Lord Howe Island
David M. Kennedy and Caell Waikari

11.00-11.30 noon **ICE-CORE RECORDS**

Ice cores – the archive of rapid climate change
Nancy Bertler, Tim Naish and Uwe Morgenstern

11.30-12.30 noon **ENHANCING CHRONOLOGY**

Some new developments in tephrochronology and implications for the MOI Stage 2 to 1 transition in New Zealand
Phil Shane

Developing a New Zealand tephrochronological framework for the Last Termination
Chris S.M. Turney, Brent V. Alloway, David J. Lowe and Siwan M. Davies

12.30-1.30 pm Lunch-IRL Café

1.30-3.00 pm **ENHANCING CHRONOLOGY con't**

Exposure dating cold-climate geomorphology using cosmogenic isotopes
Tim T. Barrows and Keith L. Fifield

^{10}Be surface exposure-age dating of raised marine terraces, Turakirae Head, Wellington
Ian J. Graham and Albert Zondervan

Developments in radiocarbon calibration: Can refinements of the calibration curve lead to increased precision?
Christine A. Prior

The search for abrupt climate change impact on New Zealand
Chris Hendy, Penny Cooke, Thomas Whittaker, and Jeremy Barker-Cole

3.00-3.30 pm Afternoon Tea

3.30-4.00 pm **ENHANCING CHRONOLOGY con't**

OSL ages for OIS 2 and older loess and aggradation river terrace deposits in the eastern North Island
Nicola J. Litchfield and Uwe Rieser

4.00 -5.00 pm **SUMMARY / RECOMMENDATIONS**

MEETING ABSTRACTS

Image courtesy of N. Bertler

Image courtesy of P. Almond

Image courtesy of GNS

THE POTENTIAL FOR RETRIEVING A HIGH-RESOLUTION SOUTHERN MID-LATITUDE RECORD OF LGM TO POST-GLACIAL CLIMATE CHANGE FROM BENEATH LAKE PUKAKI, SOUTH ISLAND, NEW ZEALAND

Brent Alloway *[1], David J.A. Barrell [2], and Dan Barker [3]

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An understanding of asynchronous climate change between Northern and Southern Hemispheres during and since the last deglaciation requires more detailed information on climate history across the critical mid-latitude temperate zones. The 500-km-long Southern Alps, extending from 42°S to 45°S at the junction between subtropical and polar air masses and near major ocean fronts such as the Subtropical Front (STF), combined with their vast sediment flux derived through high rates of mountain uplift and erosion, makes the Southern Alps environment a highly sensitive monitor of climate change.

Lake Pukaki is located on the eastern side of the Southern Alps and is one of three large post-glacial lakes occupying formerly glaciated troughs at the head of the Waitaki River. Much of the Pukaki catchment lies in Mount Cook National Park and is New Zealand's most glaciated catchment, with glaciers presently covering more than 210 km^2. Dammed behind moraines formed during the Last Glacial Maximum (LGM), the Pukaki glacial trough (Pukaki Basin) has been a very effective sediment trap that contains a near-complete record of sediment delivery from the catchment and information on climate change over the past c.17,000 calendar years since the last main retreat of ice.

To date, our collective efforts have focused on assessing the feasibility of retrieving a long sedimentary core from beneath Lake Pukaki and we have conducted seismic surveys across the lake. Recently acquired data show fine parallel reflections of lake sediment up to 400 m thickness overlying basement below the southern central portions of Lake Pukaki under c. 90-100 m of water. The reflection character suggests a relatively undisturbed sedimentary sequence implying potential preservation of a fine-scale record. We propose to core the full depth of the sedimentary sequence in order to obtain a record of unparalleled quality (annual resolution – 1 year = 3cm of sediment) of Southern Alps climate. Such a record will provide a continuous rainfall and wind record for the Pukaki catchment which then can be used to assess the frequency, scale and magnitude of abrupt events.

We are seeking to form a national & international research consortium to retrieve this high-resolution sedimentary record from beneath Lake Pukaki and document sub-decadal (annual?) scale biotic and abiotic signatures of climate history. Variations in climate proxies will assist us to construct and compare regional and inter-regional paleoclimatic signatures and rates of change. The core provides an important linkage between adjacent glacial (i.e. Tasman) and marine (i.e. DSDP-594) records and offers the prospect, not only of making a major contribution to the knowledge of southern mid-latitude climate dynamics, but will also significantly improve our knowledge of the hydrology and climatology of South Island drainage basins. Ultimately, this project aims to: 1) improve our knowledge of climate dynamics and ability to predict abrupt climate change in NZ, and 2) provide a stronger scientific foundation for future societal initiatives to improve regional economic and environmental resilience and adaptability.

AN INTEGRATED LGM TO POST-GLACIAL PALEOENVIRONMENTAL RECORD FROM TARANAKI, WESTERN NORTH ISLAND, NEW ZEALAND

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Taranaki, situated in western North Island, has a number of important regional attributes that promote the preservation of multi-proxy LGM to post-glacial paleoenvironmental records. Firstly, its exposed western coastal position with an adjacent broad continental shelf is ideally located for registering subtle fluctuations in windiness, precipitation and temperature. Secondly, the region has been dominated by an intermittent but continuously active Egmont Volcano that has provided a steady supply of volcaniclastic deposits over a c. 127 ka interval *[1]*. This eruptive centre has facilitated the preservation of lake and peat sediments as well as provided the primary source of andic deposits whose properties are significantly influenced by climatic fluctuations. In addition, Egmont-sourced tephra beds have proven themselves as useful chronostratigraphic markers enabling regional and inter-regional correlation.

Coalesced fans of laharic, pyroclastic and alluvial deposits extending from Egmont Volcano have facilitated the formation of peat deposits either in enclosed depressions developed at the fan margins or upon initial depositional surfaces. One such preserved peat deposit was identified beneath a prominent lahar deposit at Durham Road and this section provides a key late last glacial to early post-glacial record of vegetation and climate change in central Taranaki *[2, 3]*. Elsewhere on depositional surfaces, allophanic-dominated soils (Andisols) have accumulated from episodic accretion, and subsequent weathering of aerially transported fine-grain sediment of dominantly andesitic provenance. The strongly contrasting morphological characteristics of reddish (Sr-) and loess-like yellowish (Sy-) beds indicate that the intensity of surficial weathering has not remained constant and that variations reflect climatic oscillations *[2, 4, 5]*. The age of Sr- and Sy- beds can be established from the presence of numerous ^{14}C-dated Egmont-derived andesitic tephras, three widespread TVZ silicic tephras found within the succession, and by matching the climate intervals deduced from the succession of beds to the standard $\delta^{18}O$ stages of deep sea cores. The two-fold subdivision of the uppermost yellowish bed (Sy1) lends support to recent sub-subdivision of LGM glacial deposits of Westland (see Suggate and Almond, *this volume*). Aerosolic quartz flux within andic beds has also been determined and indicates a pronounced peak coinciding with the accretion of Sy1 during $\delta^{18}O$ Stage 2 *[6]*. Quartz flux determined at two sites (Waitui & Onaero) is near-synchronous but is not constant. Variations in quartz flux appear to reflect fluctuations in wind strength during the LGM.

Finally, the proximal Egmont-sourced tephrostratigraphy is well-known *[1]* and has already been pivotal in evaluating the paleoclimatic correspondence between the bio- and soil-stratigraphic records in Taranaki. Efforts are now underway that focus on geochemically characterising proximal tephra beds so that they might be correlated with equivalent layers preserved in distal high resolution onshore (i.e. Waikato, Pukaki maar crater, Kaipo, Tutira) and offshore (i.e. MD97-2121) successions.

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[6] Alloway, B. V., Stewart, R. B., Neall, V. E., and Vucetich, C. G. (1992c). Climate of the last glaciation in New Zealand, based on aerosolic quartz influx in an andesitic terrain. *Quaternary Research* **38**, 170 -179.

THE LATE-GLACIAL CLIMATE OF NEW ZEALAND: EVIDENCE FROM NUMERICAL MODELLING OF THE FRANZ JOSEF GLACIER

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During the Younger Dryas, temperatures in the North Atlantic region returned to full glacial conditions, with cooling demonstrated in many localities. In the mid-latitudes of the Southern Hemisphere, it has been debated as to whether a Younger Dryas cooling occurred. The Waiho Loop is the best known evidence of Younger Dryas glacier advance in New Zealand (Denton and Hendy, 1994), but no quantitative attempt has been made to determine the climatic significance of the advance. We address this problem by applying a degree-day mass balance and numerical flow model to the Franz Josef Glacier, New Zealand, with the aim of studying the advance to the Waiho Loop moraine. Our results indicate that full glacial conditions, with 4.1-4.7°C of cooling with no change in precipitation are required for a Waiho Loop advance. The same glacial advance can be simulated by increasing precipitation with no change in temperature, but the required precipitation increase is extremely large and unrealistic. It is unlikely that the Waiho Loop was formed during the late-glacial because local pollen records preclude a return to glacial conditions in New Zealand at this time. The ^{14}C dates which Denton and Hendy (1994) argue date the Waiho Loop advance come from Canavans Knob, 1.6 km up-glacier of the Waiho Loop. An advance to Canavans Knob requires a cooling of 3.1°C with no change in precipitation, or a 2°C cooling with a 50% increase in precipitation. This relatively modest cooling is consistent with pollen data. Hence we suggest that the glacier advanced to Canavans Knob, but not the Waiho Loop, during the late-glacial period and that the Waiho Loop is an older feature. The Canavans Knob ^{14}C dates require a remote source for the dated wood fragments to put the advance in the Younger Dryas chron. Transport times for wood fragments along the glacier calculated from the numerical flow model indicate that the advance occurred a few decades earlier than previously suggested.

