Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

Towards a climate event stratigraphy for New Zealand over the past 30,000 years

Science Report

By D. J. A. Barrell, B. V. Alloway, J. Shulmeister and R. N. Newnham (editors)

SR 2005/07
March 2005

Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

Towards a climate event stratigraphy for New Zealand over the past 30,000 years

by D.J.A. Barrell, B.V. Alloway, J. Shulmeister and R.M. Newnham (editors)

Contributing authors:
B.V. Alloway, P.C. Almond, P.C. Augustinus, D.J.A. Barrell, N. Bertler, C. Briggs, L. Carter, C.H. Hendy, N.J. Litchfield, D.J. Lowe, B. Manighetti, M.S. McGlone, R.M. Newnham, A.S. Palmer, H. Rother, P. Shane, J. Shulmeister, R.P. Suggate, P.J. Tonkin, M.J. Vandergoes, P.W. Williams

Institute of Geological & Nuclear Sciences science report 2005/07

Institute of Geological & Nuclear Sciences Limited
Lower Hutt, New Zealand

March 2005

BIBLIOGRAPHIC REFERENCE

Barrell, D.J.A., Alloway, B.V., Shulmeister, J., Newnham, R.M. (editors) 2005: Towards a climate event stratigraphy for New Zealand over the past 30,000 years. Institute of Geological & Nuclear Sciences science report 2005/07, 12 p. and poster.

Component reference:
Augustinus, P.C., Shulmeister, J., Newnham, R.M., Shane, P., Alloway, B.V. (compilers) 2005: Auckland maars. i*n* Barrell, D.J.A., Alloway, B.V., Shulmeister, J., Newnham, R.M. (eds.) 2005: Towards a climate event stratigraphy for New Zealand over the past 30,000 years. Institute of Geological & Nuclear Sciences science report 2005/07, 12 p. and poster.

D.J.A. Barrell, Institute of Geological & Nuclear Sciences Ltd, Dunedin, New Zealand
B.V. Alloway, Institute of Geological & Nuclear Sciences Ltd, Lower Hutt, New Zealand
J. Shulmeister, Department of Geological Sciences, University of Canterbury, Christchurch, New Zealand.
R.M. Newnham, School of Geography, University of Plymouth, Plymouth PL4 8AA, United Kingdom.

For further information and contact details of all authors, go to the New Zealand paleoclimate research website at www.paleoclimate.org.nz

ISSN 1171-9184
ISBN 0-478-09884-7

CONTENTS

POSTER

Towards a climate event stratigraphy for New Zealand over the past 30,000 years (back pocket)

ABSTRACT

A poster summarizing a representative selection of evidence for environmental conditions and climate change in New Zealand during the last 30,000 years has been prepared as a "first-step" contribution to the INTIMATE (INTegration of Ice-core, Marine And TerrEstrial records) initiative of the INQUA (International Union for Quaternary Research) Paleoclimate Commission. This international initiative aims to establish a more detailed knowledge of the nature, timing and regional to global extent of climatic and environmental changes associated with the Last Termination (the end of the Last Glaciation).

The poster depicts key New Zealand onshore and offshore records for the Last Glacial Maximum (LGM) and the Last Glacial-Interglacial Transition (LGIT), from a variety of latitudes and elevations. Inset maps show New Zealand's oceanographic setting, principal currents and water masses, extent of glaciers, and distribution of vegetation zones at approximately 22,000 calendar years ago and at modern times (incorporating the inferred vegetation distribution at *c*. 1250 AD, before deforestation associated with human settlement). A calendar-age timescale is based on a combination of volcanic ash (tephra) and radiometric dates. Paleoclimate records from ice cores from Antarctica and Greenland are presented for comparison with New Zealand records.

High-resolution records are presented for sediment-filled volcanic craters in Auckland (total carbon, carbon isotopes and pollen), wetlands in northeast North Island, central North Island and western South Island (pollen), marine sediments off eastern North Island (oxygen isotopes), and stalagmites in caves in northwest South Island (carbon and oxygen isotopes). In addition, the poster includes a range of lower resolution or fragmentary records of climate events, based on glacial landforms and deposits (central Southern Alps, South Island), river terraces and deposits, loess deposits (eastern North and South Islands), and aeolian quartz silt in non-quartzose, loess-like, andesitic tephric deposits of western North Island.

