Quaternary research in New Zealand since 2000: an overview

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With the AQUA milestone of 30 years it seems an appropriate time to review the progress and achievements of Quaternary research in New Zealand. This article highlights some of the major achievements since the formal review of New Zealand's Quaternary record by Newnham et al. (1999). The focus here is on paleoclimate and geochronology and is by no means a comprehensive review. We encourage members to write future articles for Quaternary Australasia (QA) about their exciting projects to keep the wider Australasian community informed.

One of the main differences between Australian and New Zealand Quaternary science is the wide use of tephrochronology to correlate and date deposits and events across the landscape, helping to link terrestrial and marine records, especially in the North Island. There have been significant advances using glass-based fission-track dating, corrected for annealing, and the use of the electron microprobe and laser ablation inductively-coupled plasma mass spectrometry for obtaining major- and trace-element analyses, respectively, to chemically fingerprint individual glass shards in tephras to aid their correlation (Shane, 2000; Lowe, 2011). Also the identification and analysis of cryptotephras (concentrations of glass shards not visible as a layer) have greatly expanded the geographic range of many tephras, allowing the application of tephrochronology as a stratigraphic and dating tool across much wider areas than previously possible (Gehrels *et al*., 2008).

Significant improvements in radiocarbon dating, using both liquid scintillation spectrometry and accelerator mass spectrometry, which allow for small samples and a wide range of materials to be dated (e.g. pollen concentrates: Vandergoes and Prior, 2003; Newnham *et al*., 2007c), and robust dating of samples as old as c. 60 cal ka (e.g. Hogg *et al*., 2007), have led to better chronological control on climatic and volcanic events. These improvements include the internationally-agreed calibration curves (INTCAL and MARINE) (Hogg *et al*., 2009; Reimer *et al*., 2009), and changes in the way age modelling of records is undertaken using Bayesian statistical methods (e.g. Buck *et al*., 2003; Lowe *et al*., 2008; Hogg *et al*., 2009). The Kawakawa tephra, a key marker bed for the last glacial in New Zealand, has recently been re-dated using 14C and Bayesian age modelling, moving its age from c. 27,000 to c. 25,000 cal yr BP (Vandergoes *et al*., in press). A major development has also been the update of the Southern Hemisphere radiocarbon calibration curve using a combination of dendrochronology and 14C dating of kauri and other tree rings (SHCAL04; McCormac *et al*., 2004; Hogg *et al*., 2011). There is now a continuous kauri tree ring record that stretches back 2000 years, which has also highlighted changes in ENSO (Fowler *et al*., 2012). This work and other tree ring data have contributed to the Aus2K collaboration (Turney *et al*., 2010; Gergis *et al*., 2011).

High resolution records, dated in part using tephra and radiocarbon, have also been published from a number of lakes and bogs providing information about the last glacial cycle and the Holocene. These include records from the Auckland maars (Newnham *et al*., 2007a; Augustinus *et al*., 2008, 2011), Lake Poukawa, drilled as part of the PEP II project (Pole-Equator-Pole; Shulmeister and Dodson, 2002), Kaipo bog (Newnham and Lowe, 2000; Hajdas *et al*., 2006), Okarito bog (Vandergoes *et al*., 2005; Newnham *et al*., 2007b), the Subantarctic islands (McGlone *et al*., 2002; 2010), and Lake Maratoto (Green and Lowe, 1985), which has recently been selected as the Australasian auxiliary record for the "Global Stratotype Section" for the base of the Holocene, defined by the Konini tephra (unit b), and palynology (Walker *et al*., 2009). Lake Tutira was also drilled as part of the MARGINS program, and has recorded evidence of large storms and earthquakes over the mid-late Holocene (Page *et al*., 2010) as well as ENSO/SAM interactions (Gomez *et al*., 2012). We would like to suggest that several of these lakes and bogs are suitable candidates for "iconic" status (see Kathryn Fitzsimmons' article – this issue), especially Lake Maratoto.

Figure 1: Lake Maratoto, adjacent to partly drained peatlands (upper part of photo) ~10 km south of Hamilton, is protected by a QE II Trust covenant (photo by David Lowe).

Detailed palynological studies over the past 12 years have increased our knowledge of vegetation succession and centennial to millennial scale changes in climate. Palynological change, together with wiggle-match dating of the Kaharoa eruption using celery pine tree-rings to 1314 ± 12 AD (Lowe *et al.*, 2002; Hogg *et al.*, 2003), also provided a date for the first environmental impacts of humans in New Zealand at c. 1250-1300 AD. Subsequent dating of exotic rat bones and rat-gnawed seeds has confirmed the timing of Polynesian settlement to c. 1280 AD (Wilmshurst *et al.*, 2004, 2008).