LATE CENOZOIC GLACIAL HISTORY OF THE RENNICK GLACIER, NORTHERN VICTORIA LAND, ANTARCTICA

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[4] Research School of Earth Sciences, Australian National University, Canberra, Australia

The project involves mapping and dating of fluctuations of the Rennick Glacier system which flows directly from the Northern Victoria Land (NVL) sector of the Transantarctic Mountains (TAMs) into the Southern Ocean. The record from the Rennick Glacier is significant for understanding ice sheet response to Late Cenozoic global climate change as such a history would be difficult to obtain from outlet glaciers draining Southern Victoria Land due to the influence of the Ross Ice Shelf buffer on the timing of glacier expansion.

The timing of the phases of late Quaternary glacial expansion remains virtually unknown in NVL, although exposure-age dating using cosmogenic nuclides (CNs) ^{10}Be and ^{26}Al has recently proved successful in dating phases of ice sheet growth elsewhere in the TAMs. This method is ideally suited to dating moraines developed during phases of expansion of the Rennick Glacier system as there are no materials available for dating these episodes using more conventional methods, and allowed the dating of multiple phases of glacier expansion identified during morphostratigraphic mapping of the drift sequences. The moraines and associated drift sheets were emplaced largely during and subsequent to MIS 6, with the CN exposure ages providing evidence for phases of local ice cap expansion as well as phase of thickening of the EAIS. Thick LGM ice extended over the region with maximum thickening between 29 and ~16 kyr followed by lowering and establishment of near present levels by ca 13 kyr in the upper part of the system, and by 7 kyr in the lower sector where glacier surface levels were controlled by grounding line fluctuations driven by glacioeustacy. This contrasts with the post-LGM record from Marie Byrd Land (Stone et al. (2003) where steady deglaciation has occurred since 10.4 kyr and lag the disappearance of the Northern Hemisphere ice sheets by several thousand years. The contrast suggests that NVL ice contributed little to late glacial-Holocene sea-level rise.

Multi-collector-ICP-MS and LA-ICP-MS U-series dating of subglacial calcite collected from ice-moulded bedrock surfaces in the lower Rennick Glacier provides a tightly constrained series of ages that complement the exposure age dating of the same sites. The calcite precipitates indicate multiple phases of calcite growth that correspond with phases of ice sheet thickening. However, the U series ages indicate that there has been minimal erosion of the ice-moulded bedrock hummocks with thick ice present cover the region for at least the last 350 kyr, a model that conflicts with the simple exposure history interpretation of the CN ages and indicates the importance of multi-method approaches to dating geomorphic features.

Reference:

Stone, J.O. et al., 2003. Holocene deglaciation of Marie Byrd Land, west Antarctica. *Science*, 299: 99-102.

CSIGG - CENTRAL SOUTH ISLAND GLACIAL GEOMORPHOLOGY MAP

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An international collaborative effort is underway to produce a regional glacial geomorphic map of the central part of the Southern Alps, South Island, New Zealand. The map is intended to provide a fundamental platform for a diverse range of current and future research and analyses of paleoclimate records in the region. The maritime setting and alignment of the Southern Alps athwart the mid-latitude westerly wind belt creates a unique environment for quantifying the dynamics of climate fluctuations. In particular the climatic transition from the super-humid western slopes to the near semi-arid rain-shadow eastern slopes over a zone less than 100 km wide presents an opportunity to quantify the roles of precipitation, temperatures and other variables within past episodes of climate change recorded in glacial and associated deposits.

The mapping uses a range of traditional techniques including aerial photograph interpretation and field examination, supported in many places by dating and pollen analyses to provide chronological context. The map focuses on the accurate depiction of morphology, the main elements of which are moraine ridges, areas of hummocky ground or recessional moraine, and outwash alluvial terraces and plains. The map is compiled at 1:50,000 scale, with an intended presentation scale of 1:100,000.

An important feature of the map is its compilation in a GIS system, which allows easy presentation of a single dataset in a variety of tailored ways, based on the range of attributes assigned to each map unit. For example, the map can be displayed with a full chronological interpretation, whereby map units are assigned to a best-estimate Marine Oxygen Isotope (MIS) Stage number, presented either as MIS values, or the equivalent NZ glacial/interglacial stage name. Alternatively, the same map can be displayed in colours that simply depict the nature of the morphologic type, such as moraine ridge, moraine, or alluvial surface, with or without a generalised age connotation. In the GIS environment, it is also easy to display dating, or analytical, results overlaid on the map, and the data can be interrogated online to obtain the site-specific results.

The mapping is well advanced. Digital coverage presently extends from Karangarua north to the Grey River on the western side of the Southern Alps, and encompassing the Waitaki catchment to the east. In the near future we will extend the mapping in the east to include the Rangitata, Ashburton and Rakaia catchments. We also intend to build a database of dating and analytical results, and as part of this it is planned to convert the GNS Rafter Radiocarbon database into a GIS format, so that relevant results can be displayed in conjunction with the CSIGG map. A preliminary draft of the CSIGG map is available for viewing and interrogation at http://wyvern.gns.cri.nz/website/csigg/. The major collaborators to the project are listed at that web address.

EXPOSURE DATING COLD-CLIMATE GEOMORPHOLOGY USING COSMOGENIC ISOTOPES

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Exposure dating is based on the principle that the accumulation of cosmogenic isotopes (those produced by interactions with cosmic rays) in surface rocks is a function of time. A basic assumption is that a surface is created 'instantaneously' at some point and remains in the same geometry until sampling. Concentrations of cosmogenic isotopes (e.g., ^{10}Be, ^{26}Al, and ^{36}Cl) are typically of the order of 10^{-12} with relation to their stable counterparts, and therefore usually require measurement by accelerator mass spectrometry. Virtually, any rock can be exposure dated; the isotope that needs to be measured depends on the lithology. A quartz mineral separate is usually favored due to its simple chemistry and because cosmogenic ^{10}Be and ^{26}Al can both be isolated relatively easily. The isotope ^{36}Cl can be produced by a variety of reactions and so is found in most rocks. However, the number of reactions and the fact that it also occurs naturally means that the age calculation is not straightforward. To calculate an exposure age, the production rate of the isotope must be well known. Several factors (particularly altitude and latitude) control the cosmic ray flux, and therefore scale the production rate at any particular site and need to be carefully accounted for when calculating an exposure age. Exposure dating has revolutionized the way we study glacial landscapes. By directly dating glacial debris we can now construct quantitative chronologies for the advance and retreat of ice. In Australia we identify at least 5 distinct glacier advances during the Early to Late Kosciuszko glaciation from 70,000-15,000 (Barrows et al., 2001, 2002). Exposure dating of periglacial deposits reveals a maximum of cold-climate activity from 16,000-23,000 yr (Barrows et al., 2004).

References:

Barrows, T. T., J. O., Stone, L. K., Fifield, and R. G., Cresswell, (2001). Late Pleistocene glaciation of the Kosciuszko Massif, Snowy Mountains, Australia. *Quaternary Research*, 55: 179-189.

Barrows, T. T., J. O., Stone, L. K., Fifield, and R. G., Cresswell, (2002). The timing of the last glacial maximum in Australia. *Quaternary Science Reviews*, 21: 159-173.

Barrows, T. T., Stone, J. O., and Fifield L. K. (2004). Exposure ages for Pleistocene periglacial ages in Australia. *Quaternary Science Reviews*, 23: 697-708.

ICE CORES – THE ARCHIVE OF RAPID CLIMATE CHANGE

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Ice Cores provide the most direct, continuous and high resolution record of climate variability over the past 1 million years (EPICA Community Members, 2004, Nature 429). Their analysis has allowed human-induced global warming to be extracted from the background climate state and led to the discovery of rapid climate change events (Alley 2000, Mayewski & White 2002). Until 1992 scientists argued that climate operated slowly and gradually. It was thought that global temperature cooled by about -8ºC from interglacial to glacial over the period of about 100,000 years and warmed 'relatively' fast within 2,000 to 4,000 years to the next interglacial. But ice core records revealed that natural climate variability can operate extremely rapidly, with temperature shifts in Greenland of as much as -30ºC within decades (Mayewski & White 2002).

Ice cores from New Zealand and the Antarctic margin can address the lack of longer-term climate observations in the Southern Hemisphere (Mullan et al. 2001, Mann & Jones 2003) with near instrumental quality (Alley 2000, Mayewski & White 2002). Their study helps us to improve our understanding of regional patterns of climate behaviour in Antarctica and its influence on New Zealand (Chen et al. 1996, White & Cherry 1999, Ribera & Mann 2003), leading to more realistic regional climate models (Mullan et al. 2001).