The poster reflects work-in-progress and aims to assist comparison of the New Zealand paleoclimate records with those from the wider Australasian region and elsewhere. The immediate goal is the establishment of an Australasian-INTIMATE climate event stratigraphy by the New Zealand and Australian paleoclimate communities, for presentation at the 2007 INQUA Cairns Symposium.

KEYWORDS

Quaternary, Holocene, Last Glacial Maximum, interglacial, paleoclimate, glaciers, vegetation, oceanography, ocean currents, dating, tephra, carbon content, carbon isotopes, oxygen isotopes, marine core, foraminifera, pollen, speleothems, glacial sequences, river fluvial sequences, loess, aeolian quartz, Auckland, Kaipo, Taranaki, Otamangakau, Gisborne, Hawkes Bay, Wairarapa, Nelson, Buller, Westland, Okarito, Southern Alps, Canterbury.

INTRODUCTION

OVERVIEW (by B.V. Alloway, D.J.A. Barrell, R.M. Newnham & J. Shulmeister)
INTIMATE (INTegration of Ice-core, Marine And TerrEstrial records), a core programme of the INQUA (International Union for Quaternary Research) Paleoclimate Commission, aims to establish a detailed knowledge of the nature, timing and regional to global extent of climatic and environmental changes associated with the Last Termination (the end of the Last Glaciation). Initiated in 1997 and facilitated through a series of international workshops, the project strives for improved precision in establishing the ages of, and effecting high resolution correlations between, events of the Last Termination.

There have been two major factors behind the drive for high resolution correlations and improved precision. First was the publication of the GRIP and GISP2 ice-core records from Greenland (Alley *et al*. 1993; Johnsen *et al*. 2001), which showed that environmental changes during the Last Termination were more abrupt and more complex than had previously been realized. This highlighted a need for methods that enable the sequence of events during the Last Termination to be reconstructed at a resolution of decades. The second was a growing realization of the severity of problems affecting radiocarbon dates, the most widely used method for dating Last Termination events. INTIMATE members have proposed a number of mechanisms for advancing the state of knowledge. These include an event stratigraphy approach for correlation (Bjorck *et al*. 1998; Walker *et al*. 1999; Lowe *et al*. 2001); improved protocols for both radiocarbon dating (e.g. Wohlfarth 1996; Lowe and Walker 2000) and tephrochronology (Turney *et al*. 2004); correlation based on stratigraphical methods thought to reflect synchronous regional or global changes, e.g., marine oxygen isotope (MIS) stratigraphy (Hoek and Bohncke 2001); and more effective use of sites with annually laminated sediment sequences (e.g. Litt *et al*. 2001).

Members of the NZ paleoclimate community attended the inaugural NZ-INTIMATE workshop at Lower Hutt in August 2004. The focus of the meeting was to:

- identify key New Zealand onshore and offshore records for the Last Glacial Maximum (LGM) and the Last Glacial-Interglacial Transition (LGIT).
- promote ways to improve procedures for establishing precise ages of, and effecting high resolution correlations between, onshore and offshore New Zealand records.

The outcome of this meeting was a unanimous agreement to prepare a poster summarizing New Zealand climate records spanning the last 30,000 years, emphasizing continuous records (e.g. cores) from a variety of latitudes and elevations, supplemented with fragmentary records (e.g. glacial, fluvial, and loessial deposits). The poster reflects work-in-progress that will be updated as new data become available. The poster is intended to assist comparison of the New Zealand paleoclimate record with records from the wider Australasian region and elsewhere. The goal is the establishment of an Australasian-INTIMATE climate event

stratigraphy by the New Zealand and Australian paleoclimate communities, for presentation at the 2007 INQUA Cairns Symposium. The poster is presented in the back pocket of this publication and the following text describes the various components of the poster and presents a full reference list.

LAND AND OCEAN MAPS (compiled by D.J.A. Barrell, C. Briggs, L. Carter, D.J. Lowe & R.M. Newnham)
A series of maps show the oceanographic setting, principal currents and water masses, extent of glaciers and distribution of vegetation zones of New Zealand at approximately 22,000 calendar years ago, and in modern times. The 'modern' vegetation zones represent the inferred natural vegetation cover at approximately 1250 AD, immediately prior to human settlement (Hogg *et al.* 2003).

