GEOLOGICAL SOCIETY OF NEW ZEALAND
NEW ZEALAND GEOPHYSICAL SOCIETY
NEW ZEALAND GEOCHEMICAL & MINERALOGICAL SOCIETY
JOINT ANNUAL CONFERENCE

Geosciences '08
Te Papa, Wellington

Programme and Abstracts

Compiled by Richard Wysoczanski

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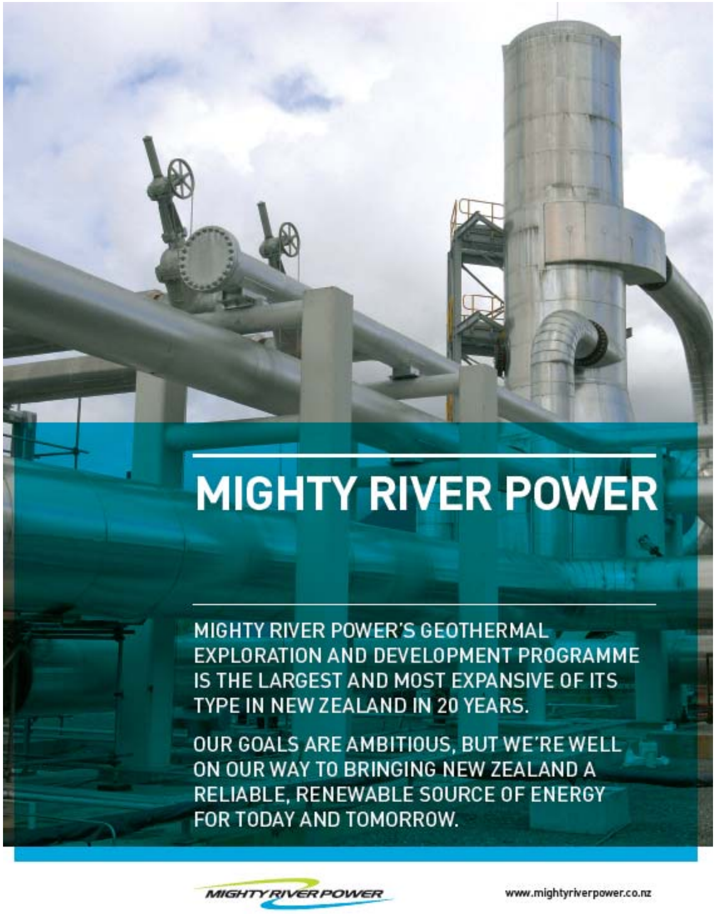

downtown
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the city's downtown quarters
Lambton
Willis
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Te Papa at dusk
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PORT NICHOLSON
YACHT CLUB
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GENERAL INFORMATION:

Welcome to Geosciences'08, the joint annual conference of the Geological Society of New Zealand, the New Zealand Geophysical Society and the New Zealand Geochemical and Mineralogical Society. With over 350 registrants, we are able to offer a very full programme including 8 scientific symposia, 7 meetings and 6 field trips. The conference commences with two field trips and an ice breaker on Sunday 23rd November. The scientific sessions and meetings run from Monday 24th November, until the closing ceremony at 5 pm, Wednesday 26th November. Two post-conference field trips complete the programme.

THE VENUE:

Te Papa Tongawera is the Museum of New Zealand, housing and displaying the nation's natural and cultural treasures. It is situated on Cable Street on the waterfront in the heart of the nation's capital, in easy walking distance of the CBD, restaurants and entertainment.

In 1998 the Geological Society was first to hold a conference at Te Papa. In 2008 Te Papa celebrates its 10th anniversary, making it an ideal venue for this year's annual conference of the geoscience community, who have shared in its development and growth. The Earthquake Commission and GNS Science are partners of Te Papa and we are grateful to them for providing the venue for the conference as part of their Gold-level sponsorship.

During the conference, the museum will be open to the public and we encourage delegates to view the displays. Guided tours are available from Te Papa's Information Desk, and a unique guided tour of geological exhibits is offered as part of the field trip programme.

All conference events will be held at Te Papa, except for the icebreaker and BBQ, which are a short walk from Te Papa along the waterfront.

Event locations:

Oceania Room, level three: Registration and the Conference Information Desk, poster sessions, morning and afternoon teas, trade displays, and the Awa Press book launch.
Soundings Theatre, level two: Opening and closing ceremonies, all plenary talks, Barrett, Geophysics and Geology Symposia.

Rangimarie rooms 1, 2 and 3 (Telstra Centre) level three: Symposia and intra-conference meetings. NB Rangimarie rooms 1 and 2 will be joined togther on the Tuesday and Wednesday.
Wellington Foyer, level two: Conference Dinner and Te Papa Information Desk during Museum hours.
Wellington Brewery Bar and Restaurant, cnr Cable and Taranaki Sts, on the waterfront: Ice breaker and registration on Sunday 23rd November.
Royal Port Nicholson Yacht Club, 103 Oriental Parade, Oriental Bay: BBQ, Monday 24th November.

REGISTRATION & INFORMATION DESK:

Registration will begin at the icebreaker from 5:00 pm on Sunday 23rd November at '*The Brewery Bar and Restaurant*'. During session days (Monday – Wednesday) registration is available at the conference Information Desk, (Oceania room, Level Three of Te Papa) from 7:45 am.

SATCHELS:

There is no conference satchel. Each delegate will receive conference material, including electronic files, at arrival. Please bring your own bag. If you have satchels from previous conferences that you are willing to recycle, please bring them to the registration desk from Monday morning. These will be available for students to take, if needed, when they register.

SCIENCE PROGRAMME:

There are over 260 presentations (143 oral, 119 poster), including 5 plenary talks, at Geosciences'08 - a record number for this conference. These are grouped into eight symposia:

- **(1)** Antarctic - Southern Ocean - New Zealand Climate Linkages: A Symposium Honouring Professor Peter Barrett (short title: **Barrett**);
- **(2)** New Zealand's Future Energy Environment (**Energy**);
- **(3)** Bridging the Strait: Active Geological Processes and Natural Hazards in Central New Zealand (**Strait**);
- **(4)** Geophysics and Tectonics (**Geophysics**);
- **(5)** Magmas: Mantle to Surface (**Magmas**);
- **(6)** Geochemistry - A Geochemistry Window into Earth's Origin, History and Future (**Geochemistry**);
- **(7)** Geology - A General Session to Celebrate the 150th Anniversary of Hochstetter's and Haast's Work in New Zealand (**Geology**); and
- **(8)** New Zealand Cold Seeps / Gas Hydrates / Methane-derived Authigenic Carbonates (MDACs) - Present and Past (**Seeps**).

Oral and Poster Presentations:

All Oral presentations are 15 minutes (including questions), except for Plenary talks, which are 30 minutes. Presentations can be given as PowerPoint 2003 (PC) or Pdf files only. They can be downloaded at the registration desk any time during the conference, but we request that they are submitted at least one session prior to the presentation. Computers will also be available to check presentations. Note that there will only be ONE screen available for presentations.

There are three concurrent sessions on Monday 24th Novermber, and two concurrent sessions on Tuesday 25th and Wednesday 26th. Monday sessions are in either Sounding Theatre, Rangimarie room 1, or Rangimarie Room 2. On Tuesday and Wednesday, they will be in either Soundings Theatre, or Rangimari rooms 1&2, which will be joined together. See the scientific programme for symposium locations and times.

There are TWO dedicated poster sessions, and ALL posters will be displayed during either the Monday or Tuesday poster session in the Oceania Room. Posters for display on Monday can be put up from Monday morning and must be removed by Tuesday lunch time. Posters for display on Tuesday can be put up from Tuesday lunch time, and removed before 5 pm, Wednesday.

Poster presentation times and locations are given in the scientific programme, with M or T denoting Monday or Tuesday, followed by a board number. e.g. M01 = Monday dedicated poster sesion, poster board one.

Poster presentations must be no wider than 1.15 m. The poster boards are 1.2 m high, but 1.1 m off the ground so it is possible for posters to hang below the 1.2 m height. Velcro dots must be used to secure the poster to the board (please bring your own). Pins are not suitable.

FIELD TRIPS:

All field trips depart from outside the main entrance of Te Papa. Field guides will be distributed and lunch provided.

Pre-Conference Field trips:

Wellington Fault: Neotectonics and Earthquake Geology
John Begg, Rob Langridge, Russ Van Dissen (GNS Science), Tim Little (VUW)
Sunday 23rd, 09:30 - 17:30

Turakirae Head Coastal Geomorphology/Geology
David Kennedy (VUW) and Mauri McSaveney (GNS Science)
Sunday 23rd, 10:00 - 17:30

Mid-Conference Field trips:

Café to Espresso: Geology at Te Papa (half day)
Short Tours with the Curators, Te Papa

Hamish Campbell and Te Papa curators (GNS Science and Te Papa)
(as arranged)

Post-Conference Field trips:

Southern Wairarapa Fault & Wharekauhau Thrust (Palliser Bay)
Tim Little (VUW), Liz Schermer (W. Washington University), Russ Van Dissen, John Begg (GNS Science)
Thursday 27th, 08:30 - 18:00

Wanganui Basin: Plio-Pleistocene Record of Sea Level Change
Warren Dickinson (VUW), Gavin Dunbar (VUW), Brad Pillans (ANU), Brent Alloway (VUW), Kyle Bland, Alan Beu (GNS Science)
Wednesday 26th 17:00 to Friday 28th 17:00

REFRESHMENTS:

Morning tea will be served on each of the session days in the Oceania Room. Afternoon tea will be served only on Wednseday 26th November. Complimentary refreshments (including beverages and snacks) will also be served at the poster sessions on Monday and Tuesday for a limited time, after which a cash bar will be available.

Te Papa has two cafes available to the public: *Te Papa Café*, level one, and *Espresso*, level four.

SOCIAL EVENTS:

Icebreaker

An informal 'icebreaker' function will be held in conjunction with registration in the Function Room (upstairs) at the Brewery Bar and Restaurant, cnr of Taranaki and Cable Streets on the waterfront adjacent to Te Papa, from 5:00-7.00 pm Sunday 23rd November. Due to the large number of expected attendees, delegates are invited to use all parts of the Brewery Bar, including downstairs and outside, once they have registered upstairs. Snacks will be served, and drink vouchers honoured, throughout the establishment, as long as you are wearing your conference nametag. Drink vouchers can be found in your registration pack.

BBQ

A BBQ at the Royal Port Nicholson Yacht Club will be held from 7.00 pm on Monday 24th November. To attend, you must have prepaid during conference registration. Drink vouchers for those that registered are included in your registration pack. In case of poor weather, only limited seating will be available indoors.

Conference Dinner

The Annual Conference Dinner (theme: "*A night in Wellywood*", fancy dress optional) will be held on Tuesday 25th November in the Wellington Foyer, Te Papa. Pre-dinner drinks will be available from 7.00 pm, and dinner will be served at ~7.30 pm. The cost of the Conference Dinner is not included in the standard registration price and tickets need to be ordered and paid for along with registration. The dinner will consist of an entrée, a mains buffet and dessert. Refreshments will be provided for a limited time, with a cash bar to follow. The yearly awards for the Geological Society and the Geophysical Society will be presented after dinner. There will also be prizes for the best/most imaginatively dressed participant in the theme of the dinner.

INTRA-CONFERENCE EVENTS AND MEETINGS:

Several meetings will be held during lunch breaks throughtout the conference, with the Awa Press book launch and the Geological Society of New Zealand AGM held immediately after the scientific programme. Please note that food cannot be consumed in the Rangimarie rooms or Soundings Theatre.

Awa Press book launch

Awa Press cordially invite you to the launch of 'The Amazing World of James Hector' (edited by Simon Nathan and Mary Varnham), Monday 24th November 5:15 - 6:30 pm, Oceania Room, Te Papa. Refreshments will be available. Space is limited.

GSNZ AGM

The 54th Annual General Meeting of the Geological Society of New Zealand will be held in Soundings Theatre, Tuesday 25th November, 5 pm. See the October newsletter for details.

Lunch Time meetings:

1. 33rd International Geological Congress, Olso August 2008 (Peter Barrett)

Monday 12.30 pm, Rangimarie 1

Over 6000 geoscientists (~30 from NZ) took part in this 9 day meeting. The theme was “Earth System Science: Foundation for Sustainable Development” and the oral and poster sessions, displays and promotions provided an amazing update on the state of the earth sciences globally. In this review of the meeting, Alex Malahoff will give an overview of the conference, and Mark Rattenbury will talk on OneGeology, Ian Graham on resource issues and Peter Barrett on environmental issues. In the meantime check out the website at www.33igc.org for webcasts of plenary papers and end-of-day forums ranging from evolution and biodiversity to geohazards to health and the environment to resources the earth and the cosmos.

2. Oil and Gas Special Interest Group (Don Haw)

Monday 12.30 pm, Rangimarie 2

The Oil and Gas Special Interest Group is holding a brief lunch time discussion meeting on Monday for all interested Conference participants. This group has published regular summaries of Oil and Gas exploration activity, in our Newsletter for the past year. We need to know how this new initiative has been received by our readership, and how best to meet their expectations in the future. Anyone interested in Oil and Gas matters, especially from an Earth Science point of view, are encouraged to attend. The meeting will be held Monday in the Rangimarie 2 Room at 12:30 pm. If you cannot attend please make contact with Don Haw during the conference.

3. DRILLNZ: scientific drilling for the benefit of New Zealand (Rupert Sutherland and Chris Hollis)

Tuesday 12.30 pm, Rangimarie 1&2

A meeting to update the NZ Geoscience community on progress towards membership of international drilling programmes, the Integrated Ocean Drilling Program (IODP) and the International Continental Scientific Drilling Program (ICDP), and to discuss an initiative to promote and coordinate NZ's participation in international drilling projects under the DRILLNZ banner. See: drill.gns.cri.nz

4a. IAS National Correspondent Informal Meeting (Karoly Nemeth)

Tuesday 12.30 pm, Rangimarie 3

Karoly Nemeth (Massey University) is holding an informal half-hour side-meeting in Rangimarie 3, Tuesday 12.30 pm during Geosciences '08 to discuss ideas about how New Zealand’s sedimentology research and activities could be represented to the International Association of Sedimentologists (IAS). The meeting will be a quick information exchange on how the country’s sedimentological research could be linked more strongly to the IAS. Any sedimentologist with ideas on the subject is welcome.

4b. New Zealand Bid to host the IAVCEI – CVS – IAS 4th International Maar Conference: an interdisciplinary meeting on monogenetic volcanism.

Tuesday 1.00 pm, Rangimarie 3

Karoly Nemeth, Shane Cronin (Massey University), Jan Lindsay and Ian Smith (Auckland University) are holding a half-hour meeting in Rangimarie 3, Tuesday 1 pm during Geosciences’ 08 to present an initial plan to bring the 4th International Maar Conference to New Zealand. The Maar Conferences started in 2000 in Germany, the type locality of maar volcanoes primarily concentrating on young maar volcanoes. The second conference was held jointly by Hungary, Slovak Republic and Germany in 2004 primarily concentrating on sub-surface architecture of maar volcanoes. The 3rd meeting will be in Argentina in April 2009 (www.3imc.org) with an extended scope focusing on transitional processes from maar to any type of monogenetic volcano. Since Auckland is built on an active monogenetic volcanic field with large a number of phreatomagmatic volcanoes it is a logical place to offer a potential host location for the 4th International Maar Conference with a much broader scope, including any type of monogenetic volcanism. Since New Zealand has not hosted any major volcanological congress since the Cities of Volcanoes meeting in 2001, a planed February 2011 date would mark a ten years “anniversary” and would certainly boost research efforts and output by at least the “monogenetic part” of the New Zealand volcanic community. This short informal meeting will give you an update of the progress of the planning, and will call for help to get as broad as possible support from the New Zealand community to maximize the gain New Zealand would be able to achieve with hosting such a congress.

5. Getting the best for NZ Earth Science from IUGG Melbourne 2011 and IGC Brisbane 2012 (Des Darby and Adrian Pittari)
Wednesday 12.30 pm, Rangimarie 1&2
Desmond Darby (GNS Science) and Adrian Pittari (University of Waikato) are holding a side-meeting in Rangimarie 1, Wednesday 1 pm during Geosciences '08 to develop ideas for:
(a) workshops you may wish to host at IUGG Melbourne 2011 and/or IGC Brisbane 2012
(b) field trips in New Zealand you may wish to lead before and/or after the Melbourne and Brisbane meetings
(c) workshops you may wish to hold in New Zealand, possibly in association with the New Zealand field trips.
Please bring your ideas to the side-meeting.

6. Historical Studies Group, GSNZ (Mike Johnston)
Wednesday 12.30 pm, Rangimarie 3
An informal meeting to discuss matters of mutual interest including material for the Journal.

AWARDS AND GRANTS:

The announcement and presentation of annual awards for the Geological Society and the Geophysical Society will be made at the conference dinner. Student awards (sponsored by Awa Press) for oral and poster presentations will be announced at the closing ceremony in Soundings Theatre. Student travel grant cheques may be collected from the Registration Desk during the conference.

CAR PARKING:

Car parking is available on site at a daily charge of $12.00. Evening rate for arrival after 5pm is $6.00.

Abstracts

(in alphabetical order, by session)

Bibliographic reference:

Author, A.B. (2008). Title of abstract. Geological Society of New Zealand Miscellaneous Publication 124A: p.

PLENARY TALKS

Soundings Theatre

Monday 24th

8:30 Peter Kamp
Renewable electricity generation target (90%) and the need for more natural gas and geothermal exploration

15:00 Will Howard
Southern Ocean influence on the carbon cycle and ice sheets: is the Pleistocene the key to the Cenozoic?

Tuesday 25th

8:30 Simon Turner
Time scales of island arc magmatic processes

15:00 Tim Stern
Mantle deformation beneath New Zealand and implications for vertical movements of the crust

Wednesday 26th

8:30 Brad Pillans
Quaternary adventures in Zealandia: from Wanganui to The West Island

SOUTHERN OCEAN INFLUENCE ON THE CARBON CYCLE AND ICE SHEETS: IS THE PLEISTOCENE THE KEY TO THE CENOZOIC?

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The Southern Ocean plays a critical role in the operation of the global climate system and carbon cycle, and its sediment proxy records provide key constraints on models of CO_2 cycles. The carbon cycle of the glacial Southern Ocean is distinctly different from its interglacial state, with a net effect of enhanced CO_2 uptake. The glacial "state" of the Southern Ocean is one of lowered temperatures, equatorward-shifted frontal zones, sea-ice fields, and ice-rafted debris deposition. Associated with these large-scale shifts are changes in the ventilation rate of Southern Ocean deep-water masses and their physical circulation, enhanced particle fluxes and biological pumping in the subantarctic zone.

The effects of these perturbations combined with changes in ocean alkalinity and $CaCO_3$ solubility have influenced atmospheric CO_2 over the past ~800,000 years. Importantly, the ocean may still be changing geochemically and driving trends in the atmosphere that continue through the Holocene, with implications for the assumption of pre-industrial "steady-state" in carbon cycle models, and for hypotheses of human influence on the carbon cycle in the Holocene. These mechanisms are "closed-system" drivers of the carbon cycle, i.e., they partition carbon between the ocean and atmosphere and dominate atmospheric CO_2 changes on Pleistocene time scales. A key question as we consider longer-term Neogene and Palaeogene variations is at what time-scale do "open-system" mechanisms (e.g. weathering, uplift) become dominant?

A challenge for palaeoclimate research is to estimate the timing of Southern Ocean carbon cycle changes and the amplitude of atmospheric CO_2 change they may drive. As hypotheses for the inception of Antarctic glaciation turn to CO_2-driven mechanisms, the role of the Southern Ocean itself in driving carbon cycle feedbacks becomes a crucial question.

The relationship between Antarctic ice-sheet growth and Southern Ocean temperature is also a key question. Some models of future global warming project greater snow accumulation as an initial response to warming, reflecting the competing processes of atmospheric warming driving melting versus warmer oceans driving greater inland precipitation. Can feedbacks between sea-surface temperature and ice accumulation be tested? The Pleistocene North Atlantic was warm while orbital forcing was favourable for boreal ice-sheet growth. The relevance to the Southern Hemisphere is that the current orbital configuration of low, and decreasing, axial tilt may tend to favour summer snow preservation and, combined with greater snow accumulation from a warmer ocean, could lead to net accumulation in the short term. This idea could be tested for the Pleistocene by comparing the records of accumulation-rate changes in inland Antarctic ice cores with marine records of sea-surface temperature in the moisture source-regions of the subtropical-to-temperate Southern Ocean.

ENERGY AVAILABILITY AND EMISSIONS REDUCTION IN NEW ZEALAND TO 2025: CHALLENGES AND OPPORTUNITIES FOR THE ENERGY RESOURCES SECTOR

P.J.J. Kamp, M. J. Atkins, A. S. Morrison, J.R. Neale & M.R.W. Walmsley
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Some 23% of New Zealand's annual electricity demand is typically met by thermal generation from natural gas and coal, being higher in dry years. The former Government's 90% Renewables electricity generation target for 2025 required a substantial reduction in the amount of thermal generation, while at the same time having to cope with increasing electricity demand. From 2006 to 2007 there was a large net reduction (14%) in emissions from the electricity sector, largely achieved by substituting gas for coal-fired generation. Fuel substitution is a useful strategy to reduce emissions, but under a 90% Renewables regime even the amount of gas-fired generation must be restricted. What is this limit for gas-fired generation and hence is there an imperative to explore for more natural gas resource? This depends upon several variables: (i) the electricity demand growth forecast(s); (ii) the generation mix, including geothermal, which has an emissions profile even though it is now regarded as a renewable source of energy (factor of 0.115 kt CO2-e per GWh); (iii) the operability and stability of the electricity system and market; (iv) security of supply; and (v), the economics of the different generation technologies. In choosing the 90% renewable target, to what extent was the policy development based on rigourous analysis and hence is such a target achievable and economically sustainable?

Carbon Emissions Pinch Analysis (CEPA) is a recent extension of traditional thermal and mass pinch analysis to the area of emissions targeting and planning on a macro-scale (i.e. economy wide). This paper presents a carbon pinch analysis of the New Zealand electricity sector and illustrates some of the issues with realising meaningful emissions reductions. The current large proportion of renewable generation (e.g. from hydro) limits the opportunity for the achievement of emissions reduction. Several scenarios are presented demonstrating the difficulty of meeting the expected increased electricity demand whilst simultaneously reducing emissions. It is likely that the 90% Renewables target will need to be relaxed by the new Government if electricity supply is to be assured. However, there is clearly a need for substantially increased generation from geothermal sources to help meet the growth in electricity demand while simultaneously contributing to emissions reduction. There is every reason to actively explore for more natural gas, notwithstanding the likely increase in demand arising from more direct use of gas in the industrial, commercial and residential sectors, as gas-fired generation has a critical role between now and 2025 to transition the electricity sector to a generation mix with a lower emissions profile.

QUATERNARY ADVENTURES IN ZEALANDIA: FROM WANGANUI TO THE WEST ISLAND

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Arriving in New Zealand in February 1975, to begin fieldwork for an ANU PhD thesis on quantitative models of landscape evolution, was like entering geological Disneyland. Within days I was standing on the summit of Tongariro, being showered with lapilli from the erupting Ngaruhoe, little realising that this event was tiny compared to the huge Quaternary rhyolitic eruptions from Taupo Volcanic Zone. Thus began my Quaternary adventures in which tephras were to play pivotal roles in dating sedimentary sequences in southern North Island.

The extensive flight of marine terraces in South Taranaki-Wanganui was the focus of my PhD, where progressive dissection of an emerging coastline could be documented. Chronology was the key, including fission track dating of Rangitawa Tephra (courtesy of Barry Kohn) and amino acid racemization dating of fossil wood. Sir Charles Fleming was characteristically gracious when I discovered several more terraces than he had mapped earlier. “I always knew there were more terraces”, he said casually, “but they didn’t seem to fit the four-glaciation model of the time”.

As a lecturer in geology at Victoria University (1983-93) I had the luxury of further easily-accessible fieldwork in Wanganui Basin. I enjoyed fruitful collaborations with Brent Alloway, Alan Beu, Bob Carter, Tony Edwards, Matt McGlone, Tim Naish, Vince Neall and Alan Palmer, to name a few. Invariably, we followed in the footsteps of Sir Charles whose magnificent 1953 Bulletin on Wanganui Subdivision ranks among the greatest contributions to New Zealand stratigraphy. Chronology was again the key to success, with a combination of magnetostratigraphy, biostratigraphy and tephrochronology. Appropriately, the first NZ ‘Friends of the Pleistocene” field meeting was held at Wanganui in 1986, with Sir Charles as guest of honour. Standing at an outcrop of shelly sands on Brunswick terrace (~300 ka), I asked Charles if he would like to say anything. He looked embarrassed and then quietly said “Well, no. After all it is 40 years since I was last here!”

Returning to ANU in 1994, I resumed my efforts to unravel regolith/landform evolution on longer timescales in the astonishingly ancient landscapes of Australia. Dare I say it? Chronology was the key, especially paleomagnetic dating of oxidised regolith profiles up to 100 m deep. Viewed from the black sand beaches of Taranaki, the red centre of Australia is like another planet. Indeed, there are strong similarities between the stony deserts of Central Australia and the surface of Mars. However, while the timescale for landscape evolution may be 2 to 3 orders of magnitude different, the underlying controls on landscape development are the same – structure, process and time, as classic geomorphologists, such as Sir Charles Cotton, concluded.

In this talk I will highlight some the exciting science behind my Quaternary adventures.

MANTLE DEFORMATION BENEATH NEW ZEALAND AND IMPLICATIONS FOR VERTICAL MOVEMENTS OF THE CRUST

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In New Zealand, we have excellent evidence for crustal movements in the form of fault offsets, rock uplift data, erosion, and sedimentation rates. What is more difficult to acquire is knowledge about how the subjacent mantle lithosphere (or lid) deforms. This is important in compressional settings as thickening and subsequent removal of mantle lithosphere can have profound consequences for vertical movements of the overlying crust. Seismic experiments carried out during the past 15 years have provided new evidence for thickening and removal of mantle lithosphere in central South Island and western-central North Island, respectively.

Teleseismic arrivals for earthquakes recorded on a dense array of seismographs in central South Island (as part of the SIGHT project) show a 1 sec advance that can be ascribed to a high seismic velocity body directly beneath a 12–17 km thick crustal root. High seismic velocities are interpreted to represent an excess of cold, thickened, mantle lithosphere, and the overall geometry suggests both crust and mantle lithosphere were thickened in a uniform fashion. Most of the thickening occurred in the past 5-10 my. About 1400 m of suppressed elevation, or “negative dynamic topography”, for central South Island is calculated from the modelled excess mass of lithospheric thickening. In other words, the crustal thickness beneath the Southern Alps is larger than needed to isostatically balance the surface elevation because of the downward “pull” of excess, cold, mantle lithosphere.

In contrast, the central and western North Island displays positive dynamic topography. Here the land surface stands at a relatively high elevation given its measured crustal thickness, and seismic evidence points to the mantle lid of western and central North Island being attenuated or absent. Geological and offshore seismic reflection evidence shows much of the surface uplift for western and central North Island started around 5 Ma near the Taranaki coast. These contrasting, yet roughly coeval, vertical movements for two parts of New Zealand are difficult to explain within the context of plate tectonics. They can, nevertheless, be attributed to different stages of a common process — i.e. uniform thickening of the crust and mantle lithosphere (central South Island), then rapid, possibly convective, removal of the mantle lithosphere after ~15–30 Myr of shortening (western-central North Island).

TIME SCALES OF ISLAND ARC MAGMATIC PROCESSES

Simon Turner
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U-series isotope measurements have revolutionised the Earth sciences by offering the only quantitative constraints on time scales applicable to the physical processes that take place on the Earth. Over the past decade numerous studies have been undertaken on magmatic systems from a variety of tectonic settings providing new information about the mechanisms of melt formation, transport, differentiation and degassing. There are now several detailed U-series studies of a number of arcs and of individual volcanoes within these arcs. Until recently, U-Th-Ra data appeared to indicate fluid addition of U occurs over 10's kyr with the last increments adding Ra only a few 100-1000 years prior to eruption. However, recent data from Tonga suggest U addition also occurred very recently. This supports models in which melting is controlled by the thermal structure of the mantle wedge and provides the most compelling case for channelled melt ascent. U-Pa data require some form of dynamic melting involving a matrix flow rate which is similar to the local rate of convergence. Magma differentiation appears to occur over 10's kyr consistent with the time scales for crystallization by conductive cooling at mid to lower crustal depths. Degassing post-dates differentiation and occurs over decades prior to eruption.

SYMPOSIUM: BARRETT

ANTARCTIC – SOUTHERN OCEAN – NEW ZEALAND CLIMATE LINKAGES: A SYMPOSIUM HONOURING PROFESSOR PETER BARRETT

Monday 24th November

Soundings Theatre

Barrett 1: 9:00 – 10:30
Barrett 2: 11:00 – 12:30
Barrett 3: 13:30 – 15:00

Plenary: Monday 15:00 (Soundings Theatre)

Posters: Monday 15:30 – 17:00 (Oceania)

PALEOCENE UNCONFORMITIES FROM MARLBOROUGH AND GREAT SOUTH BASIN – POSSIBLE RECORDS OF ANTARCTIC DEEP-WATER FLOW AND SEA-LEVEL FALL

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This poster signals the intent of upcoming research on unconformity analysis in some South Island Paleocene sections as well as noting preliminary results from reconnaissance field work undertaken in the Clarence valley.

A regionally extensive unconformity surface contained within Paleocene sedimentary sequences throughout New Zealand is hypothesised to reflect fundamental paleoceanographic changes in the Southern Ocean during this period. These fundamental changes are suggested to have occurred as a result of ephemeral ice sheet growth on Antarctica during a time of otherwise global greenhouse (warm/ice-free) climate. The presence of an Antarctic ice sheet and resultant proto-Deep Western Boundary Current prior to the opening of the Tasmanian Gateway and Drake Passage brings into question the validity of the 'gateway model' for ice sheet growth and suggests that the presence of ice on Antarctica may be more a consequence of pCO_2 changes in the atmosphere than of thermal isolation of the continent.

As part of a wider collaborative study, the aim of this research is to first determine that the sedimentology of Paleocene erosion is consistent with deep-water scour coupled with significant sea-level fall. A second objective is to not only show that this unconformity surface is associated with regional cooling and intensified upwelling, but also to ascertain if it is correlated with a 2-3 Myr peak in the Cenozoic deep-sea carbon isotope record, known as the Paleocene Carbon Isotope Maximum (PCIM). The cause of this event is uncertain, but it is inferred to record a period of enhanced carbon burial due to increased marine productivity.

Stratigraphic, sedimentologic and geochemical investigations of key sections from Marlborough (Clarence valley, Kaikoura and Haumuri Bluff) and Great South Basin (Campbell Island) will be utilised to achieve the aims of the research. In the Marlborough region, this surface is contained within the Muzzle Group where it corresponds to the lower contact of the Amuri Limestone Formation. The unconformity truncates progressively more Late Cretaceous and Early Paleocene strata towards the southwest of the region. Within the Amuri Limestone Formation an organic-rich siliciclastic mudstone is recognised that is correlated with the Waipawa Formation. The reconnaissance field work in Clarence valley suggests that the basal contact of this unit at Mead Stream is unconformable, contrary to published literature. At Campbell Island this unconformity lies between the Garden Cove Formation and the overlying Tucker Cover Formation, representing a break in sedimentation from the Teurian to Mangaorapan.

MID-MIOCENE CLIMATIC VARIATION IN THE BRYCE BURN SECTION, SOUTHLAND, NEW ZEALAND: A MULTI-PROXY STUDY

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A climatic optimum is thought to have dominated the middle Miocene, followed by a subsequent slow cooling, inferred to be related to the formation and growth of the East Antarctic Ice Sheet (EAIS). The Milankovitch cycles of the earth's orbit has shown links to the growth and decay of glaciations, and may drive alterations in the EAIS, with implications extending beyond Antarctica. This study, based on high resolution sampling of middle Miocene strata in the Waiau Basin, uses environmental and paleoclimate proxies to track the oceanographic, and thus Antarctic ice volume history, during this period.

The Waicoe Formation, within the Waiau Basin of Western Southland, is dominated by a massive, variably calcareous, grey marine mudstone of middle Miocene age (12-16Ma). The mudstone deposited has a relatively high and uniform sedimentation rate (20-25 cm/kyr) which provides a sound base for a high resolution, multi-proxy study through the Bryce Burn section.

122 samples were collected from Bryce Burn at approximate stratigraphic intervals of 1 meter, or 4000 years. These were prepared for anisotropic magnetic susceptibility (AMS) analysis using the Otago Palaeomagnetic Research Facility (OPRF) MFK1-A Kappabridge. Results show a distinct magnetic fabric within the samples, suggesting magnetic grain alignment caused by variable currents. Anhysteric remanent susceptibility (ARM) measurements were also completed using the 2G Cryogenic magnetometer, also at OPRF.

Splits of AMS samples were used for micropaleontological analysis. Processed, samples appear to have a minimal sand fraction, and are variably calcareous. Planktic to benthic ratios are variable, typically with planktics < 65%, and with many samples dominated by benthic foraminifera. The presence of some shallow water species implies down-slope movement of some horizons. Some samples are significantly pyritic, suggesting an anoxic environment. Planned $\delta^{18}O$ and $\delta^{13}C$ stable isotope and Mg/Ca ratio studies will provide further information about the ocean chemistry at the time of deposition.

It is expected that this new multi-proxy data set will reveal the chemical and physical oceanographic setting around New Zealand and thus the behaviour of the EAIS during the middle Miocene climatic optimum.

QUANTIFYING AEOLIAN SEDIMENT FLUX ON SEA-ICE IN MCMURDO SOUND, ANTARCTICA

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Aeolian sediment accumulates on the surface of annual sea ice in Southern McMurdo Sound (SMS). The sediment is sourced from the surrounding ice-free areas and is subsequently released into the water column during summer ice melting. While this process has long been suggested as an important source of sea-floor sediment there is scant information on the origin, distribution and mass flux of wind blown sediment to the sea-floor. Furthermore, it is suspected that the aeolian sediment released from the sea-ice provides iron which is known to trigger phytoplankton blooms in the region.

We carried out a pilot study in conjunction with the ANDRILL SMS drilling project during the austral summer of 2007. This involved collecting seventy-five snow pit samples (50x50cm down to sea-ice) every 500m within three 4 km^2 grids. These were spaced 5 km apart in a wind parallel transect from the edge of the McMurdo Ice shelf, past the drillsite towards to ice edge.

Snow samples were melted and the sediment allowed to settle before being dried and weighed. Particle size was analysed using a Beckman-Coulter laser-sizer and elemental composition determined using X-ray florescence (XRF) analysis. Results show a marked decrease in the average mass of aeolian sediment from 6.13g per 0.25m^2 near the McMurdo Ice shelf to 1.94g per 0.25m^2 closer to the ice edge, equating to 24.0 and 7.8 tons of aeolian sediment per km^2 respectively.

Particle size analysis shows all samples have well-defined fine to very fine sand modes with a subordinate, broad, silt mode suggesting the sediment is a mixture of material moved under storm conditions (sand) and under lighter but more pervasive winds (silt). Sediment <10 microns can potentially supply bio-available iron to the water column and comprises a significant proportion (15 to 30%) of these samples. Grain composition will be used to ascertain the provenance of the sediment and distinguish if there is any compositional difference between the coarse and fine modes.

Future work will compare the aeolian sediment to samples recovered from the seafloor and within the AND 2-2A drillcore to assist with development of a sedimentation model for the SMS area. Furthermore, we plan to investigate the iron content of the sediment with a view to understanding the role of aeolian sediment in triggering phytoplankton blooms in the region.

GLOBAL TEMPERATURE OVER THE LAST 100 MILLION YEARS – FROM GREENHOUSE TO ICEHOUSE

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The deep-sea isotope record has for 50 years indicated, with increasing confidence, the global warmth of the Late Cretaceous-early Cenozoic Greenhouse world, and the shift in the Ice House world of the last 34 Ma. In this talk we present an improved record of global average temperature based on deep Pacific Basin oxygen isotopic data corrected for ice volume by the recently published 100 Ma sea level history of Kominz et al. (2008, Basin Research), verified by the Mg/Ca proxy for ocean temperature. The curve is calibrated using estimates of past global average temperature from 5 time slices. The Greenhouse world was 6-7°C warmer than today and with a much lower latitudinal gradient between poles and equator. Ice sheets were small to moderate-sized (8-12 million cubic km), restricted to the Antarctic interior, and ephemeral (lasting < 200 kyr in a quasi-3 Myr cycle). Both plant paleoecology and geochemical proxies indicate atmospheric CO_2 levels were several times higher than modern. Climate modeling experiments indicate this is consistent with the high average temperatures of this period. Two transient events disturbed the Earth's Greenhouse climate: the Cretaceous/ Paleogene impact event (65 Ma) and a massive methane discharge (55 Ma), the latter increasing global temperature by 5°C. However, neither of these remarkable events resulted in a permanent shift in the climate system from its existing state. Early Cenozoic temperatures declined from 50 to ~34 Ma, when a significant shift in deep-sea oxygen isotope values occurred. This, along with physical evidence of a continental ice sheet on Antarctica extending beyond the present-day ice margin, marked the shift to the icehouse world of today. This was also a period of both variably declining atmospheric CO_2 levels and the final separation of Australia-South America from Antarctica that brought about a profound change in ocean circulation. Modelling suggests both influenced Antarctic ice sheet development but the former more so. Antarctica's early ice sheets were dynamic, changing climate and sea level (magnitude tens of m) on earth's orbital and Myr periods, but these fluctuations diminished around 14 Ma with further cooling and the development of a persistent ice sheet on East Antarctica. Timing of first Northern Hemisphere ice sheets is debated but ice extends at least to 7 Ma. A major expansion occurred at ~2.6 Ma resulting in increasingly extreme oscillations in climate and sea level, culminating in the 100 kyr cycles of the past 800 kyr.

Antarctic ice core records show a close association between CO_2 and temperature over the past 800,000 years. Anthropogenic CO_2 emissions have increased atmospheric levels well beyond the envelope for this period. It seems that from a geological perspective, without concerted intervention now, there is a credible risk of Earth's climate by the end of the century reverting to Greenhouse World temperatures but with "residual" polar ice sheets.

RECENT RAPID DEEPENING OF THE SOUTHERN MCMURDO SOUND RECORDED IN THE ANDRILL SMS DRILL CORE

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The ANDRILL SMS site in the southern McMurdo Sound was drilled in 387 m water depth yet the first recovered facies in the core indicates a subaerial volcanic vent dated at 692 +/- 38 ka. What caused the rapid deepening at the site? We will discuss 3 possibilities, 1) deep erosion during the last glaciation, 2) volcanic loading, and 3) tectonic subsidence.

The top 37 m of the core is a volcaniclastic breccia with clasts of vesicular and porphyritic (clinopyroxene and olivine phenocrysts) basaltic lava in a glassy matrix. Some lava clasts have yellow-red oxidized rims. These record an autoclastic breccia formed by a subaerial lava flow. In addition, interbedded minor sands near the base of the interval are composed of 98% cuspate glass shards indicating subaerial explosive eruption. The sands are trough cross-bedded indicating reworking in a nearshore shallow marine environment. Together these show a hitherto unknown small volcanic vent, possibly related to the nearby Dailey Islands.

So how did a 692 ka volcano become submerged in 387 m of water? The first mechanism to examine is Model 1) deep incision at the last glacial maximum by the Koettlitz Glacier. However, the SMS core records several Pleistocene glaciations yet the interglacial sediments remain nearshore marine, not deep water facies. Second, if the Koettlitz Glacier eroded off the SMS volcano then why didn't it also erode the rest of the Dailey Islands? And third, if the top of the volcano was eroded off then the subaerial and nearshore marine sediments would have been removed rather than preserved. Therefore we don't find Model 1 plausible. It's possible that Model 2), volcanic loading by either the local Dailey Islands or by Mt Erebus, caused rapid subsidence. The Dailey Islands are too small and too far from the drill site to cause subsidence to <400 m water depth. Mt Erebus is more likely, however when the seismic sections are examined, the SMS drill site is out of the Erebus moat by several kilometers. Therefore Model 2 is also not plausible. Model 3), tectonic subsidence in the transtensional Terror Rift, is the most likely explanation of rapid subsidence. Transtensional settings create some of the most rapidly subsiding basins of any tectonic setting. In addition, the SMS drill site is at a bend in the rift, the Discovery accommodation zone, allowing more voluminous volcanism and where more rapid subsidence could be expected. Finally, the SMS site lies just south of the mapped Ross Fault and north of the Blue lineament based on lineament mapping and alignment of volcanic centres (Damaske et al, 1994; Wilson, 1999) and as such may have locally rapid subsidence. Therefore, Model 3, a transtensional tectonic setting, is the most likely cause of the rapid subsidence in the last 692 ka.

INTENSIFICATION OF THE SOUTHERN ANNULAR MODE OVER THE LAST 150 YEARS

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Southern Hemisphere climate variability is dominated by two oscillating drivers: the Southern Annular Mode (SAM) and the El Nino Southern Oscillation (ENSO). Combined, the two forcings can enhance or partially offset their influence on Southern Hemisphere climate.