This is important on all time scales. The pacing of Dansgaard-Oeschger Events, culminating in the Younger Dryas – Antarctic Cold Reversal climate oscillation, can only be resolved with continuous and well-dated records, such as ice core records from high accumulation sites. Furthermore, the influence of higher frequency oscillating climate drivers, such as ENSO, Antarctic Circumpolar Wave, Antarctic Circumpolar Wave, Transpolar Index, Pacific Decadal Oscillation, etc. can be investigated using sub-annually resolved climate records from ice cores.

The presentation aims to summarise the results of the international ice core community on the climate variability the since the Last Glacial Maximum and to provide an outlook of their use for the next decade.

SEDIMENT FLUX TO THE NEW ZEALAND OCEAN – RESPONDING TO CLIMATIC, SEA-LEVEL, OCEANIC AND TECTONIC DRIVERS

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The sediment flux to the ocean, bordering a collisional plate boundary, is large but variable as revealed by 136 kyr-long record derived from a 34.9m-long, giant piston core (MD97 2121) taken off eastern New Zealand. This core was analyzed to yield a century or finer scale record for Marine Isotope Stages (MIS) 1 and 2, but the analysis was extended to MIS 6 to test the validity of the younger record. Mass accumulation rates (MARs) were derived for terrigenous and biogenic (carbonate and silica) components using a stable isotope age model refined with tephra-based and radiocarbon dates.

Terrigenous MARs change in phase with glacio-eustatic fluctuations of sea level. Highest rates ($\geq$ 30g/cm^2/kyr) coincide with late regressive-lowstand-early transgressive phases when rivers discharged at or near the shelf edge. These rates include an unspecified aeolian component. Lesser, but still high terrigenous MARs (20-30g/cm^2/kyr) occur during peak warm phases of marine isotope stages (MIS 5 and 1) when a strengthened Subtropical Inflow introduced sediment via local erosion of the seafloor and high discharge rivers to the north of MD97 2121. However, during prolonged highstands, such as the last 6.5 kyr, the ocean flux declined, confirming the efficiency of a tectonically subsiding inner to middle shelf, and along-shelf transport regime to capture sediment. Although a time of lowered sea level, MIS 4 has the lowest MARs (10-15g/cm^2/kyr). Either it was a time of reduced fluvial input or sediment transport was mainly along the continental shelf or both these processes. Superimposed on these glacial-interglacial cycles are short-term climatic imprints, for example, around 4.5 kyr, the pattern of sedimentation changed when the supply became more fluctuating in quantity and grain size; a phenomenon attributed to a change in terrestrial erosional styles commensurate with the onset of strengthened ENSO cycles.

Biogenic MARs near the margin are also high, being 2-4 times larger than in the open ocean. Peak fluxes of biogenic carbonate (5-6g/cm^2/kyr) and silica (2-2.5g/cm^2/kyr) occur during warm stages following rapid rises in the glacial-interglacial transition. Such times of high oceanic productivity are related to the warmer temperatures and the interchange of macronutrient-rich/micronutrient-poor Subantarctic Water with macronutrient-poor but micronutrient-rich Subtropical Water. That peak production occurs out of phase with aeolian MAR maxima, suggests that Fe-fertilization by airborne dust is not the dominant control.

^{10}Be SURFACE EXPOSURE-AGE DATING OF RAISED MARINE TERRACES, TURAKIRAE HEAD, WELLINGTON

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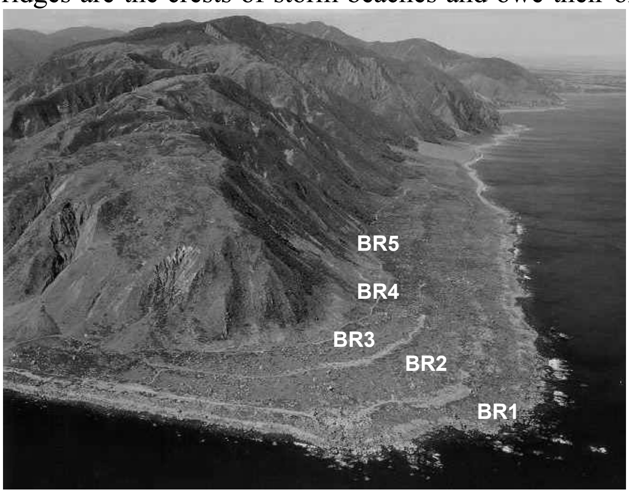
Geological processes at the Earth's surface have a profound effect on human activity. Interactions between various elements of the landscape influence the harshness of floods, the danger of earthquakes, the severity of landslides, the potential of soil erosion of croplands, and the reliability of water supplies. Landscape constantly evolves through the forces of tectonics, climate, weathering and hydrology, and analysis of its evolution provides insight into the controls on processes. Of prime importance is an understanding of the timing of events, allowing determination of cause and effect, and rates of change. The time period most relevant to this is the last two Myr, the Quaternary Period. Geological surfaces and deposits are, however, difficult to date by conventional methods within this time period. Surface exposure-age dating (SED) using cosmogenic isotopes (i.e. nuclides produced by cosmic rays) can help resolve this problem. Geological materials, exposed to high-energy cosmic ray particles (principally neutrons and muons), build up small amounts of unstable and stable nuclides through nuclear reactions between these rays and target nuclei (e.g., O, Si, K, Ca, Cl, Al, Fe, Mg). Of all cosmogenic nuclides, particularly useful are the radio-nuclides ^{10}Be, ^{14}C, ^{26}Al and ^{36}Cl, and the stable nuclides ^{21}Ne and ^{3}He, which can be measured precisely by accelerator and noble-gas mass spectrometry, respectively. Measurements of these isotopes, either singly or in combination, have been used successfully to determine the timing of glaciations, debris and lava flows, tectonic uplift, meteorite impacts and erosion rates over the time period 0-10 Ma, but particularly 5-50 ka.

The coastal section at Turakirae Head is a gazetted site of special scientific interest preserving a flight of Holocene marine terraces with sporadic outcrops of Mesozoic greywacke. The beach ridges are the crests of storm beaches and owe their origin to a very stormy coast, and episodic tectonic uplift. The most recent uplift (BR1) occurred as a result of the Wellington - Wairarapa earthquake of 1855, the next (BR2) formed prior to 1855, while the third (BR3) is AMS radiocarbon dated at c. 330 BC. The higher terraces (BR4 & BR5) are both considered younger than c. 7000 BP, coinciding with the end of the post-glacial sea level rise when extensive beaches began to form globally. The beach ridges BR1-BR4 are tilted relative to sea level, at a mean rate of c. 4 m per 1000 years. ^{10}Be SED of BR5, 26m above present sea level, is consistent with this uplift rate. Correction of the sea level, >60° latitude ^{10}Be production rate (taken to be 5.2 atoms g^{-1} SiO_2 y^{-1}) was required for geomagnetic latitude (-7%), altitude (+2%), site geometry and sampling depth. Exposed rock surfaces at the sampling site show little sign of erosion, and are covered with only sparse, thin layers of moss, so correction for these geological factors was not required. Calculated exposure ages of 5.5 - 6 ka are broadly consistent with, though slightly younger than the expected age of c. 6.5 - 7.0 ka, marking post-glacial sea level rise.



THE SEARCH FOR ABRUPT CLIMATE CHANGE IMPACT ON NEW ZEALAND

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The discovery of evidence for Abrupt Climate Changes, firstly in Greenland ice cores, and subsequently in North Atlantic oceanic sediments has thrown the field of palaeoclimate research on its 'ear'. The magnitude of the changes (typically half a full glacial/interglacial scale), and the speed of the change (in less than a decade, and maybe within a year) are very hard to duplicate with existing climate models. The recent discovery from speleothem data that the abrupt climate changes resulted in failure of the East Asian monsoon in China and the appearance of a monsoon in what is now semi-arid Brazil, suggests to us that Abrupt Climate Changes result in a re-organisation of atmospheric circulation patterns. Our objectives are:

1. To identify whether abrupt climate changes occurred within New Zealand at times which could be correlated with those identified in the Northern Hemisphere.
2. To evaluate the impact that such changes, if identified, had on the climate of the New Zealand Region.

New Zealand evidence shows significant fluctuations in clastic sedimentation in Bounty Trough and grass pollen production rates in South Westland, both of which may be driven by fluctuations in the extent of glacial outwash. We intend to quantify these and to use a variety of techniques to improve their chronologies. Microtephra chronology offers some potential for correlation between records and links back to sites where conventional radiometric dating maybe less problematic. Ocean core records from available Bounty Trough cores are being worked through at high resolution for oxygen isotope, faunal distribution, clastic sediment abundance, texture and mineralogy. Recent advances in $^{230}Th/^{234}U$ dating has made speleothems an attractive source of palaeoclimatic data, and although interpretation of oxygen isotopic records are problematic, inclusion of isotopic and trace element records from speleothems close to the South Island glaciers will also be undertaken.

REFINED MICROFOSSIL-BASED PALEOCLIMATE RECORDS FROM LATE QUATERNARY MARINE CORES, OFFSHORE EASTERN NEW ZEALAND

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Climatically-influenced changes in microfossil assemblages often provide the least ambiguous and most reliable means of correlation between sediment cores. Moreover, integrated study of a wide range of microfossil groups permits correlation across environmental and latitudinal transects, with the potential to correlate paleoclimate records in deep marine cores with local nonmarine and shallow marine records as well as with marine records from different latitudinal zones. However, recognition of climate signals in microfossil assemblages at a given site requires a thorough understanding of the climatic and hydrographic influences on the regional distribution and preservation in sediments of the fossils' modern counterparts.