TIMESCALE (compiled by B.V. Alloway & D.J. Lowe)
A calendar-year timescale is shown on the poster. Air-fall tephra from volcanic eruptions in central North Island provide valuable time-line markers within the stratigraphic record. Tephra are widely preserved within and offshore of the North Island, but only one tephra (Kawakawa) is currently identified in the South Island. Much of the age control for the paleoclimate records, and tephra, comes from radiocarbon dating. All records have been aligned to the calendar timescale following conversion of radiocarbon dates to calibrated ages (calendar years before 1950), using INTCAL98 (Stuiver *et al.* 1998) via either the CALIB (Stuiver *et al*., http://radiocarbon.pa.qub.ac.uk/calib/) or OxCal (Bronk Ramsey 2001) calibration programmes. For radiocarbon ages older than the range of INTCAL98 calibration, the estimates of calendar age are based on the GRIP regression curve (Bard *et al*. 2004). Other numerical dating methods used to constrain the paleoclimate records, such as Optically Stimulated Luminescence (OSL), Uranium/Thorium (U/Th) and surface-exposure cosmogenic isotopes (e.g. ^{10}Be) have ages that are expressed in calendar years prior to the year of sample collection. Thus there may be an up-to *c.* 55 years mis-match between calibrated radiocarbon ages and those obtained by other methods.

DESCRIPTION OF RECORDS

In the selected paleoclimate records, the focus is on published data. Locations are shown on the maps on the poster and information sources are listed in the references. The selected records are a representative sample of the highest resolution, most precisely dated, or otherwise significant, New Zealand paleoclimate data for the last 30,000 years. This is not an exhaustive array of available paleoclimate evidence for this time period in New Zealand.

HIGH RESOLUTION RECORDS

Auckland maars (compiled by P.C. Augustinus, J. Shulmeister, R.M. Newnham, P. Shane & B.V. Alloway)

Marine and lake sediments filling the Pukaki, Onepoto and Pupuke volcanic explosion craters are interbedded with numerous macroscopic tephra. Pukaki maar has yielded pollen evidence for paleovegetation between 9.5 and 27.5 calendar years BP. Latest isotopic and organic content data are presented from analyses-in-progress on sediments from Onepoto and Pupuke maars; the data are expected to yield high resolution paleoprecipitation and paleotemperature records.

Kaipo wetland (compiled by D.J. Lowe & R.M. Newnham)
This small wetland at 980 m altitude north of Lake Waikaremoana, eastern North Island, is potentially sensitive to climatic change because it lies a short distance below the modern treeline. It contains a sequence of peat and mud deposits spanning 18,000 years, with interbedded macroscopic tephra. A proxy paleoclimate record is provided by pollen.

Otamangakau wetland (compiled by M.S. McGlone)
This wetland at 600 m altitude on the northeast margin of Tongariro Volcano, central North Island, contains a c. 80,000 year long sequence of peat and mud deposits interbedded with macroscopic tephra. A proxy paleoclimate record is provided by pollen. Only the late-glacial record is shown here.

Marine core - MD97-2121 (compiled by B. Manighetti & L. Carter)
This 35 m giant piston core retrieved from 2314 m water depth, 117 km east of Cape Turnagain, off eastern North Island, provides a high resolution multi-proxy paleoenvironmental record back to Marine Isotope Stage (MIS) 6.

Speleothems (compiled by P.W. Williams)
Eight stalagmites from limestone caves in the Nelson and Buller regions, northwestern South Island, have provided high-resolution oxygen and carbon isotope data. The resulting composite record of $d^{18}O$ and $d^{13}C$ from 23,400 calendar years BP to the present is constrained by 43 U/Th dates (using the TIMS method) with 2s errors averaging ± 1.1%. Six climatic phases are recognized.

Okarito wetland (compiled by M.J. Vandergoes, C.H. Hendy & R.M. Newnham)
This wetland at 70 m altitude lies in a basin enclosed within old moraines at Okarito, western South Island. A 10 m long core contains a sequence of peat and silt deposits extending back to MIS 6. Pollen provides a proxy paleoclimate record.

Antarctic & Greenland ice cores (compiled by N. Bertler)
Isotopic variations from the EPICA Dome C site in Antarctica and the GISP2 site in Greenland are presented to allow comparison of polar paleoclimate records with the NZ paleoclimate record.

FRAGMENTARY RECORDS

Glacial sequences (compiled by D.J.A. Barrell, R.P. Suggate, P.C. Almond & H. Rother)
Moraines and outwash surfaces of extensive LGM glaciers and small, localized, modern glaciers provide physical evidence of glacial events. LGM glaciation was widespread in the New Zealand mountains but many of these areas have been ice-free since the LGIT. A potential 0 to 30,000 year record exists only in the higher parts of the Southern Alps, central South Island, where glaciation persists to the present day.