A 130m deep ice core record ($\delta^{18}O$, δD, deuterium excess, major ion and trace elements) from coastal Victoria Land in the Ross Sea Region provides insights into the relationship between regional temperature, sea-ice extent, SAM, and ENSO. Our results show that more than 50% of the regional temperature variability can be explained by combined SAM and ENSO forcing. Sea-ice extent is negatively correlated to temperature variability with more (less) extensive sea-ice during warmer (colder) years. This inverse relationship is explained by a positive ENSO forcing of sea-surface temperatures and a negative ENSO forcing of regional air temperature. Transfer functions are used to convert water isotope and deuterium excess records into a proxy index for SAM. Our data suggest that over the last 150 years mean annual SAM increased overall by almost 1 sigma standard deviation. The increase occurs predominantly during 1868-1944 and 1971-present. We conclude that ozone depletion can only partially explain the observed intensification of the polar vortex.

USING PLANKTONIC FORAMINIFERA TO LINK THE PALEOECOLOGY AND PALEO-OCEAN TEMPERATURE OF THE SOUTHERN OCEAN

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Using Laser Ablation (LA)-ICPMS, Mg/Ca ratios, an established proxy for ocean temperature, have been measured in the planktonic foraminifera *Globigerinoides ruber* and *Neogloboquadrina incompta.* The samples originate from a variety of sites in the South Pacific Ocean with widely differing water temperatures and preservation states and will be used to develop Mg/Ca paleo-water temperature calibration for New Zealand. Because we can sample individual chambers within foraminifera shells, LA-ICPMS can help unravel the relative contributions of vital (biological) and environmental effects on shell geochemistry, such as, whether intra-chamber Mg/Ca variability is a result of depth migration or gametogenic biomineralisation and their relative contribution to total shell Mg/Ca.

A preliminary LA-ICPMS Mg/Ca temperature calibration for *G. ruber* is significantly different from those already published, that is Mg/Ca=0.61exp0.07T, compared to Mg/Ca=0.38exp0.09T for mid-North Atlantic foraminifera (Anand *et al.*, 2003) suggesting calibrations may be only regionally applicable. A possible reason for this difference is that Mg/Ca uptake is known to vary with carbonate ion concentration which differs between ocean basins.

The final calibration will be applied to fossil foraminifera from “super” interglacial periods Marine Isotope Stages (MIS) 11 and 31 in the New Zealand region at Ocean Drilling Program (ODP) Site 1123, when global mean temperatures were thought to be warmer than today. These periods are of special interest because they may provide insight into the response of the ocean to future warming. In particular, MIS-31 is emerging as a significant point in time where both low and high latitude records indicate significant changes in bottom water production, ocean circulation and a greatly reduced Ross Ice Shelf (Scherer *et al.*, 2003; Naish *et al.*, 2007). An open question is what was the oceanographic response to these changes in the NZ region? Analysis of MIS-31 material from ODP 1123 will be used to examine whether the ocean temperature signals, particularly from ice-shelf melting can be identified at this site, and thus reconstruct a paleoceanographic scenario for New Zealand.

MACQUARIE RIDGE SEDIMENTARY AND OCEANOGRAPHIC REGIMES

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In April 2008 NIWA's research vessel *Tangaroa* spent a month surveying the oceanography, geology, seamounts, and marine chemistry along the Macquarie Ridge. The Macquarie Ridge is a relatively understudied region of the world, yet it plays an important role in the Southern Ocean as it is one of only three topographic obstructions to the Antarctic Circumpolar Current (ACC) forcing this major current through narrow gaps in the ridge and diverting it from its normal path. We have compiled all the sedimentary data from the Macquarie Ridge and adjacent Solander Trough and Emerald Basin since the *Eltanin* Voyages of the 1960s. The sediment composition is compared with the location of the main ACC oceanographic fronts.

Terrigenous sediment from the south island of New Zealand dominates the northern end of the Solander Trough, mixed with pelagic carbonate. Holocene pelagic carbonate and biogenic silica sediments are found at the southern end of the Solander Trough. South of the Solander Trough (52°S) little sediment has been recovered, with one *Eltanin* sample retrieving manganese nodules. This is the location of the main Subantarctic Front which flows through several gaps in the Macquarie Ridge between 52°S and 55°S. The northern Emerald Basin sediments (~56.5°S) are a mixture of pelagic carbonate and biogenic silica which underlie the northern Polar Front, while in the south of the basin the sediments are dominated by mud, manganese nodules and biogenic silica. The latter is dominated by sponge spicules, but also Antarctic assemblages of radiolaria and diatoms. The >4000 m deep Hjort Basin, just east of the southern end of the ridge, is crossed by the southern Polar Front and the sediments are predominantly biogenic silica with diatomaceous mats alternating with mixed radiolarian and foraminifera sands. Little sediment has been found on the Macquarie Ridge itself. The samples collected from the ridge are volcanic rocks with rare occurrences of carbonate-cemented bioclastic sediments. Manganese crusts were found overgrowing the sediments on the ridge at 59°S.

THE MANY ROLES OF ANTARCTIC ICE IN UPPER CENOZOIC CLIMATE CHANGES

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Antarctic ice interacts with global climate through its high albedo, production of oceanic bottom water, effect on sea level and possibly by occasional large-scale surges. At some time scales it is a climate-driver but at others the climate-drivers lie elsewhere. Upper Cenozoic growth of the Antarctic icecap drove global cooling through albedo and bottom water effects, but Upper Quaternary variations of Antarctic ice appear largely to have been driven by variations of seasonal radiation in the northern hemisphere, which governed global ice-age climates. Other changes more speculatively driven from Antarctica include Pliocene onset of Australian aridity and deepening aridity in the middle Pleistocene. Lastly, Antarctic ice may have dramatic effects at much shorter time-scales: instability near the ice-cap margin arguably contributed significantly to rapid sealevel rise events, not only during the last ice age but also in the last interglacial period, when global climate was warmer than today.

HOLOCENE EUSTATIC SEA-LEVEL CHANGE IN NEW ZEALAND

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A revised Holocene sea-level curve for the New Zealand archipelago is presented based on 141 dates compiled from 26 published and unpublished reports, papers and theses. Data have been restricted to studies which present both an accurate description of the facies association and relate dated material to an established vertical datum. All dates are calibrated to sidereal years. Calibration of fossil molluscs utilised the marine model calibration curve Marine04 with a ΔR value of -7±45 to correct for the marine reservoir effect. For wood, peat and other materials that derive their carbon from terrestrial sources the non-marine calibration curve for the Southern Hemisphere was used.

Sea-level rose from -5 m PMSL c. 8500 cal yr BP to +0.3 m above present mean sea-level (PMSL) by 7550 cal yr BP. While this is 500-1000 years earlier than previous estimates (*1*), it is consistent with recent reconstructions of Holocene sea-level change for the east coast of Australia (*2*, *3*). However, the rate of rise in New Zealand is substantially less than along the Australian east coast. From 7550-5800 cal yr BP sea-level rose to +0.8 m PMSL. Sea-level then fluctuated ±0.2 m until c. 4500 cal yr BP, when it reached maximum elevation of +1.0 m PMSL. This mid-Holocene sea-level maximum in New Zealand c. 4500 cal yr BP was predicted (*4*, *5*), and is reflected in stratigraphic studies (*6*, *7*, *8*). From 4500-3000 cal yr BP sea level fell from +1.0 m to +0.2 m PMSL followed by a rapid transgression from 3000-2700 cal yr BP where sea-level rose to +1.0 m PMSL. Sea-level remained stable at this level until 2000 cal yr BP, when it fell to present mean sea-level. These relative highs and lows of sea-level from 4500-2000 cal yr BP were hypothesised to control phases of beach ridge development (*7*), though unequivocal evidence for these sea-level fluctuations was lacking. Similarly, periods of lower sea-level c. 3000 cal yr BP and after 2000 cal yr BP coincide with periods of dune formation in Northland (*9*).

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SOUTHERN OCEAN PHYTOPLANKTON EVOLUTIONARY RESPONSES TO CLIMATE CHANGE: LESSONS FROM THE PLIOCENE FOSSIL RECORD

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Recent observations show that Southern Ocean phytoplankton (an important component of the biological carbon pump) are already responding to climate change. These observations cannot, however, indicate how organisms might respond over longer timescales or when climate extremes exceed the Holocene range. Here we present a high-resolution reconstruction of Antarctic diatom origination and extinction that spans the Pliocene, the most recent period in earth history with global temperature and atmospheric *p*CO2 higher than they are today. We use a comprehensive database of fossil diatom ranges from drillcore records around the Antarctic region, which were integrated into the most parsimonious composite sequence of species first and last appearances using the quantitative biostratigraphic approach Constrained Optimization.

This reconstruction, which has a nominal average resolution of ±33kyrs, identifies 3 highly significant turnover events that stand out against otherwise relatively uniform, low background rates of the last 15 million years. Of particular interest are two turnover pulses lasting ~200kyrs each, centered on ~4.9Ma and ~3.5Ma, during which both origination and extinction rates increased abruptly by an order of magnitude. These significant episodes have not previously been documented in this or any other marine fossil group. Both coincide with intervals of increased environmental variability, as measured by global benthic $\delta^{18}O$ variance across a 200kyr moving window, and seem to correlate with paleoecological and sedimentological evidence for warm/deglacial climatic excursions. These turnover pulses were followed by an episode of rapid extinction between 2.6-1.7Ma that was apparently associated with climatic cooling and sea-ice expansion, from which Antarctic diatom biodiversity never recovered. More work is needed to determine the primary drivers and ecological thresholds involved in the observed nonlinear response of diatom evolution and extinction to paleoenvironmental change, and to gauge the potential sensitivity of this important ecosystem to future climate perturbations.

THE HOLOCENE CLIMATIC HISTORY OF NIELSEN BASIN, MAC ROBERTSON SHELF (EAST ANTARCTICA)

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A total of 16 Jumbo Piston Core (JPC) were acquired along the continental shelf of the East Antarctic Margin during cruise *NBP0101* of the *RV/IB Nathaniel B. Palmer* in order to study Antarctic Holocene marine records. We present here a Holocene paleoclimate record from JPC40, a 23.92-m high-resolution marine sediment core from Nielsen Basin, Mac Robertson Shelf (70ºE to ca. 60ºE). Nielsen Basin is a U-shaped sinuous trough with steep slopes and flat floors ranging from 400 to 1300 m depth, formed by glacial erosion during the Quaternary, providing a unique high-resolution sequence of well preserved Antarctic marine Holocene sediment.

JPC40 was described and analysed every 2.5 cm for $\delta^{13}C$, magnetic susceptibility (MS), biogenic silica and total organic carbon (TOC). Three lithologic intervals were identified and dated by AMS radiocarbon: (a) The base of the core (23.92 to 21.55 m) is dominated by a diamicton deposit from the LGM period *ca.* 14 cal ka BP. (b) From 21.55 to 21.08 m, cm-scale diatomaceous and terrigenous laminations (likely varves) define the deglacial transition *ca.* 12 cal ka BP. (c) The Holocene section begins with a homogenous sandy-mud layer at 18.03-21.08, which transitions into interbedded laminated and bioturbated siliceous mud and ooze (SMO) (18.03-0 m).

The varved unit (b) is also observed in other Mac Robertson Shelf cores and is interpreted as a short interval of high primary productivity, confirming a fast ice-shelf retreat in Nielsen basin immediately after the Meltwater Pulse 1A (*ca.* 14.2 ka BP.). Although the lithology of the Holocene section (c) is relatively uniform, geochemistry reveals distinctive episodes. From 12 to 7.5 ka BP lower values of $\delta^{13}C$ suggest a general warming corresponding to the Holocene Climate Optimum (HCO). At the end of this HCO, *ca.* 8.5 cal ka BP, a drastic alteration in the geochemical properties (very low values of $\delta^{13}C$, MS and bulk density) possibly shows a centennial-scale warming event that could be teleconnected with the abrupt climatic deterioration also referred to as the 8.2 ka event in the Northern Hemisphere. Finally, from 7.5 ka to present, $\delta^{13}C$, Opal and MS presents a cyclical pattern of 400-500 year possibly driven by solar forcing.

RELICT ICE AND OTHER PROBLEMS IN THE DRY VALLEYS, ANTARCTICA

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The 8 Ma relict ice in Beacon Valley, Antarctica has been the topic of much debate since Sugden and others reported it in 1995. However, the occurrence of relict ground ice, is not unique to Beacon Valley, and it is found in a variety of forms within one metre of the surface in many parts of the Dry Valleys. This ice is important because it not only drives the development of Dry Valley landscapes but also contains a paleoenvironmental record. Furthermore, it is our best analogue for understanding the presence of ice on Mars. Here, we compare the properties and occurrences of ground ice from the Beacon, Pearse, Victoria, and Wright Valleys and Table Mountain.

The origins of relict ground ice are complex and may overlap. Ablation models suggest this ice should be younger than 10,000 years, yet it persists under very old surfaces. In appearance, it ranges from clear massive ice, to debris-rich ice, to pore-filling ice in sediments and soils. Our studies suggest that the ice can result from *in situ* processes or from stranded remnants of past glaciers and lakes. Highly deformed debris-rich ice may result from accumulated strain of multiple advances and retreats of cold-based glaciers or from rock glaciers and gelifluction processes. Although we cannot provide absolute dates for the ice, their relative ages also give insight to their origins.

To improve our understanding of the Antarctic climate system, it is crucial to understand climatic signatures that may be present in these features. Although these features probably may not yield high resolution climate data, their data provide an terrestrial history that will complement marine and ice core data. For example, ^{10}Be in soil profiles suggests the Dry Valleys were much wetter prior to 4 Ma, a finding which compliments the Andrill core record from Windless Bight.

ROSS SEA FORAMINIFERAL MG/CA-BASED SEA SURFACE TEMPERATURE ESTIMATES ASSOCIATED WITH THE RETREAT OF THE ROSS ICE SHELF AT 1.07MA

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Computer modelling suggests the temperature of the surface of the ocean plays a key role in the mass balance of the Ross Ice Shelf (RIS) by influencing the rate of basal melting that occurs underneath it. Furthermore, modelling also suggests that the presence or absence of a "buttressing" ice shelf is important to the stability of the feeder ice sheets, in this case the West Antarctic Ice Sheet (WAIS) which has 4-6 m of sea level equivalent in ice and is inherently unstable because most of it is grounded well below sea level.

Two drill cores (CRP-1 and AND-1b) from McMurdo Sound show that Marine Isotope Stage (MIS) 31 (1.07 Ma) is significant because it marks the youngest occurrence of sediments indicative of seasonally open water conditions at both sites, showing substantial retreat of the RIS occurred then. However, sediment deposited after MIS 31 is represented only by glacial-dominated sediment, suggesting a critical environmental threshold had been crossed enabling the RIS to form and persist.

We have attempted to quantify sea surface temperatures (SSTs) during MIS 31 by measuring Mg/Ca, a proxy for SST, in well preserved shells of the planktonic foraminifera *Neogloboquadrina pachyderma* from the CRP-1 drill core in order to determine the ocean temperature associated with the last known major retreat of the RIS.

We calibrate our results by measuring Mg/Ca in modern *N. pachyderma* from the Ross Sea and Southern Ocean which have measured SSTs ranging from -1.2ºC to 14ºC.

ICE SHELVES IN A WARMING WORLD

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Recent ice shelf collapses (e.g. Larsen B, Ward Hunt) have been associated with increased surface air temperatures that lead to the formation of surface melt-water ponds. The presence of surface melt-water appears to provide a final trigger for shelf collapse (due to refreezing and hydraulic fracturing) especially if the shelf has experienced previous thinning and weakening.

To test the hypothesis that significant summer warmth is a sufficient indicator of ice shelf collapse, global climate model output is analysed to determine regions where significant summer warmth above the melting point occurs. Preliminary results of the method capture the location and approximate timing of the Larsen and Ellesmere Island ice shelf collapses, but miss the current disintegration of the Wilkins ice shelf. A long term climate simulation, utilizing a realistic carbon dioxide emission scenario, suggests that in several centuries the line determining ice shelf stability will have migrated to the front of the Ross and Filchner-Ronne Ice Shelves. Collapse of these shelves (as simplistically represented in a climate model by a flux of freshwater to the present-day ocean) would result in a melt-water plume that would encircle Antarctica and cross the Antarctic Circumpolar Current to pool off the coast of Chile.

THE EFFECT OF SUBMERGED PLATEAUX ON PLEISTOCENE GYRAL CIRCULATION AND SEA-SURFACE TEMPERATURES IN THE SW PACIFIC

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The NZ micro-continent spans the interface between a subtropical gyre and the Subantarctic Circumpolar Current. East of NZ, its 20° latitudinal extent includes a complex of submerged plateaux, ridges, saddles and basins which, in the present interglacial, are partial barriers to circulation and steer the Subtropical (STF) and Subantarctic (SAF) fronts. This configuration offers a singular opportunity to assess the influence of bottom topography on oceanic circulation through Pleistocene glacial – interglacial (G/I) cycles, its effect on the location and strength of the fronts, and its ability to generate significant differences in mixed layer thermal history over short distances.

For this study we use new planktic foraminiferal based sea surface temperature (SST) estimates from over 1100 samples (~300,000 specimens) spanning the past 1 million years from a latitudinal transect of four deep ocean drilling sites (594, 1119, 1123, 1125). We conclude that: 1. the effect of the shallow submerged Chatham Rise, was to dynamically trap the STF along its crest; 2. the effect of the more deeply submerged Campbell-Bounty Plateaux was to dynamically trap the SAF along its steep southeastern margin; 3. the effects of saddles across these submarine impediments was to facilitate the development of jets of subtropical and subantarctic surface water through the fronts, forming localised downstream gyres or eddies during different phases in the G-I climate cycles; 4. the deep Pukaki Saddle across the Campbell-Bounty Plateaux guided a branch of the SAF to flow northwards during each glacial, to form a strong gyre of circumpolar surface water in the Bounty Trough; 5. the shallower Mernoo Saddle, at the western end of the Chatham Rise, provided a conduit for subtropical water to jet southwards across the STF in the warmest interglacial peaks (MIS 11, 5.5) and for subantarctic water to flow northwards during glacials.

Thus complex submarine topography can produce distinct differences in the climate records over short distances with implications for using such records in interpreting global or regional trends. Conversely, the local topography can amplify the paleoclimate record in different ways in different places, thus enhancing its value for the study of more minor paleoceanographic influences that elsewhere are more difficult to detect.

SUPPORT FOR GREENHOUSE CLIMATE MODELS RUNS HOT AND COLD IN EARLY PALEOGENE MID-LATITUDE NEW ZEALAND

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New evidence from Canterbury Basin highlights an extreme temperature contrast between late Paleocene and early Eocene times in the mid-latitude southwest Pacific, indicative of warming by 10-15°C from temperate to tropical conditions within <5 million years. For Eocene calcareous mudstone at mid-Waipara River, paleotemperature estimates derived from $\delta^{18}O$ and Mg/Ca in well-preserved tests of planktic foraminifera and the archaeal membrane lipid temperature proxy, TEX_{86} (Hollis et al., in press) indicate tropical to hyper-tropical sea surface temperatures (SSTs) of 30-35°C during the Early Eocene Climatic Optimum (EECO). This climatic event is approximately equivalent to the Mangaorapan Stage, which is associated with local incursions of tropical molluscs and larger foraminifera. Higher in the section and also further south, at Hampden Beach (Burgess et al., 2008), the same SST proxies record gradual cooling to 21-25°C by middle Eocene (Bortonian) times. In contrast, TEX_{86} results for upper Paleocene glauconitic mudstone at mid-Waipara indicate cooler SSTs of 17-20°C, which is consistent with the scarcity of subtropical-tropical indicators within the marine biota. This interval contains only sparse, poorly preserved calcareous microfossils, which are unsuitable for paleotemperature analysis.

Modelled ocean circulation patterns and sea temperatures under early Paleogene greenhouse conditions (2240 ppm CO_2) predict temperate conditions (annual SST of 15-20°C) for the New Zealand region, which is consistent with Paleocene paleotemperature estimates and close to middle Eocene estimates. However, paleontological and geochemical indicators for tropical conditions during the EECO imply that the role of ocean currents or other poorly known mechanisms of poleward heat transport is much greater under hyper-greenhouse conditions than is allowed for in existing climate models.

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KERGUELEN PLATEAU BENTHIC FORAMINIFERA AS A PROXY FOR LATE NEOGENE PALEOCLIMATE

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The late Neogene (<5 mya) was a time during which climate oscillated dramatically between extremes of glacial and deglacial periods. The Kerguelen Plateau, located within the Southern Ocean, is a critical location during the late Neogene due to bottom water production and extreme polar conditions occurring around Antarctica. The record from ODP Sites 747, 748, 751 and 744 drilled in 1988 as part of Legs 119 and 120 is used here to interpret Pliocene-Pleistocene changes in the environment.

This research focused on using benthic foraminiferal assemblages from Ocean Drilling Program Leg 119 and 120 Sites (747A, 748B, 751A, and 744B) to interpret changing Pliocene-Pleistocene paleoclimate and paleoceanography. The stratigraphic record of hiatuses and ice-rafted debris at Kerguelen Plateau during the late Neogene was probably due to changing glacial dynamics of the East Antarctic Ice Sheet.

The dynamic nature of paleoclimate in the Pliocene on the Kerguelen Plateau is reflected in the presence of Pliocene Dissolution Events (Sites 748, 751, and 744) and Pliocene Warming Events (748, 747, and 751) recorded in the sediments (Bohaty and Harwood, 1998).

Benthic foraminiferal assemblages from the region record slight differences in species composition from site to site. However, there are two major influencing factors driving the benthic assemblages; these are seasonal flux of phytodetritus, reflected in the dominance of *Epistominella exigua*, and the availability of carbonate for test construction and preservation.

ANTARCTIC JOURNEYS WITH PETER BARRETT: HIGHLIGHTS FROM VUWAE 16 (1971) AND THE CAPE ROBERTS PROGRAMME (1999)

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This presentation will not be about any new geological or paleoclimate breakthroughs, but will instead recall some of the memorable events and behind-the-scenes activities that were associated with two major programmes that Peter led.

The first event in which I was associated with Peter was the VUWAE 16 expedition in 1971, the same year that Peter was appointed Director of Antarctic Research at VUW. The expedition was in two parts, and while one part was organised and led in the field by Peter, he arranged for me to lead the second part, which was to enable Phil Kyle to complete his Ph.D. study of volcanism in northern Victoria Land. It was not only both the best and the worst expedition I have ever been involved in, but the one with the most memorable experiences, as I hope to illustrate.

The other memorable event was the Cape Roberts Programme, of which Peter was Chief Scientist. I was invited to join this, at short notice, as sedimentologist and presenter, during its final year in 1999. It was a novel and stimulating experience to deal on a daily basis with highly-qualified and motivated scientists from seven different countries, often with very different interpretations of the data coming from the cores. I found the sociology of the mix just as fascinating as the excellent science that was emerging from the drill-cores. Peter's skill in reconciling the competing interests, and getting all concerned to work harmoniously together never ceased to impress me. A couple of incidents illustrate his diplomatic and managerial ability.

WATER MASS STRUCTURE AND FLOW OVER GLACIAL-INTERGLACIAL CYCLES IN THE SW PACIFIC OCEAN

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Depth profiles of oxygen and carbon isotopes contained in benthic foraminifera from depths of 1200 – 4800 m, provide an insight into the structure and behaviour of water masses over selected times in the past 160 ka. The data are from 10 cores off eastern New Zealand, located mainly on North Chatham Rise. This region lies under the Pacific Deep Western Boundary Current – the largest single inflow of the global thermohaline circulation that transports several water masses into the Pacific Ocean. The benthic isotopic profiles are related to the structure of water masses at present and inferred for the past. Those waters have retained a constant structure of (from deep to shallow) Lower Circumpolar Deep Water – Upper Circumpolar Deep Water/North Pacific Deep Water – Antarctic Intermediate Water with no significant change in the depths of water mass boundaries between glacial and interglacial periods.

Sortable silt particle size data for four cores are also examined and reveal that the strength of the deep Pacific inflow, while variable, appears to have remained fairly constant on average. Some of the lowest LGM values of benthic $\delta^{13}C$ in the world ocean (-1.03 ‰ based on *Cibicidoides wüllerstorfi*) are found here at ~2200 m. Comparable values have been recorded in the Atlantic sector of the Southern Ocean, whereas those from the rest of the Pacific are distinctly higher confirming that the Southern Ocean was the source for the nutrient-enriched water seen here. Oxygen isotopic data are compatible with a glacial, cold deep-water mass of high salinity, but lower nutrient content deeper than ~3500 m. This contrasts with the South Atlantic where highly nutrient-enriched water extends right to the ocean floor. The deeper reaches of the Antarctic Circumpolar Current are not homogeneous around the Southern Ocean with the Kerguelen Plateau and/or Macquarie-Balleny Ridges forming barriers to the eastward spread of the deepest, low-$\delta^{13}C$ water out of the South Atlantic in glacial periods. These barriers, combined with an inferred high density of bottom waters due to salinity, restricted inter-basin exchange thus creating three domains dominated by bottom waters from the Weddell Sea, Adélie Coast and Ross Sea. We suggest that the Ross Sea was the main source of the deep water entering the SW Pacific below ~3500 m.

TOWARDS UNDERSTANDING THE NEOGENE GLACIAL HISTORY OF THE ANTARCTIC ICE SHEETS

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The geological record of the Antarctic ice sheets through the Late Neogene is extremely sparse and has been greatly debated over the past three decades. Much of the debate has centred on two distinct arguments. One argument is that the East Antarctic Ice Sheet has been more or less stable and cold for the last ~14 million years. This is supported by the $\delta^{18}O$ record from benthic foraminifera that implies a profound cooling ~14 million years ago, interpreted as expansion of the EAIS to perhaps its present-day extent. A number of lines of physical evidence from the on-land geological record in Antarctica agrees with this viewpoint, including geomorphologic, surface age dating, and sedimentary studies from the Transantarctic Mountains. A second argument is that the East Antarctic Ice Sheet was much more dynamic, and is based on the occurrences of the Sirius Group in the Transantarctic Mountains, and dated as Pliocene in age on the basis of a sparse marine diatom assemblage. These are hypothesized to have been derived from diatomaceous sediments deposited in interior seas in East Antarctica, and subsequently glacially eroded, transported and deposited as the Transantarctic Mountains were overridden by the East Antarctic Ice Sheet. This concept requires one or more significant deglaciations of East Antarctica, with wet-based glaciation and vegetation existing in the TAM until ~3 Myr. Late Neogene deposits from the Prydz Bay region (East Antarctica) are also supportive of significant ice volume fluctuations of the East Antarctic Ice Sheet at this time.

Although uncertainty remains about the scale of Antarctic ice sheet dynamism, the Early and Middle Pliocene (5-3 million years) generally is regarded as a time of global warmth, and an important window into Earth's future climate if projections of anthropogenic global warming are correct. Direct physical records of Antarctic Cenozoic glacial history have recently become available through geological drilling programs such as ANDRILL. This talk will discuss this debate in light of recent studies from the Allan Hills, a high-elevation nunatak with exposures of Sirius Group in the Transantarctic Mountains; as well as new stratigraphic drill core evidence from the ANDRILL McMurdo Ice Shelf project.

PETER BARRETT; 30 YEARS OF GEOLOGICAL DRILLING IN MCMURDO SOUND; A STORY OF REVELATION AND PERSISTENCE

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When you work in the Trans-Antarctic Mountains and Dry Valleys of Antarctica eventually after "camping rough" for several weeks you may have a divine revelation: Antarctica is old, the outcrops are old, nothing you find is younger than Jurassic (for the most part), the Valleys and geomorphology also look old. There is a little bit of 'probably' younger dirt that sort of looks 'glacial' in the valley floor and walls but here there is little outcrop or things to date.

The Dry Valley Drilling Project (DVDP) was the first significant attempt to drill in Antarctica and use drilling as a tool to look below the surface for geological history. DVDP was funded primarily by the United States Antarctic Program but was international with scientists (and drillers) from the US, NZ and Japan taking part. For the time the technology was new and well resourced, drilling and science went through a steep learning curve and at times the project appeared to be playing catch up, looking for scientific problems to solve. However this project and later ones probably didn't get the credit both in the science and technology that they deserved until several years later. DVDP started a trend in the "smaller" Antarctic drilling projects where scientists found that to promote their science they had to become intimately involved in the process of site survey, funding and planning even before they got the chance to actually drill.

Students and staff from Victoria University participated in DVDP from the inception doing "the hard yards" from coring volcanic rocks on Ross Island, glacial sediments in the Dry Valleys to offshore seismic survey. Peter Barrett had just completed the Glomar Challenger cruise in the Ross Sea in 1972-73 where a tantalising record of Antarctic glacial history was found, and the promise of the marine continental shelf geological record to directly date Antarctica's glaciations. Peter started with DVDP logging Taylor Valley floor glacial drill and then with Sam Treves led the move offshore in 1975 to find "the holy grail" and drill marine sediments in DVDP15.

DVDP 15 was the first of several McMurdo Region drill holes that have used the sea ice and more recently the ice shelf as a platform for geological coring to access Antarctica's younger past climate records. Improvements in drilling technology and its application in this marine environment have been a progressive journey from DVDP to ANDRILL. Peter Barrett has been instrumental in advocating and leading these programmes since the mid 70's through into this new century. His determination and persistence have shown the way forward to reveal Antarctica's Climate Secrets, not inferred from the deep sea many thousands of kilometres away but from the source; Antarctica.

AN ICE CORE INDICATOR OF ROSS ICE SHELF STABILITY?

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We present high resolution stable isotope ($\delta^{18}O$) and major ion chemistry data for a 2 m deep snow pit sampled at Mt Erebus Saddle (MES), Antarctica. Our objectives are to assess the potential of the 168 m MES ice core record to investigate polar ocean-atmosphere interactions. MES is uniquely located at the edge of the Ross Ice Shelf, just 15 km from the seasonally open water of the Ross Sea. An age model developed using well-resolved annual peaks in methylsulfonate (MS^-) and $\delta^{18}O$ indicates the record encapsulates 5 years of snow accumulation. The chemical species MS^-, a product of phytoplankton photosynthesis, shows large (>60 ppb) and significant interannual variations in concentration. The MS^- record correlates with satellite-derived chlorophyll *a* concentration variability within the MS^- record reflects interannual primary productivity changes. The measurements for the Ross Sea region ($r^2 = 36\%$) indicating that austral summers which exhibit low MS^- concentrations experienced anomalously heavy summer sea ice cover in the Ross Sea. This increased sea ice cover and associated reduced primary productivity can be explained by the presence of large icebergs (B-15 and C-19), which carved off the Ross Ice Shelf in 2000 and 2002. The icebergs restricted sea ice breakout in the Ross Sea thereby reducing the open water area available for phytoplankton photosynthesis. Concentrations of marine aerosol species (Na, Mg, Cl) are strongly depleted in the summers of 2002/03 and 2003/04. It is hypothesised that the increased summer sea ice cover in these years reduced the ocean-air exchange of sea salt aerosol that results from bubble bursting at the exposed ocean surface. The sea salt aerosol record from the independent MES ice core also displays concomitant depletions with MS^-. When viewed in the context of the long-term sea salt record of the MES ice core (currently 30 years) these depleted periods are clearly anomalous events. A joint biogenic and marine aerosol proxy for large-scale iceberg rafting events in the Ross Sea has thus been identified. Once applied to the MES ice core record, this proxy has the potential to catalogue the occurrence of large-scale iceberg rafting events in the Ross Sea over the last 2,000 years. This will enable us to determine whether events like the carving of B-15, the world's largest recorded iceberg, have been regular occurrences over the past two millennia, or if this reflects an early warning sign of future Ross Ice Shelf instability.

A 210 KA TERRESTIAL PALYNOMORPH RECORD FROM A MARINE SEDIMENT CORE, WEST COAST, SOUTH ISLAND

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Fossil pollen assemblages provide an important record of vegetation, and by inference environmental change, over time. Terrestrial sites containing long continuous pollen records are rare and are often difficult to date beyond the range of ^{14}C (~40 ka). Therefore we are extracting pollen from marine cores and river samples proximal to the Okarito swamp, which yielded a detailed record of vegetation change over the last glacial cycle (Vandergoes *et al*., 2005; *Nature*).

Three cores collected by the *RV Tangaroa* (Tan 0513) from overbank deposits of the Hokitika and Cook submarine canyon systems have been dated by $\delta^{18}O$ stratigraphy. The resulting age models give a basal age of 70 ka for core TAN0513-47 with an average sedimentation rate of 2.84 cm/ky, 130 ka for TAN0513-27 (2.49 cm/ky) and 210 ka (1.58 cm/ky) for TAN0513-14 suggesting we can extend the paleo-vegetation for Westland by at least 60Ky.

Pollen analysis has focussed on; (a) comparing the terrestrial pollen assemblage from Okarito with the marine record from TAN0513-14 over the period of time they have in common to assess differences in environmental sensitivity due to differences in catchment area and transport history; (b) to examine in more detail the factors driving vegetation change at Southern Hemisphere mid-latitudes during the Late Quaternary including sea level, sea surface temperature, local insolation and atmospheric CO_2 concentrations.

EVIDENCE FROM NEW ZEALAND SPELEOTHEMS THAT HEINRICH EVENTS IMPACTED THE CLIMATE IN THE SOUTHWEST PACIFIC

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We present a new, high-resolution, independently-dated, palaeoclimate record from a stalagmite which formed in Hollywood Cave (42.0°S, 171.5°E) on South Island, New Zealand. Over 700 stable oxygen and carbon isotope measurement pairs are supported by a chronology from 18 sequential ^{230}Th dates. The stalagmite grew between 73 and 11 kyr B.P. Growth rates varied from ~1–54 mm/kyr and data resolution yields one sample per 10–320 years.

Weak covariance between δ^{13}C and δ^{18}O in the speleothem calcite suggests that recorded climate signals are primarily driven by precipitation source and annual amounts. Both stable isotope proxies indicate relatively cold and dry conditions prevailed for much of the period 73-11 kyr B.P. However, this period was interspersed with abrupt-onset, millennial-scale shifts to wet and cool climate occurring 67.7-61, 56-55, 50.5-47.5, 40-39, 30.5-29, 25.5-24.3, 16.1-15, and 12.2-11.8 kyr B.P. Significantly, these eight abrupt climate changes strongly match widely accepted ages for Heinrich events H6-H0 (including H5a). Many of these abrupt events can also be matched to known periods of glacier advance in the Southern Alps, New Zealand, which, arguably, were driven by increased mean annual precipitation and reduced potential for summer melting. Furthermore, preliminary stable isotope data (> 550 δ^{13}C and δ^{18}O pairs) from two North Island (~38°S) stalagmites also demonstrate abrupt climate shifts from relatively dry to wet during the period 60-6 kyr B.P. The demonstration of co-eval climate changes in antipodean locations provides compelling evidence for globally synchronous climate variability during the last glacial period. We suggest the following hypothesis for the climate teleconnection between New Zealand in the southwest Pacific and the North Atlantic. Discharge of copious volumes of ice into the North Atlantic shut down and reduced the strength of the meridional overturning circulation. Ensuing cold climates in Europe and Asia forced a southerly shift of tropical heat and the position of the intertropical convergence zone. This lead to a steepening of the thermal gradient across the mid-southern latitudes, driving strengthening of the Antarctic circumpolar westerly circulation. Rainfall totals increased in North Westland and mean summer temperatures decreased.

FROM OCEANS TO THE LAND: PRELIMINARY APPLICATION OF TEX_{86} TO DEVELOP PALEO-TEMPERATURE ESTIMATES FROM NEW ZEALAND LAKES

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Ratios of archaeal etherlipids (e.g., TEX_{86} index) that show temperature-dependent membrane changes have been used successfully to develop (paleo-)temperature records from marine sediments. These lipids have also been identified in freshwater terrestrial environments but their application for (paleo-)temperature estimation has yet to be firmly established. In an effort to develop new techniques for producing quantitative estimates of past temperature change, we explore whether the TEX_{86} as a traditionally marine-based molecular temperature indicator can be reliably used to produce land climate records from lake systems. Recently, bacterial etherlipids, detectable in a wide range of environments, have been shown to similarly provide the potential of temperature derivation. Their distribution patterns will be included in (paleo-)environmental interpretations.

Modern and glacial age sediments of New Zealand lakes were used to test for the content of etherlipids. Analyses of archaeal and bacterial lipids include organic-geochemical procedures such as solvent extraction, compound separation, gas chromatography/mass spectrometry (MS), and liquid chromatography/MS. Lake paleo-temperatures inferred from TEX_{86} are about 13.8 ^{o}C for the early Holocene and 11.6 ^{o}C during glacial times. In comparison, today's summer air temperature for this lake is around 14.2^{o}C. The lipid-based temperatures correspond well with similar age pollen and fossil insect (chironomid) based paleotemperature reconstructions from a nearby lake. These first results are promising and imply that the TEX_{86} can be used as a sufficiently accurate tool for the estimation of lake water temperature and that a new calibration may not be necessary.

The novel application of this technique may provide a valuable new tool for understanding terrestrial paleoclimate records and a unique method to test the correlation between New Zealand lake and ocean temperature reconstructions.

SYMPOSIUM: ENERGY

NEW ZEALAND'S FUTURE ENERGY ENVIRONMENT

Monday 24th November

Rangimarie 1

Energy 1: 9:00 – 10:30
Energy 2: 11:00 – 12:30

Plenary: Monday 08:30 (Soundings Theatre)

Posters: Monday 15:30 – 17:00 (Oceania)

THE GEOLOGY OF THE MOKAI GEOTHERMAL FIELD – RESULTS OF THE LATEST DRILLING PHASE AUGUST 2008

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The Mokai geothermal field is located 25 km northwest of Taupo, within the Maroa Volcanic Centre. Mighty River Power and the Tuaropaki Trust have recently begun drilling exploration wells to assess expansion possibilities for the Mokai geothermal field. Four deep (1838m – 2291m) exploration step-out wells have been drilled, seeking to establish the true extent of the geothermal resource. This latest drilling has enabled the previous assumptions about the geological structure of the Mokai geothermal field to be tested.

The latest exploration drilling phase began in March 2008, with MK18, MK19, MK20 and MK21 all being completed by August 2008. Four key points are made from this exploration phase:

- The Whakamaru Ignimbrite, which occurs across the entire field, has a maximum thickness of 782 metres in MK19. The Whakamaru Ignimbrite was one of the target formations for drilling, but in the case of MK19 and MK19, the increased thickness did not correspond to more productivity.

- Rhyolite B (north and south) was seen in MK18 and MK19, but not in MK20 or MK21, confining this unit more to the northwest and southeast rather than simply north and south.

- Rhyolite C has not been seen in any of the new wells, confining it at this stage to just the production area.

- Rhyolite E is a difficult unit to constrain as it occurs at a depth beyond most of the Mokai wells. MK17 was the only well that encountered it prior to the latest drilling phase, with an estimated thickness of 275 metres. Its possible MK20 just intersected this unit.

Structure contours constructed based on the elevation of formation tops throughout the Mokai field and thickness isopach maps appear to show the location of the centre of the caldera. Units are shown to dip and thicken towards the southeast, which was highlighted with MK19 having the thickest Ignimbrite D and Whakamaru Ignimbrite formations.

SEDIMENTARY FACIES DEVELOPMENT IN OFFSHORE SOUTHEASTERN TARANAKI BASIN, NEW ZEALAND FROM ATTRIBUTE ANALYSIS OF 2D AND 3D SEISMIC REFLECTION DATA

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This paper describes our progress in constraining the tectono-sedimentary history, paleogeography and facies distribution of the offshore south-eastern Taranaki Basin through investigation of 2D and 3D seismic reflection surveys. As part of the GNS seismic facies mapping project, 16 seismic horizons have been interpreted on 2D and 3D data and tied to wells in the Kupe and Central graben area. The interpreted horizons are used for reconnaissance and characterisation of seismic facies via seismic attribute analysis as well as structural reconstructions. Amplitude maps from 2D and 3D surveys are combined to visualize large parts of the depositional system. Multiple attributes based on amplitude, frequency, and coherency are used simultaneously for classification of facies via artificial neural networks in the Kerry 3D data set. Observed facies, geomorphology and stratal patterns are then correlated with available well data to infer age, lithology, and paleoenvironment. Seismic interpretation and structural models suggest convergent tectonics as early as Late Eocene- Early Oligocene, which is corroborated by growth strata within Turi Formation equivalents in the footwall of the Manaia fault and contemporary formation of the Waiokura syncline. Attribute maps give firm constraints on paleogeography and sediment transport directions at various stages of basin evolution, which include 1) the delineation of Cretaceous depocenters, 2) Miocene channel and fan systems and 3) Plio-Pleistocene shelf development. These observations have significant implications for the evolution of the petroleum system as well as the geodynamics of the broader central New Zealand region.

HOT FRACTURED ROCK IN AUSTRALIA

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Geodynamics Limited is the most advanced of a number of hot fractured rock developments in Australia. It has drilled 3 deep wells at their "Habanero" site and is currently drilling a step out well at the "Jolokia" site 9 km west. These wells are located in the Cooper Basin, near Innaminka in the Simpson Desert. The heat source is a radiogenic granite at a depth of >3000m. This large granite body is overlain by 3 – 4 km of sediments, which act as an insulator to keep a large proportion of the radiogenic heat that is generated down in the granites.

The first well was Habanero 1, drilled to 4,421m. This well was found to have a shut-in wellhead pressure of 350 bar due to geo-pressuring in the granites. The surprise large pressure meant that the wellhead was no longer equipped for discharge, so no chemical sampling was possible from this well though fluid influxes into the mud system did give a clue to the chemistry of the water. At this stage, the project was no longer "Hot **Dry** Rock" and became "Hot **Fractured** Rock".

Habanero 2 was drilled to 4342m. Although there were technical drilling problems with the well, we were able to collect chemical samples. Samples of the fluid were collected at high pressure (350bar) and high temperature (200°C) from the wellhead. After the wellhead, the fluid was depressurised and then fed to a conventional geothermal separator. Further steam and water samples could then be collected at the separator pressure.