To improve the rigour of microfossil-based correlation and paleoenvironmental interpretation of marine cores in offshore eastern New Zealand, microfossil assemblages are being identified and analysed in 40 surface sediment samples, representing seven W-E depth transects between southernmost South Fiji Basin and southern Campbell Plateau. Census studies of planktic foraminifera, radiolarians, diatoms, dinoflagellate cysts and terrestrial palynomorphs are being accompanied by detailed component-specific ^{14}C-dating in order to establish the validity of the assumption that surface sediments record "modern microfossil distributions". Preliminary results indicate that within-sample and between-sample ages are highly variable within a range of ~550 to ~8600 BP (conventional ^{14}C age), but only one surface sediment sample so far has yielded a pre-Holocene age (~25-40,000 BP).

Census studies completed for planktic foraminifera, radiolarians and dinoflagellate cysts confirm that the Subtropical Front is the primary biogeographic barrier offshore eastern New Zealand, clearly separating assemblages with Tropical-Subtropical affinities from those with Subantarctic-Antarctic affinities. However, major local surface currents, such as East Cape and Southland Currents and their associated eddies, have significant influence on microfossil assemblages that initially complicate, but will ultimately help to elucidate the paleoclimate records in marine cores close to the Chatham Rise. Examples from MD97-2121 and ODP 1123 will be used to illustrate this point.

SEDIMENTATION DURING THE LGM AND OIS 3 IN THE TASMAN SEA: PRELIMINARY DEEP-WATER CORING EVIDENCE FROM OFF LORD HOWE ISLAND

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Surface water circulation in the Tasman Sea is characterised by the interaction of a range of surface water bodies. The Tasman Front, which marks the southern limit of warmer tropical waters, is probably one of the most distinct oceanic boundaries in the sea at present. The front represents the limit of the pole-ward flowing East Australian Current. The warmer waters of this current maintain coral reef growth as far as 33°S at Lord Howe Island, the southernmost coral reef in the world. During the LGM the front is thought to have moved north allowing cooler water to permanently encircle Lord Howe.

Lord Howe Island has a rhomboidal shaped shelf 24 km wide and 36 km long with an average depth of 50 m, and represents the only significant subaerial landmass in the centre of the Tasman Sea. Reef growth has occurred cyclically on the shelf throughout the Late Quaternary. A shelf of slightly smaller dimensions also surrounds Balls Pyramid 20 km to the south. A piston core was collected from a water depth of 780 m in the trough which separates the two shelves. This core recovered 2.8 m of carbonate sediment composed of fine grained sandy-mud.

Oxygen and carbon isotope analyses have been conducted on this core using the planktonic foraminifera *G. ruber* and *G. bulloides* as well as the benthic *Uvigerina* sp.. Preliminary analysis combined with radiocarbon dating indicates the core dates back to isotope stage 3, with the transition into and out of the LGM being well preserved. The rate of sedimentation also appears to be much higher than for other cores collected in the Tasman for this period and probably represents the influence of the two islands.

Data analysis is still in its preliminary stages and the core will be analysed in the next year to refine the interpretation of the isotope data. Such investigations will include: compositional analysis, foraminiferal species associations and other microflora/fauna. The data so far suggests a great potential to reconstruct a high-resolution record of both oceanic circulation, as it lies at a major oceanographic boundary, as well as carbonate production across a periodically flooded shelf.

OSL AGES FOR OIS 2 AND OLDER LOESS AND AGGRADATION RIVER TERRACE DEPOSITS IN THE EASTERN NORTH ISLAND

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Eighteen new Optically Stimulated Luminescence (OSL) ages have been obtained from loess and aggradation river terrace deposits along five major rivers in the Hawke's Bay and Gisborne Regions. Two OSL dating methods were used, the multiple aliquot additive-dose method, which measures luminescence of silt-sized feldspar, and the Single Aliquot Regeneration (SAR) method, which measures fine quartz sand luminescence.

Loess OSL ages are 18.5 ± 1.4 (Waipawa River), 23.1 ± 1.8 ka (Tukituki River), 18 ± 1.8, and 39.7 ± 2.5 ka (Ngaruroro River). The Waipawa and Tukituki River samples are from loess that rest directly on aggradation gravel. The Ngaruroro River samples are from two loess units (in the same section) resting on aggradation gravel. The ages and the stratigraphic relationships suggest they are Ohakea (OIS 2) and Rata Loess (late OIS 3). No Kawakawa Tephra has been identified in these sections.

Six OSL ages of silt aggradation deposits of the lowest, most widespread, aggradation terrace are 20.9 ± 1.5, 23.7 ± 1.7, 23.9 ± 1.8, (Ngaruroro River), 19.6 ± 2.0 (Waiau River), 16.3 ± 1.5 (Mata River), and 17.0 ± 1.5 ka (Waiapu River). Two ages of sand aggradation deposits (SAR technique) are 7.95 ± 2.1 and 11.2 ± 3.2 ka (Ngaruroro River), but on stratigraphic grounds, are interpreted to be minimum ages. Two ages of silt coverbeds resting on aggradation deposits are 13.2 ± 0.9 (Waipawa River) and 11.3 ± 0.8 ka (Ngaruroro River). These OSL ages confirm widespread river aggradation during OIS 2, simultaneous with deposition of Ohakea Loess, and terrace abandonment at approximately the Last Termination.

Four OSL ages of silt aggradation deposits of older terraces are 115.2 ± 11.2 ka (Waiau River), 75.3 ± 5.5 (Hangaroa River), 67.6 ± 6.8, and 70.0 ± 6.3 (Mata River). These terraces are tentatively assigned to OI Substage 5d and OIS 4, and thus correlate with the Greatford and Porewa Loesses.

These ages confirm regional-scale loess and river aggradation during cold (full-glacial) and/or cool periods of OIS 2, late OIS 3, OIS 4, and OI Substage 5d.

IMPROVED CHRONOLOGY FOR LATEGLACIAL CLIMATE REVERSAL RECORDED AT KAIPO BOG TEPHROPALYNOLOGICAL SEQUENCE, NEW ZEALAND

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The pollen record at Kaipo Bog (Newnham & Lowe 2000, Geology 28, 759-762) from ~1000 m elevation near treeline in northeastern New Zealand was unusual in depicting an early, ~1,000 year-long, cooling event that interrupted deglacial warming in the region. The cooling signal began *ca.* 100-200 years after deposition of the Waiohau Tephra. Previously, terrestrial records from New Zealand had shown either no deglacial cooling event (e.g. Singer et al. 1998, Science 281, 812-814) or one that seemed essentially synchronous with the Younger Dyras (YD) cooling of the Northern Hemisphere (Denton & Hendy 1994, Science 264, 1434-1437). At Kaipo Bog, the cooling (estimated at ~2 deg C) overlapped the latter part of the Antarctic Cold Reversal and the early part of the YD. Subsequent work elsewhere in the Southern Hemisphere, however, has shown a similar pattern to that in the Kaipo Bog record (e.g. Huelmo/Mascardi Cold Reversal, Hajdas et al. 2003, Quaternary Research 59, 70-78), thus indicating that this event and the climatic processes involved were more widespread than initially thought. New pollen records from two New Zealand sites (Kettlehole, Otamangakau), both at ~600 m elevation, also showed a similar 'early' reversal (Turney et al. 2003, Geology 31, 223-226), the start at Otamangakau being marked approximately by Waiohau Tephra.

The original Kaipo Bog chronology was considered to be sound, with a total of 21 stratigraphically coherent tephrochonological (n = 8) and radiocarbon ages (n = 13) spanning the interval from Rerewhakaaitu Tephra (17.6 cal ka) to Opepe Tephra (10.2 cal ka). Comparatively large standard errors for the conventionally radiocarbon-dated bulk sediment samples (reported in Lowe et al. 1999, NZ Jl Geology & Geophys. 42, 565-579), however, left assertions regarding the precise timing of events open to question. Consequently, we obtained a further 20 AMS radiocarbon ages spanning the interval 14.6 to 10.2 cal ka to provide a high-precision, fine-resolution chronology for the interval 17.6 to 10.2 cal ka in the Kaipo bog tephropalynological profile. The new ages, fitted to the INTCAL98 calibration curve, provide an improved chronology that confirms the original assertion that the deglacial cooling straddles both the ACR and YD. The start of the cooling was at *ca*. 13.8 cal ka, perhaps ca. 200 years earlier than estimated previously, and the abrupt end was at *ca*. 12.6 cal ka. Warm, moist conditions were attained by the time Konini Tephra was deposited at *ca*. 11.9 cal ka. We aim to develop a final chronology, possibly using wiggle matching, when INTCAL04 becomes available. Tephra marker beds at Kaipo critical to regional climatostratigraphy include Rerewhakaaitu (*ca*. 17.6 cal ka), Waiohau (*ca*. 14.0 cal ka) and Konini (*ca*. 11.9 cal ka) (Newnham et al. 2003, Quaternary Science Reviews 22, 289-308).