Landforms and glaciogenic deposits from the best radiocarbon and surface-exposure dated, central South Island, glacial sequences provide a fragmentary record of glacial events in the western and eastern sides of the Southern Alps.

Fluvial aggradation or degradation and loess accumulation (compiled by N.J. Litchfield, A.S. Palmer, P.C. Almond, P.J. Tonkin & D.J.A. Barrell)
River aggradation and loess deposition were widespread during the LGM. The LGIT marked a general onset of river incision and an extreme localization of loess deposition. Stratigraphic and age information are presented for the best-dated fluvial and loess sequences in New Zealand. Fluvial records are from eastern North Island (Gisborne-Hawkes Bay) and northeastern South Island (North Canterbury). Loess records are from southeastern North Island (Hawkes Bay-Wairarapa), western South Island (South Westland) and eastern South Island (Canterbury).

Aeolian quartz (compiled by B.V. Alloway)
Aeolian quartz silt is disseminated through non-quartzose, loess-like, andesitic tephric deposits at Onaero in North Taranaki, western North Island. Quartz accumulation rates and total quartz content are interpreted to be proxies for paleowind intensity.

ACKNOWLEDGEMENTS

Belinda Smith Lyttle (GNS) assisted with poster design and draughting. Fiona Petchey (Waikato University ^{14}C Dating Laboratory) assisted with calibration of tephra ages. Reviews by Ursula Cochran (GNS) and James Crampton (GNS) contributed improvements to the report and poster.

REFERENCES

Overview

Alley, R.B., Meese, D.A., Shuman, C.A. Gow, A.J., Taylor, K.C., Grootes, P.M., White, J.W.C., Ram, M., Waddington, E.D., Mayewski, P.A., Zienlinski, G.A. 1993. Abrupt increase in Greenland snow accumulation at the end of the Younger Dryas. *Nature* 362, 527-529.

Bjorck, S., Walker, M.J.C., Cwynar, L.C., Johnsen, S., Knudsen, K-L, Lowe, J.J., Wohlfarth, B., INTIMATE members. 1998. An event stratigraphy for the last termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. *Journal of Quaternary Science* 13, 283-292.

Hoek, W.Z., Bohncke, S.J.P. 2001. Oxygen isotope wiggle matching as a tool for synchronizing ice-core and ice-core records over Termination 1. *Quaternary Science Reviews 20*: 1251-1264.

Houghton, J. *et al*., Climate Change 2001. The Scientific Basis (Third Assessment report from IPCC Working group 1), 1-94, Cambridge University Press, UK.

Johnsen, S.J., Dahl-Jensen, D., Gundestrup, N., Steffensen, J.P., Clausen, H.B., Miller, H., Masson-Delmotte, V., Sveinbjornsdottir, A.E, White, J. 2001. Oxygen isotope and paleotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP. *Journal of Quaternary Science* 16, 299-307.

Litt, T., Brauer, A., Goslar, T., Merkt, J., Balaga, K., Muller, H., Ralska-Jasiewiczowa, M., Stebich, M., Negendank, J.F.K. 2001. Correlation and synchronization of the Last Termination continental sequences in northern central Europe based on annually-laminated lacustrine sediments. *Quaternary Science Reviews* 20, 1233-1249.

Lowe, J.J., Walker, M.J.C. 2000. Radiocarbon dating of the last glacial-interglacial transition (ca. 14-9 ^{14}C yr BP) in terrestrial and marine records: the need for new quality assurance protocols. *Radiocarbon* 42, 53-68.

Lowe, J.J., Hoek, W.Z., INTIMATE group. 2001. Inter-regional correlation of paleoclimatic records for the Last Glacial-Interglacial Transition: a protocol for improved precision recommended by the INTIMATE project group. *Quaternary Science Reviews* 20, 1175-1187.

Turney, C.S.M., Lowe, J.J., Davies, S.M., Hall, V.A., Lowe, D.J., Wastegård, S., Hoek, W.Z., Alloway, B.V. 2004. Tephrochronology of Last Termination sequences in Europe: a protocol for improved analytical precision and robust correlation procedures (a joint SCOTAV–INTIMATE proposal). *Journal of Quaternary Science* 19, 111-120.

Walker, M.J.C., Bjorck, S., Lowe, J.J., Cwynar, L.C., Johnsen, S., Knudsen, K-L, Wohlfarth, B., INTIMATE members. 1999. Isotopic events in the GRIP ice-core: a stratotype for the late Pleistocene. *Quaternary Science Reviews* 18, 1143-1150.