The liquid phase is a NaCl brine with about 2/3 the salinity of seawater. Being derived from a late stage granite, the water is enriched in the LILEs with 10s of ppm of Rb and Cs. Lithium and boron are also enriched with concentrations of several hundred ppm. The gases comprise about 1.8% by wt of the total flow. As in a regular magmatic geothermal system, the principal gas is CO_2, but this CO2 is thought to have diffused down from the overlying gas saturated sediments over several hundred million years. H_2S concentrations are much lower than those in the TVZ and with the radiogenic granite, helium concentrations are high. With the petroleum sedimentary layers above the granite, methane is also very high with about 1000ppm in the total flow.

Habanero 3 was drilled to 4221m. An extended discharge test in March of this year showed good productivity. Chemical samples showed that the fluid was very similar to Habanero 2 fluids and a bottom hole temperature of 244°C was measured. A circulation test between Habanero3 and Habanero1 will have been completed by the time that this talk is presented.

MAPPING, VISUALISATION, AND RESERVOIR CHARACTERISATION OF MID-MIOCENE MARINE CHANNELS IN THE KUPE REGION, OFFSHORE TARANAKI BASIN

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As part of the FRST-funded, GNS Science, Taranaki Basin Seismic Facies Mapping Project, we have identified a suite of deep-water channel systems on 2D and 3D seismic data within, and to the west of, the offshore Kupe Field. We have seismically mapped six channel complexes of Mid Miocene age. Channel imaging resolution varies according to seismic data quality. The channels are up to several kilometres wide and tens of kilometres long, with a depth of incision up to 320 ms in TWT. These channels are inferred to be dominantly mud filled, but appear to contain coarse-grained basal deposits. The larger channels appear to be more canyon-like and display a multi-erosional history. The smaller, shallower channels appear to have associated levees. All of the channel complexes display a degree of sinuosity, as inferred by the presence of Lateral Accretion Packages. They constitute a large-scale slope channel network feeding into basin floor sandy fans, as represented by Moki Formation deposits in the Maari and Maui Fields to the west and north-west.

We employ single and multitrace seismic attributes to improve the visualisation of the channel complexes and to aid the delineation of their spatial extent. In addition, sedimentological and petrophysical data from possible equivalent intervals in local wells are used to calibrate seismic attributes and potential reservoir properties. This procedure allows iterative interpretation of lithofacies in areas with limited well control.

The seismic mapping of the location and character of these channel systems, and identification of their lithological constraints, is significantly improving our understanding of evolving sub-environments and potential reservoir distribution along the Neogene prograding margin within the Taranaki Basin.

SEARCHING FOR NEW HYDROCARBON RESOURCE POTENTIAL OF NEW ZEALAND

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New Zealand needs more resources in energy if it is to expand its economy. As a result over the last few years, Crown Minerals has purchased existing seismic data and acquired new 2D seismic data across selected offshore areas to stimulate exploration activity. This work has also provided an important link to commercialise the science of GNS and NIWA that has indicated a number of new basins with hydrocarbon potential. This seismic data and associated geotechnical studies have played a key role in attracting major exploration companies with financial capacity and technical capability to explore offshore deep water basins. Data acquisition is therefore an incentive to encourage these majors to re-look at New Zealand's potential.

The $NZ 21 million fund has enabled Crown Minerals to purchase and acquire approximately 22,000 km of 2D seismic data over the offshore deep water Taranaki, Northland, East Coast, Great South and Raukumara basins all of which have been made freely available to industry as data packs to support competitive bidding for acreage across these basins. The data packs also contained geotechnical reports about the basin, and specialist studies such as satellite seep detection, gravity and magnetic, basin modelling and seismic interpretation. Much of these studies were carried out by GNS, and the integration of this work with the new seismic data has in some cases provided a new insight into the petroleum potential of these basins. .

The data acquisition initiative has covered a small proportion of New Zealand’s petroleum basins and it is believed even greater potential exists across the broader territorial waters of New Zealand. Acquiring new data across offshore basins is entirely driven by economic priorities however the results of this work provides a rich source of data for broader scientific research that might not otherwise be available due to prohibitive cost to fund this type of activity.

Going forward, Crown Minerals is considering acquiring data across the Pegasus Basin, south east of Wellington and Marlborough; Reinga Basin north-west of Northland; Bellona Basin and the Westport Trench on the southern edge of the Challenger Plateau; the southern and eastern areas of the Great South Basin and outer basins of the Campbell Plateau and the gas hydrates off the East Coast.

The stimulation of the industry also has an effect in that we need to staff this industry from professional geologists to rig workers. There is a serious skills shortage worldwide in Geology, Geophysics, Chemistry and Maths so we must promote our industry within the universities and technical institutes by taking on local students as summer and part time workers while they are carry out their studies and to provide projects for those in indirect fields such as chemistry, maths and economics.

THE POTENTIAL FOR GEOLOGICAL STORAGE OF CO_2: OPPORTUNITIES FOR NEW ZEALAND AND ITS ENERGY SECTOR

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Geological storage (geosequestration) of carbon dioxide or Carbon Capture and Storage (CCS) is being increasingly identified world-wide as a potential mitigation measure in the reduction of greenhouse gas emissions, primarily from energy production using fossil fuels. New Zealand's top four stationary sources of anthropogenic sourced CO_2 emit about 10 million tonnes of carbon dioxide annually. Most of this can be captured at source, pressurized and pumped underground into deep geological structures such as depleted oil and gas reservoirs. New Zealand is following a number of countries in assessing potential storage resources for CCS. Several small- to medium-scale projects are currently successfully storing CO_2 underground in Norway, Canada and Algeria with larger-scale projects planned for Europe and Australia.

Opportunities for carbon capture and storage in New Zealand are currently being assessed with an emphasis on site characterisation, monitoring and verification and risk assessment. This research is aimed at establishing a knowledge and capability platform for CCS in New Zealand, potentially paving the way for pilot-scale injection projects, with a longer-term goal to contribute to reducing New Zealand's greenhouse gas emissions. This talk will provide an update on progress towards identifying the storage resource in New Zealand and discuss how this may influence development in the energy sector.

STRUCTURAL EVOLUTION AND PETROLEUM SYSTEMS OF THE MURCHISON BASIN (SOUTH ISLAND, NEW ZEALAND)

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Application of standard basin analysis approaches to hydrocarbon exploration in South Island sedimentary basins is complicated by the long history of tectonism affecting the source-reservoir-seal-trap assemblages during sedimentation in successive divergent, convergent and transform plate-margin settings. In particular, maturation, migration, entrapment and survival of hydrocarbon fluids are controlled by: (i) thermal regime and fluid circulation, (ii) vertical and lateral mobility of crustal blocks hosting sedimentary basins; and, (iii) reactivation of deep discontinuities.

All these factors play a significant role in the case of the Murchison Basin (MB), a narrow N-S depression, located on Australian crust west of the Alpine Fault. Widely distributed seeps prove the generation and movement of hydrocarbons in the MB, but the preservation, location and commercial viability of reservoirs are yet to be demonstrated.

Several features indicate the influence of deep structure during the development of the MB: (1) its location above the Anatoki Thrust, the suture between the Buller and Takaka terranes, and within the Median Batholith; (2) short-wavelength deflection of the fault-bounded depression, which was subject to high subsidence rates in both extensional and compressional regimes from the Oligocene to the Middle Miocene, followed by rapid uplift with an estimated removal of > 3.5 km of Eocene and younger sections; (3) anomalies in surface heat flow (up to 108 mW/m^2) and in mantle-sourced fluids released through the upper crust; (4) crustal seismic activity, with episodic rupture in large reverse-slip earthquakes (e.g. Mw 7.8 Buller earthquake, 1929).

The structural geometry of the MB, defined from surface mapping, available seismic reflection surveys and drilling is characterized by kink-like folding of an anisotropic multilayer, repeatedly detached above inherited basement highs, and constrained within up-thrusted basement blocks at the basin margins. Buckling of the sedimentary cover sequence and fold growth (25-19 Ma) overlap with compressional inversion (with thrusting and strike slip components) of inherited normal faults (e.g. White Creek, Maunga, Tainui, 21-16 Ma), followed (post 15 Ma) by truncation by low angle crosscutting thrust faults, especially along the eastern margin (Tutaki Fault).

Surface and subsurface data are interpreted through a set of crustal cross sections that highlight the reactivation of structures in the Australian crust translated against the plate boundary, the propagation of thrust shortcuts in the footwall of the Alpine Fault, the mixed style of thin and thick-skinned deformation, and the likelihood that sections of MB are overridden beneath basement thrusts. These insights as to its structural complexity improve the basis for effective identification and eventual quantification of viable oil and gas prospects within the MB.

PALAEOGEOGRAPHY OF A MID MIOCENE TURBIDITE COMPLEX, MOKI FORMATION, SOUTHERN TARANAKI BASIN

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The Moki Formation, Taranaki Basin, is a Mid Miocene (Late Altonian to Early Lillburnian) sand-rich turbidite complex bounded above and below by the massive bathyal mudstone of the Manganui Formation. The Moki Formation is more than 300 m thick in places and contains thick, tabular sandstone packages interbedded with mudstone. Good hydrocarbon shows in the Moki Formation have been documented in numerous wells and the formation provides the reservoir for the Maari oil field currently under development.

Previous regional studies have been based primarily on well data and resulted in varying palaeogeographic interpretations. This study, restricted to the southern offshore region of the basin, aims to better constrain the palaeogeography of the Moki Formation by combining well data with seismic interpretation to identify key stratal geometries within the sediment package.

Nearly 30,000 km of 2D seismic and two 3D surveys, along with data from 18 wells and two cores were reviewed and key sections analysed in detail. This included regional seismic interpretation, wireline log correlation and construction of two-way travel-time (TWTT) structure maps of the Mid Miocene interval. Significant stratal geometries have been identified which provide insights into the structure, distribution and progressive development of the Moki Formation. These include: a clearly defined eastern limit of the fan complex, thinning and fining of the distal turbidite complex onto the basin floor in the north and west, evidence of fan lobe switching, spectacular meandering channel systems incised into the formation at seismic scales, and the coeval palaeoshelf-slope break in the south east of the basin.

This study presents an improved palaeogeographic interpretation of the Moki Formation, which shows that during the Altonian, sandstone deposition was localised to a small fan body in the vicinity of Maui-4 to Moki-1 wells. By Clifdenian times the fan system was well-established, centred around the southern and central wells. With continued sediment supply to the basin floor during the Early Lillburnian, the fan system prograded markedly northward and spilled onto the Western Stable Platform.

THE POTENTIAL FOR SHALE GAS PROSPECTIVITY IN NEW ZEALAND

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Shale-gas is an emerging play type around the world. The gas is typically contained in "tight", fine-grained, organic rich, self-sourced reservoirs (i.e. gas source and reservoir are the same rock). The gas typically contains high proportions of thermogenic or biogenic methane that is stored as free gas in matrix or fracture porosity, or as adsorbed/dissolved gas on the organic material and/or clays. Shale gas reservoirs often require special completion, stimulation and/or production techniques in order to achieve economic success. The reservoirs are typically distributed through relatively large rock volumes, occur over wide geographic areas, and are found within low and/or variable permeability reservoir rocks. Shale gas resources are characterised by low flow rates, long production life, and variable pressure regimes. Naturally occurring (or artificially stimulated) fracture networks can enhance production in shale gas reservoirs with low matrix permeability, which would otherwise be unproductive.

Shale gas is currently one of the most important and active exploration plays in the United States. Extensive research was undertaken throughout the 1980's and early 1990's to evaluate the shale gas potential, and to enhance production, from Devonian- and Mississippian-aged shale formations in the United States. To date, little research has been carried out on shale gas play potential in New Zealand.

The East Coast Basin of New Zealand's North Island may demonstrate shale gas prospectivity. Shales within Whangai and Waipawa formations are currently being investigated in the East Coast Basin. The Whangai Formation has average TOCs of 0.4-0.8%. Outcrop sampling indicates that the Waipawa Formation has a TOC content generally ranging between 2-6%, up to 12%. Outcrop samples of the Waipawa Formation have been described as immature to marginally mature. Outcrop samples of the Whangai Formation are slightly more mature than the Waipawa Formation, probably due to greater burial depths. Preliminary fracture studies have measured cumulative fracture trace lengths on two dimensional rock surfaces as a first step to quantifying fracture porosity with encouraging results for overall potential fracture volumes.

SEISMIC STRATIGRAPHY OF CAPEL AND FAUST BASINS, NORTHERN TASMAN SEA, AND IMPLICATIONS FOR PETROLEUM POTENTIAL

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The Capel and Faust basins are large Cretaceous rift basins previously identified in the northern Lord Howe Rise region. Geoscience Australia (GA) acquired 6000 line km of high-quality 2D seismic data in the area during the GA-302 survey in 2006–2007. High-resolution multibeam bathymetry, gravity and magnetic survey data were subsequently acquired by the *RV Tangaroa* in late 2007.

The data sets have been integrated to reveal basin architecture and spatial relationships at a range of scales. Correlations are made between seafloor features observed in the bathymetric image and large-scale subsurface structure apparent in the seismic and potential field data. The use of 3D visualisation has enabled iterative testing and refinement of the geological interpretations from an early stage in the project workflow.

The data have revealed a series of discrete depocentres up to 150 km long and 40 km wide, filled with sediment up to 6 km thick. Preliminary interpretation of the GA-302 seismic data identified two syn-rift and two post-rift sag megasequence packages overlying a heterogeneous pre-rift basement. The syn-rift section is inferred to comprise an Early Cretaceous volcaniclastic and non-marine megasequence (*Syn-rift 1*), and a ?Cenomanian to Campanian fluvio-deltaic megasequence (*Syn-rift 2*). Stratigraphic and structural architecture suggests a westward shift in the locus of rifting between *Syn-rift 1* and *Syn-rift 2* phases. An upward succession from shallow-marine siliciclastics to bathyal carbonates is expected in the overlying sag megasequences.

Sediments within the depocentres of the Capel and Faust basins are likely to be buried deeply enough to generate oil and gas, particularly given the heat flow measured in the region. Analogies with the Taranaki Basin in New Zealand and eastern Australian basins suggest that the pre-rift basement may include Mesozoic coal measures, which, together with any organic facies within the lower syn-rift section, would represent possible source rocks. Reservoir sandstones of fluvial to shallow marine facies are likely within the upper syn-rift to lower sag sections. Large potential trapping structures are also present.

The research contributes to understanding the tectonostratigraphic evolution and petroleum prospectivity, and to future marine bioregional planning, of this vast trans-Tasman frontier region.

THE FRUITS OF PAPATUANUKU – MAORI AND GEOTHERMAL ENERGY

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Although already playing a minor role in the energy sector, Geothermal Energy is poised to make a significant contribution to New Zealand's future energy environment. In 1958 New Zealand was at the forefront of Geothermal Energy when it commissioned Wairakei - the world's second geothermally driven electricity generation plant. However, despite this early start in the sector, a number of factors resulted in an environment that was not conducive to continued, concerted efforts to develop Geothermal Energy in New Zealand. For some years it languished, until more recently, changes in that environment have led to a surge in development of Geothermal Energy (e.g. commissioning of 100 MW station in Kawerau by Mighty River Power, September 2008).

An outcome of recent Treaty of Waitangi tribunal and other court rulings will result in the emergence of Maori as major players in the Geothermal Energy arena. The reputation of Geothermal Energy as renewable and sustainable makes it highly desirable to Maori as it meets the requirements of kaitiaki (‘stewards’), and replenishes of the three baskets of of matauranga Maori, known as traditional knowledge, and the development if new science and commercial knowledge. Maori commerce and science today finds credence in adopting a long-term sustainability strategy that incorporates the quadruple bottom-line of economic well-being, environmental well-being, social-cultural well-being, and spiritual well-being. This presentation will give an outline of the pathways of both risks and opportunities to scientific and commercial development, as well as a Maori model of Geothermal Development.

FAULT DILATATION AND GAS MIGRATION IN THE KUPE FIELD, TARANAKI BASIN, OFFSHORE NEW ZEALAND

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Many petroleum fields are located somewhat paradoxically on or adjacent to heavily faulted active plate boundaries. When fields are cut by active faults they are commonly thought to be susceptible to up-dip fault-induced leakage. Relay ramps and associated zones of fracturing close to faults may increase permeability around faults further enhancing migration and increasing risk to sealing within the field. However, the presence of hydrocarbon reservoirs adjacent to some active faults suggests that leakage up these faults is slower than the rate of reservoir charge.

In this study of the Kupe Field in offshore eastern Taranaki Basin, we used seismic interpretation and fault seal modelling to investigate the relationships between fault geometries and kinematics and their impact on gas migration in the field. Interpretation and modelling results constrain the evolution of the characteristic geometry of the incipient fault population, the distribution of low velocity anomalies within the 3D volume (inferred to be sites of potential gas migration) and the implications for the geological evolution and technical development of petroleum systems in the Kupe Field.

Our interpretation of the reprocessed Kerry 3D seismic reflection volume defined numerous incipient, en-echelon arrays of steeply dipping, NE-striking, conjugate normal faults that locally extend from deep source-rocks to the sea floor. In plan view, low velocity anomalies are often spatially associated with the fault tip segments that are sub-parallel to SHmax (derived from borehole breakout data), possibly indicating up-dip gas migration on these structures. In cross-section, low velocity anomalies are associated with clusters of faults that cut to source-rock depths. Fault modelling established a degree of spatial correlation between faults modelled to have high probabilities of dilating and faults or fault segments striking sub-parallel to SHmax. These observations suggest that incipient, plate boundary-related faults may be at risk for leaking in the Kupe area. However, the field contains several pools of hydrocarbons and preliminary evaluation suggests that in spite of relatively long and possibly active fault traces, the low velocity zones are apparently confined to a critical range of fault orientations that may change with depth.

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EVALUATION OF A BIOGENIC GAS RESOURCE IN THE MANAWATU-WANGANUI REGION

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Petroleum exploration in the 40 000 km^2 Wanganui Basin has been generally low-graded because of the lack of evidence for hydrocarbon source rocks and maturation within the basin. There have, however, been numerous instances of methane-rich gas in shallow water-wells. For example, a water-well on the Thorburn property, Castlecliff, drilled in 1917, flowed gas with 74% methane which was collected and used for domestic purposes as late as the 1970s. The area is currently being explored by Hugh Green Energy Ltd as Petroleum Exploration Permit 38 771.

A well on the Angelo property, close to the Tararua range-front east of Levin, flowed dry gas from a 1.5 m thick sand bed at 20 m depth in Otaki Formation (OIS 5) strata. Gas composition included 58% N_2, and 40% CH_4, with 1.36 ppm C_2H_6 and no higher hydrocarbons. Stable isotopes indicate microbial methane generated by reduction of CO_2. Flow-testing of the well demonstrated a shut-in pressure of 24.5 kPa, with a sustained gas flow of 20 m^3/hr at 3.75 kPa over 24 hours.

Samples of both cuttings and water from recent water-wells in the permit were submitted for headspace gas analysis using SIFT-MS (selected ion flow tube – mass spectrometry) by Syft Analytics Ltd. Samples of free gas were also analysed by GCMS at GNS Rafter Laboratory.

Thirty-two well cuttings samples underwent headspace analysis, with some wells having several samples submitted from different depths. Alkanes ranged up to 700 ppm C1, 130 ppm C2, 35 ppm C3, 7 ppm C4 and 0.9 ppm C5.

Water samples were taken from wells that are producing from 20 to 700 m depth. Eighteen samples yielded greater than 1% methane in the headspace. Higher alkanes ranged up to 280 ppm C2, 74 ppm C3, 25 ppm C4 and 2.7 ppm C5.

Biogenic gas generation is inferred from the numerous Pleistocene peat and lignite lenses, most commonly down to 30-50 m subsea, but locally down to 300 m subsea. No isotope analyses of gas samples with high levels of C2-C5 have, but the presence of higher hydrocarbons (C3 plus) suggests a thermogenic source may also be present.

Future work in PEP 38 771 will included interpretation of recently-acquired airborne geophysical data to map possible productive fairways, and direct sampling of gas in ground using Geoprobe drilling technology. These data will lead to a resource estimation study.

SEISMIC INVERSION OF CRETACEOUS TO RECENT SEDIMENTS IN THE DEEPWATER TARANAKI BASIN

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Recent developments over the last few years in the area of Amplitude Versus Offset (AVO) techniques have resulted in the Simultaneous Inversion method being developed. This development has come from advances in combining older independent AVO and post stack Inversion methodologies. Hampson Russell's Simultaneous Inversion is a full pre-stack inversion. This new pre-stack inversion technology aims to obtain reliable estimates of P-wave velocity, S-wave velocity and density, from which we can predict both fluid and lithology properties.

The S-Impedance estimate can be used to derive VpVs (P wave velocity to S wave velocity) ratio volumes that are used for locating hydrocarbons, as the Vp/Vs ratio will drop in the presence of oil and particularly gas.

A density estimate can also be derived from this methodology, depending on factors, which may help to distinguish between gas dissolved in water and commercial hydrocarbon saturations.

From the derived attributes P-impedance and S-impedance, more accurate Lambda- -Mu-Rho parameters can be estimated. A cross-plot of Mu-Rho (Rigidity * Density) against Lambda-Rho (Incompressibility * Density) can give a better separation of the gas sands from surrounding sediments such as shale, in hydrocarbon bearing intervals.

GNS Science now has the Hampson Russell AVO & STRATA software packages and has applied this new methodology to a selection of 2D lines in the Deepwater Taranaki Basin area, to enhance the knowledge of the area from pre-existing seismic data. This has highlighted some areas of potential hydrocarbon interest for future exploration. Some of these areas of interest have been subjected to cross plot analysis with interesting results illustrated.

MIGHTY RIVER POWER GEOSCIENCE RESEARCH PROGRAMME

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Last year, Mighty River Power committed to a geoscience research program with an annual budget of $750,000, exclusive of in-kind support. The program is designed to leverage strategically important aspects of geothermal technology in which New Zealand has considerable technical expertise and which can provide significant benefit to the company's geothermal development program.

The overall objectives are to optimize generation, reduce exploration and development costs, avoid or mitigate environmental impacts and build domestic capability in geothermal research and technology. Funding to research institutions is on a project-by-project basis, either by direct payment for research services, by TEC scholarship or other graduate student support, or by support for ongoing research projects. The company's research focus falls into the following four broad categories with timeframes ranging from a few years to a decade.

The principal focus to date has been on geophysical research. In partnership with GNS Science, the company has supported research on 3D modelling of Rotokawa magnetotelluric data and on the deep structure of the TVZ. Seismic monitoring systems have been installed at Kawerau and Rotokawa, to study the relationship between seismicity and deep injection, and to refine seismic monitoring methods for later research studies, such as shear wave splitting.

Chemistry projects focus on the inhibition and mitigation of power plant scale and the potential for mineral recovery. The company built a state-of-the-art power plant cycle test facility to optimize plant design and test mineral scale mitigation strategies for the Kawerau project. This facility is now online at the Rotokawa plant station and available for research studies. Mighty River has supported 2 TEC scholarships to date on geothermal fluid chemistry research.

Geologic research has focussed upon the interplay between rock mineralogy and electrical resistivity, conducted at GNS Science. The intention is to broaden support of regional studies of stratigraphy, volcanism, tectonism and deep hydrology of the TVZ, to better understand the principal geologic setting of New Zealand's prolific geothermal resources.

Environmental studies related to geothermal energy extraction, particularly with respect to the dynamics of hot spring systems, ground subsidence and greenhouse gas sequestration, are targets of future research.

(U-Th)/He AND U-Pb DOUBLE DATING OF DETRITAL ZIRCON AND APATITE FROM FIORDLAND EOCENE-MIOCENE SEDIMENTARY SECTION FOR PROVENANCE HISTORY

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This poster addresses the application of (U-Th)/He and U-Pb dating of detrital apatite and zircon from Eocene - Miocene sedimentary successions in the Fiordland region. The objectives of this research project are to establish and interpret the provenance of these sedimentary rocks, and to establish constraints on the timing of exhumation of plutons and metamorphic complexes in Fiordland from which the detrital grains were derived. To date very few (U-Th)/He ages have been determined on apatite and zircon separated from New Zealand rocks, and U-Pb dating of zircon has been essentially limited to basement rocks. Hence this will be the first application in the area of the sedimentary provenance of cover rock successions. An Eocene-Miocene sedimentary succession is well exposed along the eastern margin of Fiordland, particularly around the shores of lakes Te Anau, Manapouri and Hauroko, and at higher elevations within the Fiordland block. The quartzo-feldspathic composition of the sediments suggests that they were derived from crystalline basement within Fiordland. Published numerical ages of many plutons and associated metamorphic complexes indicate numerous phases of Paleozoic to Cretaceous intrusion and metamorphism in the Fiordland block.

The working hypothesis for the MSc project is that distributions of single grain apatite and zircon ages for grains separated from the Eocene - Miocene sedimentary section will enable the sample host sediments to be tied back to particular igneous and metamorphic suites exposed in different parts of Fiordland. Moreover, the ages obtained using different radiometric dating methods ((U-Th)/He versus U-Pb geochronology) applied to the same detrital crystals by double dating, will produce constraints on the timing of cooling within the host plutons and metamorphic complexes. Integrating information about the stratigraphic ages of the detrital grains will help tighten constraints on the timing of exhumation of the basement suites, as well as the provenance history of the grains. The combined information will be used to better understand the tectonic development and exhumation history of Fiordland.

TARTAN FORMATION, GREAT SOUTH BASIN – ORGANIC CHARACTERISTICS OF A POSSIBLE FUTURE ENERGY SOURCE

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Geochemical identification of the Tartan Formation via organic richness (Total Organic Carbon and Total Organic Nitrogen) and bulk organic carbon isotopes ($\delta^{13}C$) has been undertaken on 75 sidewall core and cuttings samples from five Great South Basin wells. The Paleocene Tartan Formation is an organic-rich, shallow marine mudstone that is a potential source of petroleum in the Great South Basin. It is up to c. 57 m thick and laterally extensive, and is considered analogous to the organic-rich Waipawa Formation.

The immature Tartan Formation, as well as the immediate under- and overlying marine formations (Wickliffe and Laing, respectively) have been sampled in wells Kawau-1A, Hoiho-1C, Toroa-1, Pakaha-1, and Takapu-1A (Tartan absent). Tartan Formation sidewall cores have TOCs of typically 2 to 15%, TON of 0.2 to 0.5%, and $\delta^{13}C$ values of c. -21.0 to -15.8‰, compared to TOC, TON and $\delta^{13}C$ values of typically <2%, <0.1% and -28 to -25‰, respectively, for the enclosing formations. C/N ratios are >20 for all Tartan Formation samples indicating a significant terrestrial contribution, whereas this is seen to a lesser extent in the Wickliffe and Laing formations.

The enrichment in ^{13}C within the Tartan is consistent with that of the Waipawa Formation found in several of New Zealand's other major sedimentary basins, but in the more distal Hoiho-1C ($\delta^{13}C$ up to -15.8‰) and Kawau-1A ($\delta^{13}C$ up to -18.2‰) wells, the enrichment exceeds those previously reported for the Waipawa.

The heavy carbon isotopic signature of the Tartan Formation suggests that any discovered oils and gas condensates generated and expelled from this formation would be similarly enriched in ^{13}C. In the Taranaki Basin, oils recovered from the Kora-1 well show enriched $\delta^{13}C$ values consistent with an organic contribution from its time equivalent formation (i.e. Waipawa). Gas condensates and oil shows thus far discovered in the Great South Basin have $\delta^{13}C$ values of c. -28 to -26‰, consistent with derivation from older, coaly source rocks.

3D STRATIGRAPHIC MODEL, WELL CORRELATION AND SEISMIC TO WELL TIES IN THE KUPE REGION, SOUTHERN TARANAKI BASIN, NEW ZEALAND

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The Seismic Facies Mapping Project, currently being undertaken by GNS Science, aims to develop a 3D atlas of structure, stratigraphy and seismic facies maps in the Taranaki Basin. The Kupe region has been the target area for the pilot project and some of the results are presented in this study.

As a result of a lithological, geophysical and biostratigraphic study from 8 wells in the Kupe area, the stratigraphic framework for the upper Haumurian (Upper Cretaceous)–Opoitian (Lower Pliocene) siliciclastic succession in the Kupe Field is revised and a new chrono- and lithostratigraphic model for the geological correlation with Petrel software is created. The model is directly comparable with the Kerry-3D seismic survey and 2D lines data and their interpretation. This poster describes the data and methods for establishing the stratigraphic model in the Kupe Field and shows their applications in terms of well correlations and seismic-to-well ties.

Twelve Cenozoic key biostratigraphic events have been selected from eight boreholes in the region to mark New Zealand stage zonal boundaries. These events are now identified in each well and stored in the form of chronostratigraphic stage boundaries in Petrel. The New Zealand stage boundary criteria (Cooper, 2004) are adequate for the stratigraphic subdivision in Kupe and are retained with some modification. However, in the Whaingaroian (Oligocene) to Opoitian (Lower Pliocene) interval, cosmopolitan planktonic foraminiferal markers are sparse or absent in the Kupe region whereas age-supporting benthic foraminiferal events occur consistently across the region and are used to mark the stage boundaries. Faunal provincialism developed during the Oligocene–Pliocene in the Kupe region indicates that the Kupe sub-basin was characterised by more proximal open marine conditions than the rest of the Taranaki Basin at the time.

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MIGHTY RIVER POWER'S NEW 90 MW GEOTHERMAL POWER PLANT AT KAWERAU

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The Kawerau geothermal field is the northernmost high-temperature (up to 300°C) geothermal system in the Taupo Volcanic Zone. Development of the shallow (<1000m) reservoir at the Kawerau geothermal field was started in the 1950's by the Tasman Pulp & Paper Company, and has supplied steam to the paper mill operations at Kawerau for process heat since 1957. Mighty River Power began deep exploration drilling in 2004, and the new power plant produces from a high temperature (300°C) reservoir in greywacke basement rock between 1200m and 2500m deep, below and offset from existing production in the field. Mighty River Power's new 90 MW power station at Kawerau, powered by a Fuji dual-flash turbine generator, is the largest single geothermal development in New Zealand in more than 20 years.

The new development extracts an additional 45,000 t/day of geothermal fluid from six production wells within or near the mill complex, with 100% injection of spent fluids in three 2500m deep injection wells at the NE margin of the field. Analyses of the expanded resource development for the new 90MW power station predicted that the planned deep injection would provide sufficient pressure support in the geothermal reservoir, minimizing further pressure decline and resulting in relatively low subsidence rates, comparable to previous experience at Kawerau.

To provide tools for reservoir monitoring, the new Mighty River Power development at Kawerau includes ongoing precision levelling surveys, installation of a permanent seismic monitoring system to track the flow of injectate, shallow and deep pressure and temperature monitoring in dedicated monitoring wells, collection of rock property information, numerical reservoir simulation updates, and three-dimensional subsidence modelling and prediction.

STRUCTURE AND PETROLEUM PROSPECTIVITY OF THE RAUKUMARA BASIN, NORTH ISLAND, NEW ZEALAND

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The Raukumara Basin lies beneath the offshore Raukumara Plain, adjacent to northeast North Island, New Zealand. There are no offshore petroleum exploration wells in the region and until 2007 there were few seismic lines; consequently little was known about the basin or its petroleum potential. However, a recent multi-channel seismic reflection survey acquired by MED Crown Minerals, has allowed provisional correlation of offshore stratigraphy and structure with the geology of the Raukumara Peninsula. These data have also been used for an assessment of the petroleum potential of the basin. The Raukumara Basin is located in a forearc setting between the volcanically active Havre Trough and the Hikurangi subduction zone. It covers an area of approximately 30,000 km² with the c. 100 km wide southern part of the basin containing a remarkably undeformed Cretaceous-Cenozoic sedimentary succession up to 11,000 m thick.

On the basis of seismic interpretation, the succession within the Raukumara Basin is subdivided into three sedimentary megasequences (from bottom to top X, Y, and Z), with basement defined as everything below megasequence X. Basement includes deformed and metamorphosed Gondwana convergent margin sediments and possible ocean crust forming the Gondwana trench and foreland. Megasequence X is interpreted as Late Cretaceous and Paleogene passive margin succession up to 7000 m thick. Megasequence Y is interpreted as an Early Miocene allochthonous succession up to 3000 m thick and correlates with the onshore East Coast Allochthon. Megasequence Z is interpreted as Neogene convergent margin sediments and volcaniclastics up to 3500 m thick.

The occurrence of oil and gas seeps on the adjacent Raukumara Peninsula demonstrates the presence of an active petroleum system nearby. Petroleum source rocks in the Raukumara Basin are inferred to include Waipawa Formation and Whangai Formation marine shales and are predicted to currently be in the oil expulsion window. Reservoir rocks are inferred at many levels within the Raukumara basin, especially in the Neogene succession (megasequence Z), and numerous petroleum exploration leads have been identified on seismic data, including possible petroleum charged turbidite sand bodies greater than 10 km across. Direct hydrocarbon indicators are also observed on seismic data. These features, plus its proximity to land make the Raukumara Basin one of the most prospective frontier basins in the New Zealand region.

OIL FROM NEW ZEALAND COALS—NATURALLY

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The recent development of the Tui Area oil fields (50 MMbbl) has had a material impact on New Zealand's GDP, export earnings and self-sufficiency in oil. When the Maari Field (49 MMbbl) comes on stream later this year, our self-sufficiency will rise to more than 60% from just 15% two years ago, saving the country billions of dollars over the coming decade and reducing our dependency on imported supplies. What links Tui, Maari and most other Taranaki oil fields is that their oil was derived from Cretaceous–Tertiary coaly rocks; source rocks that even today are dismissed as too gas-prone by some international exploration companies. This presentation reviews the key findings of Government-funded research at GNS Science over the past 10 years that has addressed (1) the fundamental controls on the oil and gas potentials of coaly source rocks in New Zealand basins, and (2) prediction of the depth and timing of petroleum generation and expulsion. Directions of future petroleum geochemistry research to help further reduce pre-drill geological uncertainties, thereby improving the chances of additional, new oil and gas discoveries, will also be outlined.

New Zealand black oils are typically waxy and highly paraffinic. The primary control on the paraffinic oil potential of the source coals, shaly coals and coaly mudstones—the so-called continuum of coaly source rocks—is their abundance of leaf-derived liptinite macerals (cutinite and liptodetrinite). This in turn is a function of the input and preservation of gymnosperm- and angiosperm-derived leaf biomass within the precursor peat mires and associated mud-rich backswamps. Coals that formed in planar, rheotrophic (i.e., flow-fed) mires typically have greater contents of leaf-derived liptinite—and hence greater paraffinic oil potentials—than coals that formed in raised, ombrotrophic (rain-fed) mires. This relates to the better preservation potential of surface leaf litter under the generally higher groundwater levels within planar mires and backswamps. Thin, planar mire coal seams tend to be associated with relatively high rates of accommodation space increase, and thus are characteristic of the mid–Late Cretaceous syn-rift coal measure sequences in New Zealand basins. Total oil potentials and oil expulsion efficiencies of the coaly source rocks have also commonly been enhanced by marine influence within the coal measure depositional environment. The degree of marine influence and the amount of leaf-derived liptinite both also modify the temperature and thus the depth at which oil is first generated and expelled.

Future research will focus on enhanced quantification and prediction of the timing, depth, quantum and phase (oil vs. gas) of petroleum charge at basin to prospect scales, as well as improved resolution of oil-source rock correlation (in terms of source age, facies and maturity) to better constrain the identification of kitchen areas and migration pathways.

TIMING OF INITIATION OF REVERSE DISPLACEMENT ON TARANAKI FAULT, NORTHERN TARANAKI BASIN: CONSTRAINTS FROM THE ON LAND RECORD (OLIGOCENE TE KUITI GROUP)

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Structures associated with the wedge of basement overthrust into Taranaki Basin along the Taranaki Fault are regarded as hydrocarbon plays and have been tested by drilling through the tip of the overthrust. The timing of initiation of reverse displacement on Taranaki Fault is difficult to interpret from available seismic reflection data across it because the evidence has been masked by later movements. The record from the basin, as summarised in King & Thrasher (1996), suggests that the fault evolved from normal to reverse character during the mid-Oligocene. This was inferred from formation of a foredeep parallel to, and west of, Taranaki Fault and a marked increase in its paleo-water depth, as indicated by foraminiferal assemblages of Late Oligocene age.

A comprehensive re-assessment of the lithostratigraphy and sequence stratigraphy of the Late Eocene-Oligocene Te Kuiti Group exposed on land east of Taranaki Fault in central-western North Island, between Port Waikato and Awakino, provides new constraints on the early history of Taranaki Fault displacement. New age control has been achieved by a review of existing foraminiferal biostratigraphy combined with determination of Sr isotope ages from macrofossil samples. Six unconformity-bound sequences have been identified and mapped within the Te Kuiti Group. A major subaerial unconformity between sequences TK3 and TK4 combined with a basinward shift in the position of onlap for sequence TK4 indicate a dramatic change in stratigraphic development and basin dynamics during the mid-upper Whaingaroan at c. 29 Ma, corresponding to the change from mild extension (sag basin) to shortening across the Taranaki Fault Zone. We consider sequences TK4 – TK6 to each represent tectonic cycles of subsidence and basin inversion and we attribute the origin of these cycles to periodic locking of the Taranaki Fault décollement in underlying Murihiku basement, the accumulating strain causing uplift in the basin east of the fault zone, followed by free displacement, relaxation in the upper crust and subsidence. A 1st-order model is presented of the Late Oligocene to earliest Miocene vertical and horizontal displacement of basement on the Taranaki Fault Zone for a west–east transect through Awakino. It implies that the mid- to Late Oligocene displacement on the fault zone in the vicinity of Awakino was episodic, and that the thrust belt was narrow (c. 15 km). North of Kawhia Harbour there will have been a different displacement history with most of the total displacement occurring during the development of the c. 29 Ma unconformity at the base of Sequence TK4, whereas to the south between Awakino and Kawhia Harbour the majority of the total displacement occurred during the Otaian and at the end of it. The Manganui Fault is part of the Taranaki Fault Zone and probably became active at c. 27 Ma during development of the unconformity between sequences TK4 & TK5.

WHAT WE KNOW (AND WHAT WE DON'T!) ABOUT GEOLOGY AND PETROLEUM POTENTIAL OF THE OFFSHORE NORTHLAND BASIN

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The offshore Northland Basin is a major sedimentary accumulation lying to the west of the Northland Peninsula. It merges with the Taranaki Basin in the south and its deeper units are separated from Deepwater Taranaki by a buried extension of the West Norfolk Ridge. Sedimentary thicknesses increase to the northwest and the Northland Basin may extend into Reinga. Its total area is at least 25,000 km^2 and if the Reinga Basin is included, it may be up to 75,000 km^2or about 25% of the area of the North Sea.

As in Taranaki, it was thought that petroleum systems of the Northland Basin include Cretaceous to Recent sedimentary rocks. However, Waka Nui-1, drilled in 1999, penetrated no Cretaceous sediments, but unmetamorphosed Middle Jurassic coal measures were drilled. Economic basement may be older meta-sediments of the Murihiku Supergroup. Thick successions onlap the dipping Jurassic unit and a representative Cretaceous succession is likely to be present within the basin.

Known potential source rocks include the around Waka Nui-1Middle Jurassic coal measures and the Waipawa Formation black shale. Inferred source rocks include Taniwha Formation coaly sediments, possible Late Cretaceous coaly units and lean but thick Late Cretaceous and Paleogene marine shales.

Below the voluminous Miocene volcanoes of the Northland arc, the eastern margin of the basin is dominated by a thick sedimentary wedge that appears to have been thrust to the southwest. This is interpreted to be a Mesozoic equivalent of the Taranaki Fault, a back-thrust to subduction along the Gondwana Margin. The ages of sedimentary units within the wedge are unknown, but are thought to include a basal Jurassic succession, which dips generally to the east and is truncated by an erosional unconformity. A southwestwards-prograding succession overlies the unconformity and its top surface forms a paleo-slope onlapped by sediments of Late Cretaceous to Neogene ages. The upper succession in the wedge may be of Early Cretaceous age, perhaps the equivalent of the Taniwha Formation or the basal succession in Waimamaku-2.

The main part of the basin was rifted to form a series of horst and graben features. The age of rifting is almost totally unconstrained, but the structural tend is northwest-southeast or parallel to the Early Cretaceous rifting of Deepwater Taranaki.

Thick successions overlie source units which are likely to be buried deeply enough to expel oil and gas and more than 70 slicks have been identified on satellite SAR data suggesting an active petroleum system. Numerous structural and stratigraphic traps are present and the potential of the Northland Basin is thought to be high.

SYMPOSIUM: STRAIT

BRIDGING THE STRAIT: ACTIVE GEOLOGICAL PROCESSES AND NATURAL HAZARDS IN CENTRAL NZ

Monday 24th November

Rangimarie 2

Strait 1: 9:00 – 10:30
Strait 2: 11:00 – 12:30

Posters: Monday 15:30 – 17:00 (Oceania)

A NEW MODEL OF ACTIVE FAULTING IN COOK STRAIT: STRUCTURE, SLIP RATE, EARTHQUAKES, AND FAULT INTERACTIONS

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A new interpretation of active faulting in the wider Cook Strait region has been developed, in part as a component of the It's Our Fault project, revealing the relationships between the Marlborough Fault System, the North Island Dextral Fault Belt, and the southern Hikurangi margin. The submarine faults were mapped at NIWA using high-quality multibeam bathymetric data together with seismic reflection profiles, and are integrated with the onshore active fault database at GNS Science to reveal a complete deformation picture of the region. The combination of submarine and onshore data enable us to estimate Late Quaternary fault slip rates.