GLACIER-CLIMATE STUDIES IN NEW ZEALAND: PRESENT DAY MEASUREMENTS AND MODELLING OF QUATERNARY ICE EXTENT

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Glaciers are valuable climatic indicators because they record past climatic changes both directly in their annual snow layers, and indirectly through moraine records. Glaciers advance and retreat according to well-understood physical principles, which allows a quantitative link between moraine records and climate to be established.

Computer models of glaciers can be constructed and used for several purposes, including studying present day glacier dynamics, predicting future glacier response and reconstructing past ice extent and associated climatic changes. We have been funded to develop numerical models of New Zealand glaciers over the next two to three years. Our objectives are as follows:

1. Determine the climatic significance of the Waiho Loop moraine near Franz Josef Glacier, South Westland. We have completed this work – see Anderson and Mackintosh, this volume.
2. Constrain present-day glacier-climate relationships in the Southern Alps, in particular, the latitudinal and altitudinal gradients in mass balance. This is a collaborative project involving several NZ universities and CRIs. We are currently studying the Franz Josef and Brewster Glaciers, and there are plans to extend this work to the Fox and Dart Glaciers and Mt. Ruapehu. The data will be used to develop model boundary conditions for Objectives 3 and 4.
3. Develop a 2D or 3D model of the ice field that covered the Southern Alps during the last glaciation. Our aim is to calculate past temperature and precipitation fields at different time slices during the last glacial cycle, and to critique field evidence of past glacier extent.
4. Predict the future response of New Zealand glaciers and their contribution to sea level change.

Additionally, Uwe Morgenstern is leading a GNS/international effort to retrieve and analyse ice core records from the Tasman Glacier in the Southern Alps. The first core will hopefully be taken in late 2004. We hope that this core will reveal instrumental-quality climate proxy information spanning the last few centuries. Julian Thomson will provide a short summary of progress to date.

THE INTIMATE DETAIL OF MARINE CLIMATE CHANGE: A HIGH RESOLUTION RECORD

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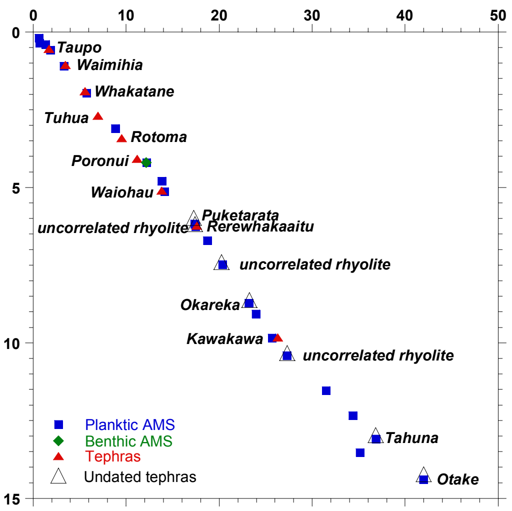
The INTIMATE initiative's stated aim is to improve clarity and precision of chronology surrounding the last glacial termination. The principal focus is construction of an event-based stratigraphy for the time period, and correlation across palaeoclimatic domains including land, ocean, and ice. Correlation will be based on synchronous regional or global events, such as oxygen isotope stratigraphy, together with improved protocols for radiocarbon dating and tephrochronology. To assist in this important endeavour, high-resolution marine records are of major importance. Probably the most detailed and comprehensively-dated marine record from the SW Pacific is core MD97-2121, from offshore eastern North Island, New Zealand. This core offers resolution down to a few decades across Termination 1, and contains numerous identifiable tephra layers. With 27 AMS radiocarbon dates forming a strongly linear sequence and a detailed oxygen isotope stratigraphy, MD97-2121 presents a highly reliable chronological template for marine climate change in the region.

An excursion in organic productivity during the early Bølling-Allerød warm event (~14.8-13.0 ka) was followed by a pause in warming correlating with the Antarctic Cold Reversal (~14.5-12.5 ka). This pause affected both surface and deep waters, and was characterized by vigorous mixing/low stratification of surface water and little seasonality. Deep water resumed warming by 12.7 ka, whereas surface waters remained cool and well mixed throughout most of Younger Dryas time (13.0-11.5ka) until ~12 ka. Comparison of the AMS ^{14}C-based age model with that derived from published ages of known tephra layers, enables an assessment of possible changes in the reservoir age of SW Pacific waters across different time periods. The timing of rapid climatic oscillations such as the Antarctic Cold Reversal, revealed in stable isotopic profiles, is also accurately constrained by the tephra time markers.

New AMS ^{14}C dates on planktonic foraminifera in the vicinity of several tephras from Marine Isotope Stages 3-2 are presented, including some for previously poorly-constrained events. These include the *Okareka, Te Rere, Puketarata Tahuna* and *Otake* tephras.



Left: Age control for marine sediment core MD97-2121.

The remarkable linearity of the age model enables a very high degree of confidence in timing-based inferences. Previously poorly-dated or uncorrelated tephras can be assigned robust age-estimates and placed in context on the oxygen isotope curve.

TWO LGM BEETLE FAUNAS EAST OF THE MAIN DIVIDE, SOUTH ISLAND, NEW ZEALAND: LOWER AWATERE VALLEY AND LYNDON STREAM, RAKAIA RIVER VALLEY

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The introduction of fossil beetle research to the New Zealand provides a new dimension to paleoclimate reconstructions and challenges the perception of a 'cold' NZ last glacial maximum (LGM) environment. The fossil beetles have essentially opened a can of LGM bugs.

Beetle fossil fauna from two LGM sites east of the main divide have specifically identified forest environments with diverse, rich ecosystems (Marra & Leschen, 2004; Marra et al, submitted). Locating these diverse and productive LGM ecosystems has pinpointed forest stands in our grassland picture of the LGM landscape in South Island east of the main divide. The fact that there two of these forested sites have been found indicates that forest patches were not uncommon during the LGM, especially in locations protected from glacial disturbance.

Paleotemperatures were estimated for the two sites from beetle fossils. The temperature estimates between these two sites differ by up to 3^{O}C. In the lower Awatere Valley, 31 species belonging to 12 families were identified from LGM backwater fluvial deposits dated between 20,600 +/- 300 and 19,100 +/- 500 cal yrs BP. The estimates of summer (February) mean temperature was about 3.5 - 4 ^{O}C cooler than present day, and July (winter) mean daily minimum temperature was about 4 - 5 ^{O}C cooler (Marra et al., 2004). However, temperature reconstruction of the lake sediments in the Lyndon Stream (Rakaia Valley) dated 24, 360 +/- 340 cal yrs BP (Schluechter, pers.comm.) were between 0.5 ^{O}C warmer and 1.9 ^{O}C cooler than present day in February (summer) and mean minimum winter temperatures ranged between 1 ^{O}C warmer and 2.2 ^{O}C cooler than the present day (Marra et al., submitted). These apparently surprising results confirm and quantify existing climate reconstructions from plant macrofossils from this site (Soons and Burrows, 1978). They are consistent with new evidence of relatively mild conditions at least during some periods within the LGM chron in NZ and clearly demonstrate a climatic-fluctuating LGM.

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ICE CORE RESEARCH IN THE NEW ZEALAND SOUTHERN ALPS

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The past holds the key for prediction of future climate changes. Only when the causes of past climate fluctuations are understood will it be possible to predict and plan for future changes. Instrumental climate records are, however, too short for precise identification of decadal and longer climate behaviour. Glaciers, with climate proxies to near instrumental precision, play an important role as archives of global climate history. Ice cores can help to understand natural variations and to identify human influences on climate.

Because of New Zealand's isolated position in the South Pacific Ocean, and its location with respect to the jet stream, Southern Alps glacier records are potentially very valuable for the study of timing and extent of changes in the jet stream and consequent impacts on New Zealand and global climate.

Research on New Zealand’s temperate glacier ice faces the challenge of meltwater percolation, which tends to obscure glaciochemical variations in the firn and snow. Another challenge is high snow accumulation rates, which limit the length of the preserved ice records.

Using tritium and ^{210}Pb, we have dated the old ice in the lower part of three glaciers in Mount Cook National Park to reveal the approximate length of ice records that can be expected. The oldest ice at the terminus indicates the time span that can be expected in deep ice cores from the neve. The ice at the terminus of Franz Josef and Fox Glaciers on the West Coast is 40 and 50 years, respectively. However, the Tasman Glacier on the east side of the Southern Alps, contains older ice. At the end of the white ice, we measured an age of 90 years. However, the oldest ice at the terminus is not accessible on the surface as it is covered by rock debris. The ice thickness at the end of the white ice is still several hundred meters, suggesting a total ice record of several hundred years.

Our previous work / initial studies showed that the bomb tritium from the nuclear weapons testing period in the 1960s is well preserved in the Tasman Glacier ice, suggesting little or no inter-annual exchange processes during ice formation. The specific seasonal bomb tritium peaks allow for accurate ice dating back to 50 years, and the natural pre-bomb tritium allows for approximate dating of ice back to 100 years. No old ice is yet available, but we plan to use ^{32}Si (half-life 140 years) to calibrate annual layer dating farther back in time to 1000 years.

We are currently also testing the integrity of the Southern Alps temperate ice as archive of climate proxies (i.e. how well these climate signals are retained in the ice). We are comparing the chemical signature in fresh snow and in old ice to identify how these signals are influenced by melting. Initial analysis of ice from the Tasman Glacier for its chemical and stable isotope composition reveals that this ice retains its chemical and isotope composition although chemical species are washed out of the ice at lower elevations in the heavily-meltwater percolated ablation zone.