Wohlfarth, B. 1996. The chronology of the last termination: a review of radiocarbon-dated high resolution terrestrial stratigraphies. *Quaternary Science Reviews* 15, 267-284.

Land and ocean maps

Barrell, D.J.A., Suggate, R.P., unpublished data, 2004. Map of maximum extent of LGM glaciers in New Zealand. Contact David Barrell, GNS, New Zealand.

Carter, L., Garlick, R.D., Sutton, P., Chiswell, S., Oien, N.A., Stanton, B.R. 1998. Ocean Circulation New Zealand. *NIWA Chart Miscellaneous Series 76.*

Carter, L. 2001. Currents of change. *Water & Atmosphere* 9, http://www.niwa.co.nz/pubs/wa/09-4/.

Chinn, T.J.H. 1978. New Zealand Glacier Inventory 1978 – unpublished digital map. Contact David Barrell, GNS, New Zealand.

Leathwick, J., McGlone, M., Walker, S., Briggs, C., unpublished data, 2004: Predicted potential natural vegetation of New Zealand. Contact Craig Briggs, Landcare Research, New Zealand.

Newnham, R.M., Lowe, D.J., Williams, P.W. 1999. Quaternary environmental change in New Zealand: a review. *Progress in Physical Geography* 23: 567-610 (originally published as Plate 7, New Zealand Historical Atlas, 1997).

Timescale

Bard, E., Rostek, F., Ménot-Combes, G. 2004. Radiocarbon calibration beyond 20,000 ^{14}C yr B.P. by means of planktonic foraminifera of the Iberian Margin. *Quaternary Research* 61, 204-214.

Bronk Ramsey, C. 2001. Development of the radiocarbon program OxCal. *Radiocarbon* 43, 355-363.

Froggatt, P.C., Lowe, D.J. 1990. A review of late Quaternary silicic and some other tephra formations from New Zealand: their stratigraphy, nomenclature, distribution, volume, and age. *New Zealand Journal of Geology and Geophysics* 33, 89-109.

Hajdas, I., Lowe, D.J., Newnham, R.M., Bonani, G., submitted. Timing of the late-glacial climate reversal in the Southern Hemisphere: a high-resolution radiocarbon chronology for Kaipo bog, New Zealand. *Quaternary Research.*

Hogg, A.G., Higham, T.F.G., Lowe, D.J., Palmer, J.G., Reimer, P.J., Newnham, R.M. 2003. A wiggle match date for Polynesian settlement in New Zealand. *Antiquity* 77, 116-125.

Lowe, D.J., Hogg, A.G. 1992. Application of new technology liquid scintillation spectrometry to radiocarbon dating of tephra deposits, New Zealand. *Quaternary International* 13-14, 135-142.

Lowe, D.J., de Lange, W.P. 2000. Volcano-meteorological tsunamis, the *c.* AD 200 Taupo eruption (New Zealand) and the possibility of a global tsunami. *The Holocene* 10, 401-407.

Lowe, D.J., Newnham, R.M., Ward, C.M. 1999. Stratigraphy and chronology of a 15 ka sequence of multi-sourced silicic tephras in a montane peat bog, eastern North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 42, 565-579.

Manighetti, B., Palmer, A.S., Eden, D.N., Elliot, M. 2003. An occurrence of Tuhua Tephra in deep sea sediments from offshore eastern North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 46, 581-590.

Newnham, R.M., Eden, D.N., Lowe, D.J., Hendy, C.H. 2003. Rerewhakaaitu Tephra, a land-sea marker for the Last Termination in New Zealand, with implications for global change. *Quaternary Science Reviews* 22, 289-308.

Sparks, R.J., Melhuish, W.H., McKee, J.W.A., Ogden, J., Palmer, J.G. 1995. ^{14}C calibration in the Southern Hemisphere and the date of the last Taupo eruption: evidence from tree-ring sequences. *Radiocarbon* 37, 155-163.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van der Plicht, J., Spurk, M. 1998. INTCAL98 radiocarbon age calibration, 24,000-0 cal BP. *Radiocarbon* 40, 1041-1083.

Wilson, C.J.N. 2001. The 26.5 ka Oruanui eruption, New Zealand: an introduction and overview. *Journal of Volcanology and Geothermal Research* 112, 133-174.