In Cook Strait there is a general discontinuity between the major faults of North and South islands, and the predominant structural trend swings from SW-NE on land to E-W offshore. The submarine faulting is characterized by seabed traces typically 10 to 90 km length, 5 to 20 km-wide step-overs between fault tips, and moderate to high slip rates. The style of deformation, basin development, and inversion structures indicate that faults accommodate a combination of strike-slip and extension between Wellington and Blenheim, and a combination of strike-slip and compression in southern Cook Strait off eastern Marlborough. The continental slope to the south is dominated by thrust faults. Based on scaling relationships, we estimate potential earthquakes with moment magnitude ranging from Mw 6.6 to 7.9, associated with the major faults above or south of the Hikurangi subduction interface.

Submarine paleo-earthquake records are derived from highly episodic displacement history on the Wairau, Cloudy, and Vernon faults in Cloudy Bay. These records are longer than those available from the Wairau and Vernon faults on land. Six ruptures are inferred on the Wairau Fault since 12 ka, 4-5 on the Vernon Fault since 18 ka, and five on the Cloudy Fault since 17 ka. For each of these faults, the data indicate variable slip per event and variable duration between individual events.

We investigate the interactions between major faults, and the present day state of stress, by modelling Coulomb static stress changes in the brittle crust resulting from 2000 years of secular tectonic loading perturbed by paleo- and historical earthquakes on the major faults. Several models are developed involving known paleo- and historical earthquakes, as well as inferred paleoearthquakes on faults for which we have no paleo-records, including the Hikurangi subduction interface. Despite limitations, all models consistently indicate a high present state of static stress associated with major fault terminations in central Cook Strait. These results have implications for seismic hazard in the region.

RECURRING SLOW SLIP ON THE HIKURANGI SUBDUCTION INTERFACE

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A long-duration slow slip event has been occurring since late 2007 at 30-50 km depth on the Hikurangi subduction interface, near the bottom of the zone of inferred high interseismic coupling beneath the southern North Island, New Zealand. The event is centered about 50 km northwest of Wellington, New Zealand's capital city, and has been recorded by more than 10 continuous GPS stations. The observed surface deformation was most rapid from December 2007 through February 2008, but is still continuing in September 2008. The maximum slip in the event has been more than 200 mm, representing about 6 years of accumulated plate motion. The event appears in part to have re-ruptured the area that slipped during a previous 1-year duration slow slip event in 2003-04, though the earlier event was poorly constrained. Slip of 200 mm in the 2007-08 slow slip event is somewhat larger than the amount of plate motion that has accumulated in the time since the 2003-04 event.

We have observed a series of short-duration (1-2 week) slow slip events since 2002 at 10-15 km depth in the Gisborne region of the northeastern North Island, also near the bottom of the zone of inferred high interseismic coupling. These occur about every two years, and their sizes imply that all the plate motion in this depth range is taken up by the slow slip events. The most recent Gisborne slow slip event appears to have been triggered by a nearby M_W 6.7 normal-faulting earthquake within the subducted slab.

REFINED LATE QUATERNARY SLIP RATE ON THE CENTRAL WAIRARAPA FAULT, NEW ZEALAND

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The Wairarapa Fault is one of the most active faults in the North Island Dextral Fault Belt. Current knowledge regarding its Late Quaternary slip rate is particularly dependent on one site: the Waiohine River terraces, central Wairarapa. These Post- Last Glacial Maximum terraces preserve a remarkable record of progressive displacement on the Wairarapa Fault. The variably displaced terraces were recently mapped in detail using Real-Time Kinematic (RTK) Global Positioning System (GPS) and laser-ranging theodolite (EDM) techniques. Digital Elevation Models (DEM) produced from these data, together with high-resolution aerial photography, allowed us to measure the displacements of 6 terrace surfaces, 5 risers and 2 paleo-channels. For a specific riser, its horizontal and vertical incremental offset typically matched the difference in width of the terrace below that riser, and the difference in height of that riser (respectively) across the Wairarapa Fault. This correspondence supports a model of complete terrace riser trimming by the river at the time of abandonment of the terrace at the base of that riser. The survey data on the progressively offset terraces indicate an average ratio of horizontal to vertical displacement at the Waiohine terraces of 6.5 ± 3 (1σ).

A channel incised into the youngest terrace (F), displayed 12.4 ± 1.6 m (which we interpret as 2σ error) dextral offset, interpreted as 1855 displacement. Terrace riser D-E displayed 23.1 ± 1.4 m (2σ) dextral offset, implying 10.7 ± 2.1 m (2σ) of dextral slip during the penultimate earthquake. These slip measurements are ~20 % smaller than those reported for the 1855 and penultimate events on the southern Wairarapa Fault (south of the Waiohine terraces) implying that co-seismic slip decreases northward along Wairarapa Fault earthquake ruptures.

A series of paleo-channels incised into the uppermost of these terraces, the so called “Waiohine” surface (our terrace A), have previously been reported to display 130 m dextral displacement. We looked carefully for these channels using aerial photography, our DEM’s, and targeted auger surveys, and were unable to locate any of these landforms. For this reason, we question this interpretation of offset channels. The largest measurable displacement that we identified at the site is 101.1 ± 5.8 m (2σ), which corresponds to the next youngest riser incised immediately below the “Waiohine” surface (riser A-B). Under a complete trimming model, the abandonment age of terrace B corresponds to the age of riser A-B. In order to date this offset, we collected 5 samples of silt and sand from above and below the gravel tread of terrace B at two localities near the Waiohine River for luminescence (OSL) dating. These results are not available at the time of writing of this abstract. Together with the above slip estimate, these new ages for terrace B hopefully will provide a rigorous constraint on the late Quaternary slip rate of a central part of the Wairarapa Fault. Current published estimates for the age of terrace A near this site are based on 3 OSL ages for silts deposited on that terrace, ranging from ~10-13 kyr. Together with these ages, the cited offset of riser AB implies a minimum Late Quaternary dextral slip rate of ~6.9 mm/yr.

MODELLING GROUND MOTIONS FOR SUBDUCTION EVENTS

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We are working on defining ground motions from large plate boundary earthquakes at specified locations in the Wellington region in terms of response spectra and acceleration time histories. These motions should provide input for risk modelling, for a potential major earthquake additional to those associated with the active faults of the region.

Broadband waveforms will be modelled applying the hybrid technique combining deterministic and stochastic approaches. We follow the proposed recipe by Irikura et al. (2004) to predict strong ground motions. First we characterize the fault parameters using waveform inversion. Then, we define the source model of a future large earthquake by three parameters: outer, inner, and extra fault parameters. The outer fault parameters define the entire source area and seismic moment of the earthquake. The inner fault parameters are parameters characterizing fault heterogeneity inside the fault area. The extra fault parameters are related to the propagation pattern of the rupture.

We are presenting here results from the validation of Irikura's code and recipe using the strong motion dataset from the 2003 Fiordland earthquake.

Irikura, K., H. Miyake, T. Iwata, K. Kamae, H. Kawabe, and L. A. Dalguer (2004). Recipe for predicting strong ground motion from future large earthquake, Proceedings of the 13th World Conference on Earthquake Engineering, Paper No.1371.

ACTIVE DEFORMATION UNDER STATE HIGHWAY 1 NEAR WAIKANAE

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Adkin (1951) proposed that a major active fault, upthrown on the inland (eastern) side, ran along the back of the coastal plain between Paekakariki and Otaki. This possibility - first considered, at the suggestion of Ongley, by Oliver (1949) - was soon forgotten when Te Punga (1962) concluded that the 'fault-scarp' cliff resulted from marine erosion by the post-glacial sea. However Adkin's proposal still has some merit: here we provide stratigraphic, gravity and seismic evidence that a significant fault exists under SH1 just north of Waikanae township (Greenhill to Te Kowhai Roads). In this area Adkin (1951) inferred 75' of vertical offset since Otaki Sandstone time, Te Punga (1962) detailed the stratigraphy, and Fleming (1969) showed that the strata in the cliff face were gently anticlinally deformed.

Our most definitive geological data comes from a cross-section across State Highway 1 near Te Kowhai Road. Largely based on borehole logs, it was made as part of a 2003 groundwater resources investigation by Edwards and shows that the top of the greywacke basement falls rapidly away westwards, forming a now almost totally buried cliff that is at least 80 metres high. This cliff is inferred to be a fault scarp that has been episodically modified by marine erosion during past high-stand sea-levels. For the interval between the last interglacial and post-glacial sealevel high stands a vertical throw of about 0.20 m/kyr on the fault seems likely.

The geophysical data, mainly collected along Peka Peka and Hadfield Road, show a significant vertical offset (up to 500 m) in the basement underneath State Highway 1. Seismic reflection data suggest about 120 m offset of the shallow horizons 400 m east of the highway along Hadfield road. Furthermore, west of the highway a ~ 250-400 m deep trough of low (1-2 km/s) seismic P-wave velocity is identified. We interpret this trough of low velocity rock as representing a fault-generated depression now filled with fault pug, sand and some gravel.

Further young-looking faulting is seen subsurface between SH1 and the coast, although the age of these faults cannot be determined. We also note that faults may have influenced the location of the post-glacial seacliff elsewhere on the Kapiti Coast.

SUBSTRATE AND BIODIVERSITY MAPPING IN COOK STRAIT USING MULTISCALE ANALYSIS OF REMOTELY SENSED DATA

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We are developing a method to characterise seafloor substrate and habitat from bathymetry and backscatter data acquired in Cook Strait using a Kongsberg EM300 multibeam echosounder. Object-oriented classification techniques provide the means to characterise submarine habitats at multiple scales with the ability to quantify uncertainty in the resulting products. Because increases in the habitat variety is associated with species diversity, morphometric analyses have the potential to bridge the gap between geology and benthic habitats by providing quantitative information about their fine-scale interrelationships. In Cook Strait, a wealth of multibeam data are available, augmented by an extensive geological database (photos, sediment samples). This provides a unique opportunity to ground-truth and quantify the backscatter signal. Firstly, we utilize bathymetry to derive a quantitative classification of seafloor complexity by adapting morphometry theory developed by terrestrial ecologists. The resulting fuzzy classification maps are geo-referenced, high resolution, scale-independent, reproducible and have assigned levels of uncertainty. The results improve understanding of the degree and form of relationships between physical variables and benthic marine biota, and identify the best analysis methods to relate these variables to biological data. Many physical and biological processes acting on the seabed are highly correlated with bathymetric features, such as ridges and channels. These physical attributes can be key predictors of habitat suitability, community composition and species distribution and abundance. The methods improve insight into classification and related uncertainties of morphometric classification. Secondly, we use the acoustic backscatter strength, which is associated to grain size, surficial heterogeneity and small-scale topography, to provide information on substrate composition and roughness. Backscatter signal processing removes the modulation effects of recording equipment, large-scale topography and water column, thus providing a calibrated level of reflectivity. The processed data demonstrate the potential of quantitative backscatter signal analysis by emphasising topographic, geological and possibly biological features otherwise not recognised with conventional surveying. Backscatter image segmentation from colour, shape, smoothness, compactness and texture are applied at various scales. Grey Level Co-occurrence Matrix are integrated with segmented data to identify homogeneous regions in terms of acoustical response, which in turn enables us to map the distribution of marine habitats. The object-oriented technique generates measures and maps of the classification uncertainty and segmentation reliability. The results provide an improved understanding of the utility of different marine biophysical variables as surrogates for benthic habitats, and promote the use of spatial uncertainty techniques, at local and regional scale, to assess the application of the methods for biodiversity assessment.

A REVISION OF THE LATE HOLOCENE EARTHQUAKE RECORD AND RECURRENCE INTERVAL FOR THE WELLINGTON FAULT NEAR WELLINGTON CITY

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Research in 2006-08 as part of the 'It's Our Fault' program at three sites along the Wellington-Hutt Valley (W-HV) segment of the Wellington Fault has provided updated results on the timing of its four most recent surface faulting earthquakes and recurrence interval. At Te Kopahou near the South Coast, four rupture events have occurred during the last c. 2500 yr or more. The best estimates for the ages of the most recent faulting event (MRE), penultimate event (PE), Event III and Event IV there are <800, 800-1820, 1830-2340, and >2450 cal yr BP, respectively.

At the Te Marua site, a series of late Holocene alluvial terraces were trenched to provide additional age constraints on the last 3 earthquake ruptures and their relationship to individual earthquake displacements (see Little et al., this volume). Detrital charcoal samples from sandy alluvium in an unfaulted (T1) and a faulted (T2) terrace are used to constrain the age of the MRE there to >330 and < 446 cal yr BP. While the evidence for the PE displacement has been eroded from this site it is considered to be >676 cal yr BP (>AD 1177-1274), based on charcoal samples from T2 deposits. A third trench at Te Marua provided a minimum age of >1421 cal yr BP, for a terrace (T4) that has been displaced by 3 earthquakes..

Three trenches at a new site at the Kaitoke AgResearch Farm site occurs within c. 2 km of the Kaitoke stepover (the NE end f the W-HV segment) and is characterised by an uphill-facing scarp that cuts Stage 2 to late Holocene surfaces. In trench KAF-1, a thick alternating section of faulted peat and colluvium was exposed at the site of a former shutter ridge. Radiocarbon dates from within peat that bracket the MRE to <649, and the PE to a range of 555-896 cal yr BP for this event. Beneath this, the stratigraphic section is significantly older, but yields evidence for 5-6 earthquake ruptures between c. 7300-11,600 cal yr BP, yielding a maximum recurrence interval of c. 1000 yr here.

In summary, our new results confirm the previous work on the Wellington Fault, which showed that there have been 2 surface rupturing earthquakes in the last 1000 yr. The MRE has a bracketed age of 330-446 cal yr (AD1504-1620). The PE is well constrained from multiple sites to between c. 800-896 cal yr BP (AD 1054-1150). Events III and IV have the best age constraints from the Te Kopahou site (above). The late Holocene average recurrence interval derived from these 4 events has a minimum constraint of c. 610-710 yr, which compares well with previous results, and the Holocene maximum recurrence interval from trench KAF-1 is c. 1000 yr.

COASTAL UPLIFT MECHANISMS IN THE HIKURANGI MARGIN: OFFSHORE FAULTS OR THE SUBDUCTION INTERFACE?

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Flights of Holocene marine terraces have long been recognised along the eastern North Island coast in the Hikurangi Margin and have previously been attributed to coseismic uplift on offshore upper plate faults. More recently there has been a growing recognition of the potential for rupture of the Hikurangi subduction interface, which may also result in uplift of marine terraces. In this study we continue to explore these coastal uplift mechanisms by re-evaluating the Holocene marine terrace record at selected sites as well as extending the uplift record inland by examining Holocene fluvial terraces.

Our present work is focused on the southern (Wellington) portion of the Hikurangi Margin, where the interseismic coupling on the interface is currently the strongest. We present results from the Tora coastline (~30 km south of Martinborough), where we have mapped and surveyed Holocene marine terraces between Pukemuri Stream and the Awhea River mouth, and fluvial terraces along the lower Awhea River valley. Although the higher marine terraces are discontinuous, the surveying shows no along-coast tilt of the up to seven marine terraces along this 1 km stretch. In the lower Awhea River valley up to ten sets of fluvial terraces have been identified, which are generally difficult to correlate with the marine terraces. The exception is a prominent aggradation terrace (PgT) 12-15 m above river level, which consists of thick gravel and silt deposits containing buried trees, some in upright position. Two radiocarbon dates of ~9 ka from buried trees indicate PgT was formed by valley infill during the last stages of post-glacial sea level rise. Correlative terraces have also been identified elsewhere along the east coast, and at some sites can be demonstrated to grade to an early Holocene valley-infill estuary marine terrace.

A longitudinal profile for the PgT terrace along the lower Awhea River valley shows it has a gentle downstream gradient. This is similar to the PgT profile along the lower Waikari River valley (Hawke's Bay), but is in contrast to the correlative profile along the lower Pakarae River valley (north of Gisborne). In the lower Pakarae River valley, PgT is clearly backtilted, which is consistent with interpretations that the uplift mechanism is an offshore reverse fault situated close to shore. Thus in contrast, the gentle downstream gradient of PgT in the lower Waikari River and Awhea River valleys suggests a more regional-scale uplift mechanism, possibly a large reverse fault situated farther offshore, the subduction interface, or (for the Waikari River) aseismic subduction processes. This will be further tested by dislocation modelling and similar studies at sites further south.

SLIP DURING THE LAST FOUR WELLINGTON FAULT EARTHQUAKES NEAR WELLINGTON CITY, NEW ZEALAND

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Offset of a flight of closely spaced Holocene river terraces near Te Marua, Upper Hutt by the Wellington Fault provides a remarkable opportunity to quantify the magnitude of co-seismic strike-slip on that structure near Wellington City, to evaluate the variability of slip magnitudes during that fault's last four earthquakes, and to estimate a dextral-slip rate.

Microtopographical mapping (using rtk GPS and EDM theodolite) of 8 fault-displaced terraces within a ~15 m vertical distance the Hutt River at Te Marua have yielded a set of 12 dextral-slip offset measurements (and two others at Harcourt Park). The data seem to fall into groups. From youngest to oldest, the measured landform offsets are (in metres): 5.6 ±2.7, 5.0 ±2.4, 4.9 ±2.9, 5.6 ±1.5 (Group 1); 10.2 ±6.9 (Group 2); 13.9 ±1.6, 14.0 ±2.8 (Group 3); 20.0 ± 2.0, 19.5 ±8.5, 18.9 ±5.0; 19.0 ±2.1, 19.7 ±5.3, 21.8 ±4.1 (Group 4); and 30.3 ±9.8 (Group 5). The errors embrace our uncertainty in the projection of terrace risers and channels to the fault at a confidence level that we estimate to be ~2□. The average slip magnitude of the first four groups suggest a mean incremental (single-event) slip on this part of the Wellington Fault (averaged over the last four earthquakes) of 5.0 ± 0.2 m (2□). The same data indicate that the variability of individual single-event slips about this mean is ±0.9 m (1□Applying a wide range of possible rupture parameters and empirical scaling relationships, we estimate the magnitudes of these last four earthquakes on the Wellington Fault to have been M_w 7.4 - 7.6.

The most widely developed terrace at Te Marua to have experienced the four-event (Group 4) offset of ~20 m is T6. Sand deposited on the fluvial gravel of T6 yielded an Optically Stimulated Luminescence (OSL) age of 4.5 ± 0.44 ka (1 □), implying a dextral-slip rate of ~4.4 mm/yr. Whereas the 6 terraces higher than T6 yielded upwardly increasing OSL ages consistent with their known older ages (T12, a major aggradation terrace, yields ages of ~13 ka for silts both above and below its gravel tread); the terraces below T6 yield OSL ages that are heterogeneous and older than ~4.5 (up to ~21 ka). We infer that the sands and silts deposited on these lowest terraces (T1-T5) were incompletely bleached at the time of their deposition, and are yielding OSL ages that provide, at best, maximum constraints for deposition. For this reason, the above slip-rate estimate based on the OSL result for T6 is considered a minimum. On T3, a trenching-derived ^{14}C age provides a minimum age constraint of ~1400 cal yrs. B.P for that terrace. Together with the ~14 m offset of Group 3 (three events), this implies a maximum dextral-slip rate of ~9.5 mm/yr.

UPPER PLATE DEFORMATION AND ITS RELATIONSHIP TO THE UNDERLYING HIKURANGI SUBDUCTION INTERFACE - SOUTHERN NORTH ISLAND, NEW ZEALAND

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Plate motion at subduction margins is accommodated for by a combination of slip on the subduction interface and by deformation - uplift, subsidence, folding and faulting - in the upper plate. Geological studies along the Hikurangi margin in the North Island have shown that since the Pliocene, shortening across the onshore part of the upper plate has not exceeded ~20% of margin-normal plate motion. This implies a dominance of slip on the subduction interface and connected imbricate thrusts offshore. Previous investigations of global positioning system (GPS) data reveal that below the southernmost North Island, the subduction interface is currently locked. Historically there have been no large subduction earthquakes in this region.

While upper plate shortening has been quantified in the central North Island, it has not been measured across the southernmost North Island, where both convergent deformation and the degree of interplate coupling is inferred to be highest. It remains uncertain how the zone of interplate locking and coupling of the southern North Island may have varied in the past and how it may have affected rates of upper plate deformation, in particular uplift, in this region.

Focusing on a transect across the southernmost North Island, we are re-evaluating coastal uplift since the late Pleistocene (~80-125 ka) and the Holocene (~5-10 ka) by surveying and dating uplifted marine terraces and near-coastal fluvial terraces, and assessing the activity of surrounding upper plate faults. Marine terraces will be investigated at White Rock, Cape Palliser, Palliser Bay, Turakirae Head and Tongue Point, with reconnaissance fieldwork so far identifying several suitable sites with dateable material. Near-coastal fluvial terraces will be studied in Opouawe and Orongorongo River valleys, with up to six fluvial terraces identified in the lower Opouawe River valley. Material suitable for dating has been observed in the fluvial terraces, include tree stumps within silt deposits and charcoal within silt coverbeds. We are also undertaking new neotectonic mapping of the faults on either side of the Aorangi Ranges, as well as the terraces offset by the Wellington Fault at Emerald Hill.

With this research we aim to provide i) new ages and elevations of marine platforms and fluvial terraces from selected sites across the southern North Island; ii) improved constraints on the location and activity of major active faults; iii) a compilation of new and existing coastal uplift and active faulting data, to create a synthesis of active tectonism for the southern North Island; iv) possible finite element modelling of coastal uplift patterns to evaluate the most likely geodynamic processes responsible, including the possibility of subduction megathrust earthquakes.

TSUNAMI HAZARDS OF COOK STRAIT

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In 1855 a massive earthquake, of magnitude 8.2, ruptured the Wairarapa fault on the North Island of New Zealand. The fault extended into Cook Strait where it caused a tsunami with run ups of up to 10 metres at locations on the coast. Parts of the Miramar peninsula, at the time largely unoccupied but now a suburb of Wellington, were inundated by the wave.

The Wairarapa Fault is one of several faults that can potentially cause tsunami affecting the Cook Strait region and the city of Wellington in particular. Other potential sources include the Hikurangi subduction zone, the Wellington Fault, and other crustal faults within Cook Strait such as the BooBoo Fault.

We have developed rupture models for earthquakes on these four faults using the best available geological and geophysical data. Using the fault models as initial conditions, we have used Geoscience Australia's ANUGA code to simulate the subsequent tsunami. ANUGA allows the propagation and inundation of the tsunami to be modelled within a single unstructured mesh; one useful feature being the ability to easily incorporate the effect of co-seismic uplift on the inundated terrain. The Wairarapa Fault tsunami model is particularly useful as a reference case, as much is known about the 1855 earthquake and subsequent tsunami.

In the presentation we will describe our earthquake rupture models for events on the four faults, and the results of the ANUGA simulations. We will briefly discuss the implications for tsunami hazard in the Cook Strait region, and suggest areas where future research can better constrain the substantial uncertainties in the source models.

BETTER DEFINING THE EARTHQUAKE RISK IN WELLINGTON: RESULTS TO DATE & A LOOK TO THE FUTURE

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The overall goal of the "It's Our Fault" programme is to see Wellington positioned to become a more resilient city through a comprehensive study of the likelihood of large Wellington earthquakes, the size of these earthquakes, their effects and their impacts on humans and the built environment. The "It's Our Fault" programme is jointly funded by EQC, ACC & Wellington City Council, and comprises four main phases - Likelihood, Size, Effects and Impacts. Work to date has been focused within the first phase (Likelihood). This presentation will give an overview of Likelihood Phase, along with a brief summary of results to date, and an outline of the work plan for the Effects Phase. Several presentations in this session will cover in much more detail the make-up and exciting results of specific investigations within and related to the Likelihood Phase.

Over the 2008-09 financial year, the It's Our Fault Likelihood Phase will be wrapped up, and the Effects Phase will begin. The three main aspects of the Likelihood Phase are: 1) geological investigations to extend and further constrain the sequence of surface rupture earthquakes on the major Wellington region faults, and to better constrain their location and rate of movement; 2) GPS studies of the Wellington region to constrain the extent of the currently locked portion of subduction thrust under Wellington; 3) synthetic seismicity modelling of the Wellington region to investigate the stress interactions of the major faults, and to specifically assess the rupture statistics and interactions of the Wellington-Wairarapa fault-pair. The ultimate aim of this year's Likelihood Phase efforts is a definitive statement regarding the likelihood of rupture of the Wellington Fault.

The Effects Phase will run over the next three years with the underlying focus being better definition of earthquake ground shaking behaviour in Wellington City and the Hutt Valley. Specific tasks within the Effect Phase include: 1) geological and geotechnical characterisation of Lower Hutt and central Wellington; 2) seismic instrumentation of these two areas and inversion for physical parameters such as depth to effective bedrock and near-surface shear-wave velocity profiles; 3) characterization and simulation of subduction-interface earthquake motions; 4) probabilistic liquefaction assessment and topographic amplification effects; and 5) ground motion modelling, including comparison and integration of various ground motion estimation techniques over a range of shaking levels from weak to very strong (e.g. Wellington Fault rupture).

KINEMATIC MODEL OF THE TRANSITION FROM SUBDUCTION TO STRIKE-SLIP USING GPS AND ACTIVE FAULT DATA

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We present a kinematic model of the active tectonic transition from the North Island to the South Island, constrained by GPS velocities and onshore and offshore fault slip rate and location data. Such an endeavour has only recently become possible, due to the ongoing efforts to characterize the offshore faults in Cook Strait, as well as recently improved constraints on the behaviour of the onshore faults. Compilation of these active fault datasets is partially funded by the "It's Our Fault" project, which aims to better understand the sources of earthquake hazard in the Wellington region.

To interpret these data, we use an approach that inverts the kinematic data simultaneously for poles of rotation of tectonic blocks and the degree of interseismic coupling on faults in the region. We obtain an excellent fit to estimated offshore and onshore fault slip rates and slip vectors, and the geodetic data. Overall, our kinematic model requires a dominance of strike-slip faulting within Cook Strait (in agreement with recent offshore mapping results). Convergence related to the Hikurangi subduction margin becomes very low offshore of Marlborough, indicating that nearly all of the relative plate motion has been transferred onto faults in the upper plate in the northern South Island. This result has implications for assessing the subduction interface earthquake hazard beneath the northern South Island.

Our best-fitting kinematic model suggests that northeastern Marlborough may undergo rapid vertical axis rotation as a part of the rapidly rotating (3-4°/Myr) North Island forearc block, while tectonic blocks in central and southern Marlborough undergo negligible vertical axis rotation. This result agrees well with clockwise paleomagnetic declinations from ~4 Ma rock samples in the northeastern Marlborough region, and suggests that paleomagnetically-observed <4 Ma rotation of that region is continuing today. Interestingly, our best-fitting inversion for the poles of rotation between the more rapidly clockwise-rotating northeastern Marlborough blocks and the less rapidly rotating Marlborough blocks farther to the south places the poles of rotation near the western edge of the northeastern Marlborough blocks. Such a kinematic scenario is consistent with the structural mapping of that rotation boundary by Little and Roberts (1997), and with their suggestion (based on paleomagnetic data and bedrock structural orientations) that the boundary between these differentially rotating domains of Marlborough is acting as a hinge point or pivot for this vertical-axis rotation. The results of our study also highlight the remarkable consistency in the Marlborough region between datasets spanning decades (GPS), thousands of years (active fault data), and millions of years (paleomagnetic data and bedrock structure).

Little, T.A., Roberts, A.P. (1997). J.G.R - B: Solid Earth, 102 (B9), pp. 20447-20468.

IN SEARCH OF EVIDENCE FOR SUBDUCTION EARTHQUAKE-RELATED TECTONIC SUBSIDENCE AT BIG LAGOON, BLENHIEM

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A large earthquake on the subduction interface beneath Wellington is potentially one of the greatest hazards for the region with not only strong shaking possible but also subsidence, uplift and tsunami inundation of coastal areas. One of the main techniques for detecting evidence of past large subduction interface earthquakes is to document the sudden (coseismic) vertical deformation that occurs in such earthquakes. Where this vertical deformation occurs at the coast there can be significant changes to coastal waterbodies as the relative sea level rises or falls; such changes may be preserved in the geologic record. As part of the Past Subduction Zone Rupture task of the It's Our Fault project we have investigated three locations in the Wellington region: Pauatahanui Inlet, southeastern Lake Wairarapa and Big Lagoon. We have found that the Holocene stratigraphy of Big Lagoon has the greatest potential to yield a subduction earthquake record.

Four cores have been obtained from the margins of Big Lagoon; the cores reach depths of 6 - 10 m and contain a mixture of silts, sands and gravels. Faunal and floral assemblages enable reconstruction of the Big Lagoon paleoenvironments through time and constrain estimates of past relative sea levels. Marine inundation of the former alluvial plain environment of Big Lagoon occurred at c. 8.5 ka. The basin gradually infilled under the rising and stabilising eustatic sea level trend and the paleoenvironments show a general transition from subtidal to intertidal to high tidal. Within the topsoil of two cores there is evidence of probable coseismic subsidence related to the 1855 or 1848 historical earthquakes.

The elevation of the radiocarbon samples obtained from the Big Lagoon cores indicates that tectonic subsidence has occurred during the Holocene in the lower Wairau Valley. All the radiocarbon samples that post date eustatic SL stabilisation (c. 7ka) are presently at a lower elevation than that at which they were deposited with respect to sea level. At the Big Lagoon locality we expect the signal of a subduction zone earthquake to be sudden land subsidence; this would translate to a paleoenvironmental signal of a sharp rise in relative SL. Sharp rises in relative SL are not seen in the Big Lagoon cores collected to date, despite the evidence of tectonic subsidence. We infer two possible interpretations regarding tectonic signals at Big Lagoon: (1) tectonic subsidence of Big Lagoon has occurred gradually and at slower rates than sediment infilling thus we never see a relative SL rise; (2) tectonic subsidence of Big Lagoon, by events on upper plate faults or the subduction interface, has occurred coseismically but our core locations did not capture the sensitive and spatially-restricted paleoenvironments required to record such changes. At present we cannot definitively distinguish between these two interpretations but already some constraints on the maximum size of a subduction earthquake can be made and we will to return to the area this field season to continue the study.

SYMPOSIUM: GEOPHYSICS

GEOPHYSICS AND TECTONICS

Monday 24th November

Rangimarie 1

Geophysics 1: 13:30 – 15:00

Tuesday 25th November

Soundings Theatre

Geophysics 2: 9:00 – 10:30
Geophysics 3: 11:00 – 12:30
Geophysics 4: 13:30 – 15:00

Plenary: Tuesday 15:00 (Soundings Theatre)

Posters: Monday 15:30 – 17:00 (Oceania)

SEISMIC INVESTIGATION OF THE LOUISVILLE SEAMOUNT RIDGE

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The Louisville Ridge is a 4000 km long chain of hotspot seamounts that trends north-northwest, approximately 800 km northeast of the North Island (Ballance et al. 1989). Towards the west, this ridge subducts beneath the Tonga-Kermadec Trench – an erosive convergent margin. Seismic line LOUDC1 was collected by GNS Science along the Louisville Ridge during 2000-2001 as part of the continental shelf programme. Magnetic data (incomplete due to sea conditions) and gravity data were also collected to complement the reflection seismic data. The seismic data were collected using a six sub array airgun source and a 6000 m long steamer with 480 channels and a group spacing of 12.5 m.

The purpose of this study was to improve the interpretation of the seismic line by reprocessing part of this line adjacent to the trench using GLOBE Claritas. Earlier studies within this area have partially constrained geological features, but most of the work was based on multibeam studies (e.g. Wright et al. 2000) that do not provide the depth control of multi-channel seismic data. Velocity analysis has involved combining stacking velocity methods for shallow reflections with deeper crustal models published elsewhere (e.g. Java Trench) and geology from drill cores or dredging.

The major features interpreted in the data are sedimentary basins and seamounts – some, which have been extensively eroded to become guyots. A notable feature underneath the seamounts is a “crustal swell” that has been mentioned by other authors (Balance et al. 1989). This swell, which is possibly due to flexure, has an amplitude of ~1.5 km and has a reasonably long wavelength (~100 km) that continues along the length of the line. The only place where it is not noticeable is in the immediate vicinity of the Tonga Trench. It is anticipated that the subduction of seamounts will have a profound geological effect. It is assumed at this margin that the seamounts are subducting as a whole as there is no evidence of slumping or landslides in the seismic record that would be present if such events had occurred. However, the only subducted seamount that is obvious in the seismic data is around 1/8 the size of Osbourn seamount, which lies immediately to the east. Therefore, when the Osbourn seamount is subducted its size may require it to be broken up.

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STRUCTURAL GLACIOLOGY AND GROUND PENETRATING RADAR SURVEY OF FOX GLACIER

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Fox Glacier is located in the South Westland region of New Zealand's South Island, and from the neve at ~3000 m altitude, the glacier descends for 13 km, terminating at an altitude of ~270 m in temperate rainforest, 17 km from the present coastline. The steep gradient allows for rapid ice flow and a short response time (~6-9 years). Despite being a very dynamic glacier, very little research has been carried out on Fox Glacier in recent years with most research in the area being concentrated on neighbouring Franz Josef Glacier. Deformation in glaciers occurs as a result of gravity-driven flow of ice by creep. Superimposed on the deformation fields, fixed in space by the three-dimensional geometry of the glacier, are the dynamic deformation effects of strain caused by variations in basal sliding rates at various timescales. Although structural features such as folds, faults, crevasse traces, foliation and ogives are commonly described on glaciers, the origin and significance of many of these structures remains unclear. Recently, attempts have been made to relate such features to cumulative (or finite) strain-rate in ice. In glaciers, strain-rates may be used to determine stresses (via Glen's flow law for ice), and attempts have been made to link strain-rate tensors to the development of foliation and crevasses. We mapped surface structures on Fox Glacier using remote sensing in the form of aerial photographs, and field observations, to produce a structural glaciological interpretation of the glacier surface. In general longitudinal compressive strain occurs throughout much of the ablation area, with local deformation effects such as transverse crevassing resulting from increased bed gradient over ice falls.

In addition, cumulative strain and strain rates were calculated for three different areas of Fox Glacier and possible relationships between observed structures and measured strain rates were explored. There is a high degree of spatial variability in the structural formations observed and the cumulative strain and strain rates measured. Variations may be linked to valley topography including long-profile gradient and valley width. Strain rates of 208.8 a^{-1} and -162.1 a^{-1} were recorded on the glacier, though we caution that this study gives only a 'snap-shot' of the strain-rate conditions, as the study was conducted during the highly dynamic summer ablation season, and annually-averaged results would be much lower. Ground penetrating radar (GPR) profiles were undertaken using 25 MHz and 50 MHz antennae at Victoria Flat, above the first ice fall. Both surveys recorded multitudes of englacial reflectors, the majority of these interpreted as meltwater present among structural discontinuities. A strong basal reflector was also determined, indicating a depth-to-bedrock of ~150 m at Victoria Flat.

A VELOCITY MODEL FOR AUCKLAND; USING SEISMIC AND COMPLEMENTARY METHODS

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Auckland City is built on and around the potentially active Auckland Volcanic Field (AVF). This field has been active for over 200 000 years with the most recent volcanic eruption occurring only 600-800 years ago forming the island of Rangitoto. The warning time for a future AVF eruption is ill-constrained, and there may be as little as a few days to weeks between the onset of detectable precursory earthquakes and the eruption itself. An effective monitoring system and a sound understanding of the crust and magmatic system are therefore essential to mitigate the effects of a possible future eruption. Despite this, of the 24 earthquakes recorded originating in the Auckland region between 1995 and 2005, only ten have been located reasonably reliably (an uncertainty of position and depth ≤10 km). This was mostly due to the large amount of urban noise drowning out the signal from these relatively low magnitude earthquakes, but also in part due to the accuracy of the velocity model used. Given that little detail is known about the crust of the Auckland region, the velocity model currently used to locate earthquakes in Auckland is a regional model used for most of New Zealand.

The major components of the Auckland shallow crust are Permian to Cretaceous greywacke basement, overlain by Early Miocene Waitakere volcanics and Miocene Waitamata sediments. In the central part of Auckland these are intruded and capped by the Quaternary basalts of the AVF. Very little is known about the lower crust; however, the total crustal thickness in the region is thought to be ~30 km.

We have used refraction data and direct measurements of rock properties to look at the shallow crust, combined with a petrographic study of xenoliths from the St. Heliers volcano to look at the lower crust, with the aim of working towards a local velocity model for the area. The refraction surveys used quarry blasting as the source and incorporated at least 20 surface seismographs. Urban noise and poorly compacted young (Miocene) sediments hampered the refraction survey with compression (P) waves not being recorded at distances greater than 16 km. Results from our refraction survey, augmented by records of the quarry blasts on GeoNet's Auckland permanent seismographs and direct rock properties using a Pundit tester and density logs offer preliminary velocities of 2.70 km/s to 6.20 km/s for the upper 15 km of the crust beneath Auckland.

GEOMETRY OF THE HIKURANGI SUBDUCTION THRUST AND UPPER PLATE, NORTH ISLAND, NEW ZEALAND

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We use 2800 line km of seismic-reflection data to map the offshore character and three-dimensional geometry of the Hikurangi subduction thrust and outer forearc wedge to depths of c. 15 km. Several first order subduction characteristics (e.g., convergence rate, apparent plate locking, margin morphology) vary systematically over relatively short along-strike distances on the Hikurangi margin, making it an excellent natural laboratory for studying subduction tectonics and assessing the significance of variations in subduction thrust geometry. For 200 km along-strike south of Hawke Bay, the subduction thrust is relatively smooth, dips less than 8 degrees, and the wedge is characterised by accretion of young sediment and topographic slopes of less than 3 degrees. In Hawke Bay and north for 200 km, a kink in the subduction thrust is apparent, with a down-dip increase in dip to angles greater than 8 degrees at depths of 10-15 km; there is a corresponding steepening of the topographic slope to greater than 3 degrees outboard of the kink and the wedge is characterised by lithified sedimentary rock and slope failure. We suggest that the kink in the subduction thrust is caused by a combination of a northward change in subducting lithosphere chemistry and subduction rate that, in turn, controls fluid release rates and intra-slab deformation patterns. The subduction thrust geometry, in combination with a northward increase in subducting plate roughness and decrease in sediment cover, causes the observed spatial change in character of the subduction thrust and forearc wedge.

CRUSTAL STRUCTURE BETWEEN THE RAUKUMARA BASIN AND RAUKUMARA PENINSULA, NORTHEASTERN NEW ZEALAND

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Forward models of seismic refraction data imply a northward increase in depth of c. 12 km to the base of Raukumara Basin, and a reduction in depth to the base of the crust from c.35 km beneath Raukumara Peninsula to c. 18 km beneath Raukumara Basin. We record a clear arrival from the mantle wedge with model velocities of 8.0-8.2 km/s. A westward and northward migration of Neogene sedimentary depocentres is interpreted from seismic-reflection data and is inferred to track the growth of East Cape Ridge and Raukumara Peninsula, respectively. The zone of highest topography and greatest uplift is farther from the trench at Raukumara Peninsula than East Cape Ridge. We note a spatial correlation between the locus of maximum uplift and the intersection between the base of the crust and the subduction thrust. We propose that crustal thickness plays a key role in modulating where crustal underplating can occur. Specifically, the density contrast between subducted sedimentary or crustal material is inferred to provide sufficient buoyancy for it to escape from the subduction channel near the base of the crust. This mechanism of uplift provides a viable explanation for the difference in distance between the trench and ridge crest between the Raukumara Peninsula and the East Cape ridge, and may also explain the morphology of the trench slope and the eastern margin of Raukumara Basin. As material is accreted to the base of the upper plate its thickness increases, causing uplift, over-steepening and collapse of the trench slope, and a westward migration of the locus of uplift occurs as the total volume of the forearc wedge increases and the intersection between the Moho and subduction thrust migrates away from the trench.

NEW ZEALAND SURFACE WAVE VELOCITY MAPS AND S-VELOCITY PROFILES FROM AMBIENT SEISMIC NOISE CORRELATION

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Continuously recorded seismograms predominantly contain ambient seismic noise. While earthquake waves depict only a constrained part of the earth's interior between the hypocenter and the seismometer, seismic noise originates from a multitude of sources and in principle contains information about many different ray paths in the crust and upper mantle. Under certain conditions, cross-correlating long intervals of seismic noise between two stations has been shown to yield an estimate of the Green's function between the station pair.

By focusing on the surface waves as the most energetic part of the Green's function, Lin et al. were able to measure Rayleigh wave dispersion curves between more than 300 different station pairs in New Zealand. The results were used in a tomographic inversion to obtain lateral Rayleigh wave group-velocity distributions at a number of central frequencies.

Path coverage is the main factor limiting the resolution of surface wave tomography. In the case of ambient noise tomography, path coverage is determined by the number and spatial distribution of possible station pairs. We extend Lin et al.'s study by increasing the number of stations and extending the timespan of the dataset. In particular, we incorporate data acquired during several temporary deployments including CNIPSE (34 stations; 6 months), SAPSE (30 stations; 14 months), NORD (5 stations, 8 months) and Marlborough (7 stations; 6 months) and data from newly operational permanent stations (47 vs. 42 used by Lin et al.).

We compute Rayleigh and Love wave dispersion curves, and then estimate lateral group velocity variations and S-velocity versus depth profiles. The latter is done by using the neighbourhood algorithm, a direct search method that enables us to estimate posterior uncertainties for model parameters from variations in the dispersion curves.