Another significant development in the last few years has been the development of quantitative temperature estimates from pollen using transfer functions (Wilmshurst *et al.*, 2007). Novel environment and temperature proxies have also been applied over the last decade, including using chironomid (midges) remains from lakes (e.g., Vandergoes *et al.*, 2008), phytoliths (e.g. Carter, 2002), diatoms (e.g. Page *et al.*, 2010), and coleopteran (beetle) remains from lake and soil profiles (e.g. Marra *et al.*, 2006, 2009). These temperature reconstructions, and other evidence, across New Zealand have been used to show the diachronous timing of climate events such as the late-glacial reversal, which was coincident in part with the Antarctic Cold Reversal (ACR) (Hajdas *et al.*, 2006; Vandergoes *et al.*, 2008; Newnham *et al.*, 2012).

Speleothems have continued to be exploited for their climate records. While these can be 14C dated, they can also be independently dated using U/Th, improving their chronological control. Using the micromill has also allowed sub-millimetre sampling, and the generation of high resolution stable isotope data (Williams *et al.*, 2004, 2010; Whittaker *et al.*, 2011). The stable isotopes also indicate a late glacial cool period that overlaps with the ACR and YD (Williams *et al.*, 2005). The speleothems are influenced by both temperature and precipitation and show that the last glacial maximum in the South Island was both cooler and drier than present (Williams *et al.*, 2010; Lorrey *et al.*, 2012). These findings are supported by the record of loess deposits at Ahuriri on Banks Peninsula (Almond *et al.*, 2007). This interpretation follows the publication of Almond and Tonkin's (1999) paper on sequences in Westland, which led to a step change in our understanding of the chronology and climatic significance of loess and long-range dust accumulation in New Zealand, and how soil-forming processes interact with such accumulation. Further developments have been made over the last 10 years (e.g. Lowe and Tonkin, 2010; Eger *et al.*, 2012).

Luminescence dating has become an established technique in New Zealand, although problems with dim quartz have limited the application of single grain optically stimulated luminescence (OSL). Luminescence dating has contributed to constraining climatically controlled river aggradation and loess accumulation in the North Island (Litchfield and Rieser, 2005), and to glacial chronology in the South Island (Rother *et al.*, 2010; Shulmeister *et al.*, 2010).

Figure 2: Glacial erratic sampled for cosmogenic dating, Southern Alps (photo courtesy of Alice Doughty).

There has been an enormous amount of work mapping the glacial terrains in the South Island of New Zealand over the last 12 years. A series of spectacular geomorphic maps and thorough descriptions have been produced (Barrell *et al.*, 2011). The glacial chronology has been refined mainly using 14C dates, luminescence dating, and improved cosmogenic exposure dating using 10Be, greatly aided by a new calibration for the Southern Hemisphere from a site in the Southern Alps (Putnam *et al.*, 2010a), and by the use of the Kawakawa tephra as a marker bed (Almond *et al.*, 2001; Berger *et al.*, 2002; Suggate and Almond, 2005). Cosmogenic exposure ages have confirmed the existence of ACR moraines east of the main divide (Putnam *et al.*, 2010b), but raised further questions about the age of the enigmatic and "iconic" Waiho Loop moraine on the west of the divide (Barrows *et al.*, 2007). Our understanding of what factors drive the glacial advances and retreat in the Southern Alps has also been progressed by numerical modelling work (Anderson and Mackintosh, 2006; Golledge *et al.*, 2012).

Previous reviews of the Quaternary work in New Zealand have tended to focus on terrestrial environments. Since 2000 there has been significant progress in our understanding of changes in the ocean currents and circulation of the SW Pacific. Work on long cores from the Deep Sea Drilling Program (DSDP) has continued, and has been complemented by studies on new cores drilled as part of the Ocean Drilling Program's (ODP) Leg 181 in 1998. Most recently, "Matacore", a New Zealand-France research programme, began in January 2006 during Leg 152 of the ship Marion Dufresne, which collected 31 cores around the region (Proust *et al.*, 2008). Several of these cores extend back to the Pliocene and beyond (Carter *et al.*, 2004) and have increased our knowledge of the early Quaternary, including the changes in periodicity at the Mid-Pleistocene Transition (Naish, 2005; Crundwell *et al.*, 2008). New long records of volcanic activity in the Taupo Volcanic Zone have also been developed using analyses from the marine cores (e.g. Shane *et al.*, 2006; Allan *et al.*, 2008). ANDRILL is another international programme that has provided long cores in the Ross Sea to understand Quaternary changes in Antarctica. The ANDRILL-site 1B cores have provided evidence of ice-sheet collapse during past interglacials, including most recently marine isotope stage (MIS) 31 around one million years ago (Naish *et al.*, 2009).