HIGH RESOLUTION RECORDS

Auckland maars

Hagg, J. and Augustinus, P.C., unpublished data, 2004: 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.*

Horrocks, M., Augustinus, P.C., Deng, Y., Shane, P., Andersson, S, in press, 2005. Holocene environments recorded in a New Zealand maar crater: Lake Pupuke. *New Zealand Journal of Geology and Geophysics*.

Pepper, A.C., Shulmeister, J., Nobes, D.C., Augustinus, P.C. 2004. Possible ENSO signals prior to the last Glacial Maximum, during the deglaciation and the early Holocene from New Zealand. *Geophysical Research Letters* 31, L15206.

Sandiford, A., Alloway, B.V., Shane, P. 2001. A 28,000 - 6,600 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.

Sandiford, A., Newnham, R., Alloway, B.V., Ogden, J. 2003. A high resolution, southern hemisphere mid-latitude LGM to Holocene record of vegetation and climate change from northern New Zealand. *Palaeogeography, Palaeoclimatology, Palaeoecology* 201, 235-247.

Kaipo wetland

Lowe, D.J., Newnham, R.M., Ward, C.M., 1999. Stratigraphy and chronology of a 15 ka sequence of multisourced silicic tephras in a montane peat bog, eastern North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 42, 565-579.

Newnham, R.M., Lowe, D.J. 2000. Fine-resolution pollen record of late-glacial climate reversal from New Zealand. *Geology* 28, 759-762.

Otamangakau wetland

McGlone, M.S., Topping, W.W. 1983, Late Quaternary vegetation, Tongariro region, central North Island, New Zealand. *New Zealand Journal of Botany* 21, 53-76.

Turney, C. S. M., McGlone, M. S., Wilmshurst, J. M. 2003. Asynchronous climate change between New Zealand and the North Atlantic during the last deglaciation. *Geology* 31, 223-226.

Marine core MD97-2121

Carter, L., Manighetti, B., Elliot, M., Trustrum, N., Gomez, B. 2002. Source, sea level and circulation effects on the sediment flux to the deep ocean over the past 15 ka off eastern New Zealand. *Global and Planetary Change* 33, 339-355.

Manighetti, B., Carter, L., Gannsen, G., in review. Multiple species $d^{18}O$ record reveals the "Antarctic Cold Reversal" in mid-latitude Southwest Pacific. *Geochemistry, Geophysics, Geosystems*.

Speleothems

Williams, P.W., King, D.N.T., Zhao, J.-X., Collerson, K.D. 2005. Late Pleistocene to Holocene composite speleothem ^{18}O and ^{13}C chronologies from South Island, New Zealand - did a global Younger Dryas really exist? *Earth and Planetary Science Letters* 230, 301-317.

Okarito wetland

Vandergoes, M.J., Newnham, R.M., Hendy, C.H., Lowell, T.V., Preusser, F., Fitzsimons, S.J, Hogg, A.G., Kasper, H.U., Schlüchter, C., in review. Regional insolation forcing of late Quaternary climate change in the Southern Hemisphere". *Nature*

Vandergoes, M.J., Fitzsimons, S.J. 2003. The Last Glacial-Interglacial Transition (LGIT) in south Westland, New Zealand: paleoecological insight into mid-latitude Southern Hemisphere climate change. *Quaternary Science Reviews* 22, 1461-1476.

Antarctic & Greenland ice cores

GISP2 Homepage http://www.gisp2.sr.unh.edu

Jouzel, J., Masson, V., Cattani, O., Falourd, S., Stievenard, M., Stenni, B., Longinelli, A., Johnsen, S.J., Steffensen, J.P., Petit, J.R., Schwander, J., Souchez, R., Barkov, N.I. 2001. A new 27 ky high resolution East Antarctic climate record. *Geophysical Research Letters* 28 (16), 3199-3202.

Schwander, J., Jouzel, J., Hammer, C.U., Petit, J.R., Udisti, R., Wolff, E. 2001. A tentative chronology for the EPICA Dome Concordia ice core. *Geophysical Research Letters* 28 (22), 4243-4246.

Special Issue 1997. The Greenland Summit Ice Cores. *Journal of Geophysical Research* 102, 26,315-26,886.

Stenni, B., Masson-Delmotte, V., Johnsen, S., Jouzel, J., Longinelli, A., Monnin, E., Rothlisberger, R., Selmo, E. 2001. An Oceanic Cold Reversal during the last deglaciation. *Science* 293, 2074-2077.