SEISMIC REFLECTION CHARACTER OF THE HIKURANGI SUBDUCTION INTERFACE, NEW ZEALAND, IN THE REGION OF REPEATED GISBORNE SLOW SLIP EVENTS

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Changes in reflection character and geometry of the Hikurangi subduction interface offshore the east coast of North Island, New Zealand, observed in deep (8-12 s twt) 2D prestack time migrated seismic reflection data may relate to changing seismogenic properties and can potentially help define locations of slow slip.

Slow slip events have been recorded on the Hikurangi subduction interface in the Gisborne area, every two years since the installation of continuous Global Positioning System (CGPS) instruments in 2002. Preliminary inversion of CGPS displacements suggest the slow slip occurs on the subduction interface with a down-dip limit of 15 km, however, the other dimensions of the slow sliding segment are poorly constrained.

The subduction interface offshore Gisborne includes subducting seamount asperities (capable of building up seismic stress) coupled with fluid-rich subduction erosion material (increased pore-pressures promote more stable slip) and may potentially provide an explanation why slow slip is constrained within this area. Margin perpendicular profiles image the subduction interface beneath the minor accretionary wedge and outer arc high as a narrow band of reflectivity overlying a subducting seamount on the down-going plate. Landward of the subducting seamount the subduction interface is defined as the top-most reflector of a 1 s wide band of high amplitude reflectivity which terminates up-dip against the seamount. This seismic character terminates down-dip when the subduction interface steps down to a lower level of 15 km at a distance of ~20 km from the shoreline, coincident with the CGPS constrained down-dip limit of slow slip. The step-up in decollement level and introduction of a wedge of high amplitude reflections on the down-going plate is likely to be related to the accumulation of fluid-rich material that has been eroded from the accretionary wedge and/or overlying plate due to seamount subduction. The mapped region of the subduction interface with this reflection character is interpreted to potentially facilitate slow slip and has been inverted with the CGPS displacements for slow slip events in 2002, 2004 and 2006 to model the amount of slip on this surface during each event.

DEEP REFLECTORS AND THE CRUST - MANTLE BOUNDARY UNDER THE CENTRAL TAUPO VOLCANIC ZONE

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Seismic studies of the central North Island have consistently shown the Taupo Volcanic Zone to be a region of attenuated continental crust above a mantle with anomalously slow seismic wave speeds (~7.4 $km.s^{-1}$). However, the depth to the Moho and composition of material between 20-30 km depth remain somewhat contentious, with some workers suggesting these are mantle rocks upwelling to a shallow Moho transition zone (e.g. Stratford & Stern, 2004), whereas others advocate a model of voluminous underplating and place the continental at 30 km depth (e.g. Harrison & White, 2004). The NIGHT (2000-2001) and MORC (2005) active source seismic experiments detected two sets of unusually reflections form interfaces at ~20 and ~30 km (hereafter PmP_1 and PmP_2 respectively), which effectively bound this interval. An understanding of the changes in physical properties across these associated with these reflectors will perhaps allow us to resolve whether this 10km thick interval is represents thinning of or accretion to the continental crust. Tomographic and ray-tracing models of the MORC /NIGHT data indicate that the PmP_1 reflector extends across the TVZ, while the reflector 30 km reflector is constrained to be an isolated body located directly below the axis of the TVZ. The amplitude of observed PmP_2 arrivals varies significantly with offset (avo). PmP_2 is not observed at source-receiver offsets < 40 km, whereas at offsets > 70km PmP_2 are up to 10 times stronger than PmP_1 and Pg arrivals. Synthetic waveform modelling of the relative avo properties of PmP_2 and PmP_1 indicate that the unusually bright PmP_2 amplitudes can only be produced by an interface with a positive Vp contrasts > 1.5 km/sec (i.e. decrease in temperature) or a drop in Vs to <0.5 km/sec (i.e. an increase in fluid content/partial melt). The limited extent and implied large change in physical properties across the interface suggest that the PmP_2 reflector is not the continental Moho as such. We suggest that the reflector is a body of increased partial melt accumulated within the upper mantle or perhaps at the base of an otherwise unreflective Moho.

Harrison, A. J. & White, R. S. 2004, Crustal structure of the Taupo volcanic zone, New Zealand; stretching and igneous intrusion Geophysical Research Letters, 31
Stratford, W. & Stern, T., 2004, Strong seismic reflections and melts in the mantle of a continental back-arc basin Geophysical Research Letters, 2004, 31, 6622-6627.

MONITORING EARTHQUAKES IN NEW ZEALAND: THE EXPANSION OF GEONET'S SEISMIC NETWORKS

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New Zealand's seismograph networks are continuing to expand as the GeoNet project enters its eighth year. The seismic monitoring networks include the New Zealand National Seismograph Network (NZNSN), the Strong Motion Network, and regional networks above the Hikurangi subduction zone and near volcanic centres. In addition, many seismographs are co-located with or located in close proximity to continuous GPS stations. The NZNSN provides a backbone of broadband seismometers and strong motion accelerometers at ~100 km spacing throughout the country. The Strong Motion Network provides additional strong motion instruments throughout densely populated areas and regional seismograph stations, equipped with short period seismometers, supplement the network coverage even further.

With the installation of the Strong Motion Network finished and the National Seismograph Network nearing completion, a major focus of the GeoNet Project's network development is now the expansion of these regional seismic networks – ultimately working towards a target station spacing of 30 km in the area overlying the Hikurangi Subduction Zone. A major project has also been the extension of network coverage to include our outlying islands – seismic, GPS and tsunami sites are now operational on Chatham Island, and the same is due to be completed on Raoul Island, in the Kermadecs, by the end of December.

The seismic data collected from these networks enables real-time earthquake location, has utility in modelling earthquake hazards, and will inevitably enhance our understanding of New Zealand tectonics, aiding disaster resilience and response. Last year, 'ShakeNZ' was launched on the GeoNet homepage – an application that uses the live incoming data from seismographs to reflect the intensity of earthquake shaking each instrument is currently recording. The utility displays the Modified Mercalli Intensity (MMI) of shaking experienced at stations across New Zealand, allowing quick estimations to be made of the likely location and impact of an earthquake within seconds of it occurring. The website also displays a selection of live seismic drums, information about recent earthquakes and the option for users to submit 'felt reports' describing earthquakes they have felt. All earthquake data collected by GeoNet is freely available for public research via the GeoNet website, www.geonet.org.nz.

SURFACE EXPRESSION OF MANTLE SHORTENING AT AN ACTIVE CONTINENTAL MARGIN

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We use teleseismic P-wave advances to show the mantle lithosphere has thickened beneath the central South Island of New Zealand. About 100 km of shortening has been absorbed within the South Island in the last 10 Myr or so. A 3D ray tracing model is implemented to model teleseismic rays from a variety of azimuths. Our best fitting shape for the thickened mantle is for a sub-vertical, near symmetric body directly beneath the crustal root of the Southern Alps. Dimensions of the body are 125 km thick and ~100 km wide, the centre around 110 km deep and an average Vp contrast with the regular mantle of ~0.6 km/s. The surface response to this is a mountain range that is suppressed in its elevation; a mean 1600 m elevation yet a crustal root about 17 km thick. A further measure of the imbalance comes from a pervasive negative isostatic gravity anomaly of about –30 mgals.

In central and western North Island a similar amount (70–100 km) of shortening occurred in from late Oligocene to late Miocene times. Evidence for shortening comes from a Miocene fold and thrust belt with associated foreland basin. Subsidence curves from the basin provide an estimate of total shortening. At 5 Ma compression ceased and the region underwent a regional (400 km in extent) and rapid (few Myr) rock uplift of 2.5 km (or surface uplift of about 1100 m). Widespread volcanism followed thereafter. Today there is evidence that the mantle lithosphere has gone from much of the central and western North Island. Isostatic gravity anomalies are in the +20–60 mgal range.

We interpret both negative and positive dynamic topographies of the South and North Island as, respectively, an early and late response to the same process. i.e. uniform thickening, then rapid release of mantle lithosphere in the early stages of a developing continental margin.

3-D TOMOGRAPHIC IMAGING OF THE ALPINE FAULT, CENTRAL WESTLAND, NEW ZEALAND

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The Alpine fault in the South Island of New Zealand is a 500 km long oblique-transform fault lying in the plate boundary zone between the Australian plate to the west and the Pacific one to the east. The central portion of the fault displays the paradoxical ambiguity of having the highest uplift rate along the fault and yet having relatively muted seismicity. In this study we undertake a detailed crust and upper mantle 3D tomographic study in the ~ 60 km long section between the Karangarua and Whataroa rivers.

In 1995 a detailed seismic exploration programme (SIGHT) collected data from the central section of the Alpine fault. Offshore shots from an 8000 cu inch air gun array were recorded by a total of about 200 seismographs deployed on two parallel lines across the central South Island. About 20 offshore ocean bottom seismographs also recorded the air gun shots. 23 chemical explosions were recorded on land by about 800 seismographs. These data provide an unprecedented chance to image the mid section of the Alpine fault in 3D. Individual shot gathers show rich sets of reflections and phases including reflected phases from depths as large as 80 km. In particular the cross-line shot to receiver geometries reveal some of the best data.

Previous work has involved classical 2D interpretations, and a regional 3D tomography using earthquakes and first-arrival shot data. Here we focusing on a 3D interpretation of crustal - mantle structure in the region between the two lines with a tomographic inversion that uses both first arrivals and reflection phases. We use a new method of seismic travel time tomography, implementing the Fast Marching Method (Sethian and Popovici 1999), developed by Nick Rawlinson and Malcolm Sambridge at Australian National University in Canberra (ANU).

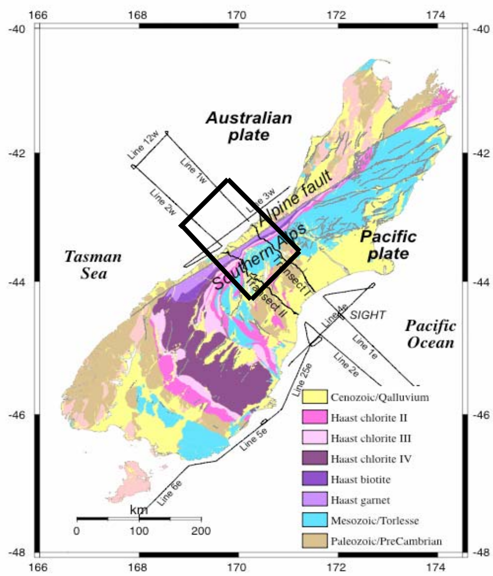

Plate CC:
geology / SIGHT location lines.

INVESTIGATION OF THE SPATIAL AND TEMPORAL CHARACTERISTICS OF THE NEW ZEALAND SEISMIC NOISE FIELD

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The use of seismic interferometry methods (estimation of the Green's function between station pairs by cross-correlation of seismic noise) to construct tomographic models of New Zealand requires an understanding of the spatial and temporal characteristics of the ambient seismic noise field. A prior study (Lin *et al*. 2007) of the azimuthal distribution of the ambient noise field considered a year-long average of the signal to noise ratio of the cross-correlation peaks at positive and negative time lags for station pairs from 42 seismic stations. The results of the study showed directional variations in noise levels that are compatible with measured differences in average sea state.

The aims of the current study are to quantify spatial and temporal (seasonal) variations in the seismic noise field in conjunction with an oceanic wave state model. This involves the analysis of a larger data set over a longer time period, and requires more sophisticated processing of GeoNet data than undertaken by Lin *et al*. A preliminary analysis of differences between the New Zealand environment and other environments in which the azimuthal distribution of seismic noise sources has been investigated using beamforming, is presented. The applicability of using frequency domain beamforming and triangularisation to analyse data from sub-arrays in New Zealand is then discussed. Methods by which estimates of the seismic noise field spatio-temporal characteristics can be related to contemporaneous oceanographic observations of the wave climate are also highlighted.

STRAIN LOCALISATION AND DUCTILE SHEAR ZONES: IMPLICATIONS OF MAGNETOTELLURIC RESULTS FROM THE MARLBOROUGH FAULT SYSTEM, NEW ZEALAND

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In actively deforming regions, shear strain in the ductile region of the crust should promote the electrical interconnection of any fluid present. Thus, actively deforming ductile-shear-zones that contain even small amounts of fluid should be significantly more conductive than their surroundings. A line of 72 magnetotelluric (MT) soundings made at ~3 km intervals across the northern part of New Zealand's South Island provide a test of this idea. This line crosses the Marlborough Fault System, a system of four major strike-slip faults (the Wairau, Awatere, Clarence and Hope faults) that accommodate the shear component of motion between the Australian and Pacific plates. Two-dimensional modelling of the MT data show localised zones of high conductance in the ductile part of the crust at the down-dip projection of the Awatere and Clarence Faults. Similar localised conductive zones also occur in the ductile crust adjacent to the near vertical Wairau and Hope Faults. The apparent correlation between the mid-crustal conductive zones and the strike-slip faults in Marlborough support the view that conductive zones observed in regions of active strike-slip faulting mark localised zones of high ductile-shear-strain.

TECTONIC RECONSTRUCTIONS OF NEW ZEALAND, AUSTRALIA AND ANTARCTICA SINCE LATE CRETACEOUS

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The region between New Zealand, Australia and Antarctica plays a key role in global tectonic reconstructions. Despite many studies since 1960, its detailed evolution has yet to be defined.

Using reinterpreted magnetic profiles, bathymetric and gravity data in the Southwest Pacific Ocean, the Tasman Sea and the Indian Ocean South of Australia, we will make new tectonic reconstructions and reconsider the plate boundary evolution south of New Zealand for times older than the Hawaii-Emperor bend (40-85Ma). Reinterpretations of magnetic profiles available from the Southwest Pacific are presented in this poster.

SEISMIC REFRACTION STUDIES ACROSS PIGROOT CREEK, NORTH OTAGO: SEARCHING FOR THE WAIHEMO FAULT

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The Waihemo Fault System in North Otago is a complex system, which extends from Shag Point (and perhaps further offshore), to Kyeburn Diggings in the NW. Here it is offset by the Dansey Pass Fault, and appears to continue in a NW trend, where eventually it merges with the Hawkdun Fault system. Cretaceous sediments in the hanging wall indicate a sense of normal movement. However, the fault is currently accepted as being a reverse fault, with the reactivation of the structure occurring in the late Cenozoic. Some lateral displacement may also have occurred. However, this cannot, as of yet, be quantified. The timing and history of the reactivation of the fault – and complexities of the structure – are investigated in my work.

The fault is only partly exposed, making direct measurement of displacement difficult. Geophysical techniques such as gravity and seismic analysis may give an indication to the structure of the Waihemo fault at depth. At Pigroot Creek (45.189°S, 170.426°E) the fault is exposed, and it is here that the first seismic survey was carried out. The data were recorded using the University of Otago’s 48-channel seismic system, 2 RAS-24 seismometers, a hammer source, Mark Product geophones and a SERCEL cable system. GPS data were collected simultaneously. Seismic processing was done using GLOBE Claritas analysis software.

Offshore data were also collected using the University of Otago's RV Polaris, a Ferranti 5210A high-resolution Boomer source, and Teledyne-Benthos C3D (side-scan bathymetry)/ CHIRP (sub-bottom profiling) equipment.

Preliminary results of seismic refraction analysis, and offshore interpretation are presented. If sufficient information can be gathered using these techniques, the process will be repeated at numerous other locations across the Waihemo Fault, including further offshore acquisition. This may give an indication to the structure of the fault which cannot be gathered from geological observations alone.

MANTLE WEDGE SEISMICITY UNDER THE WESTERN MARGIN OF THE RAUKUMARA PENINSULA, NORTHEAST NORTH ISLAND

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Crustal seismic reflection data across the eastern Bay of Plenty and Raukumara Peninsula margin image an intriguing localised zone of strong reflectivity at a depth of about 35 - 40 km (12 – 16 s twt), that coincides with a local increase in seismicity. The zone lies within the mantle wedge as Moho is clearly imaged on the seismic reflection data and the top of the subducting slab is clearly defined by seismicity. The distribution of seismicity within the region shows the occurrence of two similar local seismicity hot spots in the mantle wedge, about 60 km to the northeast and to the southwest of the original zone, sub-parallel to the plate boundary strike. The hotspots lie 40 km east of the eastern margin of the Taupo Volcanic Zone (TVZ) in the south and about 25 km east in the north. The southern hotspot lies approximately across strike from the andesite/rhyolite change in the TVZ. In 3D the zone of seismicity forms a narrow column, about 10 - 15 km in diameter, in the mantle wedge from the subducted plate at 50 km to about 30 km depth. The strong reflectivity suggests a partial melt or fluid origin, but the subducted plate is too shallow here for normal back-arc melt generation. Possible causes of the hotspots include fluids originating from dewatering of the subducted Hikurangi plateau, and processes associated with the future phases of crustal ablation along the eastern margin of the TVZ.

BASEMENT EVOLUTION IN THE BOUNTY TROUGH – GREAT SOUTH BASIN REGION BETWEEN GONDWANA SUBDUCTION CESSATION AND NEW ZEALAND-ANTARCTICA SEAFLOOR SPREADING

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The basement grain of the Paleozoic-Mesozoic rocks within the southern South Island, New Zealand extends SE-NW parallel to the fossil Gondwana convergent margin. Terrane displacement, offsets of magnetic domains and basement alignments are interpreted in terms of NE oriented transform faults within this accretionary margin.

Gravity modelling across the South Island shelf break highlights crustal thinning of c. 30-50% within a c. 20-40 km band which extends c. 600 km NE-SW. Such a linear zone of crustal thinning is interpreted as being controlled by pre-existing NE transform faults, similar to those producing offsets observed in the northern Chatham Rise and within the central Bounty Trough. This latter motion is interpreted as having occurred consequent to jamming of the north Chatham Rise Gondwana convergent margin by entry of the Hikurangi Plateau into the margin at c. 100 Ma. A change to NW-SE extension at c. 96 Ma led to transform and extensional faulting within the New Zealand sector of Gondwana, almost orthogonal to earlier extension.

POST-SEISMIC DEFORMATION OF THE FIORDLAND 2003 EARTHQUAKE — YES, NO OR MAYBE

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The Secretary Island earthquake (21st August 2003) in Fiordland, was the largest earthquake ($M_W = 7.2$) in New Zealand for 35 years. Immediately following the rupture, GPS equipment deployed at eleven sites in the region enabled the measurement of the co-seismic surface displacement. This established that the maximum horizontal and vertical displacements were in the order of 20cm and enabled dislocation modelling of the slip plane.

Although the immediate effect of any major earthquake results in co-seismic deformation, the post-seismic deformation is of interest in understanding the visco-elastic response of the earth after an earthquake event. To provide insight into this, GNS science and Otago University have re-occupied sites in the Fiordland block for a total of six campaigns at approximately 1 year intervals. Ideally monitoring should be with Continuous GPS (CGPS), but owing to the remoteness and difficult terrain, it has only been possible to carry out periodic campaign style GPS occupations. We present an analysis of the post-seismic deformation and compare the observed station velocities with the National Deformation Model.

LITHOSPHERIC SHORTENING AND DUCTILE DEFORMATION IN A BACK-ARC SETTING: SOUTH WANGANUI BASIN

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South Wanganui Basin, New Zealand, is located behind the southern end of the Hikurangi subduction system. One of the strongest geophysical characteristics of the basin is the -150 mGal Bouguer/isostatic gravity anomaly. Sediment fill can only partly explain this anomaly. 3-D gravity models show that the gravity anomaly associated with the basin is generally consistent with a downwarp model of the entire crust. However, the downwarp of the Moho has to be 3-4 times larger than the downwarp of the sediment-basement interface to fit the observed gravity anomaly. Hence, a model of lithospheric shortening where ductile thickening of the crust increases with depth is proposed.

Finite element modelling demonstrates that the crust, in order to produce the ductile downwarp as predicted, is best modelled with at least two distinct different layers. The model requires the top 15-20 km of the crust to behave purely elastic and the lower part to be viscoelastic with a viscosity of 10^{21} Pa s. The existence of this ductile lower continental crust can be explained due to fluids released from the subducting slab accumulating in the lower crust. This is supported by receiver function analysis results. These results propose a 10±2 km thick low S-wave velocity layer in the lower crust.

The vertical loading necessary to create the basin are high (up to 200 MPa) and are difficult to explain by slab pull forces transmitted via a strongly coupled subduction interface. An additional driving mechanism proposed is a thickened mantle lithosphere inducing normal forces on the base of the crust. However, the driving mechanism of the basin is still not fully resolved.

Receiver function analysis shows that the crust of the subducting Pacific plate underneath the mainland in the lower North Island is abnormally thick (~10 km) for oceanic crust. This matches with results from the 3-D gravity modelling.

A NUMERICAL INVESTIGATION OF FACTORS CONTROLLING THE DEPTH OF INTERSEISMIC COUPLING ON THE HIKURANGI SUBDUCTION INTERFACE, NEW ZEALAND

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The Hikurangi subduction margin, East Coast North Island, New Zealand, is characterised by subduction of thick and buoyant crust of the Hikurangi Plateau, and along-strike variations in convergence obliquity, surface heat flow (low in the south, high in the north), inferred pore-fluid pressure and seismic style (locked in the south, aseismic in the north). The depth of interseismic coupling is > 25 km below Wellington and < 15 km below Hawke's Bay. It is generally assumed that this coupling depth coincides with the base of the seismogenic zone and is determined by the 350ºC isotherm or the intersection between the subduction thrust interface and the hangingwall Moho (whichever is shallowest). We have applied a numerical thermal model to the shallow (< 50 km deep) region of the Hikurangi subduction zone to assess the importance of temperature, and other factors of along-strike variability, in controlling the observed variation in coupling depth.

The model reproduces low surface heat flow as observed in the southern Hikurangi margin. We propose that greater surface heat flow in the north is caused by shear heating and convective heat transport by fluids escaping from the interface. The model predicts that the Hikurangi megathrust is comparatively cold (350ºC isotherm deeper than 25 km), so that if the lower limit of the interface seismogenic zone is thermally controlled, it should occur near the depth of the hangingwall Moho. This agrees with observation in the locked segment below Wellington, but a purely thermal model cannot explain the shallow interseismic locking depth in the central and northern fault segments.

In crustal strength curves, changing fluid pressure is capable of moving the brittle-viscous transition vertically by tens of kilometres. We propose that subduction zone seismic style will vary depending on the fluid pressure regime both in the hangingwall and along the interface, and define four end-member types of megathrust fault segments. (I) Both the hangingwall and the interface are highly overpressured. The interface is weak, but brittle and fully coupled. This model agrees with observations below Wellington. (II) The hangingwall is hydrostatically pressured, and the interface is highly overpressured. Unusual seismic styles are likely to occur at depths > 10 – 15 km, through episodic fluid movement and interplay between a relatively strong, viscously deforming hangingwall and a weak, brittle interface. (III) Fluid pressure is hydrostatic both in the hangingwall and on the interface. The decollement may step into a weak, viscous hangingwall causing subduction erosion. The interface is aseismic below a shallow (10 – 15 km) brittle-viscous transition, as observed below Hawke's Bay. (IV) The interface is hydrostatically pressured and the hangingwall is overpressured. This may occur following an interface seismic rupture, and will promote brittle failure in the hangingwall.

THE MW 6.6 GISBORNE EARTHQUAKE OF 2007: PRELIMINARY RECORDS AND GENERAL SOURCE CHARACTERISATION

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Gisborne city experienced recorded peak ground accelerations exceeding 0.25g for the third time since 1966 in the magnitude Mw 6.6 earthquake at 075516 UT (8:55 pm local time) on 20 December 2007. The earthquake was at a hypocentral distance of 64 km from Gisborne at a depth of 40 km, well within the mantle of the subducted slab of the Pacific plate as it dips beneath the North Island of New Zealand. The GeoNet website received 3257 felt reports, with a strongest intensity of MM8 (heavily damaging) assigned to the main shock.

The 122 strong motion records of this event show a clear regional directional variation in the wave propagation, as well as a distinct 2Hz peak widely observed throughout the country. At a local scale, three sites in the Gisborne region recorded accelerations around 0.2g. Recordings in Gisborne city also revealed a predominant displacement direction, parallel to the main street where most of the damage occurred.

Source studies from moment tensor solution, aftershock relocations, GPS and strong motion data showed that the earthquake occurred within the subducted plate on a 45 degree eastward dipping fault plane. The mainshock rupture area is about 10 km2 reaching a maximum slip of 2.6 m. The computed high stress drop value of 17 MPa is as expected for an intraslab event and consistent with observations of very energetic seismic waves as well as heavy structural damage.

GPS data recorded by continuous GPS instruments have also shown that slow slip occurred for about three weeks after the main shock. The slow slip was triggered on the subduction interface, rather than on the same fault plane as the aftershocks. This is the first clear-cut case worldwide of triggered slow slip, although three non-triggered slow-slip events have occurred in the same region since 2002.

INFERENCE OF SHALLOW, WEAK, AND STRESS-DEPENDENT ASTHENOSPHERE AT ACTIVE CONTINENTAL MARGINS FROM POSTSEISMIC OBSERVATIONS

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Rheological flow laws of mantle minerals (most importantly olivine) can be determined in the laboratory, but results require large extrapolations to tectonic strain rates, raising questions as to their applicability. Furthermore, laboratory experiments can say little of *in situ* environments (temperature, water content, strain rates), thus effective viscosities within the mantle are estimated with uncertainty. Here we use large earthquakes as giant natural rock squeezing experiments to infer the rheological properties of the asthenosphere in active continental deformation zones and the environment in which it flows. Our objective is to compare inferred *in situ* flow laws to those derived in the laboratory and to help understand the environment of the asthenosphere inboard of active oceanic/continental margins. In these natural experiments, the earthquakes impart significant stress through the lithosphere and into the asthenosphere, inducing flow in the latter that causes transient postseismic surface displacements. GPS observed displacements are then used to constrain finite element models of postseismic relaxation to determine the rheological properties of the asthenosphere.

We consider the postseismic response following the 2002 M7.9 Denali Fault, Alaska earthquake and the 1999 M7.1 Hector Mine, California earthquake. The former event occurs inboard of an active subduction zone while the latter event occurs inboard of a recent (<12 ma) subduction zone (currently the San Andreas Fault). In both cases a wide array of continuous GPS stations were in place to record postseismic surface displacements from immediately after the earthquake. We find that most (if not all) postseismic displacements that occurred beyond about a half-rupture length away from each event were caused by flow within a weak asthenosphere below a strong 40-50 km thick lithosphere. In both cases transient postseismic displacement time series could not be explained by a Newtonian rheology, but are well predicted when using a stress-dependent power-law rheology as suggested by laboratory experiments of samples deformed by dislocation creep. Postseismic responses are explained by power-laws with parameters (A, n, Q) within the uncertainties of experimental flow laws for wet olivine. These asthenospheres are wet, hot (1200-1300°C), and experience a background strain rate of the order of 0.1-1.0 µstrain/year. Perhaps most interesting is the transient nature of the effective viscosity of these asthenospheres associated with their stress dependence. Immediately after each earthquake the effective viscosities of the asthenosphere directly beneath the rupture are as low as 10^{17} Pa s. Within a year the effective viscosities have risen to more than 10^{18} Pa s and within a decade they have recovered to background levels of the order of 10^{19} Pa s.

AZIMUTHALLY ANISOTROPIC PHASE VELOCITY OF NZ

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I investigate the surface wave velocity structure of New Zealand based on phase velocity measurements made on broad-band, cross-correlated ambient noise. Continuous data from broadband stations from the GeoNet array are filtered, cross correlated on a day-by-day basis, and then stacked. It has been show both empirically and theoretically that this approach provides an approximation of the Green Function (the response of one station to a ballistic point source at the other) between the two stations. The correlation functions are processed with multiple filters and phase-matched filtering. Following filtering, phase information is unwrapped from the signals. Using phase shift and inter-station distance, the phase velocity is easily calculated if the phase cycle can be determined. The appropriate phase cycle is chosen interactively, using a background dispersion model for comparison. Reliable phase velocity dispersion curves for Rayleigh waves Love waves have been measured using this approach. Measurements are made between 5 and 100 second periods. The shortest periods have sensitivity even to the upper crust, whereas the longer periods sample well into the mantle. Using such broadband data greatly increases our ability to recover lithospheric structure. I invert these phase data with a linearized LSQR approach, solving for both isotropic and azimuthally anisotropic Rayleigh- and Love-wave velocity.

GEOMETRY AND STYLE OF COMPRESSIONAL INVERSION IN THE NELSON AREA, ONSHORE AND OFFSHORE

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In the South Island of New Zealand, northwest of the Alpine Fault, sets of N-S to NNE-SSW oriented normal faults established during the Late Cretaceous-Eocene (in connection with the Tasman and Emerald rifting) have undergone compressional inversion since the early Miocene. Fault reactivation accommodates E-W shortening of the Australian crust against the Alpine Fault, and is still occurring in the present tectonic regime with rupture in large earthquakes (e.g. the 1868 **M**~7-7.5 Farewell Spit, 1893 **M**~6.9 Nelson, 1929 **M**7.8 Murchison, and 1968 **M**7.1 Inangahua earthquakes).

Occurrence of compressional inversion is generally indicated by a combination of: (1) reverse-slip (with transpressive components) on steep faults (□ > 50°); (2) double vergence at the shoulders of inverted grabens; (3) harpoon-like geometry of the "everted" synrift sequences; (4) negligible net reverse displacement along faults of regional extent; and, (5) shifting of syntectonic depocentres from the hangingwall to the footwall block of the inverted faults. However, the configuration of the inherited extensional structures (e.g. symmetrical vs. asymmetrical grabens, transfer zones), the orientation and intensity of superposed shortening, and the rigidity contrast between adjacent, fault-bounded blocks have resulted in patterns of selective reactivation, and in a mixed tectonic style of partial compressional inversion, followed by propagation of newly-formed, cross-cutting thrust faults, in accord with expectations from frictional fault mechanics.

Our study focuses on the Kahurangi, Wakamarama and Pikikiruna Fault systems in the Nelson region and adjacent offshore. We present a series of regional transects that combine the data of marine seismic reflection surveys (from the public Crown Mineral database) with structural and morphotectonic analyses inland. Our interpretation emphasises the variation in style and modes of structural inversion (both along E-W and N-S transects), the strong vertical gradients recorded inland by the elevation of marker horizons and in the offshore by the depth of an early (?) Pliocene unconformity, and the regional signature of distributed compressional reactivation over a large area onshore and offshore.

There is no clear evidence for Holocene surface rupture associated with active fault traces, but the preservation of a tectonically-controlled landscape and the historical seismicity (possibly related to offshore faults, e.g. 1868 Farewell Spit earthquake) suggest the likelihood of reactivation for faults that maintain favourable orientation in the present tectonic regime. However, the definition of fault geometry at depths of earthquake nucleation (5-15 km) remains a critical issue for assessing compressional inversion hazard in the Nelson area and elsewhere through the South Island.

CONTINUED EXPANSION OF GEONET CONTINUOUS GPS NETWORK

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Beginning in 2001, GNS (via the GeoNet project) has established a telemetered network of continuous GPS (cGPS) receivers across the North and South Islands of New Zealand. The network is designed for earthquake, volcano, and landslide hazard research and monitoring and compliments Land Information New Zealand's (LINZ) 32 PositioNZ stations. Currently GNS manages over 120 permanent, continuously recording GPS monuments with plans to install 18 more this year. Much of the expansion in recent years has occurred along the transpressional Hikurangi Margin and within the Central Volcanic Zone of the North Island. The network continues to yield exciting discoveries for earthquake and volcano researchers. Among such discoveries are numerous episodic 'silent' slip events within the Hikurangi subduction zone and surface deformation at Taupo.

Looking forward, GeoNet expects an increasing demand for high-rate real-time GPS data for both commercial and research applications. Commercial uses of real-time data include land surveying and kinematic GPS for risk analysis. Real-time GPS data also has promise for monitoring landslide and volcanic hazards and for assessing tsunamigenic potential for large earthquakes. The growing need for real-time data presents significant challenges to the GeoNet team as the network design is improved for high-rate GPS data streams. In cooperation with LINZ, GeoNet is pioneering new applications and products using the growing GeoNet continuous GPS network.

STRUCTURES INVOLVED IN THE VERTICAL DEFORMATION AT LAKE TAUPO (NEW ZEALAND) BETWEEN 1979 AND 2007: NEW INSIGHTS FROM NUMERICAL MODELLING

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Since 1979, repeat levelling measurements have been conducted on the lake filling the caldera of the dormant Taupo rhyolitic volcano in the North Island of New Zealand. Interpretation of these data through numerical modelling provides information on the structures involved in the relative vertical crustal movement throughout the southern end of the Taupo Volcanic Zone (TVZ), an area of active back-arc extension. The best-defined feature is a long term global subsidence of the northern part of the lake (7mm.y^{-1}) due to the cumulative effect of the crust stretching and a deep deflation source. This long term subsidence is occasionally disturbed by strong short-term uplifts linked with overpressure sources located below the northern part of the lake, near the Horomatangi Reef, an active geothermal field. Episodes of uplift can be attributed to various combinations of the following two processes taking place beneath the geothermal field (1) Movement or formation of rhyolitic magma (deepest sources) (2) Pressurization of the shallow hydrothermal fluid reservoir that traps volatiles exsolved from a crystallizing rhyolitic magma (shallowest sources). The pressurization of the shallow hydrothermal system gives rise to tensional stresses in the upper crust to generate uplifts, and results in seismic and aseismic fault ruptures. In the future, the recognition of uplift periods at long term will allow us to forecast the shallow seismic swarms along the Kaiapo fault and below the Horomatangi Reefs as observed between March and August 2008.

A LARGE SUBMARINE LANDSLIDE IN THE RAUKUMARA BASIN

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Seismic reflection data from immediately north of Raukumara Peninsula reveal a basin containing sediment that is up to 12 km thick. Seismic sections include a unit up to 1.5 s twt (3 km) thick that has discontinuous variably-dipping internal reflections, with fault-bounded blocks, or chaotic, or transparent internal character. This unit is found between East Cape Ridge and the middle of Raukumara Basin, and is unconformable with only very minor discordance to sedimentary units below and above. Adjacent to East Cape Ridge, the unit dips towards the northwest and is deformed, while near the middle of Raukumara Basin it dips gently to the northwest and pinches out. The unit is interpreted as being a large submarine landslide and may be lithostratigraphically correlated with the East Coast Allochthon on Raukumara Peninsula.

GEOPHYSICAL INVESTIGATION OF SHALLOW BASIN-MARGIN STRUCTURES EAST AND WEST OF STEWART ISLAND

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Stewart Island lies between the Great South Basin and the Solander Basin, south of the South Island. To the east, the Great South Basin is the Campbell Plateau's largest sedimentary basin and has accumulated up to 8.6 km of sediment since it was formed during mid-Cretaceous rifting related to the separation of New Zealand from western Antarctica. West of Stewart Island lies the Solander Basin which formed during the Cretaceous - late Eocene extensional regime that led to the opening of the Tasman Sea. Hydrocarbon exploration using seismic and well data have suggested that some of the rift basins formed by the spreading of the Tasman Sea and the break-up of Gondwana have become significant petroleum basin depocentres.

A detachment fault associated with late Cretaceous rifting from Gondwana has recently been proposed for the region on the southeast coast of Stewart Island (Kula et al. 2007). Information on the offshore geometry and extent of this, the Sisters shear zone, is limited – particularly with regard to its morphology and geological history. Recent work has allowed the dating of rifting episodes across the zone, but its general form is still mostly unknown. This study investigates the shear zone using high-resolution seismic imaging to reconstruct sea-floor morphology and shallow fault geometry. This involves collecting high frequency data using sub-bottom imaging (CHIRP and boomer) and interferometric side scan aboard the University of Otago's *R/V Polaris II*. These data will be used in conjunction with existing industry data acquired farther offshore.

A 240 km line of multi-channel seismic reflection data, recorded aboard *R/V Maurice Ewing* in 1996, has imaged several complex structural features along the Stewart Island shelf adjacent to the Solander Basin. Reprocessing of these data focuses on faulting that appears to outcrop on the seafloor, as well as unclear surface features on the shelf margin. The collection of high-frequency boomer data in January 2009 aims to improve resolution and geophysical interpretation of these features.

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WHAT ON EARTH DOES GRANULAR PHYSICS HAVE TO DO WITH LANDSLIDES?

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How does one respond to a geologist who asks this question? Where does one begin? Granular physics is the physics of how grains behave when they are together in a mass. Landslides are masses of grains: every landslide, with no exception. So one might expect that an understanding of granular physics might be some help in understanding landslide behaviour. This is indeed so. Of particular interest to me, is an aspect of granular physics that neatly explains why no landslide has ever behaved exactly as we expect of landslides, and why none will ever behave that way, other than purely from random chance.

The distribution of grain-contact forces between grains in a granular mass under load (i.e. affected by gravity) is a statistical variable, and only its average value (or total force) is capable of being known without direct measurement at each grain contact. The gross landslide driving force thus is capable of being known. But, granular physics reveals that the operating mechanism of the driving force is not though the total or the mean, but through the larger and smaller grain-contact forces; that is, the tails of the statistical distribution of forces. Landslides move by relative motions between adjacent grains, and this motion is governed mainly by Coulomb friction; the relative motion of two particles is governed by the ratio of normal to tangential grain-contact forces, and the physical laws that control these forces. A high normal force and a low tangential force at a grain contact will not cause them to slide against one another. Conversely, a low normal force and a high tangential force will cause sliding. You may well ask about grain rotation (rolling), but a random grain mass is not a neatly meshed gear train, and some sliding somewhere is a necessity for rolling and for landsliding.

The above explains why the high and low contact forces count, but the highs count more than the lows, because very high normal forces between grains, while inhibiting slip, can break of one of the grains, if its strength is exceeded.

Although geotechnical theory uses mean stresses, real landslides do not. They use the improbable tails of the distribution about the mean stresses and constantly rearrange them. A mass of grains under load always self-arranges its grains to balance grain-contact forces throughout the grain mass. An active landslide is simply a grain mass trying to balance its grain contact forces; this sometimes takes a while, but sometimes occurs catastrophically. Catastrophic rearrangements of grain-contact forces most often occur when too many grains break at once. Breaking of one grain at high stress shifts load onto other grains, and if some of them break as a result, the grain breakages escalate, and things go with a rush.

So, might granular physics tell us something about fault rupture too?

DEPTH CONVERSION IN THE STRUCTURALLY COMPLEX KUPE REGION: A PILOT STUDY FOR BASIN WIDE METHODOLOGIES

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The Kupe region of the Taranaki Basin lies in a highly complex structural setting, resulting from multiple basin-wide extension, compression and wrenching events since the Cretaceous. These complexities create several pitfalls in velocity model estimations, due to lateral heterogeneity caused by thrusting and compounded by the lack of well control in the lower part of the thick Cretaceous sequence.

The study area covers approximately 4500 square kilometres. Previous depth conversion efforts at this scale have utilised thickness versus travel-time curves derived from available well velocities throughout the basin. We have adopted techniques such as geo-statistical modelling in order to combine well and seismic stacking velocities, therefore resulting in a more accurate velocity model.

This investigation represents a pilot study to develop depth conversion methodologies which can be applied in other parts of the Taranaki Basin as part of the GNS Seismic Facies Mapping project. It is the first step towards building a database of subsurface velocity information and calibrated velocity models for the entire basin.

The ultimate goal is to create a series of 3D geological models that will be combined as input into basin reconstruction, migration and maturation studies. Accurate and reproducible depth conversion will play an important part in achieving this result.

BASEMENT GEOLOGY OF ZEALANDIA AND AUSTRALIA: STARK DIFFERENCES, BROAD SIMILARITIES AND JOLLY GOOD MATCHES

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It's axiomatic that New Zealand was formerly part of Gondwanaland and that there are broad geological similarities between parts of the New Zealand basement and Australia. The comparison most often made is between New Zealand's Western Province and the Lachlan Orogen. As part of an appraisal of New Zealand's mineral prospectivity our research team has been comparing and contrasting the regional geology of Zealandia and eastern Australia.

Differences between New Zealand and Australia include: (1) absence of New Zealand's Permian-Cretaceous greywacke and schist terranes in eastern Australia (they extrapolate offshore); (2) absence in New Zealand of the Ordovician Macquarie Arc of the eastern Lachlan Orogen; (3) absence in New Zealand of Devonian-Carboniferous New England Orogen sedimentary forearc and subduction complexes (removed by Permian continental truncation?); (4) exhumation of mainly mid-Paleozoic-Cretaceous plutonic rocks in New Zealand compared with preservation of volcanic levels in Queensland; (5) lack of Cretaceous metamorphic core complex-like features in eastern Australia.

Broad geological similarities between New Zealand and Australia include (1) Devonian Karamea Suite and coeval suites in the Melbourne Zone of the Lachlan Orogen; (2) Carboniferous-Cretaceous Median Batholith suites and plutonic and coeval volcanic rocks in the New England Orogen; (3) Ordovician-Devonian marine sedimentary rocks and coeval strata in the Lachlan Orogen; (4) possible Delamerian basement beneath Fiordland and similar culminations recognised beneath the Lachlan Orogen.

Good local stratigraphic matches between New Zealand and Australia include (1) Middle Jurassic Kirwans Dolerite and Tasmanian Dolerite; (2) Permian-Triassic Parapara-Topfer Formations and Australian intracontinental basins; (3) Permian Brook Street Terrane and Queensland's Gympie Terrane; (4) Cambrian volcanic suites in the Takaka Terrane and the Mount Read Volcanics of Tasmania; (5) using the ages of detrital zircons and micas, the likely source area for New Zealand's Rakaia Terrane is the Hodgkinson Belt of northern Queensland.

When comparing and contrasting the geology of different orogens, we have found it useful to distinguish between sedimentary protoliths, igneous rocks, and tectonic-metamorphic overprints. An appreciation of the geological differences and similarities between eastern Australia and New Zealand should help mineral exploration companies focus on prospective targets.