We are planning to recover ice cores from the Mount Cook region, starting in the neve of Tasman Glacier.

PALYNOLOGY OF THE TERMINATION OF THE LAST GLACIATION IN NEW ZEALAND

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There has been major change in the way we think about the termination of the Last Glaciation. Before the advent of isotopic techniques, it was seen largely as a global warming with its physical manifestation as sediment stratigraphy, with all that implies in terms of nomenclatural *sturm und drang*. Now, I would argue, it is largely about ocean-atmosphere processes interpreted by means of continuous, isotopic curves, with warming proxies and sediment stratigraphy very much secondary. Where does that leave that notoriously vague proxy, pollen? As I have argued before, we have to play to the strength of each climate proxy. While some climate proxies (isotopes in particular) are closely tied to a single variable, acting as minute thermometers or whatever others, such as pollen, integrate the combined effect of weather and climate. In the case of New Zealand, close linkages between land and ocean mean that pollen must also reflect what happening out at sea.

Pollen sequences should therefore be regarded as total integrators of this terrestrial/oceanic climatic regime. At the LGM they mostly represent the very cold, perhaps highly variable oceanic conditions somewhat to the south of New Zealand, rather than the milder terrestrial averages recorded in the relatively minor depression of snowline and occurrence of thermophilous beetle assemblages. Trees, being immobile and exposed to the free atmosphere, are highly sensitive to occasional, but catastrophic events such as severe radiation frost, ice glazing or prolonged drought. The erratic sweep south of the palynological forest line from 15 000 ^{14}C B.P. to 8000 ^{14}C B.P. cannot represent a strict thermal boundary, as we have known for a long time that forest was quite capable of surviving to the north and south of it. Instead, I argue it represents the tension zone between two maritime realms. To the north, warmer waters, more humid atmosphere and less variable weather; to the south, colder waters, dry atmospheres, and sea-ice outbreaks. It is possible moreover, that movement of this oceanic boundary is locally independent of a more general warming of the southwest Pacific region. Shortly after the final afforestation of the far south at 9000 ^{14}C B.P. an intense but short-lived (c. 2000 years) regionalisation of New Zealand climates occurred, with mild super-humid conditions in the north of the North Island and in the west, and dry, stable conditions to the south and east, perhaps representing a major reorganisation of the climate system, and effectively the end of the adjustment from the Last Glaciation.

While a termination event stratigraphy may be a good idea for New Zealand, it does pose the problem of how to deal with the fact that in many terrestrial locations we will have two influences: 1. a generalised perhaps hemisphere-wide trend towards warmer climates and; 2. the local effect of the adjustment of the oceanic masses and currents. Perhaps rather than attempting to correlate and quantify events at each site, and to compare them with others, the first goal should be to develop plausible, physically reasonable climate scenarios for the New Zealand region as a whole. Astronomical forcing and correlations across the Pacific and south to the ice should perhaps be left until later. The contamination of local scenarios by strong, external hypotheses seems too large a risk to run at this stage.

A 6500 (^{14}C) YEAR STORM RECORD FROM LAKE SEDIMENTS, HAWKE'S BAY, NEW ZEALAND

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A high-resolution record of storm events is preserved in the sediments of Lake Tutira, located on the east coast of North Island, New Zealand. Previous analysis of a 6 m-long sediment core established the storm chronology for the last 2250 years (Eden and Page 1998). In April 2003, a 27 m-long core was recovered that will extend the sediment record to lake formation at c. 6500 (^{14}C) years ago. The core exhibits well-defined laminations, consisting of minerogenic sediment, interspersed with black organic-rich deposits and slowly accumulating brown diatom-bearing silty clays. The layers of minerogenic sediment are the in-washing of sediment eroded from the catchment during rainstorms, and range from thin clay layers <1–5 mm thick, to graded beds >50 mm thick.

Analysis of the 6 m-long core identified periods of increased storm frequency and magnitude, usually involving sudden onset and cessation. These variations reflect, in part, variations in ENSO activity, and it is anticipated that the c.4 ka onset of strong ENSO activity will be represented in the latest core. To date, a chronology has been established for the 27 m-long core using twenty tephras, and several C^{14} dates from near the base of the core. Work is currently underway to complete the stratigraphic analysis.

This record will be compared with marine records (core MD972122), in conjunction with NIWA and NSF-funded MARGINS Source-to-Sink projects focused on the Waipaoa Sedimentary System, to test the efficacy of sediment deposits on the continental shelf to record terrestrial signals of climate and other environmental change. In addition, the Tutira core will provide an annual- to decadal-scale record of climate variability/change, and thus allow a realistic extension of historical records, which began only 150 years ago.

Reference:

Eden, D.N., and Page, M.J. 1998: Palaeoclimatic implications of a storm erosion record from late Holocene lake sediments, North Island, New Zealand. *Palaeogeography, Palaeoclimatology, Palaeoecology* ***139****:* 37–58.

LATE LAST GLACIAL LOESS IN THE NORTH ISLAND OF NEW ZEALAND: AN OVERVIEW

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The North Island of New Zealand is one of the world's most diverse loess provinces because of the interaction of climatic cycles with active and rapid tectonism and volcanism. Loess is a feature of the Pleistocene stratigraphic record south of Hamilton, approximately 37.5^{o}S. This coincides with the area that had a destabilized forest cover, grassland or shrubland and reduced vegetation cover during Quaternary cold periods. The belt of strong westerlies that in interglacial times lies well to the south, moved north, and New Zealand bore the brunt of a strong westerly airflow. Pollen evidence suggests mean annual temperatures were 5-7^{o} C lower than at present. There is ample evidence of widespread erosion.

North Island geology is the result of the subduction of the Pacific Plate below the Australian Plate which carries the North Island continental crust. Rates of uplift are high by world standards, particularly in the Mesozoic greywacke-argillite axial ranges, and the adjacent Tertiary-Quaternary mudstone-sandstone hill and steep-land. The Glacial climate resulted in destabilization of the forest or shrubland cover, and its replacement by shrubland, grassland and bare ground. Massive erosion led to an oversupply of sediment in rivers draining the greywacke-argillite ranges and through the mudstone-sandstone hill country, causing river foodplains to aggrade. These aggrading surfaces were the dust engines for the widespread quartzo-feldspathic loess, common in eastern and southern North Island.

Rivers draining andesite stratovolcanoes and adjacent ring-plains were the conduit for volcaniclastic material. The partly devegetated ring-plains and river flood plains were also dust source areas. Particularly on the west coast of southern North Island, dust was also sourced from the exposed continental shelf where the quartzo-feldspathic and andesitic sediments were spread. Dust was also sourced from andesitic tephra, reworked from eroding hillsides.

In Central North Island, erosion of thick rhyolitic tephra and ignimbrite deposits occurred. The resulting deposits formed large fans from which volcanic glass rich dust blew. In eastern North Island, dust was sourced from rhyolitic tephra, and other local sediments, reworked from eroding hillsides.

Dust generation slowed as soon as rivers began to down-cut at the end of the Last Glacial. In eastern North Island, the main aggradation surface was abandoned about 18-19 cal ka. This coincided with visible signs of soil formation, shortly before the 17.7 cal ka Rerewhakaaitu Tephra. In marine core P69 off eastern North Island, the eolian component of the sediment decreased sharply at this same time. Recently calculated mass accumulation rates for the period from the Last Glacial Maximum, until the post-glacial warming (25-15 cal ka) range from 70-150 g m^{-2} y^{-1}.

DEVELOPMENTS IN RADIOCARBON CALIBRATION: CAN REFINEMENTS OF THE CALIBRATION CURVE LEAD TO INCREASED PRECISION?

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One of the stated goals of this workshop is to "*promote ways to improve procedures for establishing the precise ages of, and effecting high resolution correlations between, these key onshore and offshore NZ records*". Radiocarbon dating is a principle method of age determination for the period of OIS 2 and 2/1 transition, but it has its limitations. Sample selection has emerged as a key issue in recent years as age disparities between different fractions selected from the same sediment become apparent. Numerous authors have cited variations between bulk sediment ages and plant macrofossils. The Hollis et al. paper (*this volume*) discussing microfossil assemblages in surface marine sediments illustrates the ^{14}C age variation that can exist between fractions as well as among different species of planktic foraminifera selected from the same sediment. Another constraint to radiocarbon age determination is that radiocarbon years are not the same as calendar years. Because of fluctuations in the production rate of ^{14}C in the upper atmosphere, the amount of ^{14}C in the atmosphere has varied over time and there is not a one-to-one correspondence between radiocarbon years and calendar years. When correlating records from different environments and applying ages derived from different dating methods, it is necessary to ensure that the same time scales are being compared. Radiocarbon ages *must* be calibrated.

Numerous calibration programs have been developed and most are based on the international consensus data set INTCAL98 (Stuiver et al. 1998). This INTCAL98 calibration is based on paired measurements between dendrochronology and ^{14}C in tree rings back to about 11800 cal BP, and paired ^{14}C and U-series measurements on corals from 11,800 cal BP back to c. 24,000 cal BP. Since 1998, however, a number of additional calibration curves have been published, pushing the calibrated interval back as far as 45,000 years. A new international consensus data set for calibration, INTCAL04, is due to be published in *Radiocarbon* later this year. This presentation will discuss progress in extending the radiocarbon calibration curve, the reliability of the different datasets that contribute to it, and the implications for dating the OIS 2 period.