FRAGMENTARY RECORDS

Glacial sequences

Almond, P.C., Moar, N.T., Lian, O.B. 2001. Reinterpretation of the glacial chronology of South Westland, New Zealand. *New Zealand Journal of Geology and Geophysics* 44, 1-15.

Basher, L.R., McSaveney, M.J. 1989. An early Aranuian glacial advance at Cropp River, central Westland, New Zealand. *Journal of the Royal Society of New Zealand* 19, 263-268.

Burrows, C.J. 1979. A chronology for cool-climate episodes in the Southern Hemisphere 12000 - 1000 yr BP. *Palaeogeography, Palaeoclimatology, Palaeoecology* 27, 287-347.

Burrows, C.J. 1980. Radiocarbon dates for post-Otiran glacial activity in the Mount Cook region, New Zealand. *New Zealand Journal of Geology and Geophysics* 23, 239-248.

Burrows, C.J. 1989. Aranuian radiocarbon dates from moraines in the Mount Cook region. *New Zealand Journal of Geology and Geophysics* 32, 205-216.

Burrows, C.J., Russell, J.B. 1975. Moraines of the upper Rakaia Valley. *Journal of the Royal Society of New Zealand* 5, 463-477.

T.J.H Chinn, NIWA, New Zealand, personal communication, 1999.

Denton, G.H., Hendy, C.H. 1994. Younger Dryas Age advance of Franz Josef Glacier in the Southern Alps of New Zealand. *Science* 264, 1434-1437.

Denton, G.H., Heusser, C.J., Lowell, T.V., Moreno, P.I., Andersen, B.G., Heusser, L.E., Schlüchter, C., Marchant, D.R. 1999. Interhemispheric linkage of paleoclimate during the last glaciation. *Geografiska annaler* 81A, 107-153.

Gellatly, A.F., Rothlisberger, F., Geyh, M.A. 1985. Holocene glacier variations in New Zealand (South Island). *Zeitschrift fur Gletscherkunde und Glazialgeologie* 21, 265-273.

Gellatly, A.F., Chinn, T.J.H., Röthlisberger, F. 1988. Holocene glacier variations in New Zealand: a review. *Quaternary Science Reviews* 7, 227-242.

Grant-Taylor, T.L., Rafter, T.A. 1962. New Zealand radiocarbon age measurements (5). *New Zealand Journal of Geology and Geophysics* 5, 331-359.

Hormes, A., Preusser, F., Denton, G., Hajdas, I., Weiss, D., Stocker, T.F., Schlüchter, C. 2003. Radiocarbon and luminescence dating of overbank deposits in outwash sediments of the Last Glacial Maximum in North Westland, New Zealand. *New Zealand Journal of Geology and Geophysics* 46, 95-106.

Ivy-Ochs, S., Schlüchter, C., Kubik, P.W., Denton, G.H. 1999. Moraine exposure dates imply synchronous Younger Dryas glacier advances in the European Alps and in the Southern Alps of New Zealand. *Geografiska annaler* 81A, 313-324.

Lowell, T.V., Heusser, C.J., Andersen, B.G., Moreno, P.I., Hausser, A., Heusser, L.E., Schlüchter, C., Marchant, D.R., Denton, G.H. 1995. Interhemispheric correlation of late Pleistocene glacial events. *Science* 269, 1541-1549.

McGlone, M.S. 1996. Lateglacial landscape and vegetation change and the Younger Dryas climatic oscillation in New Zealand. *Quaternary Science Reviews* 14, 867-881.

Mercer, J.H. 1988. The age of the Waiho Loop terminal moraine, Franz Josef Glacier, Westland. *New Zealand Journal of Geology and Geophysics* 31, 95-99.

Moar, N.T. 1980. Late Otiran and early Aranuian grassland in central South Island. *New Zealand Journal of Ecology* 3, 4-14.

Porter, S.C. 2000. Onset of Neoglaciation in the Southern Hemisphere. *Journal of Quaternary Science* 15, 95-408.

Suggate, R.P. 1965. Late Pleistocene geology of the northern part of the South Island, New Zealand. *New Zealand Geological Survey Bulletin* 77.

Suggate, R.P. 1968. The Paringa Formation, Westland, New Zealand. *New Zealand Journal of Geology and Geophysics* 11, 345-355.

Suggate, R.P. 1988. Quaternary deposition and deformation in the Buller and tributary valleys. *New Zealand Geological Survey Record* 25, 51 p.