REPEATED REMOBILISATION OF SUBMARINE LANDSLIDE DEBRIS ON THE HIKURANGI MARGIN INTERPRETED FROM MULTIBEAM BATHYMETRY AND MULTICHANNEL SEISMIC DATA

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EM300 multibeam and multichannel seismic data reveal a 230 square kilometre submarine landslide complex which exhibits many of the characteristic features of equivalent terrestrial creeping earthflow complexes. Slope failures are sourced from the shelf edge/upper slope of the Poverty Bay reentrant on the active Hikurangi subduction margin of New Zealand where tectonic deformation, via major thrust faults with slip rates of c. 3-4 mm/yr, exerts a controlling influence on seafloor physiography. Individual landslides within this submarine complex are up to 14 km long over a vertical elevation drop of 700 m. Debris streams are in excess of 2 km wide with a debris thickness of 100 m. While multibeam data is limited to c. 10 m resolution, the scale of submarine landslide features allows us to resolve internal debris detail equivalent to terrestrial landslide examples using terrestrial techniques (e.g. airborne lidar). DEM derivative surface roughness techniques are employed to delineate the geomorphic expression of features including active and abandoned lateral shears, and contractional and extensional deformation of the landslide debris. From these interpretations multiple internal failures are recognised along the length of the landslide debris. Debris deformation is also imaged in high fold multichannel seismic data and correlated to the imaged surface geomorphic features, providing insight into the failure mechanics of the landslides. Failures initiate and evolve within the quasi-stable prograding sediment wedge built onto the upper slope during lowstand sealevels. Landslides within the greater complex are at different stages of development providing information on their spatial and temporal evolution headward and laterally along the transition from shelf to upper slope margin. We infer that failures are triggered and evolve in response to sealevel rise, and/or the frequent occurrence large earthquakes along the margin.

AN EXPLANATION FOR THE WIDESPREAD ACCELERATION OF FAULT DISPLACEMENT RATES SINCE 10 KA

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Recent work suggests that average displacement rates within many normal and reverse fault systems were higher during the Holocene (<10 ka) than the late Quaternary (<300 ka). Holocene acceleration of displacement rates have been attributed to fault linkage, climatically induced loading of faults, earthquake clustering and/or to increases of tectonic tempo. If correct, the widespread increases in tectonic tempo required to account for the observed changes in fault displacement rates would have profound implications for the rates of plate tectonic processes and seismic hazard. We believe, however, that temporal variations of displacement rates during the late Quaternary coupled with a sampling bias towards those faults that are best represented in the landscape and have moved fastest during the Holocene, is a much more plausible explanation for the apparent fault accelerations. To test our model we use a compilation of fault displacement rates from a global data set of normal, reverse and strike slip fault systems (65 faults) together with 129 faults from the Taupo Rift, New Zealand. These data confirm that displacement rates on individual faults can vary by up to three orders of magnitude when averaged over time intervals of <300 kyr. These changes in displacement rate arise from variability in earthquake slip and/or recurrence intervals, which we partly attribute to fault interactions. Holocene displacement rates exceed late Quaternary rates in those systems with lower regional strain rate and, perhaps, more constituent faults. The decrease in rate variability with increasing regional strain rates reflects a reduction in the time intervals over which these variations occur rather than a decrease in the amount of variability. Therefore, faster moving systems with fewer component faults, are characterised by displacement rate variations on shorter time scales and are less susceptible to Holocene time scale sampling biases.

EVOLUTION OF THE POVERTY BAY INDENTATION, HIKURANGI MARGIN, NEW ZEALAND

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The Poverty Bay Indentation is an asymmetric tear penetrating from the trench floor virtually to shelf edge across the entire forearc slope of the Hikurangi Margin off the East Coast of the North Island, New Zealand. It is inferred to be directly related to a large seamount impact event, possibly initiating as little as 1.6 Ma during the Pleistocene.

Major geometric elements of the Poverty Bay Indentation have been effectively replicated in sandbox models as first-order responses to a seamount subduction event. Fault structures observed in the sandbox models also correlate well with observations in the Poverty Bay Indentation, with formation and propagation of the thrust dominated deformation front interrupted and modified by the impact of a subducting seamount. The main features correlating with the sandbox models are: the axial re-entrant, down which the Poverty Canyon now incises; the re-establishment of a comprehensive accretionary wedge to the south of the axis and extended propagation into the trench fill sequence, particularly towards the mouth of the canyon; the straighter north side of the indentation with respect to the curved arcuate shape of the southern wedge; and a set of faults cutting across the deformation front near the mouth of the canyon. The relationship of cross-cutting fault sets can also be observed on a smaller scale occurring north of the Poverty Canyon where the Puke Seamount is currently in the early stages of subduction and compares to the observed features illustrated in the initial stages of subduction in the sandbox models. A set of normal/strike-slip faults is developing orthogonal to the deformation front and directly inboard of the Puke Seamount, while the deformation front itself is responding to the increased compressional stress by propagation of a closely-spaced series of thrusts in the zone of increased contraction between the Puke Seamount and the frontal wedge.

A time-line for evolution and development of the present day indentation is as follows: impact of seamount, re-adjustment of the deformation front and development of anticlinal ridges followed by the development of a prograding clinoform wedge out over the impact scar, development of the Poverty Canyon incising into the axis of the indentation, gully formation and mass movement processes into the upper slope and accompanying slope basin development. Ongoing processes appear to be driven by continued smaller seamount impacts at the base of the slope, low and high sea-level stands accompanied by variations on sediment flux from the continental shelf, over-steepening of the deformation front and mass movement particularly from the shelf edge and upper slope.

THE M_W 6.7 GEORGE SOUND EARTHQUAKE OF 15 OCTOBER 2007: RESPONSE AND PRELIMINARY RESULTS

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The M_w 6.7 George Sound earthquake of 15 October 2007 occurred a few kilometres offshore in the Fiordland region, where the zone of subduction of the Australian Plate beneath the Pacific Plate intersects the offshore extension of the Alpine Fault. Rapid response deployments of portable seismographs, a strong motion recorder and GPS receivers relatively close to the epicentre soon after the main shock allowed us to relate the event to thrusting at the subduction interface. The moment tensor solution of the main shock is a reverse faulting mechanism at a shallow depth of 21 km. The sequence of aftershocks which immediately followed the main event revealed predominately reverse faulting mechanisms similar to the main shock with depths of 20 – 25 km. Re-locations of aftershocks using the portable seismograph array define a steeply SE-dipping plane which another cluster at about 7 – 12 km depth images a NW-dipping plane within the overlying plate. Preliminary results from the seismic, geodetic and near-field strong motion geophysical data acquired are consistent with rupture on an east dipping fault plane, presumed to be the subduction interface.

GRAVITY CONSTRAINTS ON THE ARCHITECTURE OF THE CAPEL AND FAUST BASINS, NORTHERN TASMAN SEA

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Residual gravity anomalies derived from satellite-altimetry and shipboard data, combined with 6000 line km of new 2D seismic reflection data (Geoscience Australia GA-302 survey, 2006–2007), show that the Capel and Faust basins comprise several elongate or arcuate depocentres. These depocentres extend up to 150 km along a general N–S trend. The petroleum potential of these basins, located 800 km east of Brisbane in 1000–3000 m of water, is currently being assessed as part of the Australian Government's Offshore Energy Security Program

Interpretation of GA-302 seismic reflection data suggests that maximum unequivocal depocentre thickness is ~3.5 s TWT (6–7 km when converted to depth using stacking velocities). Two syn-rift megasequence packages (?Early Cretaceous–?Santonian) and two post-rift sag packages (?Early Campanian–Recent) have been interpreted (see Hashimoto et al., this volume). The 20–50 km separation between seismic lines and the compartmentalisation of the basin depocentres complicates the process of linking structures between lines. However, a strong correlation exists between negative gravity anomalies and basin depocentres evident in seismic-reflection data, and between positive gravity anomalies and basement highs. This correlation between gravity and basin structure, which is consistent across the region, means that 3D mapping of faults and seismic horizons can be guided by the potential-field data.

The seismic and potential field data, together with interpreted horizons and other constraining information have been combined in a 3D visualisation environment to aid the interpretation process. Given the fragmented nature of depocentres, the ability to integrate all datasets into a single 3D environment has proven invaluable.

Interpretations are also being tested using quantitative 3D gravity modelling. Initial gravity models simplify the interpreted seismic stratigraphy into a water layer, upper sediments (1950 kg/m^3), middle sediments (2400 kg/m^3), lower sediments (2500 kg/m^3) and basement (2670 kg/m^3). This simplification is made on the basis of selecting the horizons that are likely to have the greatest density contrast.

Preliminary forward modelling of the gravity field generated by the simplified 3D model suggests that the 2D seismic interpretation is consistent with the observed gravity field. Major shorter-wavelength gravity lows generated by sediment-filled depocentres are reproduced by the model. However, the modelled gravity field in the western part of the study area is generally more negative than the observed free-air gravity field, suggesting that the model is missing mass in this area. This could mean we have not accounted for the presence of higher-density magmatic rocks within the sedimentary layers, or that the basement pick is incorrect. We are currently exploring these and other alternatives.

AMBIENT NOISE CORRELATION ACROSS THE TASMAN BASIN

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Ambient noise correlation provides a means of tomographically imaging the crust and upper mantle without reliance on either artificial energy sources (e.g. dynamite or air-guns) or natural seismicity. In conjunction with studies using permanent and temporary seismograph records to image the New Zealand plate boundary (Behr et al.) and determine seismic noise field characteristics (Brooks et al.), we have begun combining New Zealand, Australian, and New Caledonian data to address the structure of the Tasman Basin. We use 23 months' data recorded at 16 sites on New Zealand's west coast, seven sites in eastern Australia, one site in New Caledonia, and one site on Macquarie Island. The data are pre-processed using standard techniques and analysed in the 5–80 s period band. We compute trans-Tasman dispersion curves from symmetric cross-correlation functions with signal-to-noise ratios of >10 at periods of >30 s; at shorter periods, the only station pairs yielding high signal-to-noise ratio cross-correlations lie within individual networks (i.e. western New Zealand or eastern Australia). In this presentation we will show the cross-correlation measurements and preliminary path-averaged shear-velocity profiles spanning the central Tasman Basin.

LATERAL VARIATIONS OF SUBDUCTION ZONE STRUCTURES ALONG THE HIKURANGI-KERMADEC TRENCH BETWEEN 29°S AND 38°S

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The Hikurangi-Kermadec subduction zone northeast of New Zealand represents an ideal target to study lateral variations of subduction zone processes. The incoming Pacific plate changes from being a large igneous province, called the Hikurangi Plateau, in the south to normal oceanic plate north of the Rapuhia Scarp. The overriding Australian plate is continental in character in the south, forming the North Island of New Zealand, and changes to an island arc in the north. Further lateral variability exists in changes in volcanic and hydro-thermal activity, transitions from accretion to subduction erosion, backarc spreading and rifting, and is accompanied by a northward increasing seismicity.

As part of the MANGO project (Marine Geoscientific Investigations on the Input and Output of the Kermadec Subduction Zone), four marine geophysical transects of largely seismic reflection and refraction data provide constraints on the upper lithospheric structures across the Hikurangi-Kermadec Trench between 29°S and 38°S. On MANGO profile 1 in the south, the initially shallow subduction of the incoming plateau coincides with crustal underplating beneath the East Cape ridge. To the west lies the Raukumara Basin which is about 100 km wide and over 10 km deep. Seismic velocities of the upper mantle of both incoming and overriding plates are in the order of 8 km/s and are considered normal. In contrast, on MANGO profile 4, about 1000 km to the north around the volcanically active Raoul Island, the incoming oceanic crust appears to bend considerably steeper and thus causes a 50 km narrower forearc with a smaller forearc basin. Furthermore, the upper mantle velocities in both plates are relatively low (7.4-7.7 km/s), likely indicating strong bending related deformation of the incoming plate and thermal activity within the arc possibly due to spreading. The central two transects MANGO 2 and 3, though without data coverage of the structure of the incoming plate, are more similar to MANGO 4. The arc regions appear to be strongly affected by the activity of the arc. The arc crust of the northern MANGO 3 becomes significantly thinner in the backarc region due to extension, whereas the data from MANGO 2 likely show thermal activity from the adjacent arc volcanism.

THE UPPERMOST MANTLE BENEATH THE CENTRAL NORTH ISLAND, NEW ZEALAND; FROM MODELLING PN WAVE SPEEDS

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The North Island of New Zealand is situated on an oblique subduction boundary between the Pacific Plate and the Australian Plate, resulting in high volcanism, back-arc spreading, and crustal thinning within the Central Volcanic Region. Knowledge of the uppermost mantle beneath the North Island is needed to fully understand the processes involved in causing the observed surface phenomena.

Here we model the uppermost mantle Pn wave-speeds, using a least-squares collocation method. This method allows the dominant velocity features within the upper mantle to be modelled, as well as estimating mantle anisotropy and crustal variations throughout the North Island.

The resulting model shows that the North Island can be split into four distinct regions, based on mantle anisotropy and velocity. (1) The western North Island, showing velocities of 7.9 to 8.2 km/s, and no apparent anisotropy. (2) The Taranaki Volcanic Region, showing low velocities of < 7.5 km/s, and a hint of N-S fast direction anisotropy. (3) The Central Volcanic Region (CVR), showing extremely low mantle velocities of < 7.4 km/s, and trench parallel anisotropy (NE-SW fast direction). (4) The eastern North Island, showing high mantle velocities (8.1 - 8.5 km/s), and strong NE-SW fast direction anisotropy.

The mantle velocities detected beneath the CVR, are some of the lowest seen around the world. Modelling of ray-depth penetration, suggests that this low-velocity layer extends to depths of between 40 and 80 km. The low-velocities detected beneath the Taranaki region, suggest high heat in the uppermost mantle. In the western North Island, the combination of lower-than-normal mantle velocities and no apparent anisotropy, suggest that the mantle within this region is relatively warm and young. What these observations mean in terms of temperature, melt and water fraction within the uppermost mantle will also be discussed.

FAULT MECHANICS OF RECENT COMPRESSIONAL INVERSION EARTHQUAKES IN NE HONSHU, JAPAN

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The volcanic arc of NE Honshu is flanked to the east and west by areas of active compressional inversion where systems of arc-parallel, basin-bounding normal faults developed in the Miocene are undergoing reverse reactivation in the present arc-normal compressional stress field. Over the past 5 years a number of strong earthquakes have involved rupturing on steep ($\delta > 45°$) reverse faults within the crustal seismogenic zone. These include the 2008 **M**6.9 Iwate-Miyagi Nairiku earthquake, the 2007 **M**6.6 Niigataken Chuetsu-oki and **M**6.7 Noto Hanto earthquakes, the 2004 **M**6.6 (5.9. 6.3, 5.9) Mid-Niigata Prefecture sequence, and the 2003 **M**6.4 Northern Miyagi earthquake. Earlier ruptures which appear to share the same characteristics include the 1962 **M**6.5 Northern Miyagi earthquake, together with the 1993 **M**6.4 Off-Noto Peninsula and 1964 **M**7.5 Niigata earthquakes, the last two both occurring offshore along the eastern margin of the Japan Sea. The mainshocks all involve close-to-pure reverse slip on faults dipping 45-60°, though there is some evidence for subsidiary ruptures on 'Andersonian' thrusts dipping 30±5°. Notably distinct is the 1896 **M**7.2 Riku-u earthquake on the Senya Fault which bounds and dips ~30°E beneath the Ou Backbone Range. This major morphotectonic feature hosting the volcanic front is essentially a large 'pop-up' structure between opposite-facing systems of active reverse faults.

The dominance of reverse faults dipping 50±5° over those dipping 30±5° is the opposite of that found in a global compilation of reverse fault rupture dips. On the assumption of horizontal maximum compressive stress, rupturing during these earthquakes took place on faults that were poorly oriented for reactivation and close to the expected angle of frictional lock-up for standard rock friction. Continued reactivation of such structures, in preference to the formation of more favourably oriented low-dipping thrusts, requires near-lithostatic ($P_f \rightarrow \sigma_3$) fluid-overpressuring within the lower half of the seismogenic zone. A range of geophysical evidence – local occurrence of bright-spot reflectors, low-velocity zones, anomalous *Vp/Vs* ratios, and high electrical conductivity - supports the existence of a fluid-rich and variably overpressured mid-crust which extends into the lower seismogenic zone, especially in the vicinity of the major fault systems. Activity on these inherited structures holds important lessons for comparable structures undergoing active compressional inversion within New Zealand.

THE ENIGMA OF MT TARANAKI

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For a long time Mt Taranaki has been considered a geographic, geophysical and geochemical, enigma. Most of the active (or recently active) andesite volcanoes in the North Island are explicable as subduction zone andesites in that they have a consistent geophysical relationship with the subjacent Wadati-Benioff Zone. In contrast, Mt Taranaki sits out to the west, apparently isolated from the line of active cones that extend from Mt Ruapehu in the south, northeastwards to White Island and beyond. Geochemically, Mt Taranaki is distinct from the Ruapehu–White Island line in that its lavas are high in potassium and contain hornblende. A number of other Pliocene andesites and basalts of Taranaki and the Waikato share this chemistry. Forty years ago Dickinson and Hatherton (1967) pointed out a pan-Pacific linear relationship between potassium content (K) and depth (H) to the Benioff zone. Indeed, the foundations for this concept originated, in part, from trying to explain the chemistry of Mt Taranaki. Recent work has explained the isolated Mt Taranaki in terms of differing conditions at the top of the mantle wedge and therefore in the degree of fractional crystallisation for the parent basaltic magma [Price*, et al.*, 1999].

This study is explores the relationship of Mt Taranaki, and other older hi-K andesites-basalts of western North Island, within the context of new findings on crustal and upper mantle structure, surface uplift history and convective removal of the upper mantle lid. Strong spatial links exist between the occurrence of hi-K volcanics of the North Island, areas where the mantle lid has been highly attenuated, and late Miocene rock uplift. In particular, Mt Taranaki sits above a large step-change in the thickness of both the crust and mantle lid. This is the Taranaki–Ruapehu line, which is here interpreted to mark the southernmost extent of convective removal of mantle lithosphere and some lower crust. To the north of the line the crust is thinned and the mantle lid is also thinned or missing. My interpretation is built in part upon a suggestion by McKenzie (1989); that hi-K andesites-basalts represent bodies of remelted, K-rich, metasomatised mantle. The heat for the remelting is introduced via hot asthenosphere replacing the convectively removed lithosphere. Although this is not a unique interpretation for hi-K volcanism, it provides a reasonable fit with the geophysical knowledge we have to date. In the western USA a similar distribution of hi and lo-K volcanism, crust-mantle structure and uplift history exists.

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FORMATION AND SUBSIDENCE OF THE NEW CALEDONIA BASIN AND LORD HOWE RISE BY DETACHMENT OF THE LOWER CRUST IN RESPONSE TO EOCENE SUBDUCTION INITIATION IN THE WESTERN PACIFIC

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We use seismic-reflection and rock-sample data to propose a new hypothesis: the physiography of the New Caledonia Basin formed coevally with the Eocene to Miocene onset of subduction and back-arc spreading that has since evolved into the Tonga-Kermadec and Lau-Havre systems. This contrasts with a long-held view that the New Caledonia Basin and its physiographic margins formed during Cretaceous rifting associated with Gondwana breakup and formation of the Tasman Sea. Our new hypothesis is based upon evidence for large Eocene–Miocene vertical movements and observed stratal dips. Evidence includes: seismic-reflection facies that indicate a phase of Eocene–Oligocene uplift on the basin flanks to near sea level, followed by rapid Oligocene–Miocene subsidence of c. 1–3 km; dredged rock samples and seismic-reflection facies tied to boreholes that suggest coal measures in the southern New Caledonia Basin have undergone c. 3 km of tectonic subsidence since the latest Cretaceous and Paleocene, substantially after the end of Cretaceous rifting; and stratal geometry that suggests the physiography of the New Caledonia Basin was formed at the time of the Eocene–Oligocene unconformity. Sediment thickness beneath the regional Eocene–Oligocene unconformity remains relatively uniform from the flanks to the centre of the basin, and reflectors are tilted, follow topography, and internally-deformed; but strata younger than the unconformity are close to horizontal and onlap the basin margins. We suggest that a detachment fault removed the lower crust, causing subsidence, and that the exhumed material may now be found in the Norfolk Basin.

SEISMIC ATTENUATION ANISOTROPY SURROUNDING MT. RUAPEHU

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Temporal variations of seismic anisotropy and attenuation were each separately reported accompanying Mt. Ruapehu's eruption sequence in 1995-1996. It has been suggested that seismic attenuation anisotropy should accompany velocity anisotropy, yet attenuation anisotropy has never before been studied in New Zealand. A seismic attenuation anisotropy study based on shear wave splitting will provide additional information regarding controls on seismic anisotropy. This study uses existing high-quality shear wave datasets recorded at Mt. Ruapehu volcano, New Zealand. We implement a methodology previously proposed by Carter and Kendall (2006) to measure and analyze seismic attenuation anisotropy. By combining information from previous studies, we will investigate the cause of the anisotropic mechanism and seismic properties around Mt. Ruapehu.

WHAT DOES MICROSEISMICITY (BUT NO TREMOR) ACCOMPANYING SUBDUCTION ZONE SLOW SLIP IMPLY ABOUT THE SLOW SLIP ITSELF?

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Geodetically-detected episodes of slow slip in several subduction zones are accompanied by bursts of low-frequency coherent noise known as seismic tremor. It remains unresolved, however, whether a single physical process governs this association or even whether slow slip is invariably accompanied by tremor. Detailed analysis of broadband seismic data spanning a slow slip episode near Gisborne (northern Hikurangi subduction zone, New Zealand) in 2004 reveals that slow slip was accompanied by distinct reverse-faulting microearthquakes, rather than tremor. The timing, location, and faulting style of these earthquakes are consistent with stress triggering down-dip of the slow slip patch, either on the subduction interface or just below it. These results indicate that tremor is not ubiquitous during subduction zone slow slip, and that slow slip in subduction zone environments is capable of triggering high-frequency earthquakes near the base of the locked subduction thrust. Near Gisborne and in other locations (Hawaii, Boso Peninsula) where slow slip is accompanied by triggered microseismicity — "co-shocks" — the estimated upper extent of the slow slip is shallower (less than ~20 km) than in those locations from which tremor has been reported. This suggests that ambient temperature- or pressure-related conditions govern the character of the seismic response to slow slip on subduction thrusts and other large faults, with low temperatures or pressures triggering high-frequency microearthquakes and higher temperatures or pressures triggering seismic tremor.

MID-CRETACEOUS IGNEOUS ACTIVITY BETWEEN ARC MAGMATISM AND ZEALANDIA RIFTING

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New U-Pb and Ar-Ar ages for Cretaceous rhyolites, tuffs and granites in Zealandia span a 30 Ma period from near the end of Late Jurassic-Early Cretaceous arc magmatism to continental breakup. Combined with previously published data, these reveal a strong episodicity in Cretaceous magmatism outside the Median Batholith, with peaks at 112, 102, 97, (88) and 82 Ma.

112 Ma ignimbrites and tuffs are known only from the Eastern Province in association with a Cretaceous normal fault system on the northeastern edge of the Otago Schist. Although the fault system subparallels the Median Batholith and the paleo margin, they are unlike coeval rocks of the Median Batholith, and we speculate that a subducted mid-ocean ridge may have been responsible for this rare and unusual magmatism in the accretionary wedge.

Both 102 and 97 Ma groups of rhyolites and tuffs occur across the entire width of the Gondwana margin from near the paleotrench to the continental interior, indicating widespread and effectively instantaneous extension. These include the first published U-Pb zircon ages from the Houhora Complex of Northland (101.54 ± 0.23 Ma (2σ error)), and from DSDP 207A on the Lord Howe Rise (96.91 ± 0.12 Ma). An c. 82 Ma group are known only from western South Island. Overall, the rhyolites and tuffs show an increase in A-type character with time, from 112-82 Ma. This may be due to the progressive thinning of Zealandia continental crust whereby, with time, there is less opportunity for crustal contamination of mantle-derived intraplate magmas.

Extension directions associated with 102, 97 and 82 Ma magmatism and associated core complex exhumation in accretionary wedge, Median Batholith and backarc are all oriented c. 30^{o} oblique to the margin, consistent with either 1) basal traction on a subducted slab that had been captured and pulled oceanwards by the Pacific plate and /or 2) continental rifting parallel to the 85 Ma Zealandia-West Antarctic breakup margin associated with southwestwards propagation of a putative <115 Ma oceanic ridge.

INFLUENCE OF MECHANICAL ANISOTROPY ON THE FORM OF COMPRESSIVE STRUCTURES – EXAMPLE FROM THE OTAGO SCHIST

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Mechanical anisotropy plays a significant role in the geometry and nature of deformation of the Earth's crust. Layering in sedimentary rocks and basins is associated with mechanical anisotropy and is known to affect their style of faulting and folding. Little quantitative work, however, has explored the effects of mechanical anisotropy on the regional-scale architecture of continental basements during reworking, even though the basements of most continents show fabrics (such as metamorphic schistosity and compositional layering) associated with anisotropy. By virtue of its relatively simple basement geology, the Otago Schist belt of New Zealand is an ideal location to examine the effect of mechanical anisotropy on subsequent deformation. Building on observations from field studies, I use mechanical modelling to investigate the influence of mechanical anisotropy on the style of Cenozoic fault-related folding within the Otago Schist.

The Mesozoic history of the Otago basement is complex. The schist of Central Otago is characterised by strong micaceous foliation and a lineation associated with quartz rods. The basement is of relatively uniform metamorphic grade and textural grade; with a relatively flat-lying foliation over large regions, although in places Pre-Miocene structures have disrupted the schistosity and textural zonation. Preserved across much of Eastern Otago and Canterbury is the Waipounamu Erosion Surface, a time-transgressive (Cretaceous-Oligocene) surface of fluvial and marine erosion. The erosion surface is a regional unconformity that is sub parallel to the metamorphic foliation of the schists and greywackes over large areas. This surface has been folded by the Cenozoic deformation and is useful as a strain marker in the study of fault-related folding in Otago.

Blackstone Hill is one of the smaller NE-trending ridges of schist basement in the central Otago region. It has been the subject of a series of detailed studies, including structural analysis, a gravity survey and geomorphological analysis of drainage patterns. Blackstone Hill appears to be a fault-propagation antiform at that level, and the geometry of the antiform is probably related to activity along two steep reverse faults at depth. The unconformity is folded in a strongly deformed zone at the tip of the Blackstone Fault, and the unconformity's orientation varies dramatically along strike. In the NE, the unconformity is overturned in a tight fault-propagation fold. In the SW, the unconformity is steep but upright in an open fault-propagation fold. The along-strike variation in fold style coincides with variation in the orientation of the basement schistosity. Three-dimensional mechanical models show that the presence and orientation of a mechanical anisotropy, in this case a schistosity, has a marked effect on the shape of the fault-propagation fold produced.

FLUID FLUX THROUGH THE SEAFLOOR OF THE GREAT SOUTH BASIN – UNDERSTANDING MIGRATION PATHWAYS AND SUCCESS OF SEALS AND TRAPS THROUGH SEISMIC IMAGING OF FAULT AND FRACTURE SYSTEMS

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The Great South Basin is one of New Zealand's largest undeveloped offshore basins and is known to have significant oil and gas prospects. The Great South Basin lies offshore from the coast of Southland and South Otago and at over 85,000 km^2 is one of New Zealand's largest petroleum basins. Understanding the "plumbing" of the Great South Basin through seismic imaging of fault and fracture systems will provide information relating to oil and gas migration and the success of seals and traps within the basin. Using the University of Otago research vessel, the RV Polaris II, to obtain high-resolution seismic images of the shallow seafloor will provide important constraints on fluid flow and migration pathways within the Great South Basin. These high-resolution shallow seismic data can be combined with studies of public conventional 2D seismic data and new 2D data shot by industry to provide insight into migration pathways and structural traps of oil within the system.

Recent seismic data acquired in the Great South Basin, have identified a series of linear sea floor features of unknown origin. These features are up to 300 m high and appear to be structurally controlled, occurring in an arcuate trend west of the Toroa-1 well location for more than 50 km. These features seem to be associated with the Toroa Dome, an anticlinal structure near the northwest boundary of the basin. Toroa Dome was formed during the Oligocene-Miocene period by reverse movement on steeply dipping reactivated normal faults. These reactivating faults created the prospects which Pakaha-1, Toroa-1 and Tara-1 exploration wells evaluated. By identifying the genesis of the seafloor features and investigating possible fluid migration associated with them, we will gain greater understanding of hydrocarbon fluid flux occurring within major prospects and hydrocarbon plays within the basin.

A BAYESIAN APPROACH TO DETERMINING AND PARAMETERISING EARTHQUAKE FOCAL MECHANISMS

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A focal mechanism is a simple geometric representation of an earthquake's faulting process, and is typically computed in terms of strike, dip, and rake angles using observations of P wave polarities. We have developed a new probabilistic (Bayesian) method for estimating the distribution of focal mechanism parameters based on routine seismic observations. We use generalised Matrix Fisher distributions to represent uncertainties in the estimated parameters. The advantages of our approach are that it (1) models the data generation process and incorporates observational errors, particularly those arising from imperfectly known earthquake locations; (2) allows exploration of the entire parameter space; (3) leads to natural point estimates of focal mechanism parameters; (4) allows the inclusion of *a priori* information about the focal mechanism parameters; and (5) enables the resulting posterior probability density function (PDF) to be well approximated. We present here the results of our method in two situations. We first consider the case in which the seismic velocity of the region of interest (described by a velocity model) is presumed to be precisely known, with application to seismic data from the Raukumara Peninsula. We then consider the case in which the velocity model is imperfectly known, with application to data from the Kawerau region. We find that our estimated focal mechanism solutions are for the most part consistent with all available polarity data, and correspond closely to solutions obtained using established methods. Further, the generalised Matrix Fisher distributions we examine provide a good fit to our Bayesian posterior PDF of the focal mechanism parameters. Finally, we demonstrate how informative prior distributions on focal mechanism parameters can be incorporated into our model. One example of a situation in which this might be appropriate is when calculating a focal mechanism in a region of known tectonic stress state: by specifying *a priori* that the focal mechanism represent a particular mode of deformation (e.g. normal-faulting), the computation can take into account existing geological knowledge.

TSUNAMI MONITORING IN REAL-TIME

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GNS Science (via the GeoNet project), in partnership with Land Information New Zealand (LINZ), is installing a real-time tsunami monitoring network for New Zealand. To date about half a dozen stations, including one on the eastern side of Chatham Island, are fully operational. When the network is completed in 2010, it will consist of five stations on offshore islands and 15 stations at coastal locations around the main islands of New Zealand. Each station will be equipped with dual pressure gauges that will either be attached to an existing structure such as a wharf or secured to the sea floor. Sea-level data will be relayed from each remote station to the GeoNet Data Management Centre in near real-time.

Data collected from the tsunami gauges will assist in emergency response following the detection of a tsunami and be freely available for research via the GeoNet website, *www.geonet.org.nz*. Moreover, the tsunami gauge network will contribute to an international collaboration to collect and share real-time sea-level data in the Pacific. Here, we present the tsunami monitoring network, describe the station design, and discuss data acquisition and availability.

MODELING OF MULTIPLE EARTHQUAKE CYCLES IN SOUTHERN CALIFORNIA USING THE SCEC COMMUNITY FAULT MODEL

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To understand the complicated fault interactions in southern California, one useful approach is to create simulations that examine a long history of interseismic and coseismic slip on a large number of faults. Each of these faults will have different slip rates and average earthquake recurrence times, providing different time-varying contributions to the predicted surface deformation field as well as the overall stress field. When viscoelastic behavior is considered, it is necessary to 'spin up' such models so that near steady-state behavior is achieved. As a first step in providing such simulations we have computed several simulations using a subset of the faults in the Southern California Earthquake Center (SCEC) Community Fault Model (CFM). The CFM is a detailed geometrical representation of most of the major faults in southern California.

We use the analytical block model of Meade and Hager (JGR, 2005) to compute a consistent set of block rotation poles for a subset of the blocks defined in their model. Although these rotation poles were computed using simplified rectangular fault geometry, our finite element simulations use the full geometry defined by the CFM. Our present model consists of 11 blocks, which are bounded by 55 of the faults from the CFM. The model is purely kinematic, and is driven by a combination of coseismic slip above the 15 km locking depth and velocity boundary conditions consistent with the computed rotation poles applied along the lateral boundaries of the mesh.

We examine several different rheological models, including homogeneous elastic, heterogeneous elastic (using elastic properties derived from the SCEC Community Velocity Model), Maxwell viscoelastic, and generalized Maxwell viscoelastic (two Maxwell models in parallel). We use published recurrence times for the main faults, and use a simple empirical rule to assign recurrence times for the additional faults. The simulations are run for a sufficient period of time to allow each fault to experience several coseismic events. Since the faults of the CFM do not form closed blocks, we also examine the effects of allowing stress and strain dissipation using viscoelastic behavior in the upper crust.

PRELIMINARY RESULTS FROM A DIGITAL MULTICHANNEL SEISMIC REFLECTION SURVEY IN THE OUTER BAY OF PLENTY AND RAUKUMARA BASIN

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We utilised NIWA's newly purchased digital Multichannel Seismic (MCS) reflection acquisition system during the latest voyage of RV Tangaroa (TAN0810) in the back-arc environment of the outer Bay of Plenty and forearc setting of the deep Raukumara sedimentary Basin**.**

NIWA seismic system consists of one GI-gun seismic source and a digital Geometric GeoEel seismic streamer. The seven 100 m-long active sections of the streamer result in 56-channels with a 12.5 m group spacing. The streamer depth is interactively controlled by six Digicourse birds fitted along the streamer. In the near future, fitting of compasses in the birds and a GPS tail-buoy will enable us to monitor the feathering angle in real time. Real-time data and quality control are performed during acquisition allowing for tape storage, real-time display and printing of a selected range of parameters (e.g., log file, gather, spectrum, noise level). The vessel position is provided by R/V Tangaroa's differential GPS and available through the vessel intranet.

We collected five NW-SE seismic transects up to 130 km in length across the entire width of the back-arc, with the aim to quantify the modality of transfer of extensional deformation between the outer offshore part of the Taupo Volcanic Zone (TVZ), which represents the present day continental rift, and the oceanic rifting in the Havre Trough. We also collected three transects cumulating ~230 km, over the distal part of the Matakaoa Debris Flow (MDF) in the northern Raukumara Basin. There, the objective was to image the variations in sedimentary patterns along large mass transport deposits, and to provide means to better understand the mechanisms that enable 200 km-long run-out. The seismic experiment targeted the toe of the MDF, the relationships with the basin sedimentary sequence and the nature of the contact between the debris flow and the Kermadec volcanic arc to the NW.

The digital seismic system demonstrated excellent ability to provide data with an improved signal-to-noise ratio compared to that of the previous analogue system and allowed us to generate images of complex geological structures. The MCS data show penetration greater than 2 s TWT in the sedimentary basins. The frequency spectrum range 20-200 Hz and results in resolution of 2-2.5 m in the upper 250 ms. The basement is well imaged on all seismic lines except for parts where the stratigraphic sequence is thicker than 1.5 s. In the Bay of Plenty, active faults are easily interpreted and will provided material to quantify the present-day rate of extension across the back-arc. In the Raukumara Basin, the MDF shows patches of coherent horizontal reflectors in its lower part, suggesting that the flow partly remobilized the superficial part of the seafloor during emplacement. The MDF sliding surface is well imaged and show variation in the seismic character along the flow transport path.

SYMPOSIUM: MAGMAS

MAGMAS: MANTLE TO SURFACE

Monday 24th November

Rangimarie 2

Magmas 1: 13:30 – 15:00

Tuesday 25th November

Rangimarie 1&2

Magmas 2: 9:00 – 10:30
Magmas 3: 11:00 – 12:30
Magmas 4: 13:30 – 14:15

Plenary: Tuesday 08:30 (Soundings Theatre)

Posters: Tuesday 15:30 – 17:00 (Oceania)

THE GENERATION OF SILICIC MAGMAS IN THE TVZ OVER THE PAST ~ 1.65 MA: INSIGHTS FROM ODP SITE 1123 TEPHRAS

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A suite of silicic tephra layers recovered from deep ocean sediment cores from ODP Site 1123 (*ca*. 1000 km east of New Zealand) provide a well-dated ~ 1.65 Ma record of explosive silicic volcanism from the Taupo Volcanic Zone (TVZ). Previous studies of these tephras have focused on their use as chronostratigraphic marker horizons. Here we use the Site 1123 TVZ tephra record as a petrogenetic archive to investigate the processes responsible for the generation of explosively erupted silicic magmas from the TVZ during the last ~ 1.65 Ma. Our previous major and trace element characterisation of single glass shards (melt quenched on eruption) from these tephra layers has identified four broad 'melt types' that are defined on the basis of both age and chemistry (Allan *et al*. in press, *Quaternary Science Reviews*). Here we present new high precision Sr, Nd and Pb isotopic data obtained on high purity glass separates from thirteen Site 1123 tephra units that encompass the extremes of chemical composition and eruption age (~1.65 – 0.027 Ma).

Major and trace element data indicate that melt (glass) compositions of Site 1123 tephras younger than ~0.83 Ma are almost exclusively more evolved (e.g. higher SiO_2, lower Zr) than the oldest tephras (1.50 -1.65 Ma) and trace element fractionation indices (e.g. Rb/Zr, Zr/Hf, Nb/Ta) show this is a reflection of greater degrees of fractional crystallisation. Chemical variability within the melt composition of some individual units document these fractional crystallisation processes. However, some units reveal strong positive correlations between compatible and incompatible trace elements (e.g. Sr vs. Rb) indicative of mixing of discrete batches of magma prior to eruption. The compositional groupings revealed by major and trace element data are not evident in the isotopic data suggesting these groupings are primarily crystallisation signatures rather than indicators of crustal contamination.

The chemical and isotopic variation observed in the 13 representative units is small when compared with other global examples of large volume silicic magmas (e.g. Yellowstone, Yemen-Ethiopia). The isotopic compositions of the Site 1123 tephras require a two-stage contamination process whereby primitive TVZ basalts are contaminated first by Waipapa crust, followed by assimilation of Torlesse crust, before evolving to more silicic compositions by prolonged fractional crystallisation. Implicit in this is that a sub-parallel contact between the two crustal lithololgies occurs at depth beneath the TVZ. The isotopically less extreme composition of Waipapa (compared to Torlesse) crust allows for the cryptic assimilation of significant volumes of Waipapa crust (up to 10%) without imparting a strong crustal isotopic signature (Sr, Nd, Pb, O) on the initial basaltic magmas. In this model most of the units (10/13) require a significant, but uniform, amount of crust (~ 30%) and almost all of the isotopic variability between units comes from the differing amounts of each crustal lithology incorporated into the magmas.

LOOKING INTO A VOLCANO – MAAR DIATREME REMNANTS FROM THE EGER RIFT

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The Eger Graben is one of the young active rift systems in central Europe. Lateral extension, active magmatic underplating and several episodes of volcanic activity took place during Neogene time. The last known eruption occured about 100 ka ago. Here we present three examples of intracontinental maar - diatreme volcanism from the western Eger Rift which took place about 20 to 26 Ma. The focus of our research was their physical volcanology, their distinct levels of preservation and how such volcanoes can contribute to the understanding of the general geological situation. The first example the “Hirschentanz tephra ring” - deals with the surface structures of maar - diatreme volcanoes. At the “Parkstein” a diatreme and a shallow subvolcanic body is exposed Aligned diatremes are reported from the Waldeck volcanic complex. The poster presented summarises this information, and also illustrates how these interesting volcanic features are presented for public sites in this area. The aim is to increase public awareness of natural features, and of earth processes. Signboards incorporating graphics from the poster have been produced for the Geopark program in Germany and for sites in the Czech Republic.

INSIGHTS INTO EXPLOSIVE ERUPTION PROCESSES: DENSITY STUDIES OF SUBAERIAL AND SUBMARINE PYROCLASTIC DEPOSITS, KERMADEC ARC

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Explosive volcanism involving crystal-poor dacite to rhyolite magmas is common in the young records of many volcanoes along the intraoceanic Kermadec arc. Such volcanism occurs at both submarine and subaerial volcanoes, and is often of a size that caldera collapse occurs. Three volcanoes present unique circumstances that can provide insights into the processes involved in explosive volcanism. Healy, Macauley and Raoul volcanoes have erupted similar silicic magmas within the last 10 kyr in deep marine, shallow marine and subaerial settings, respectively. To investigate eruption processes from these three volcanoes we have characterized the density spectrum for juvenile pumice clasts in the 16-32 mm size fraction using water immersion techniques [Houghton & Wilson, Bull Volc. 51, 1989]. At Raoul, we have data from five eruption deposits of widely contrasting dispersal (strombolian to plinian). Four of these eruptions show no evidence for involvement of external water: all samples show narrowly-defined peaks of density despite wide differences in eruption size. Only one subaerial eruption shows evidence for interaction with external water, consistent with the large density range observed. Subaerial deposits from Macauley Island show a narrow peak in density, but display a slightly wider range caused by a subtle tail-off to denser clasts. Co-eruptive submarine deposits show large variations in density, with multiple peaks identified. Although from the same eruption (as shown by continuity on seismic profiles), these submarine deposits display a significant contrast in density spectra, which reflects the syn-eruptive redistribution of clasts with diverse densities. Material dredged from 1320 to 2110 m water depth at Healy also shows a large density range, but displays a unimodal low-density peak and lacks syn-eruptive selective redistribution of clast populations. Density spectra will be used to constrain the choice of clasts for imaging of vesicle textures and geochemical studies.