As valuable as calibration is, precision in radiocarbon dating is still limited by the width of the calibrated age ranges. The further precision in radiocarbon dating required for high-resolution correlations of different records is likely to come about through better statistical analysis of sets of calibrated age ranges and through looking at calibrated ages as probability functions.

Reference:

Stuiver, M., Reimer, P.J., Bard,E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, F.G., v.d. Plicht, J., and Spurk, M. (1998) INTCAL98 Radiocarbon Age Calibration, 24,000-0 cal BP. *Radiocarbon **40(3)***:1041-1083

MOUNTAIN GLACIATIONS IN THE SOUTHERN ALPS OF CANTERBURY BETWEEN 30 – 8 KA: A REVIEW OF THE GLACIAL RECORDS FROM THE RANGITATA, RAKAIA, WAIMAKARIRI, AND WAIAU VALLEYS

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Since the early days of glacial geology in New Zealand, Canterbury's glacial valleys have played a prominant role for research on Pleistocene mountain glaciations in the Southern Alps. The classical glacial sequences of the Waimakariri and Rakaia Valleys were amongst the first mapped in New Zealand (Gage 1958, Soons 1963) and both sequences still serve as frequently cited reference records for the regional and global correlation of NZ's glacial advances. In this study, I review the glacial chronologies of the four largest Canterbury valley systems to test their overall suitability as terrestrial reference records for the INTIMATE project goals. The review is based (1) on an up-to-date compilation of all available late Pleistocene to Holocene radiocarbon, luminescence and cosmogenic dates and (2) on a detailed examination of the geomorphic criteria used to establish the glacial chronologies for the Rangitata, Rakaia, Waimakariri, and Waiau Valleys.

Results show that despite the accumulation of more than 106 geochronological dates on valley deposits, age control for glacial events during the 30-8 ka time bracket is still poor for all four valleys. Apart from the direct cosmogenic dating of a small late glacial advance near Arthurs Pass (12.4 ka - 9.3 ka BP) and some indirect information from the Rakaia Valley on the timing of the Bayfield-2 (> 22.8 ka BP) and Bayfield-3 advances (< 19.2 ka BP), age control for the main LGM advances is not available. Past difficulties in directly dating glacial moraines have led to the use of glacio-fluvial outwash terraces as the standard means for discriminating between glacial events. Age control on aggradation deposits believed to represent LGM glacial periods is also scarce but ages from the Rakaia, Waimakariri, and Waiau Valleys indicate that LGM glacial aggradation began prior to ~ 30 ka BP and ended before 14.1 ka BP. All four valleys show clear evidence for large paleolakes that formed at 13.3 ka BP (Waiau), 13.2 ka BP (Waimakariri), 11.6 ka BP (Rakaia) and 9.8 ka BP (Rangitata).

At present, missing age control for most of the key glacial events during the 30-8 ka period limits the four glacial valley records to relative chronologies in which most correlations are tentative at best. However, several current glacial projects (Shulmeister, Denton, Rother) involve extensive dating campaigns using lumi-nescence and cosmogenic techniques that are likely to substantially improve direct age control on glacial advances in the above valleys. The presented review includes a list of additional targets for which age dating is critically required.

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Gage, M. 1958. Late Pleistocene glaciations of the Waimakariri Valley, Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics*, ***1***: 123-155.

Soons, J.M. 1963. The glacial sequence in part of the Rakaia Valley, Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics*, ***6***: 735-756.

SOME NEW DEVELOPMENTS IN TEPHROCHRONOLOGY AND IMPLICATIONS FOR THE MARINE OXYGEN ISOTOPE STAGE 2 TO 1 TRANSITION IN NEW ZEALAND

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The tephrostratigraphic record for the Marine Oxygen Isotope Stage 2 to 1 transition in New Zealand is relatively well established. However, new developments in the geochemical identification of rhyolitic tephra, and in the documentation of the more frequently occurring, but less well-known andesitic tephra layers, will have an impact on the construction of detailed chronologic frameworks.

Detailed petrologic and mineralogic studies of proximal pyroclastics at Okataina have revealed many eruptions involved multiple batches of magma, and magma-mingling. As a result, different parts of the eruptive sequence may be compositionally distinct. In addition, different phases of the eruption are commonly dispersed in different azimuths, thus the resulting marker bed may be compositional different depending on location. However, careful geochemical documentation of the eruptive episode can uniquely identify the event even when stratigraphic context is poorly known. Eruptions that involved multiple magma batches include: Te Rere, Okareka, Rerewhakaaitu, Rotorua, Rotoma, Whakatane, and Kaharoa.

A new andesitic Taranaki tephra record is being developed for Auckland paleolake sequences. The layers that has been geochemically fingerprinted and temporally constrained, provide an opportunity to finely subdivide stratigraphic intervals that are bracketed by well-dated and easily recognised rhyolitic tephra. For example, seven Taranaki-sourced tephra beds are bracketed between the rhyolitic markers Rotorua (15.7 ka) and Rotoma (9.5 ka), spanning the interval of global climate change that includes the transition to the present interglacial and rapid climate cycles such as the Younger Dryas. The Auckland paleolake sequences also contain potential markers beds for the less well-constrained period prior to and during the Last Glacial Maximum, a period of extensive erosion in North Island that has produced numerous hiatuses in depositional sequences. Ten Taranaki-sourced tephra beds are recorded in the interval (25 – 15 ka).

MAAR LAKE RECORDS AND CLIMATE EVENT STRATIGRAPHY FOR NEW ZEALAND FROM 30-8 KA

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World class Late Quaternary paleo-climate archives are preserved in the sedimentary records of Auckland maars. Many maars are occupied by sea-water or infilled by estuarine sediments associated with the deglacial and early Holocene transgression. In several cases (e.g. Onepoto and Pukaki maars) the estuarine sediments are underlain by laminated lacustrine deposits. The presence of numerous identifiable well dated rhyolitic tephras of TVZ provenance (e.g. Sandiford et al., 2001) allows a detailed absolute chronostratigraphy to be erected. For Onepoto and Pukaki Maars there are very good sedimentary records and chronological control for the period from 30ka to roughly 9 ka. The Holocene component of the record can be derived from Lake Pupuke. Existing work on the basin has identified two major lines of investigation that will yield high resolution climate records.

1. Short sections of core from Onepoto Maar have had their individual laminae counted and measured. Laminae have been shown to be consistent with an annual pattern of deposition. Laminum thickness is taken as a proxy for biological productivity in the paleo-lake. Results appear to demonstrate a variable role for the El Nino Southern Oscillation and for the Inter-decadal Pacific Oscillation between the LGM and the early Holocene (Pepper et al., 2004). This work needs to be extended to the complete 30-8 ka time frame.
2. C and N isotope and elemental analyses has been undertaken at ~150 yr resolution from Onepoto and 250 yr from Pupuke to date (Hägg and Augustinus, 2003), with a pilot Oxygen isotope study of diatoms extracted from sediments spanning the late glacial in the Onepoto core. These data also show strong variations and suggest a climate forcing, with a possible Younger Dryas event in the data. These data need to be refined to sub-decadal, preferably annual resolution.

The Auckland maar records are possibly the best paleo-climate archives in the Southern Hemisphere (Vostok included!). We recommend that the Auckland maar lake sequence be adopted as one of the key reference sections for the Australasian INTIMATE project. It is a sequence that requires considerable further work.

References:

Hägg, J. and Augustinus, P.C. 2003. '*Scientific data report from the Onepoto Crater drilling (NZMaar) Project: December 2000/July 2001*'. Department of Geography Working Paper No. 18, University of Auckland, 89 pp. ISBN: 1-877320-01-3.

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Sandiford, A., Alloway, B.V., Shane, P.A.R. 2001. A 28 000-6600 cal yr record of local and distal volcanism preserved in a paleolake, Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics. **44***: 323-336.

THE WESTLAND GLACIAL SEQUENCE: ITS RELEVANCE TO "GLOBAL" BOXES WITH TIME BOUNDARIES?

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The supposedly "global" boxes, within our time frame:

- LGM: 23-19 k cal. yr BP (or possibly 24-18 k cal yr BP) – Mix et al. (2001)
- MIS 3, 2 & 1: The 3/2 boundary at 24 k and 2/1 boundary at 12 k cal yr BP (Martinson et al, 1987)
- Last Termination: 18-9 k ^{14}C yr BP = 21-10 k cal yr BP (Turney et al. 2004); or, for example, 15 k-10 k ^{14}C yr BP = 18- 11.5 k cal yr BP (Wohlfarth 1996).

The Westland glacial sequence:

The late Otira Glaciation sequence was mapped in north Westland (Suggate & Waight 1999) as two units of the Larrikins Formation (la_1 and la_2) followed by the Moana Formation (mn), representing two advances of very similar extent followed by another of only slightly smaller extent. A similar pattern was found when carrying this mapping into South Westland, where the deposits of the M5 glacial advance of Almond (1996) and Almond et al. (2001) showed two glacial maxima ($M5_1$ and $M5_2$) corresponding to la_1 and la_2 in north Westland, these being followed by a slightly smaller M6 advance corresponding to mn.