Suggate, R.P. 1990: Late Pliocene and Quaternary glaciations of New Zealand. *Quaternary Science Reviews* 9, 175-197.

Suggate, R.P. and Almond, P.C. *In press*. The Last Glacial Maximum (LGM) in western South Island, New Zealand: implications for the global LGM and MIS2. *Quaternary Science Reviews*.

Suggate, R.P., Moar, N.T. 1970. Revision of the chronology of the Late Otira Glacial. *New Zealand Journal of Geology and Geophysics* 13, 742-746.

Vandergoes, M.J., Fitzsimons, S.J. 2003. The Last Glacial-Interglacial Transition (LGIT) in south Westland, New Zealand: paleoecological insight into mid-latitude Southern Hemisphere climate change. *Quaternary Science Reviews* 22, 1461-1476.

Wardle, P. 1973. Variations of the glaciers of Westland National Park and the Hooker Range, New Zealand. *New Zealand Journal of Botany* 11, 349-388.

Wardle, P. 1978. Further radiocarbon dates from Westland National Park and the Omoeroa River mouth. *New Zealand Journal of Botany* 16, 147-152.

Fluvial aggradation or degradation

Berryman, K., Marden, M., Palmer, A., Wilson, K., Mazengarb, C., Litchfield, N., submitted. The post-glacial downcutting history in the Waihuka tributary of Waipaoa River, Gisborne district, New Zealand, and implications for tectonics and landscape evolution. *GSA Bulletin*.

Bull, W.B., 1991. Geomorphic responses to climate change. Oxford University Press, New York.

Knuepfer, P.L.K. 1988. Estimating ages of late Quaternary stream terraces from analysis of weathering rinds and soils. *Geological Society of America Bulletin* 100, 1224-1236.

Litchfield, N.J., Berryman, K.R., in press. Correlation of fluvial terraces within the Hikurangi Margin, New Zealand: Implications for climate and base level controls. *Geomorphology.*

Litchfield, N.J., Rieser, U., submitted. OSL age constraints for fluvial aggradation terraces and loess in the eastern North Island, New Zealand. *New Zealand Journal of Geology and Geophysics.*

Loess accumulation

Almond, P.C., Moar, N.T., Lian, O.B. 2001. Reinterpretation of the glacial chronology of South Westland, New Zealand. *New Zealand Journal of Geology and Geophysics* 44, 1-15.

Berger, G.W., Tonkin, P.J., Pillans, B.J. 1996. Thermoluminescence ages of post-glacial loess, Rakaia River, South Island, New Zealand. *Quaternary International* 34-36, 177-181.

Berger, G.W., Pillans, B.J., Tonkin, P.J. 2001. Luminescence chronology of loess-paleosol sequences from Canterbury, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 44, 501-516.

Formento-Trigilio, M.L., Burbank, D.W., Nicol, A., Shulmeister, J., Rieser, U. 2003. River response to an active fold-and-thrust belt in a convergent margin setting, North Island, New Zealand. *Geomorphology* 49, 125-152.

Goh, K.M., Tonkin, P.J., Rafter, T.A. 1978. Implications of improved radiocarbon dates of Timaru peats on Quaternary loess stratigraphy. *New Zealand Journal of Geology and Geophysics* 21, 463-466.

Grapes, R.H., Wellman, H.W. 1993. Field guide to the Wharekauhau Thrust (Palliser Bay) and Wairarapa Fault (Pigeon Bush). Geological Society of New Zealand Annual Conference, Wellington. *Geological Society of New Zealand Miscellaneous Publication* 79B, 27-44.

Litchfield, N.J., Rieser, U., submitted. OSL age constraints for fluvial aggradation terraces and loess in the eastern North Island, New Zealand. *New Zealand Journal of Geology and Geophysics.*

Aeolian quartz

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

Institute of Geological & Nuclear Sciences Limited

Gracefield Research Centre
69 Gracefield Road
PO Box 30 368
Lower Hutt
New Zealand
Phone +64-4-570 1444
Fax +64-4-570 4600

Rafter Research Centre
30 Gracefield Road
PO Box 31 312
Lower Hutt
New Zealand
Phone +64-4-570 4637
Fax +64-4-570 4657

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
Phone +64-3-477 4050
Fax +64-3-477 5232

Wairakei Research Centre
State Highway 1, Wairakei
Private Bag 2000
Taupo
New Zealand
Phone +64-7-374 8211
Fax +64-7-374 8199

For more information visit the GNS website
http://www.gns.cri.nz