IDENTIFYING CYCLIC ERUPTION FREQUENCY BY HIDDEN MARKOV MODELS: IMPLICATIONS FOR PROBABLISTIC HAZARD FORECASTS

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Standard renewal-based models provide estimates to the likelihood of an eruption event in the future, based on the assumption that the intervals (repose periods) between eruptions are independent and identically distributed. However, how accurate is this assumption to volcanic processes? The results of the mixture of Weibulls renewal model on a combined dataset spanning the last 6000 years from Mt Taranaki revealed distribution peaks of inter-event periods at 16 and 232 years. This observation suggests that there may be some structure to eruption frequency. Hidden Markov models (Bebbington, 2007) provide the means to quantify this observation. These models allow the distribution of time between the events (reposes) to depend on an unobserved or hidden 'state variable'. For the combined record (<6250 years B.P. – present) it was found that there were three optimum state variables corresponding to typical repose lengths: short (~25 yrs), intermediate (~75 yrs) and long (~250 yrs). Given that the last eruption occurred in AD 1860, the hidden Markov model provides strong evidence that the volcano is in a period of long repose. The resulting annual eruption probability provides a far more accurate eruption prediction than the standard renewal models alone. In addition, applying hidden Markov models to the combined dataset confirms that there is structure to the eruption frequency of Mt. Taranaki with times where short or long repose periods dominate. These periods seem to alternate on a regular 1000 – 2000 year timescale. This is in agreement with the observations of Turner et al. (2008) and is likely to be related to cyclic magmatic processes.

Bebbington M.S. (2007) identifying volcanic regimes using hidden Markov models, *Geophysical Journal International*, 171: 921-942.

Turner M.B., Cronin S.J., Smith I.E.M., Bebbington M.S., Stewart R.B. (2008) Using titanomagnetite textures to elucidate volcanic eruption histories, *Geology*, 26: 31-34.

PYROXENE RESIDENCE-TIMES FROM MT. NGAURUHOE AND MT. TARANAKI

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Andesitic magmas compose a relatively minor component of the observed volcanism generated in the North Island of New Zealand. Two active andesitic centres are Mt. Ngauruhoe, located at the southern extreme of the hyper-active Taupo Volcanic Zone and Mt. Taranaki located significantly westwards of the main subduction volcanism. These two volcanic systems differ in both their recent eruptive history and magmatic chemistry with Mt Taranaki producing high-K amphibole-phyric magmas every 200-300 years in contrast to the decadal eruption record of pyroxene-plagioclase-phyric lavas from Mt. Ngauruhoe since written records began until 1975. Detailed analysis of zoned phenocrysts from these eruptions has the potential to reveal changes in the magmatic environment during crystallisation and magma storage. Furthermore, the residence times of crystals can be calculated from elemental diffusion profiles across abrupt compositional boundaries. This compositional record progressively diminishes the longer the crystal remains at magmatic temperature, smoothing the compositional gradient. This diffusion process is quenched and preserved at eruption with the shape of the compositional profiles allowing the time spent at magmatic temperatures to be calculated and timescales of magmatic storage to be inferred.

Pyroxene phenocrysts from two samples of recent eruptions from each of Mt. Ngauruhoe and Mt. Taranaki were analysed for major elements by electron microprobe. Combined with backscatter imagery this allowed numerous compositional zones to be indentified within crystals. This has permitted diffusion modelling of Fe and Mg profiles across the final compositional boundary corresponding to the final stages of magmatic storage to be conducted. Prior to diffusion modelling, the diffusivities of these elements, which are temperature dependent, must be calculated. Three geothermometry methods were used: (1) CaO of melt inclusions in clinopyroxenes; (2) Fe-Ti oxide thermometry; and (3) two-pyroxene thermometry. This generated a range of temperatures with melt inclusion thermometry consistently indicating lower temperatures. The latter two methods were considered more reliable even if serious doubts remain concerning the exactitude of the values and indicate magmatic temperatures of 1100°C for Mt. Ngauruhoe, and at least 50°C lower for Mt. Taranaki. This resulted in preliminary calculated residence times of ca. 30 years for Mt. Ngauruhoe and ca. 200 years for Mt. Taranaki.

THE AUCKLAND VOLCANIC FIELD: GEOPHYSICAL EVIDENCE FOR STRUCTURAL CONTROLS AND SPATIO-TEMPORAL RELATIONSHIPS

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The Auckland volcanic field (AVF) coincides with an area of deep-seated crustal complexity resulting from a Mesozoic terrane suture, marked by the Junction Magnetic Anomaly (JMA). In the Auckland region, a significant discontinuity in the JMA occurs, marked by multiple lineaments. The AVF is coincident with the southern boundaries of both this magnetic discontinuity and a large anomalous high-density crustal block marked by a major gravity anomaly. Furthermore, the extent of the AVF correlates closely with the width of these anomalies, suggesting that upper crustal structures may exert significant control on both the overall location and geometry of the field. However, there is no clear correlation between individual volcanic vents and the magnetic lineament fabric. A new residual aeromagnetic map of the AVF shows that anomalies associated with the volcanoes range from 10 - 1000 nT. Volcanoes with scoria cones are associated with significant magnetic anomalies whilst maars exhibit a wide range of magnetic expressions. The most significant sources of the observed anomalies are basalt bodies which occur below the cones and some maars, and are interpreted as sub-volcanic intrusions or crater-filling lava lakes. There is no evidence in the magnetic data for substantial near-surface volumes of basaltic rocks where there are no known eruption centres or flows. No elongate anomalies are apparent either at or between centers, that might indicate magma intrusion or eruption along dyke-like conduits, though the possible occurrence of narrow or deep dykes is beyond the resolution of the present data. Paleomagnetic data have provided a unique insight into eruption patterns within the AVF, temporally linking at least five volcanoes which may have erupted contemporaneously, though which exhibit no obvious structural relationship. There is further paleomagnetic and aeromagnetic evidence for contemporaneous eruptions from some adjacent vents that are apparently aligned along regional structural trends, however there are also cases where this is not so. The five contemporaneous eruptions imply concurrent melting across the width of the mantle source region, perhaps caused by a transient increase in regional extension rate that could have initiated relatively rapid decompression melting, coupled with fracturing in the overlying lithosphere.

SEISMIC SIGNALS ASSOCIATED WITH THE 2007 LAHARS OF MT. RUAPEHU, NEW ZELAND

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Many lahar warning systems are based on the detection of ground-shaking caused by the mass flows as they travel. In 2007, two types of lahars were recorded at a monitoring station within the Whangaehu catchment on the middle slopes of Ruapehu Volcano, New Zealand. The first was generated by an outbreak of Crater Lake (18 March 2007), while a second series of flows was initiated by a small phreatic eruption on 25 September 2007. The March event was a water-rich, sediment-laden, hyperconcentrated flow; the largest September events were, by contrast, snow/ice-dominated. Interpretation of seismograph records of these flows is used here to illustrate the versatility of these instruments for characterising the internal dynamics and rheology of lahars. Lahar-produced signals are clearly distinguishable from those produced by eruptions, earthquakes and normal floods, although they show similar profiles to those of snow avalanches. Analysis of relative ground motion between 3-dimensions (particularly flow parallel and flow-transverse planes) as well as the characteristics of excitation frequencies can be used to infer features such as the dynamics of large particles and the nature of their interaction with the bed, dominant flow rheology, and gross physical composition. In confined channel settings, water-rich, sediment-laden hyperconcentrated flows show highest energy in cross-channel vibrations compared to the channel-parallel direction. This appears due to inter-particle and particle-channel collisions, fitting with observations of their high degree of turbulence. Snow-dominated flows, in contrast, show greater energy in channel-parallel signals. We interpret this to result from the insulating effect along channel margins caused by lateral deposition, as well as damping of internal turbulence and hindering particle collisions. Direct size comparisons between the snow and water rich lahars are correspondingly impossible to make due to their different type of frictional contact with the substrate. The signals generated by water-rich lahars have order of magnitude higher amplitudes than those produced by similar sized snow-dominated flows.

CARBONATITE EVOLUTION IN A LAMPROPHYRIC DYKE SWARM, SOUTH WESTLAND, NEW ZEALAND.

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A late Oligocene-early Miocene (~25 Ma) alkali lamprophyre dyke swarm intruded the Haast Schists in western South Island, New Zealand during transtensional development of the Alpine Fault plate boundary. Intrusive rocks comprise ultramafic and feldspathic lamprophyres (~64% by volume), tinguaites, trachytes (collectively 35%) and carbonatites (~1%). The evolved members of the swarm cause intense local fenitization of the country rock producing aegirine-riebeckite schists. Carbonatites show a wide range of compositions from calcite- through dolomite/ankerite- to siderite- and norsethite-rich varieties. Sr, Ca-Sr, Ca-Ba and REE carbonates and phospho-carbonates occur in accessory amounts.

Sr, Nd, and Pb isotope ratios and nodule petrology indicates magma derivation from a previously metasomatised mantle source dominated by the FOZO component. Very restricted ranges in radiogenic and stable isotope ratios indicate that all members of the swarm are co-genetic. Efficient fractional crystallisation of camptonite lamprophyre yields a phonolitic/tinguaitic residuum that then separates immiscibly to form carbonatite magma. Not all carbonatites are derived from a single lineage, so immiscibility may operate repeatedly during late fractionation. The final stages of carbonatite evolution (<400°C) are dominated by carbothermal processes, during which the carbonatites and associated silicate rocks develop LREE-depleted, MREE-enriched patterns.

EMPLACEMENT OF THE RANGIAURIA BRECCIA, CHATHAM ISLANDS

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The Rangiauria Breccia is a coarse, basanite, volcaniclastic deposit found on Pitt and Mangere Islands in the Chatham Island Group. The unit was formed by a series of violent eruptions in the Late Miocene, with at least 5 separate diatremes identifiable today. The deposits consist dominantly of vertically jointed, highly consolidated, black, vent-fill breccia, with distinctive amphibole megacrysts (up to 20 cm). The bulk of the synchronous peripheral volcaniclastics have long since been removed. There are 3 vents that are accessible for detailed study: Waihere Head and Rangiauria Point, both found on the west coast of Pitt Island, and Mangere Island. Rangiauria Point is a massive, highly consolidated, diatreme structure, standing 200m vertically out of the sea. The main edifice of Mangere Island is formed from the near vent deposits. Preserved here are a number of finely bedded layers that suggest a phreatomagmatic origin for at least part of the eruption sequence. Waihere Head contains the only traceable proximal to distal sequence. Here the fanning out of the vent is fully exposed, forming a flower structure that shows sharp contacts with the surrounding strata. In places the contact is found to be baked. At Waihere Head the sequence appears to have originated as a series of pyroclastic flows sourced from a diatreme style vent. This study is examining these deposits in an attempt to understand the emplacement mechanisms of the Rangiauria Breccia.

MINERAL ZONING IN PLAGIOCLASE: IMPLICATIONS FOR CRYSTALLIZATION HISTORY.

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Feldspar stability is a function of magma composition, temperature, volatile content and to a lesser extent pressure. In particular, plagioclase phenocrysts can grow in magmas of very diverse composition (eg. picrite to rhyolite) tectonic setting, (eg. island arc, mid-ocean ridge and intra-plate hotspots, etc) and over a wide range of crystallization temperatures. These attributes of magmatic plagioclase, combined with its ability to remain chemically zoned, provides a useful "recording tool" that reveals magma processes over prolonged periods of crystallization.

In this study we use results obtained from detailed electro-microprobe traverses across plagioclase crystals from Tanna island to investigate factors controlling magma crystallisation. Tanna island (Vanuatu archipelago) is characterized by the presence of plagioclase ultraphyric lavas and is thought to be the remnant of a large caldera complex, now subsided below sea level.

Although Tanna ultraphyric lavas are mostly basaltic trachyandesite, the groundmass compositions vary from basaltic trachyandesite though to trachyte. The extent of this groundmass fractionation is found to be directly related to the modal abundance of plagioclase phenocrysts in the samples. This suggests that the prevailing magma forming process was dominantly in-situ plagioclase crystallization rather than assimilation.

Three plagioclase morphologies are noted, including euhedral phenocrysts, sieved/resorbed crystals, and groundmass microphenocrysts. The euhedral plagioclase phenocrysts are abundant and invariably oscillatory zoned from core to rim within the range An_{58} to An_{63}. Sieved and resorbed plagioclase crystals are less common and highly anorthitic (An_{88-90}). These resorbed plagioclase crystals tend to be overgrown and enclosed by euhedral, oscillatory-zoned plagioclase. Groundmass microphenocrysts are similar in composition to those of euhedral phenocrysts. A narrow (<50microns) K-feldspar rim is commonly present in all plagioclase phenocrysts and groundmass mycrophenocrysts. These outer rims become more K-rich towards the margin (ie reversely zoned) and their compositions do not represent equilibrium crystallization pairs, as they are sequential.

The textural and compositional variations of plagioclase investigated are interpreted to represent four stages of crystallization of the magma forming process: (1) incorporation of xenocrystic anorthitic plagioclase by the host magma, (2) abundant growth of less calcic oscillatory zoned euhedral plagioclase to produce phyric textures, (3) nucleation of calcic groundmass plagioclase microphenocrysts, and (4) mantling by K-feldspar rim overgrowths.

QUANTIFYING PHYSICAL PROCESSES FROM MEASUREMENTS OF LAHARS IN MOTION AT SEMERU VOLCANO, JAVA, INDONESIA

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Most existing numerical models of lahars assume constant volume, without consideration of entrainment of substrate or deposition of particles. Bulking processes are vital to the dynamics and evolution of these flows. Due to the scarcity of empirical data, numerical treatment of entrainment commonly involves purely theoretical functions. We present data from a recent multi-parameter field study in Semeru, East Java, conducted to investigate and quantitatively describe the entrainment, bulking and de-bulking processes of active lahars. Using a variety of geophysical measurement techniques, rain-triggered lahars have been measured in the Curah Lengkong valley on the SE flank of the volcano, at a location 9.5 km from the summit. Here the channel is composed of a 30-m wide box-valley, with a base of gravel and lava bedrock. Instrumentation included video cameras (flow velocity, stage, and flow rheology), pore-pressure sensors, load cells, a 3-component broad-band seismometer, in addition to direct bedload and suspended load sampling. Two instrument sites were established 510 m apart to derive inputs and outputs for constraining reach-based numerical lahar-modelling, as well as providing a field experiment through which active processes such as entrainment, deposition and changes in rheology can be investigated. Flow types observed range from hyperconcentrated streamflows (<40 wt.% sediment) up to rare coarse debris flows (50-60 wt.% sediment). Flow depths were 0.5-2 m, peak velocities 3-6 m/s and maximum discharges between 25 and 400 m^3/s. The lahars are typically of rapid onset, with sediment concentration maxima that lag the lahar front by 10-20 minutes. Velocity, stage and sediment concentration records reflect surging and unsteady flow. Pore pressure and load sensors permit characterisation of sediment concentrations within the active flow. Seismic signals of the most sediment-rich flows demonstrate saturation across broad frequency ranges up to 70-80 Hz; the frequency component between 1-20 Hz contains the most energy and marks the difference between flows carrying/rolling boulders vs. streamflow with low sediment concentration. Comparisons of stage and wetted area suggest the flow is bulking by at least 50% between sites. Multiple peaks, observed in the stage records, provide useful "markers" that indicate that the wavelength of the lahar is also shortening down stream, as the bulk of the flow catches up with the flow front. This investigation indicates that the use of two closely located instrument sites provides a more accurate characterisation of the nature of these complex flows, thus furthering both our physical understanding and their numerical description, vital for the development of hazard mitigation tools.

PETROLOGY AND CORRELATION OF LAVA FLOWS FROM THE CENTRAL PART OF THE AUCKLAND VOLCANIC FIELD

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The Auckland Volcanic Field (AVF) is a small, monogenetic, basaltic field with at least 50 volcanic centres. The eruptive volume of the field is approximately 4km^3 with at least half of this amount produced during the eruption of Rangitoto about 700 years ago. Many of the volcanoes in the AVF have produced extensive lava flows which outcrop at numerous locations around the city and at the prominent Meola Reef, a flow which extends 2.5 km into the Waitemata Harbour. Differentiating between individual flows and correlating them to source vents has always been difficult due to the lack of subsurface information available; in particular, a lack of suitable material for radiometric dating means that few of the flows have been reliably dated.

Boreholes and core logs provide a unique insight into the geometry, structure, extent and source of these lava flows. Using borehole derived data it is possible to differentiate between flows and correlate these flows to source vents. Using more accurate flow geometry data, it is possible to recalculate volumes for individual centres to provide a better understanding of individual eruptions. Dating of these eruptions is also possible where the borehole extends through the basalt into an organic horizon.

The geochemistry of samples from 34 boreholes from the western edge of the Auckland Volcanic Field along with 37 surface samples from the same area reveals three compositional groups. Two groups represent Mt Eden and Three Kings lava flows with the third group, which includes Meola Reef flow, correlating well with Mt St John volcano. Lava flow stratigraphy in the boreholes reveals that the Mt St John flow represents the basal flow unit in this area with Three Kings lava and Mt Eden lava directly overlying this unit in places. The stratigraphic relationship between Three Kings and Mt Eden flows remains unclear. New C^{14} dates measured on organic material found within the boreholes have constrained the age of Three Kings volcano to approximately 28,600 years cal BP while C^{14} results for Mt St John suggest it is older than 50,000 years.

EVOLUTION OF BANKS PENINSULA: MULTIPLE ERUPTIVE CENTRES AT LYTTELTON VOLCANO

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Banks Peninsula has historically been viewed as the highly eroded remnants of two large volcanoes Lyttelton (11.0 – 9.7 Ma) and Akaroa (9.3 – 8 Ma), which underwent sector collapse and erosion, to produce the current morphology and distinctive harbours of Lyttelton and Akaroa. This study indicates both volcanoes developed as a series of overlapping cones, producing a complex network of inter-cone valleys. These valleys channelled erosion, with the larger of these systems forming the Lyttelton and Akaroa Harbours, respectively.

Banks Peninsula provides a unique oceanic volcanic setting, where primary volcanic landform orientations and trends can be used to establish volcanic evolution. Primary volcanic landforms are features incepted during the growth of a volcanic cone, which can be used in the identification of eruptive centres. These are constructional (lava flows, scoria cones and domes), hypabyssal (dykes and sills), and erosional volcanic features (valleys and ridges).

Constructional volcanic features such as lava flow trends are used to identify individual cones through orientations and onlapping structures, while lava flow morphology / rheology is used to highlight distinct horizons that reflect cone growth and vent shifting. Scoria cones and domes occur on the outer flanks of each volcanic edifice, often related to blocky lava horizons and dyke swarms. Hypabyssal volcanic features intrude weak planes within a volcanic cone, with radial dyke swarms converging on an eruptive centre. Erosional volcanic features are radial, incepted during and directly after volcanism that become further accentuated by erosion with time. The orientations of valleys and ridges indicate the original summit of each volcanic cone. Eruptive centres are identified when clustering of primary volcanic landform trends and orientations converge on a 500 m x 500 m zone. Each eruptive centre has an associated cone sector and cone artefacts. A cone sector, the preserved remnant of a volcanic cone, is defined by a basal footprint and an erosional crater rim. Cone artefacts are remnant arcuate features of a volcanic cone, exposed due to subsequent erosion.

VOLCANIC EVOLUTION OF LYTTELTON VOLCANO, BANKS PENINSULA

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Lyttelton Volcano, Banks Peninsula, has a complex volcanic evolution. Using field mapping, aerial photograph analysis, Corel Draw, ArcGIS, and Vulcan, the evolution of Lyttelton Volcano can be determined. Graphic representation of volcanic structures allows further analysis and direction, and provides an easy medium to present complex geological data.

The reconstruction process begins with the identification of eruptive centres, and the recognition of cone sectors and outer flank horizons associated with an eruptive centre. Topographic spot heights are then extracted from these regions, where existing contour lines reflect the volcanic structure or intersect outer flank horizons. Spot heights are placed into a Corel Draw where the projection of contours occurs, constructing the basal sequence of a volcanic cone. Cross section lines are then projected from the reconstructed basal section towards the identified eruptive centre, using dips recorded from an associated erosional crater rim, which are projected onto the basal sequence, resulting to form a plan view contour model of a volcanic cone. The reconstruction is then imported to Vulcan 7.5 (Isis), with contour heights attributed, and cone surfaces triangulated to produce a 3D model of each volcanic cone.

Highlighted within the reconstruction process is the formation of inter-cone valleys, which acted as the main erosive pathways. In the central regions of Lyttelton Volcano a large inter-cone valley system developed to form proto-Lyttelton Harbour. Modelling also indicates the importance of the pre-existing basement structure, fault regimes, and the influence of this reconstructed volcanic structure in the evolution of Banks Peninsula.

SHEAR WAVE SPLITTING ANALYSIS OF THE SEISMICITY BEFORE AND DURING THE 2008 ERUPTION AT OKMOK VOLCANO, ALASKA.

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Okmok volcano, located in the Aleution arc in the Northern Pacific Ocean, is the most active caldera system in North America in historic time, with eruptions averaging about every twelve years since written records began. The permanent seismometer network around the volcano, consisting of four 3-component broadband and nine vertical component short-period sensors, and stations on nearby islands have been used to monitor the volcano since their installation in 2003.

In some respects it can be said that Okmok Volcano is similar to Mount Ruapehu and the TVZ in the centre of the North Island of New Zealand; both systems are clearly very complex and have a wide range of magma compositions; both experience magmatic eruptions approximately every decade; and both potentially pose a hazard to people, buildings and airtraffic. It is therefore important to gain understanding of other volcanic systems such as Okmok and test new prediction tools on available data in order to better apply them to Ruapehu and other New Zealand volcanoes.

We present an analysis of the seismicity at Okmok Volcano since 2003. Using a newly developed velocity model we relocate the Alaska Volcano Observatory's Okmok seismicity catalogue using double difference and waveform alignment methods with bispectrum-verified cross-correlations. In general co-eruptive earthquakes occur in distinctly different crustal volumes than earthquakes located before the 2008 eruption but clusters are identified that occur before and during the eruption.

Using the improved Earthquake catalogue, we search for changes in shear wave splitting associated with the 2008 eruption. Traditionally, shear wave splitting has been interpreted to reflect the orientation of microcracks in response to the stress field over the earthquake's ray path. Hence shear wave splitting can be used to monitor stresses imposed by magma intrusions and pressurisation of volcanic plumbing systems. In this study we focus the shear wave splitting analysis on the seismicity multiplets to search for temporal changes in anisotropy that are independent of variations in earthquake location, source radiation and hence of the effects of spatial changes in anisotropy sampled by differing raypaths. We use the Teanby et al. *(Bulletin of the Seismological Society of America (April 2004), 94(2):453-463)* cluster analysis method to determine shear wave splitting parameters in a semi-automatic fashion and emplace strict constraints to ensure the stability of the result. Prior to the eruption each station has fast polarisations that are highly aligned, as shown by using events from both varied azimuths and from individual clusters. Preliminary analysis of data from the time during the eruption show significantly more scatter, but suggest a change in fast orientation.

WHAT CONSTITUTES UNREST AT TAUPO CALDERA, NEW ZEALAND?

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Geophysical surveillance has been undertaken at the Taupo Volcanic Centre for over 30 years. Since 2001, the Taupo Volcanic Centre has been monitored by GeoNet, an Earthquake Commission funded project to produce high quality geophysical and geochemical data related to New Zealand's earthquakes, volcanoes, landslides and tsunami. Taupo Volcano is a large caldera that has had highly explosive and voluminous eruptions, including the 1.8 ka Taupo eruption and the 26.5 ka Oruanui eruption. There have also been more than 20 much smaller eruptions in the last 25,000 years. The most recent eruptive activity was ca. 1,700 years ago. Over the past 100 years there have been several periods of unrest associated with the caldera, including notable seismic swarms in 1922, 1964 and 1983.

GeoNet data provide an enhanced capability for measuring smaller changes in geophysical signals associated with Taupo Volcano. In September-October 2007, deformation recorded on a new cGPS network showed changes of up to 5-10 mm. This has been modelled as an inflating shallow source under the lake. Associated earthquake swarms (up to 100 events per month) occurred after the deformation event, but were distributed over a wide area in and around the caldera. This magnitude of deformation and seismicity is not uncommon at Taupo Volcano, and can now be better resolved with the enhanced network coverage.

These recent data have been examined in the context of historical activity at Taupo and other caldera volcanoes, and as informed by forward and inversion modelling of deformation data. The data provide valuable information about baseline activity at Taupo against which an assessment of future unrest can be measured. Further work is required to understand the processes driving the observed changes in the monitoring data.

NEW AGES FOR THREE PHASES OF THE DUN MOUNTAIN OPHIOLITE AND TECTONIC AFFINITIES FROM ZIRCON GEOCHEMISTRY

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Laser Ablation ICPMS U/Pb zircon dating and zircon geochemistry have been used to create new models for the formation of the Dun Mountain Ophiolite. The Dun Mountain Ophiolite is a primarily mafic sequence of igneous rocks. Oceanic felsic rocks crosscut the various mafic dykes several times in the sequence and have been sampled for dating. The oldest plagiogranites from crosscutting relationships are 278 ± 3 Ma. These are cross-cut by leucocratic igneous breccias which are 277 ± 3 Ma. The age of these two lithologies can't be distinguished by this method. A granodiorite from Otama near Gore is 269 ± 5 Ma. This is resolvably younger than the other two ages and previously obtained ages of the Dun Mountain Ophiolite. This new younger age also reduces the inferred age gap with the overlying Maitai Group.

Cross-cutting relationships and whole rock geochemistry show that the above-subduction geochemical signature increases with time. The zircon geochemistry shows the same trend as the whole rock geochemistry. The tectonic origin is inferred using the U, Yb and Y concentrations in the zircons. The early plagiogranite zircons have an oceanic signature and the slightly later leucocratic igneous breccias are between arc and oceanic zircon chemistry. This excludes previous models which have had an older oceanic crust intruded by significantly younger above subduction magma. The Otama granodiorite zircons have an arc geochemistry. The Otama sequence is significantly more felsic then the rest of the Ophiolite and an arc origin has also been inferred by other workers.

DIRECTED BLAST DEPOSITS OF THE 25 SEPTEMBER 2007 PHREATIC ERUPTION AT MOUNT RUAPEHU, NEW ZEALAND

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Mt. Ruapehu erupted on 25 September 2007 at 8.26 pm NZDT generating a moderate steam column to about 4.5 km above the crater lake, and a directed ballistic and surge deposit of coarse blocks and ash to the north of the Crater Lake. It also initiated lahars in two catchments. The eruption occurred during the ski season and it resulted in the temporary closure of the ski fields.

Post-eruption monitoring by *GeoNet* focused on collection of evidence to decide whether there was new magmatic activity. Visual observations and subsequent sampling of the deposits on the summit area identified a ballistic apron extending northward as far as ~2 km from the Crater Lake (~500 m from a chairlift/rope-tow). The ballistics comprised various rock types, from old andesitic lava flows, a variety of mineral-cemented lake floor sediments, and vent-fill debris. A number of sulphur–bearing rocks contained molten sulphur textures, indicating vent temperatures at the base of the lake in excess of 119°C.

The ballistic deposit is confined to ~90° azimuth about north (ie. NNE to WNW) from the vent area (within the crater lake). Moderately strong southerly winds during the eruption had little effect on the distribution of the ballistic deposit. The surge deposit is topographically controlled within the northern plateau with minor run-up deposits partially to fully overtopping steep-sided crater walls. The directionality of the phreatic eruption is likely to be a consequence of an inclined vent. Seismic modelling of the blast pulse using finite-difference methods are consistent with this interpretation. This eruption highlights the potential for future directed blasts from Ruapehu's northern vent to occur with little or no warning.

NGAURUHOE INNER CRATER RECONSTRUCTION AND ERUPTION DYNAMICS OF THE 1954-1955 STROMBOLIAN ERUPTION

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Magma ascent dynamics is an important influence on eruption styles and processes and an understanding of them can contribute to the improvement of monitoring methods. Ngauruhoe is an active andesite to basaltic andesite composite cone volcano at the southern end of the Taupo Volcanic Zone and most recently produced explosive eruptions in 1954-55 and 1974-75. These eruptions constructed the inner crater of Ngauruhoe, largely composed of 1954-55 deposits which are the basis of this study.

The inner crater can be divided into two sectors: the northern sector which is covered in debris from the collapse of the uppermost crater rim during the 1975 eruption, and the southern sector which is composed of a pyroclastic package, here divided into six lithostratigraphic units (A to F). The four lowermost units (A-D) are attributed to the 1954-55 eruption. They are, from oldest to youngest: Unit A, a densely agglutinated spatter deposit with sharp clast outlines and a thickness of 17.5 m; Unit B, a scoria lapilli deposit with local agglutination and scattered spatter bombs up to 1.5 m in diameter and a unit thickness of 11.2 m; Unit C, a 6.4 m thick, densely agglutinated banded spatter unit with lateral variations in agglutination; and Unit D, a 10 m thick scoria lapilli with local agglutination. Units A-D consist of scoria clasts, dense angular-subangular basaltic andesite lithic clasts, and coarse ash, and all three components contain phenocrysts of plagioclase, orthopyroxene, and augite, minor amounts of olivine, Fe-Ti oxides, xenoliths of quartzite and greywacke, and a microlitic groundmass. The overlying Unit E (80 cm thick) is a series of scoria and lithic lapilli and ash beds and is considered to represent the early vulcanian episode of the 1974-75 eruption. The uppermost Unit F (average 4 m thick) was deposited during the 1974-75 eruption and is a densely agglutinated spatter deposit.

The inner crater of Ngauruhoe is dominated by 1954-55 eruption deposits principally formed through strombolian activity with varying eruption rates apparent in the degree of agglutination. Unit E represents a series of ash and lapilli-producing eruptions dominated by pyroclastic fall and surges. Although much of the 1974-75 activity was vulcanian, unit F was formed by rapid deposition of strombolian deposits. The quartzite and greywacke xenoliths likely originated from underlying Torlesse metagreywacke, and have been metamorphosed to quartz-wollastonite-diopside.

THE MAY 2008 CHAITÉN ERUPTION: ASH PROPERTIES AND IMPACT

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Chaitén volcano is located on the eastern margin of the Corcovado Gulf in the Region of Los Lagos, Province of Palena, Central Chile. It is one of 8 major volcanic centres of the Andean Southern Volcanic Zone (SVC) that terminates with Mt Hudson. Chaitén volcano was considered extinct till May this year, as only Holocene eruptions had been identified in its stratigraphic record. By contrast, the neighbouring ice-covered Michinmahuida volcano is known to have erupted during historic times (Darwin, 1838). While Chaitén's last major pyroclastic eruption has been dated at 9,370yr BP, ^{14}C ages obtained on prehistoric artefacts found in coastal settlements suggest the old obsidian dome occupying Chaitén's caldera floor may have been emplaced 5,610yr ago (Naranjo and Stern, 2004). On May 2, 2008, Chaitén volcano violently erupted, ejecting a 30km high Plinian column during the paroxysmal phase of the eruption. Since then, as a new dome of rhyolite progressively grew in the caldera, expelled ash has covered large areas of Central Chile and southern Patagonia in Argentina (Folch et al., 2008), affecting the local economy and the natural resources of the region. The nearby town of Chaitén (c.4,000 inhabitants), evacuated early in May, has since been extensively damaged by lahars sourced from ash-laden rivers draining the volcano.

Chaitén ash produced during its first week of activity has been collected from the Futaleufú district located at c.80km from source (courtesy of Ch. Hepp, INIA Temel-Aike). Our XRF results indicate a 'low-silica' rhyolitic composition (SiO_2<75%wt) typical of the SVC, and fall into analytical fields previously defined on pumices for the Chaitén-Michinmahuida volcanic group. Particle size analyses completed on the Horiba laser-scattering PSDA LA-950V2 show systematically a bi-modal distribution with peaks centred at 12-16 and 60-90µm (Median size: 43.7µm; Mean size: 65.1µm; Std Dev: 63.5µm; Standard R.I=1.53), while bulk ash samples cover the very fine silt to medium sand range (3 to 350µm; 9 to 1.5 Phi). These characteristics are comparable to those obtained for the 1980 Mt St Helens and Soufriere Hills eruptions (C. Horwell, IVHHN Report, August 2008). About 8% vol of ash fall into the category of respirable particles <4µm. Optical examination of Chaitén ash under NL and PL conditions reveal the distinctive angular shape of crystal/lithic particles (plagioclase dominant?), and the fibrous, elongated texture of glassy fragments (cristobalite). By comparison, the 1994 andesitic ash from Vulcan (Rabaul, PNG) and the 1996 ash from Ruapehu appear to be much darker, coarser and depleted in fine glass particles, suggesting a higher degree of fragmentation for the rhyolite-fed Chaitén eruption. Potential environmental impacts of the Chaitén event are discussed in light of lessons acquired from the 1991 Mt Hudson eruption (Inbar et al., 1995; Hepp et al., 2008).

THE DEVORA PROJECT: WHAT IS AUCKLAND'S VOLCANIC RISK?

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Auckland, with a population of 1.4 million, is a vital link in New Zealand's economy and is being developed as an internationally desirable place to live and work. However, Auckland is built on the potentially active Auckland Volcanic Field and is also at risk from ash fall from eruptions at large volcanoes in the central north island and Taranaki. We have recently launched the DEVORA project, which is an integrated, multi-disciplinary, multi-agency research programme funded by the Earthquake Commission aimed at a much-improved assessment of volcanic hazard in the Auckland metropolitan area with the ultimate aim of **DE**termining **VO**lcanic **R**isk in **A**uckland.

DEVORA will combine what we already know about volcanic hazard and risk in Auckland and systematically address information gaps. The 7-year research programme comprises three main themes. The Geological theme will synthesize structural, petrological and geophysical data into an integrated geological model of the AVF to provide insight into how, where, why (and how fast!) Auckland magma reaches the surface, as well as model the timing, nature and depth of precursory seismicity. The Probabilistic Volcanic Hazard theme will focus on determining the most likely scenarios and the likely patterns in evolution of the field in space and time, based largely around a rigorous dating and tephrochronology programme. New magnitude-frequency information for the AVF will be combined with similar information for ash fall from other North Island volcanoes that have impacted Auckland in the past to realistically determine the volcanic hazard outlook for Auckland.

The Risk and Social theme will address the need for more accurate and comprehensive information on the consequences of future volcanic activity in Auckland. Vulnerability analyses will be carried out to identify the nature, number, and distribution of vulnerable groups and structures in Auckland and what their expected losses may be (injuries, fatalities, building and environmental losses), and a framework for quantitative risk assessment and emergency management risk reduction will be developed. Although local authorities have begun preliminary assessments of risk and loss in Auckland, the economic and social impacts of an AVF eruption on the rest of the country are largely unknown. We intend to use the new DEVORA data to develop a risk framework for Auckland, providing local authorities, utility companies, infrastructure providers and the public with a more accurate assessment of their susceptibility to volcanic activity.

EXPLAINING THE EXTREME MOBILITY OF VOLCANIC-ICE SLURRY FLOWS, RUAPEHU VOLCANO, NEW ZEALAND

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The near-invisibility of ice-slurry flows in the geological record belies their significant hazard at snow-capped volcanoes. These four-phase flows exhibit extreme rates of volumetric bulking and unusually high mobility. Mechanisms of their motion are clarified through two examples generated on 25 September 2007 at Mt. Ruapehu, New Zealand. Brief explosions through Crater Lake ejected 5700 m3 of acidic water that entrained 60 times this volume of snow as it traveled over a snow-covered glacier. The resulting ice-slurry, traveled up to 7.7 km (height/length ratio H/L of 0.16). A co-generated second flow, took a more tortuous initial path, before riding over the already frozen deposits of the first unit and beyond (H/L 0.13). We present the first data set of the space and time-dependent kinematic properties of ice-slurry flows along with the longitudinal variation of the physico-chemical properties of their deposits. We demonstrate that ice-slurries exhibit a similar high mobility as pumice-rich pyroclastic density currents and the most mobile of recorded debris flows – flows that partially owe their high mobility to an elevated fluid-pore pressure reducing inter-particle friction. The chemistry and composition of the deposits show that during flow, vertical percolation of water through the porous ice-particle-water-air mixture generated a basal zone of high internal pore pressure. This effect is particularly strong when a thick, high-density flow front forms, which races ahead of the tail to control runout and consequent hazard.

ICE-SLURRY LAHARS: INSIGHTS FROM THE 25 SEPTEMBER ERUPTION OF RUAPEHU

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Eruption-triggered lahars are a significant hazard at many snow-capped volcanoes around the world, yet the initiation and properties of such multi-phase flows are poorly understood. A small phreatic eruption through the summit Crater Lake of Mt. Ruapehu, New Zealand, generated primary snow-rich lahars in two catchments draining the upper mountain, including one which entered a commercial skifield.

Deposit geometry, sedimentology, and geochemical characteristics indicate that the lahars were generated by several mechanisms: (1) ballistic fallout of explosively-ejected Crater Lake water and steam condensate, including contributions from lateral Surtseyan jets and base surges, which destabilised and entrained the winter snowpack; (2) explosive displacement of Crater Lake water over the lake outlet; and (3) later volumetric displacement, apparently due to instability in the sub-lake hydrothermal system. Despite a peak discharge of > 1000 m^3/s in the Whangaehu Gorge, the largest flow failed to trigger a vibration-based lahar warning system. This appears to have been a function of the low bulk density and turbulence-damped viscoplastic rheology of the ice-dominated flows, which limited energy transfer to the river bed, and their short (< 5 minutes at any single site) duration. The low preservation potential of the deposits of such flows will result in their under-representation in the geological record and serious underestimation of their hazardous potential. Current geophone-based lahar warning systems may not be sensitive enough to detect and provide warning of similar ice slurry flows at many snow-clad volcanoes, and are also vulnerable to saturation by eruption seismicity in proximal settings.

GEOMORPHIC CHANGES ASSOCIATED WITH THE 18 MARCH 2007 BREAK-OUT LAHAR FROM RUAPEHU

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Volcanic processes are dynamic agents of landscape change, creating new materials and surfaces through eruption processes or new depocentres in explosion craters or volcano-tectonic depressions. Volcanic mass-flows act to redistribute pyroclastic and other material over relatively short time frames.

At Mt. Ruapehu, New Zealand, the 110 km^3 composite volcanic edifice is surrounded by a volumetrically equivalent ring-plain composed of distal pyroclastic units and laharic and fluvial deposits. The impacts of historic lahars in the Whangaehu catchment, the outlet channel to the summit Crater Lake, has been studied by analysing shifts in channel position seen on archival aerial photographs. The predicted 18 March 2007 break-out lahar presented an opportunity to study the geomorphic impacts of a single discrete mass-flow event. This was achieved by capturing pre- and post- lahar topographic data on the flow path using airborne LiDAR (Light Distance and Ranging) surveys from which sub-metre resolution DEM's of the valley were constructed, supported by ground-based differential GPS surveys, vertical and oblique aerial and ground photography, and field mapping and granulometric studies. Comparison of these datasets permit topographic changes associated with the lahar to be quantified. For example, drainage of c. 1.3 million m^3 of water from Crater Lake resulted in the net erosion of c. 2.6 million m^3 of material from the first 10 km of flow path, of which c. 900,000 m^3 represents the volume deficit in a syn-lahar landslide scar and deposit in the upper gorge. Additional material was contributed by vertical scour of laharic deposits in the channel, lateral erosion of terrace deposits and talus fans, and removal of snow banks. These volume estimates enable constraint of stage hydrographs measured at downstream gauging stations and permit estimates of bulking factors and peak discharges during the downstream evolution of the lahar.

Detailed study of spatial patterns of erosion and aggradation indicate rapid changes in the rheology and behaviour of the lahar, likely reflecting macroscopic variations in channel geometry and gradient. Proximal regions are predominantly erosive, but aggradation of up to 14 m occurs 4-8 km downstream of Crater Lake. On the ring plain, the lahar braided into multiple distributary channels characterised by alternating areas of erosion and aggradation with wavelengths of 400-1200 m, possibly reflecting (up- or downstream) migration of macroscopic bar forms. In this area, the lahar appears to have largely redistributed material over relatively short distances, suggesting that its sediment load was continuously cycled through the active flow rather than being picked up in one place and dropped in another, more distal location. Further study and cross-correlation with instrumental and sedimentologic records will yield further insights into lahar processes at Ruapehu and worldwide.

PETROGENESIS OF MID-CRETACEOUS INTRAPLATE VOLCANISM IN NEW ZEALAND DURING THE BREAK-UP OF GONDWANA

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The Lookout Volcanics represent the remnants of an extensive sheet of mid-Cretaceous intraplate volcanic rocks erupted during the extension of proto-New Zealand. Based on the preserved outcrops in the Awatere and Clarence valleys the pre-erosion eruptive volume was ~1500 km^3. Volcanism occurred just prior to the rifting of New Zealand from Gondwana, and may have been cogenetic with a mid-Cretaceous mantle plume that created lithospheric instability, allowing rifting to begin. Moreover, it is the oldest example of HIMU-like volcanic rocks that occur sporadically throughout the New Zealand region.

Preserved in a fault angle depression bounded by the Awatere Fault located in Marlborough, South Island, New Zealand the volcanic rocks cover an area of ~50 km^2 with > 1000 m of basalt preserved near Mount Lookout. Volcanism occurred at ~96 Ma and was mostly terrestrial with minor marine tuffs and non-volcanic sediments preserved at the top of the section. We have carried out detailed sampling (103 samples) of the Lookout Volcanics and constructed a ca. 700 m composite stratigraphic section, largely based on a continuous sequence of lava flows outcropping in Middlehurst Stream. The basal section of the volcanics crops out in two separate localities ~6 km apart displaying a sharp contact between the volcanics and underlying terrestrial sediments, which in turn rest on shallow marine sediments of Ngaterian age (100.2-95.2 Ma).