Consideration of buried soils, pollen data, and ^{14}C data from the Buller valley to South Westland has been linked to the distribution of the Kawakawa Tephra to show: a) the $la_1/M5_1$ advance preceded the tephra; b) the interval between $la_1/M5_1$and $la_2/M5_2$ advances was only a few thousand years; and c) that "glacial" cold (judged by pollen) began well prior to the tephra and continued past the time of the mn/M6 advance. Accepting the $la_1/M5_1$, $la_2/M5_2$ and mn/M6 advances as representing the LGM in Westland, despite minor ameliorations between them, the New Zealand LGM extended from c.28 to c.19 k cal yr BP (i.e. it lies within both MIS3 and MIS2. Rapid retreat of the glaciers followed, interrupted by the Waiho Loop advance. It is debatable (cf. Mabin 1996) whether radiocarbon dates support an age a little older than the earliest Younger Dryas for this advance at Waiho (cf. Denton & Hendy 1994), but ^{10}Be dating of boulders on the youngest of a group of small moraines at Arthurs Pass (Ivy-Ochs et al. 1999) may indicate a youngest Younger Dryas age. More data are needed to determine whether the end of the Last Termination is marked by a widespread short period of ice advance in Westland.

Conclusions:

1) Our own sequences do not need to conform to presently-accepted global inferences.
2) Our sequences are important in consideration of what global time/event boundaries may later be accepted.

OIS 2/1 TRANSITION AND OIS 2 LOESS IN SOUTH ISLAND

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Loess stratigraphy is most instructive where loess sheets drape suites of landforms that can be linked directly to global climate events, such as marine terraces, river aggradation terraces or moraines. An accepted model links accumulation of loess to climatically controlled river aggradation. During cold climate phases rivers aggrade; the broad, unstable fan or floodplain surfaces provide an expanded loess source area. In contrast, incised rivers have narrow valleys and a limited loess source area. The stratigraphy of loess deposits is dependent on recognising buried soils, which are used to define loess sheet boundaries. Using loess stratigraphy to support an event stratigraphy requires a reliable chronology. In the past decade loess sequences have been dated by radiocarbon, tephrochronology TL, IRSL, and OSL techniques, in south, east and west of South Island. ^{14}C dating has been of limited value because of its dating range, scarcity of datable material in southern and eastern areas, and problems resulting from contamination by young carbon. Tephrochronology is restricted to a single tephra marker, Kawakawa tephra (22.6 k ^{14}C years), and luminescence dating has produced stratigraphic reversals, and ages inconsistent with the position of Kawakawa tephra. Only in loess produced in the OIS 1/2 transition has luminescence dating given consistent results. Loess of this age has been recognised on terraces above flood level of the Awatere, Waimakariri, Rakaia, Rangitata, and Waitaki rivers. Basal ages range between 13 and 18 ka, and suggest a time transgressive incision into the last OIS 2 aggradation surface. The loess of this age differs from full glacial stage loess in that it is thickest on the lee side of river valleys and thins rapidly away from source. Loess deposited in OIS 2 is widely recognised in the South Island and tends to occur as a loess sheet of consistent thickness at least intraregionally. It can be correlated as far south as Timaru and Okarito by identification of interbedded Kawakawa tephra. Further south, little work has been done to find the southern limit for correlation using this tephra. The only basal ages of the loess sheet that incorporates Kawakawa Tephra comes from TL and OSL, which range from 40 to 70 ka, indicating that the loess started accreting before OIS 2. It is uncertain whether the variation of basal age arises from errors in dating, a time transgressive base of the loess, or interregional variations in loess stratigraphy. The latter could arise from differences in resolution of the soil stratigraphy related to variations in the rate of loess deposition and soil development, buried soil morphology, or particle size. Research challenges include loess chronology, and extracting quantitative paleoenvironmental data from loess and buried soils. Efforts involving intensive age determinations, high resolution particle size variation and stable isotope geochemistry of pedogenic carbonate are in progress from Ahuriri section, Banks Peninsula.

DEVELOPING A NEW ZEALAND TEPHROCHRONOLOGICAL FRAMEWORK FOR THE LAST TERMINATION

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The precise sequence of events during the Last Termination (18 000–9000 ^{14}C ka BP), and the extent to which major environmental changes were synchronous, are difficult to establish using the radiocarbon method alone because of serious distortions of the radiocarbon time-scale, as well as the influences of site-specific errors that can affect the materials dated. Attention has therefore turned to other methods that can provide independent tests of the chronology and correlation of events during the Last Termination. Crucial to the success of this research is development of robust regional tephrostratigraphic and hence tephrochronological frameworks (Turney et al., 2004). New Zealand has a well-established tephrostratigraphic record, with much potential for developing a more integrative framework for New Zealand, which can help to underpin the overall chronology of events during the Last Termination as recent tephro-palaeoenvironmental studies have demonstrated (e.g. Newnham et al., 2003). For that potential to be fully realised, however, there needs to be a more systematic and robust analysis of tephra layers, and marker beds critical in linking and dating sites containing evidence for abrupt climatic change especially need to be dated with greater precision than currently available. The INQUA Sub-Commission on Tephrochronology and Volcanism (SCOTAV) proposes the establishment of a New Zealand Committee on Tephras (NZCOT) that will follow an agreed protocol for improving analytical and reporting procedures and develop comprehensive geochemical and geochronological tephra-related databases on behalf of the INTIMATE community. The centralised data base of the result will provide an important geochronological tool to support the INTIMATE community in New Zealand.

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LATE PLEISTOCENE TO HOLOCENE SPELEOTHEM ^{18}O AND ^{13}C RECORDS FROM SOUTH ISLAND, NEW ZEALAND, AND THEIR PALAEO-ENVIRONMENTAL INTERPRETATION

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Oxygen and carbon data from eight stalagmites from northwest South Island are combined to produce composite records of $\delta^{18}O$ and $\delta^{13}C$ with a variable resolution averaging 41 years from the global Last Glacial Maximum (LGM) to the present. The chronology is underpinned by 35 TIMS uranium series ages. Speleothem $\delta^{18}O$ values are interpreted as showing a positive relationship to temperature, although precipitation also influences $\delta^{18}O$. Delta ^{13}C is interpreted as responding negatively to increases in atmospheric CO_2 concentration, biological activity and precipitation amount.

After adjustment of 1.2‰ for the ice volume effect, the $\delta^{18}O$ record between 23 ka and 18 ka varies around -3.84‰ after which there is a rising trend. Late-glacial climatic amelioration commenced about 18.1 ka and accelerated after 16.7 ka, culminating between 14.8 and 13.6 ka with an average $\delta^{18}O$ value of -3.40‰. The late-glacial warm peak was followed by a significant negative excursion between 13.6 and 11.6 ka of up to 0.4‰ depth, here termed the NZ Late-glacial Reversal (NZLGR). This event overlapped the Antarctic Cold Reversal (ACR), which commenced ~0.9 ka earlier, spanned the entire Younger Dryas (YD) and the Kaipo cold event of NE North Island (13.6-12.6 ka), and coincided with Aurora 1 glacial advance in Fiordland. Although it ended at about the same time as the YD, it did not to have its timing or structure, because it started ca. 0.7 ka earlier was longer and not as deep. The NZLGR was followed by a climatic sub-optimum between 11.3 and 10.7 ka, although $\delta^{18}O$ values imply that it was not as warm as the period from 7 to 6.4 ka. Still warmer conditions may have marked the late Holocene from 0.7 to 0.5 ka when $\delta^{18}O$ reached its Holocene culmination at -3.15‰. This was slightly later than the Medieval Warm Period of Europe. The Holocene $\delta^{18}O$ record oscillates up to 0.25‰ from the mean. Such deviations are attributable to temperature and precipitation-related changes, such as variation in $\delta^{18}O$ values of sea water source areas of precipitation and by changes in rainfall amount.

Delta ^{13}C values were relatively high from 23 - 18 ka, then showed an abrupt decrease to 17.4 ka followed by a steady decline to a minimum from 11.3 - 10.3 ka. After this there was a general increase to 3.6 ka followed by a further general decline. The abrupt decrease in δ-values after 18 ka probably corresponds to an increase in atmospheric CO_2 concentrations, biological activity and wetness at the end of the Last Glaciation, but the cool reversal identified in the $\delta^{18}O$ record from 13.6 -11.6 ka was not reflected in $\delta^{13}C$ changes. The lowest $\delta^{13}C$ values coincided with the early Holocene climatic sub-optimum.

SUMMARY/RECOMMENDATIONS:

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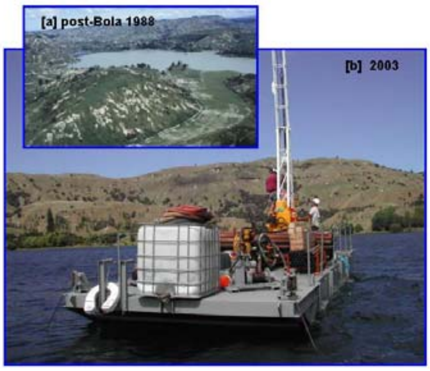

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