Figure 3: ANDRILL coring with local Quaternarists for scale (photo by Gavin Dunbar)

Suites of shorter marine cores off the east coast of New Zealand have also been studied in detail and provided information on changes in currents and circulation during the last two glacial cycles, including significant increase in ice bergs on the Campbell Plateau during the glacials (Carter *et al*., 2002; Neil *et al*., 2004). Cores from the Ross Sea, and on the continental shelf of Antarctica, have constrained the extent, timing and rate of ice sheet retreat at the end of the last glacial, and major retreat primarily due to increasing sea surface temperatures (McKay *et al*., 2008; Mackintosh *et al*., 2011).

If you were going to pick any "iconic" marine cores for the New Zealand region it would be DSDP site 594 (combined with another core taken at this same site, MD97-2120; Nelson *et al*., 1993, 2000; Pahnke et al., 2003) east of the South Island, and P69 (and its counterpart MD97-2121; Carter *et al*., 2002, 2008), east of the North Island. Ongoing work on these cores has provided considerable increase in our paleoceanographic understanding linked to global climate change and has helped to link terrestrial climate to changes in the marine environment, through the analyses of palynology and presence of many tephras (especially in MD97-2121).

One of the most rewarding initiatives over the last nine years has been the NZ-INTIMATE (Integration of Ice, Marine and Terrestrial records) project, part of the larger Aus-INTIMATE programme sponsored by PALCOMM and INQUA (see report by Jessica Reeves in this issue). The original poster and publications (Barrell *et al*., 2005; Alloway *et al*., 2007), derived from a series of workshops, were the first comprehensive attempts to compare and correlate paleo-records from a range of environments using numerous different proxies. Deposits at many of the sites were linked with tephras (Lowe *et al*., 2008). Further work in the second phase of NZ-INTIMATE has continued to bring together new records, as well as examining the spatial variability of these records around New Zealand (Lorrey *et al*., 2012). A climate event stratigraphy (CES) has now been erected for the New Zealand region using palynological records (Barrell *et al*., in press). This NZ-CES paper, and several other papers dealing with climate change since c. 30 cal. ka, are being published in a special Aus-INTIMATE issue of Quaternary Science Reviews (QSR) (see report by Jessica Reeves - this issue). We encourage you to check out this QSR volume as it will provide much more detail of the latest Quaternary research in New Zealand than can be accomplished in this short review.

Along with regular NZ-INTIMATE meetings since 2004, there have been two AQUA meetings, in 2003 at Westport, and in 2012 at Tekapo. We hope the AQUA meeting will return to Auckland in 2016.

Figure 4: Participants at the 2005 NZ-INTIMATE workshop at GNS Rafter laboratories, Lower Hutt.

Peter Almond also hosted a South Island field trip as part of the INQUA Congress held in Cairns in 2007. The 'Past Climates' meeting (in association with Aus-INTIMATE) in Wellington in 2009 was a showcase for the completed glacial mapping and dating, along with progress on other New Zealand Quaternary projects, and brought together many international colleagues, and included public lectures by Profs George Denton and Wally Broecker.

So what of the future? Well, there are numerous exciting initiatives currently underway including the proposal to drill Lake Ohau with its annual depositional layers; new temperature proxy development using biomarkers such as Tex86; lots of new data are being produced from the Matacore marine cores off the West Coast; another ANDRILL core will be drilled in 2014; and increasing use of ancient DNA (aDNA) in paleocology, paleontology, and archaeology (e.g. Allentoft and Rawlence, 2012). There are also several proposals to continue the work of Aus-INTIMATE with a project called SHAPE (Southern Hemisphere Assessment of Paleo-Environments), which will include South America and Africa, and an international focus group being developed in the UK called CELL50k (Calibrating Environmental Leads and Lags over the last 50 kyr). The acclaimed annual Quaternary Techniques course run by the GNS Science National Isotope Centre for the last nine years has had an average of 30 students/year (see report in this issue by Tom Brookman). It is clear that Quaternary science is alive and well in New Zealand and that its future looks both exciting and enlightening.

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