The predominantly mafic and alkaline samples include basalt, picrobasalt, basanite, trachybasalt and basaltic trachyandesite. No samples represent primary magmas with all samples having undergone fractionation (or accumulation) of olivine + clinopyroxene ± plagioclase ± Fe-Ti oxides. Variations in incompatible trace element ratios suggest differing degrees of partial melting of garnet facies mantle (La/Yb_N = 12.5-20.2). Initial Sr-Nd-Hf-Pb isotopic variations ($^{87}Sr/^{86}Sr$ = 0.7030-0.7039; $^{143}Nd/^{144}Nd$ = 0.51264-0.51272; $^{176}Hf/^{177}Hf$ = 0.28278-0.28283; $^{206}Pb/^{204}Pb$ = 18.82-20.32) are largely the result of mixing between a HIMU-like mantle component, and up to 28% of an Early Cretaceous upper crustal component. Oxygen isotope ratios were determined by laser fluorination analyses of olivine and clinopyroxene phenocrysts from 6 lava flows ($\delta^{18}O$ = 4.7-5.0‰ for olivine; 4.8-5.4‰ in clinopyroxene cores; 3.9-5.5‰ in clinopyroxene rims). Average olivine (4.8‰) and clinopyroxene core (5.1‰) values are 0.4-0.5‰ lower than average mantle peridotite values consistent with other HIMU rocks. Oxygen isotopic disequilibrium between clinopyroxene cores and rims suggest that the rims grew in a shallow level magma chamber that was interacting with meteoric water. The effects of crustal assimilation can also be observed in clinopyroxene phenocrysts from the most evolved sample which has elevated $\delta^{18}O$ and Sr isotopic ratios ($^{87}Sr/^{86}Sr$ = 0.7039; $\delta^{18}O$ = 5.5‰).

INVESTIGATING THE EXPLOSIVITY OF SHALLOW-SUBAQUEOUS BASALTIC ERUPTIONS

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Surtseyan eruptions are explosive and hazardous in nature, but the drivers of this dramatic activity remain poorly understood. We endeavour to increase our knowledge of these eruptions through the study of the pyroclastic products produced, both in the subaqueous and subaerial phases of eruption. Quantification of clast vesicularities, bubble number density, bubble size distribution and bubble shape as well as ash grain morphology can be used to unravel degassing and ascent histories and fragmentation processes, respectively. This data can lead to better understanding of Surtseyan eruptive styles, their dynamics and intensity, and will allow us ultimately to identify the role water plays in the explosivity of shallow subaqueous eruptions.

Pahvant Butte, southwest Utah, is a well preserved Surtseyan volcano. It erupted under ~85m of water into Lake Bonneville approximately 15,300 years ago, and the eruption-fed deposits initially built out a subaqueous mound characterised by sideromelane ash. This is topped by ‘wet’ and ‘dry’ cone-facies deposits, now intensely altered to palagonite.

This presentation focuses on samples collected from a well-bedded, broadly scoured coarse ash and lapilli lithofacies on the eastern flank of the edifice. Vesicularity indices span from 52.6% - 60.8%, but the vesicularity ranges are very broad, 20.6% - 81.0% for one extreme sample. The diverse nature of the vesicularity is reflected also in SEM images. Dense clasts display textures with isolated, tiny, serrate-edged bubbles, while mean- and high-vesicularity clasts display more numerous, medium-sized, rounded bubbles. Fragmentation at varying stages of a complex vesiculation history is thus suggested.

Black Point, eastern California, is another emergent volcano, initially erupted into Lake Russell ~13,000 years ago. Similarly to Pahvant Butte, its unconsolidated mound consists of glassy ash and lapilli and is topped by indurated, palagonitized tuff ring/cone deposits.

Again, focus here is on a continuous deposit on the southwest of the edifice. Sub-horizontal beds display pinch and swell structures and some cross-stratification. Vesicularity indices extend from 58.7% - 66.6% while vesicularity ranges are broad, 27.8% - 79.7% for example. This implies higher rates of ascent and eruption discharge, a conclusion supported by textural features of bubbles in this section such as a presence of uniformly sized small vesicles.

In both cases more complex scenarios such as staged magma degassing, particle recycling and recapitulation cannot be ruled out and analyses of ash grain morphologies as well as glass-volatile contents will further constrain these interpretations.

THE ERUPTIVE HISTORY OF RANGITOTO ISLAND, AUCKLAND VOLCANIC FIELD, NEW ZEALAND

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Rangitoto Island is the largest (58 % of the total volume of the field) and the youngest (c. 650y BP) of the basaltic volcanic centres in the Auckland Volcanic Field. This almost symmetrical volcanic edifice, situated in the Hauraki Gulf north-east of Auckland City, is easily recognisable from its broad, gently dipping lava flows that surround a steeper-sided central scoria crown. Rangitoto volcano is unique among the volcanic centres in the Auckland Volcanic Field as it composed of both alkali and tholeiitic basalt, whereas all the other centres are alkali basalt. Determining the eruptive history and magmatic evolution of Rangitoto is critical in understanding how the field will behave in the future.

A thorough volcanological and petrological study on both the lava flows and scoria cones of the volcano, as well as a small-scale vibro-coring investigation to study ash in swamp sediments on nearby Motutapu Island, were carried out to decipher Rangitoto's complex eruptive history. The vibro-coring revealed an obvious, thick (~10-100 cm) lower tephra of alkali basalt composition overlying weathered Waitemata Group or Greywacke sedimentary rocks. A less obvious upper, thinner (<5 cm) tephra of tholeiitic basalt composition is separated from the basal tephra by ~30-50 cm of swamp silts. This upper tephra is overlain by 200-300 cm of swamp silts. The tephra layers may correlate with two compositionally different Rangitoto tephra layers observed in Lake Pupuke sediment cores. Alkali basalt scoria outcrops on a cone to the north of the main central cone and may be the source of the lower alkali basalt ash layer in Motutapu Island swamps. The rest of Rangitoto Island, including the central cone and the lava field, is composed of tholeiitic basalt, which correlates with the thin tholeiitic tephra layer on Motutapu Island.

These results allow a reconstruction of Rangitoto's eruptive history. The first eruption was probably phreatomagmatic, developing into a more Strombolian style eruption to create a scoria cone north of the present summit, which dispersed a blanket of alkali basalt ash across the nearby Motutapu Island. This was followed by a significant time gap, as indicated by the vibro-cores. Activity recommenced with a second eruption, which formed a scoria cone of tholeiitic composition that largely enveloped the original alkali basalt scoria cone. Finally, lava oozed out from the base of the central scoria cone to create a lava field and Rangitoto's current shield-like appearance. Although it is theoretically possible for magma to separate at depth to form these two compositionally different basaltic magma batches, our evidence suggests that they erupted in two independent yet spatially related volcanic events. Furthermore, the sediment between the ash layers suggests a significant time gap between events, implying Auckland's most recent eruption may have occurred more recently than previously thought.

ERUPTIVE MECHANISMS OF "SOFT SUBSTRATE" MAAR/TUFF RING VOLCANOES FROM THE AUCKLAND VOLCANIC FIELD (AVF): THE ORAKEI MAAR/TUFF RING

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"Soft substrates" in volcanic fields strongly influence the eruption styles and explosivity of small-volume mafic events in volcanic fields. At Auckland, the soft-substrate of saturated sands and muds of the Waitemata Group have set up conditions for dominantly mud or slurry-magma interactions in many locations. During eruptions through these soft sediments lateral quarrying of the vent site occurs forming broad craters, and complex, wide and shallow maars/tuff rings. In the Orakei Basin, pre-volcanic sedimentary sequences crop out 5-10 m above the lake level and the maar is surrounded by a tuff ring. Basal pyroclastic successions contain thick (1-2 m) beds of coarse breccias in a poorly sorted mud-dominated matrix, with milled country rocks and rare chilled bombs. These represent the initial vent-establishment phase. Upward, these alternate with and gradually transform into more regularly bedded rhythmic successions of fine tuff and lapilli tuff (commonly with well-developed dune beds). Juvenile components are generally <20% of lapilli clasts and they are commonly rimmed by mud. Coarse juvenile clasts are universally peppered by incorporated blebs and pockets of baked mud. Fine tuff beds are vesicular and rich in rim-type accretionary lapilli and mud aggregates. The regular pattern of tuff and lapilli tuff beds up-section indicates stabilisation of the vent during the eruption, with a regular pulsatory style. Throughout this eruption, the vent area is envisaged to be dominated by a mud-slurry rather than clear water. The topmost succession are tabular fines-dominated beds with very rare juvenile lapilli coarse ash component, showing no evidence for drying of the eruption vent (ie., capping scoria sequences). Transported particles in fall and surge were dominantly substrate materials, and there was only minor primary magma involved. Hence recognition of these "reworked Waitemata Grp" tephras in distal sites is likely to be highly problematic. The accretionary lapilli-rich beds and vesicular tuffs show that the base surges were below 100^{o}C. This normally occurs at c. 500 – 700 m from a phreatomagmatic vent, and implies that the large present-day Orakei basin structure has been greatly expanded via post-eruptive slumping and subsidence of the soft substrate, into the former broad vent area. Recent drilling results (GNS+Auckland University) and the presence of marine terraces along the inner basin wall imply that the eruption took place in pre-Last Interglacial times.

EMPLACEMENT PROCESSES OF KIMBERLITE MASS FLOWS AT FORT Á LA CORNE, SASKATCHEWAN, CANADA

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The upper- and extra-vent portions of Cretaceous kimberlite volcanoes contained within a siliciclastic country rock succession have been intersected and delineated in drill cores by advanced diamond exploration programs in the Fort á la Corne region of Saskatchewan, Canada. A detailed volcanological study was undertaken on four volcanic centres: Orion Central, Body 118 of Taurus, Body 158 and Body 101. All of the studied volcanic centres consist of at least one or two volcaniclastic kimberlite depocentre(s), which, inferred through drill core correlations, occur within circular to elliptical craters of at least 140 to 205 m deep and average slope angles typically 25 to 53°. Thick (130 to 250 m) volcaniclastic packages infill the craters, and thin upwards to the crater margins where they are bound between dark marine mudstones. In some volcanic centres, a low relief positive mound marks the upper surface of the volcaniclastic package.

Although it is recognised that the volcaniclastic packages at each volcanic centre consist of unique stratigraphic and facies architectures, reflecting variations in emplacement history and processes, the following characteristics consistently occur at all centres:

1. the crater-fill to extra-crater volcaniclastic packages consist predominantly of massive to stratified, olivine-rich tuff to lapilli tuff, with a wackestone- to packstone-like grain distribution;
2. the thick central parts of each package are generally massive to diffusely bedded, coarse-grained and lithic-bearing, whereas the upper and outer parts are diffuse- to well-bedded, finer-grained, and relatively lithic-poor;
3. individual thin to thick beds are typically normal graded with massive basal zones and laminated upper zones.

These volcaniclastic packages are continuous (lacking intercalated siliciclastic horizons) across their entire thickness in at least Orion Central and Body 101. At least one or two massive, locally deformed, dark mudstone horizons are intercalated within the main volcaniclastic packages of Bodies 158 and 118.

The facies characteristics of volcaniclastic packages in all four volcanic complexes is consistent with rapid accumulation of olivine-rich pyroclastic material from syn-eruptive, subaqueous mass flows. Coarse-grained massive deposits represent sustained, high sedimentation rates, whereas finer-grained, bedded deposits at the crater margins record a lower sedimentation rate, pulsatory flow regime. Intercalated mudstone horizons may represent significant hiatuses in eruptive activity, but may alternatively represent syn-eruptive mudflow deposits through collapse of poorly consolidated crater walls.

VESICULATION CHARACTERISTICS IN PYROCLASTS OF THE 3.1 KA ONERAKI ERUPTION, RAOUL ISLAND, KERMADEC ARC

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Raoul Island is the emergent 30 square km portion of a > 200 cubic km volcanic edifice which rises 900 m from the sea floor along the Kermadec ridge. Although the island is composed mainly of basalt and basaltic andesite, the last 4000 years has seen several dacitic explosive eruptions associated with caldera formation [Lloyd & Nathan, N.Z. Geol. Surv. Bull., 1981; Smith et al., J. Volcanol. Geotherm. Res. ,156, 2006]. Fall deposits of the 3.1 ka Oneraki eruption, of possible plinian dispersal, were sampled at five stratigraphic levels. The 16-32 mm size pumice clasts of the lower four levels display narrow, unimodal density ranges. The upper level fall deposit shows a bimodal density distribution, reflecting a change in eruption characteristics as dense, degassed fragments were also ejected, but without other signs of any interaction with external water. For this study, qualitative and quantitative vesicularity data have been collected from 16-32 mm clasts from three of the stratigraphic levels to provide insights to the various processes involved in vesiculation and fragmentation of this magma. Future work will include comparisons of vesicle textures in this eruption to other dry and wet subaerially erupted Raoul deposits, and to submarine deposits of similar composition at Macauley and Healy volcanoes. By characterizing eruption products from these volcanoes and using constraints provided by the different degrees of interaction with water (and at different water depths in submarine examples) we hope to better understand the dynamics of the violent degassing processes driving these eruptions.

LAVA FLOW MORPHOLOGY AND TEXTURAL CHARACTERISTICS OF THE 1954-55 MOUNT NGAURUHOE ERUPTION, TONGARIRO VOLCANIC COMPLEX: IMPLICATIONS FOR FLOW PROCESSES

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Lava flow morphology and textural characteristics determined from field observations and aerial photograph analysis assist towards an understanding of the flow processes involved during the effusive phase of the 1954-1955 Mount Ngauruhoe eruption, Tongariro Volcanic Complex. The ca. 2,500 year old, frequently active, basaltic andesite to andesite cone volcano produced at least 11 individual a'a flows on its north-western flanks between 4th June and 29th September 1954. These overlie a highly irregular slope surface, largely formed by the partially eroded remnants of the numerous lava flows produced during the lifetime of the volcano.

The 1954 lava flows are predominantly narrow (c. 40 m width), 2.5 to 9 m thick, single-lobed, discrete units with run-out distances between c. 0.2 and 2 km from the vent. Most flows are non-channelized and are characterised by rubbly and broadly irregular flow surfaces, well-defined flow boundaries and single- or multi-toed flow front formations. However, the 30th June flow is distinguished by multiple lobes, some extending into elongated lobe fingers, while the 18th August flow is marked by flow channel drainage on steeper upper slopes, channel infilling with complex surface features on gentler lower slopes, and secondary levee formation on lower flow margins.

The 1954 lavas are typically intensely autobrecciated with no observable coherent core mass. Individual lava blocks generally consist of a scoriaceous outer carapace surrounding a relatively dense inner core. A range of inner core vesicularity values of 0 to 25% (7 to 10% average) was observed in the field with preliminary analysis suggesting a marginal increase in vesicularity down flow. Block sizes range from 5 to 50 cm with 1 to 2 m blocks commonly observed at flow fronts and on mid-flow surfaces. Accretionary lava balls up to 6 m in diameter are scattered within flow channels and at the margins of some lavas.

Underlying topography appears to have been a major control on both flow direction and surface morphology in most of the flows, while length, flow front morphology and levee and channel formation were a function of volume, effusion rate, viscosity and cooling rate. There are no systematic changes in flow dimension or morphology between successive lava flows with the exception of significantly shorter run-out distances of the final two flows.

TEMPORAL VARIATIONS IN SEISMIC ANISOTROPY ON VOLCANOES IN KYUSHU ISLAND, SOUTHERN JAPAN

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Using a newly developed automatic processing technique, we have calculated shear wave splitting on and near three active volcanoes in Kyushu, southern Japan (Aso, Unzen and Sakurajima). Shear wave splitting is considered to be caused by aligned cracks and microcracks. The polarisation of the first arriving phase, ϕ, gives a measure of the crack orientation, which is expected to align with the maximum principal stress. The delay time dt between the two phases depends upon the crack density and the path length. High quality measurements include the following: a) over 1700 from local events recorded and located near Aso Volcano between 2001 and 2008; b) over 2000 from local events recorded and located near Unzen volcano between 1988 and 1997 (spanning the most active period of seismic activity related to the large eruption in 1991); c) over 600 from regional events originating in the subducting Phillipine Sea plate recorded near Sakurajima volcano between 2003 and 2005, (during which time numerous small eruptions have occcurred, and GPS measurements have been modeled as caused by inflation of a Mogi source and a near-vertical crack). Most of the stations were located in boreholes or tunnels, providing excellent signals.

Common features at all three volcanoes are that stations closest to the craters yield the fewest good measurements, and even those tend to give varying results at closely spaced stations. Scattering from the volcanic edifice may be making the S waves difficult to pick, and the local stresses may be varied. Stations on the volcanic flanks give many good measurements. Some stations yield variations in ϕ and dt that depend upon the earthquake location. But at each volcano, some stations show changes that are better explained by variations in time than in space. Where GPS measurements are available, the variations sometimes but not always correlate with previously-modeled inflation or deflation events. The temporal variations in ϕ are large, ranging from 30^o at some stations to 90^o at other stations. These results will allow us to test models of stress changes with time on the volcanoes.

CHANGES IN SEISMIC ANISOTROPY AND GPS ACCOMPANYING THE 2004 ERUPTION OF MT. ASAMA, JAPAN, AS POSSIBLE STRESS INDICATORS

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One goal in understanding the physics of volcanoes is to relate the state of stress to measurable properties. GPS determines strain changes, which are related to changes in stress. Seismic anisotropy in the crust is usually caused by aligned cracks, which open and close in response to changing stress. Shear wave splitting occurs when two perpendicular components of shear waves travel with different speeds; the first arriving wave has a polarization (phi) parallel to the fast orientation of the anisotropic material and the delay time (dt) between the two waves depends upon the integrated effect of anisotropy along the travel path. Thus, phi yields the average crack orientation and dt is proportional to the crack density.

The eruption of Mt. Asama in 2004 was accompanied by a dyke intrusion modelled by GPS. The simple stress field response of dykes makes it an ideal place to compare the techniques. We measured phi and dt on all three-component seismic stations operating around Mt. Asama between September 2002 and May 2008. We use two sets of data; local "tectonic" earthquakes from beneath the volcano, which are within the upper crust, and deep earthquakes that originate in the subducting plates and travel through the mantle and the crust. Between 2005 and 2008, both sets of data show average phi parallel to the dyke for paths that have passed through the volcanic region, but not close to the dyke. Paths that have traveled through a region within about one dyke-length, 4 km, of the dyke, have phi nearly perpendicular to the dyke. We suggest that the dyke has originated in a regional stress field with maximum principal stress parallel to the dyke, but that in the region close to the dyke, overpressure has caused the principal stress direction to reverse its direction in a local region. Furthermore, splitting along paths that traveled through the mantle appear to be overprinted in orientation by the local stress field, although the dt of 0.4 to 0.8 s has contributions from both the mantle and crust.

On the longest-operating station, AVO, average dt measured on deep earthquakes closely parallels the GPS baseline changes between two stations on opposite sides of the dyke. Dt changes by about 0.1 s per 10 cm change in baseline length. If we assume that the change in baseline length is caused by closure and opening of coin-shaped cracks, and that the changes in dt were caused by a region on the same order as the dyke length, then using the simplest (Hudson, 1981) theory, the crack density changes by about 0.044 and the strain change is 2.5×10^{-6}. Using these two values, we calculate the ratio of the crack width to radius of 10^{-6}.

SUBMARINE EXPLOSIVE ERUPTIONS AT LO`IHI SEAMOUNT HAWAI`I- THE RESULT OF PERFECTLY CLOSED SYSTEM DEGASSING

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We examine the relative roles of magma degassing and magma-water interaction that permit basalt to erupt explosively at ~1000 mbsl on Lo`ihi Seamount, Hawai`i. The ~10 MPa hydrostatic pressure at the summit of Lo`ihi is a particularly interesting pressure regime, since CO_2 has limited solubility in basalt at these pressures, but the solubility of magmatic H_2O (the primary volatile component that drives explosive subaerial eruptions) varies as a function of initial volatile content and degassing history. The vesicularity of submarine pyroclasts, combined with residual volatile contents in quenched matrix glass and olivine-hosted melt inclusions (MIs), measured by FTIR and SIMS, provide a nearly complete record of the degassing history of the magma. We present observations from two submarine pyroclastic deposits erupted at ~1 km depth on Lo`ihi. The first is a cone-forming transitional basalt with modal vesiculary of ~40 %, matrix glass CO_2 = 24±10 ppm and H_2O = 0.45±0.07 wt.%, and MI volatiles ranging up to 743 ppm CO_2 and 0.86 wt.% H_2O. The second is a tholeiitic basalt with modal vesicularity of ~50 %, matrix glass CO_2 = 22±6 ppm and H_2O = 0.55±0.06 wt.%, and MI volatiles ranging up to 588 ppm CO_2 and 1.49 wt.% H_2O. Solubility modeling indicates that for both deposits, the matrix glass volatile contents can be achieved by near-perfect closed system degassing from a melt represented by the most CO_2 -rich MIs measured. Comparison of this data set with published, partially open degassing models for Lo`ihi pillow lavas suggests that for a range of magma compositions, near-perfect closed system degassing of CO_2 (complete) and H_2O (partial) is directly associated with explosive eruptions of magma at ocean depths of ~1 km. In a closed-system, exsolved volatiles remain mechanically coupled to the melt in bubbles that impart buoyancy to the magma. This buoyancy translates into high eruption velocities that are required to initiate hydromagmatic fragmentation by metastable fuel-coolant interactions.

MULTI-CYCLE CRYSTALLISATION AND REJUVENATION OF CRYSTAL MUSH BELOW OKATAINA VOLCANO

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Several features are consistent with the existence of a long-lived crystal mush zone beneath Okataina volcano from which rhyolite melts have been episodically extracted. Repeated extractions of crystal-poor melts (>300 km^3 erupted) over the last 300 kyrs with REE patterns consistent with extensive plagioclase and hornblende fractionation would have left a large volume of crystal residuum. Textural and crystal zoning evidence in Rotoiti and Earthquake Flat eruption ejecta are consistent with the rejuvenation of near-crystalline plutons. Some pumices contain zircons with ages spanning ~300 kyrs, demonstrating crystal inheritance from plutonic fore-runners (Charlier et al. 2003). Granitoid lithics point to the presence of associated crystalline bodies. H_2O/CO_2 contents in quartz-hosted melt inclusions indicate phenocyst growth at ~200 MPa, placing the crystal mush zone at <8 km depth. The brittle-ductile boundary is seismically located at ~7 km and may influence the depth of magma ponding by promoting sill formation. At pumice-clast-scales in Tarawera deposits, distinct rhyolite magma batches are recognised and have been simultaneously erupted. The batches are homogeneous in composition (Sr varies by < 20 ppm; Zr < 18 ppm) and Fe-Ti oxide temperature (< 40°C). Subordinate mingled pumices contain bimodal crystal and glass compositional populations indicating isolated crystallisation histories and limited syn-eruption contact. At the sub-cm scale, matrix glasses have trace element compositions (Sr, Ba, Rb) that vary by factors up to 2.5, indicating incomplete mixing of separate melts. Some quartz-hosted melt inclusions are depleted in compatible trace elements (Sr, Ti, Ba) compared to enclosing matrix glasses indicating silicic melts have percolated through an earlier formed, partly crystalline mass. The matrix glass is enriched in some elements (e.g., Ba) relative to intruded basalts indicating it is not the product of direct mixing with basalt melt. Instead, the re-melting of felsic crystals deeper in the crystal pile by basalt intrusion is inferred. Quartz crystals display a variety of CL zoning patterns and resorption boundaries consistent with multi-stage crystallisation. These patterns relate to Ti content and thus reflect changes in melt chemistry and/or temperature (50-100°C). Complex thermal histories are indicated by quartz cores with high or low Ti content occurring side-by-side; mid-crystal zoning peaks in Ti and/or Ti-rich rims. The abrupt changes in Ti profiles (90 ppm over 30 μm) are consistent with short thermal fluctuations (<1 kyr). The resulting fluctuations in temperature and volatiles induced quartz resorption and regrowth. An important implication is that rhyolite volcanoes such as Okataina could be reactivated into life over short periods.

USING TRACE ELEMENT ABUNDANCES TO ASSESS THE ROLE OF CRUSTAL MELTING IN GENERATING RHYOLITES IN THE TVZ

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A long standing problem in hypotheses for the origin of silicic magmas is the relative roles of fractional crystallisation of parental basaltic magma versus partial melting of basaltic crustal protoliths. The answer to this question is fundamental to understanding the way that continental crust has grown through geological time. Because trace elements and particularly the REE show partitioning behaviour that is sensitive to the differences between the processes of crystallisation and melting, their relative abundances provide a test of which process is likely to dominate in any specific situation. When variation in distribution coefficients is quantified and integrated with models of fractional crystallisation REE-SiO_2 systematics are quite different for each of these petrogenetic processes.

We have analysed trace element abundances in a suite of silicic samples representing the magmatic evolution of Okataina Volcano during the last 50 ka together with a comparative suite representing magmatic activity from Taupo over the same time period. These chemical data define discrete compositional magma batches produced during individual eruption episodes. They show no systematic compositional variation through time and cannot be used to infer a simple long term evolutionary process. Compositional trends within magma batches are complex and reflect a multiplicity of processes rather than a single process. Trace element abundances therefore represent the average of several different processes including partial melting, melt extraction fractionation, mingling and mixing.

Silicic magma compositions are influenced by both melting and fractionation processes and it is important to determine the relative influence of each. Our conclusion for TVZ is that the dominant process is one of crustal melting and that fractionation processes occur on a micro scale as the melts are released from a parental crustal mush. There are probably two stages in the process of forming silicic magmas beneath the TVZ. The first involves dehydration melting of basaltic or intermediate crust in amphibolite P-T conditions and triggered by the breakdown of amphibole. The driving force for this is rapid thermal input impacting on thermally preconditioned crust and is likely to take place at middle crustal levels ~12-15km. The second process is a remobilisation of stalled silicic melts at higher levels. Here a crystal mush is triggered by hydration melting through the release of volatiles as basaltic mantle-derived magmas pond and crystallise in the middle to upper crust. Thus the geochemical signals that we observe in silicic rocks of the TVZ are a combination of partial melting, extraction fractionation, mixing and mingling characterised by disequilibrium on a wide range of scales.

DEVELOPMENT OF PALEOGENE SURTSEYAN VOLCANOES, PRIMARY DEPOSITS AND POST-ERUPTIVE BIOCLASTIC SEDIMENTATION, CHATHAM ISLANDS, NEW ZEALAND

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The Chatham Islands archipelago is located 860 km east of the South Island, New Zealand, and is situated on the eastern edge of the partially submerged continental plateau, the Chatham Rise. The group comprises two main islands, Chatham and Pitt, and a smaller set of islets, which have preserved a geologic record since the Permian.

Fieldwork has identified the remains of surtseyan continental shelf volcanoes of Late Paleocene- Early Eocene age in the Red Bluff Tuff Formation. The primary volcanic facies are comprised of fragmental and coherent units. The fragmental volcanic facies are characterised by moderately to- well-sorted, well-bedded to cross-bedded, angular and vesicular coarse ash to lapilli size units, and the coherent units are syn-depositional basalt dikes and pillowed sills. Post-eruptive biogenic volcaniclastic facies also occur. They are fossil-rich (molluscs, brachiopods, corals, shark teeth, crinoids and echinoids), poorly to- moderate sorted, well-bedded to cross-bedded, sub-angular to sub-rounded lapilli size units. At least three possible eruptive centres have been recognized, with one eruptive centre located on Pitt Island and the other two on Chatham Island.

The textural characteristics, the presence of base surge deposits, spatter (up to 80cm long) and scoria bombs with breadcrust texture, sag structures and the homogeneity and thickness of the lapilli tuffs, support a phreatomagmatic cone forming eruption style, similar to that of Surtsey volcano (Iceland). Volcanoes erupted in shallow water, and grew by accumulation of fallout, base surge and ballistic deposits. Post-eruptive wave reworking created platforms that were colonised by epifauna, some of which were also reworked and broken up.

RECONSTRUCTING THE MIOCENE-PLIOCENE EVOLUTION OF AN EXTINCT SILICIC SYSTEM: CHRONOSTRATIGRAPHIC AND PETROGENETIC INSIGHTS FROM MAJOR AND TRACE ELEMENT ANALYSES OF SINGLE GLASS SHARDS, OFFSHORE NORTH ISLAND, NZ

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The NW trending Coromandel Peninsula is the subaerial remnant of the Neogene Coromandel Volcanic Zone (CVZ), which is regarded as a tectonic precursor to the Taupo Volcanic Zone (TVZ), currently the most dynamic and voluminous rhyolitic volcanic centre on Earth. Due to poor exposure, burial, or erosion of terrestrial eruptive deposits our understanding of the CVZ volcanic history is incomplete, hindering attempts to better gauge its relationship with the TVZ.

Numerous tephra beds have been recovered in well-dated deep-sea cores offshore of eastern North Island by the Ocean Drilling Program (ODP) Leg 181. ODP Site 1124, ~720 km from the CVZ, penetrated sediments of the Rekohu Drift (3966 m water depth) yielding an unprecedented record of major explosive volcanic eruptions. This record is used to formulate a detailed tephrochronology and eruption history for the Coromandel and early Taupo Volcanic Zones from ca. 2 Ma back to 12 Ma. The Site 1124-C core includes 76 Miocene-Pliocene volcanic glass shard bearing layers >1 cm thick, some of which pre-date the earliest known terrestrial ignimbrites. The temporal distribution of tephra reflects pulses of eruptions punctuated by periods of reduced activity or non-deposition, inferring eruptive frequencies for major explosive volcanic eruptions on the order of 1 per 82,000 kyr for the Pliocene and 1 per 100,000 kyr for the Miocene.

We present the major, minor and trace element chemistries of single glass shards (as small as 20 μm) determined by wavelength dispersive electron probe microanalysis and laser ablation-inductively coupled plasma-mass spectrometry of 72 tephra units. Rhyolitic and minor dacitic volcanic glass shards are characterised by medium-to high-K calc-alkaline, arc-type, major element compositions.

PROBING THE SUB-VOLCANIC DEPTHS – THE NATURE OF THE SUB-VOLCANIC CRUST AND CRUST-MANTLE BOUNDARY IN TARANAKI

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Determining the nature of the subvolcanic crust and upper mantle relies largely on seismic data, augmented by fragments of subvolcanic lithologies carried to the surface as xenoliths in lavas. The magmas sample the vertical extent of the sub-volcanic plumbing system from mantle source to supracrustal rocks. Much data on subvolcanic crustal to upper mantle compositions is derived from xenoliths in intraplate alkaline rocks as these magmas appear to rise rapidly from their mantle source, more readily sampling the strata through which they pass. The record of xenoliths from subduction zone magmas, however, is much less comprehensive and most examples of xenoliths in subduction volcanics come from the western Pacific. They have been used in arcs generally as clues to magma generation, pre-eruptive processes and interaction with the crust, as well as characterising the composition of the mantle wedge. Xenoliths in arc rocks are predominantly interpreted as cognate and supracrustal in origin.

In this paper we examine the deeper sourced xenoliths from Egmont volcano, Taranaki, and suggest that remnants of sub-volcanic stratigraphy are frequently preserved in arc basaltic andesite to andesite rocks, but in a more cryptic way than in intraplate alkaline basalts. Because the lower crust/upper mantle zone that interacts with arc magmas (the "hot zone") is generally hotter and appears to contain a greater melt fraction than that encountered by alkaline basalts, the lower crustal lithologies are more easily disaggregated and recorded predominantly as either single crystals, glomerocrysts or xenoliths, not all of which are cognate. Arc xenoliths also differ from those found in intraplate basalts in the widespread occurrence of amphibole in the former where pervasive hydrous metasomatism reflects the more fluid-rich environment of arc magma systems.

Some Egmont xenoliths also contain glass of rhyolitic to trachyitic compositions with up to 6 % K_2O that represent partial melts of the sub-volcanic lower crust and may give rise to the andesite magma compositions erupted by mixing with lower crustal residual crystals and glomerocrysts.

U-SERIES ISOTOPE AND EXPERIMENTAL CONSTRAINTS ON THE GENESIS OF HIGH-MG ANDESITES AT WHITE ISLAND, NEW ZEALAND

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On White Island, New Zealand, the intensified period of strombolian-volcanian and phreatomagmatic explosive activity that commenced in March 1977 led to eruption of unusually primitive, high-Mg andesites. These are Fo_{80-93} olivine-saturated rocks that have MgO contents up to 10% (Mg# = 65-71) and SiO_2 of 56-58%. They have incompatible trace element characteristics that are typical of arc rocks. $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$ ratios (0.7049-0.7053, 0.51282-0.51266 and 0.28301-0.28298, respectively) are consistent with subducted sediment addition and/or crustal input but there is no clear correlation of either isotope ratio with MgO. The rocks have modest (3-10%) ^{238}U excesses at low ($^{230}Th/^{232}Th$) ratios (0.697 to 0.722). ^{226}Ra-^{230}Th disequilibria is also restricted but, unusually, includes both ^{226}Ra excesses and deficits with ($^{226}Ra/^{230}Th$) = 0.94-1.07. $(^{210}Pb/^{226}Ra)_o$ ranges from 0.98 to 1.52 requiring gas accumulation that may increase over time and with decreasing MgO. Sr/Y and Tb/Yb ratios are both low and relatively invariant at 8 and 0.3, respectively, and along with the ^{238}U excesses preclude an origin in which residual garnet was involved. The occurrence of some ^{226}Ra deficits suggests the presence of residual amphibole during partial melting for some samples. Rapid magma ascent (to preserve the ^{226}Ra disequilibria) limits the amount of possible melt – wall rock interaction that might reduce source-derived Tb/Yb ratios in the mantle or raise $^{87}Sr/^{86}Sr$ in the crust. The White Island high-Mg andesites did not form by partial melting of eclogite in the subducting Pacific plate. Their primitive, olivine-saturated compositions suggest that their source was peridotitic and experimental data suggest that melting and a harzburgitic residue at low temperatures at 0.5-1.5 GPa and in the presence of elevated alkalis can reconcile the high SiO_2 and MgO of the rocks.

PROCESSES IN WET ERUPTION PLUMES: INSIGHTS FROM THE ORUANUI SUPERERUPTION OF TAUPO VOLCANO, NEW ZEALAND

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The behavior of volcanic plumes arising from the explosive interaction of magma and surface water involves a complex interaction of hot ash and water phase-changes with height in the atmosphere. Although recent models predict that these water-rich eruption clouds should be somewhat reduced in height (i.e., less powerful) than their dry Plinian counterparts, the fall deposits from the 26.5 ka Oruanui supereruption of Taupo volcano show evidence for interaction with large volumes of lake water (ca. 100 km^3) and exceptionally powerful dispersal (Walker Dispersal Index values of 0.5 to $5x10^5$ km^2).

The dynamics of the eruption column required for such powerful transport of material are still unclear, requiring techniques from both physical volcanology and atmospheric physics. Field measurements of thickness, grain size and compositional characteristics of the Oruanui deposits have been used to infer wind dispersal and transport patterns, describing the behavior of the plume with time and distance from vent. Occurrences of preserved accretionary lapilli are particularly illustrative of circulation patterns and particle velocities within the eruption clouds. SEM images showing internal growth characteristics of individual aggregates are used to determine the extent of interaction with water and/or ice phases, and, therefore, their formative heights in the atmosphere. These characteristics will be useful in future work for quantifying fluid dynamical parameters in the development (or adaptation) of an atmospheric dispersion model that incorporates the influence of moist convection in water-rich eruption columns.

MOLTEN ROCK AND DIRTY WATER: SOME EXPERIMENTAL RESULTS

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When a magma encounters water, heat is transferred and the magma typically fragmented to varying degrees by a range of processes. Explosive MFCI interactions can result from extremely rapid heat transfer during fine fragmentation, but under other conditions interactions extend from quiet steaming to non-explosive granulation. Among the many variables in natural environments inferred to play a role in determining the style of magma-water interaction is the presence of impurities, such as particulate sediment, with the water. Phreatomagmatic pyroclastic deposits dominated by country-rock fragments or recycled pyroclasts, and the mingled igneous-sedimentary rock "peperite" are products of volcanism involving magma, particulate sediment and water.

At the Physical Volcanology Lab in Wuerzburg, Germany, we ran a simple set of experiments to investigate the effect of such particulate mixtures. Magma (~200 gm) made by melting crushed basalt was poured from a fixed height into a receptacle with pure water, and water with 10 %, 20 %, and 30 % suspended mud. Thermocouple and force measurements were collected during and after each pour, and reveal that with increasing sediment concentrations, the rate of heat transfer from magma to coolant, and the intensity of thermal granulation, is progressively and substantially reduced. For pours into water, virtually all heat transfer from magma to water is complete within a few seconds after the pour, whereas with 30 percent suspended clay this stretches to more than 10 minutes. The change reflects reduced fragmentation of the magma, reduced heat capacity of the coolant, and strongly reduced convection in the coolant. A separate pour into a liquefied sand-clay sediment (64 percent sediment by mass) produced similarly reduced heat transfer, but the increased coolant density resulted in quiet but pervasive hydrodynamic fragmentation of the melt into sub-centimetric glass balls, many of which welded together within the sediment.

We interpret these results as indicating that interactions of magma with sediment-laden water or liquefied sediment are less intense and energetic than those of magma with pure water, other things being equal. This implies that significantly explosive MFCI interactions are less likely with sediment-laden coolants, but eruption products such as sediment-rich pyroclastic beds indicate that despite inauspicious starting conditions, such explosions nevertheless occur. Future work will address the forcing conditions for making magma interact with these recalcitrant coolants in ways capable of producing the explosive eruptions inferred from deposits and known from observed eruptions.

MAGMA SYSTEMS AT TAUPO VOLCANO: INSIGHTS FROM U-Th MODEL-AGE SPECTRA IN ZIRCONS

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In the last 61 kyr, there has been erupted c. 580 km^3 of silicic (overwhelmingly rhyolitic) magma from vents under or just north of Lake Taupo. About 90% of this volume was vented in the 27 ka Oruanui event, but a complex sequence of >12 eruptions before and 28 after the climactic event show how the magmatic systems feeding these eruptions in the broader Taupo-Maroa area have evolved in time and space. Zircon model age spectra from a suite of eruptions prior to the Oruanui show that systems which vented contrasting compositions from sources only 15 km apart underwent independent crystallization (i.e., thermal) histories. Precursor leaks of the system that fed the Oruanui eruption itself are compositionally similar and have a common 90-100 ka peak in their zircon model-age spectra, but differ in the relative proportions and ages of younger (shortly pre-eruptive) crystallization peaks. Field data show that the vent sites for two of these precursor events (Okaia, 30 ka; Tihoi, c. 45 ka) were sited within the modern lake, overlapping with the footprint of the Oruanui chamber. Despite the spatial overlap of vent areas, however, the three units concerned have distinctly different modes in their younger crystallization ages. Their common chemistries and older 90-100 ka model age peaks imply that they share a common source (mush) zone, but the model-age spectra show that the melt-rich bodies in each eruption were independently extracted. Thus the c. 530 km^3 Oruanui melt-dominant body is implied to have formed essentially in its entirety between the Okaia and Oruanui events, i.e., in only about 3000 years (from 30 to 27 ka, each +/- 1 kyr). Post-caldera dacites and rhyolites are chemically and isotopically distinct from the Oruanui, with no mixing relationships. The first of the rhyolites (Unit B at 11.8 ka) has a peak in model-ages identical to the young Oruanui peak, but the slightly older (16 ka) Puketarata rhyolite erupted nearby, 15 km north of Taupo, is dominated by zircons with model ages post-dating the Oruanui. The crust in the Taupo area includes several independent magma generation systems, active over tens of thousands of years or more, that can be provoked into segregating volumes of melt-dominant magma at sometimes extraordinary rates. We infer that tectonic processes are likely to control the timing and rates of growth and release of these melt-dominant bodies.

SYMPOSIUM: GEOCHEMISTRY

GEOCHEMISTRY - A GEOCHEMICAL WINDOW INTO EARTH'S ORIGIN, HISTORY AND FUTURE

Tuesday 24th November

Rangimarie 1&2

Geochemistry 1: 14:15 – 15:00

Wednesday 26th November

Rangimarie 1&2

Geochemistry 2: 9:00 – 10:30
Geochemistry 3: 11:00 – 12:30

Posters: Tuesday 15:30 – 17:00 (Oceania)

SEARCHING FOR A SUPERNOVA TRIGGER FOR SOLAR SYSTEM FORMATION

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Nickel has five isotopes (58, 60, 61, 62 & 64) and is potentially a powerful early Solar System chronometer and tool to identify the astrophysical setting in which our Solar System formed. Variations of ^{60}Ni abundances in meteorites might result from the decay of short-lived ^{60}Fe ($t_{1/2}$ = 1.49 Myr), if ^{60}Fe was injected by a supernova into the proto-Solar System shortly before or during Solar System fomation. Furthermore, variations in the abundances of the two neutron-rich Ni isotopes, ^{62}Ni and ^{64}Ni, in meteorites may also be a powerful tracer for different stellar nucleosynthetic inputs into the proto-Solar System and time-scales of mixing of different nucleosynthetic components in the proto-planetary disc. Recently published Ni isotope data for meteorites has produced conflicting results [1-5]. [1,2 & 4] have found no evidence for measurable Ni isotopic anomalies in the Fe-Ni metal of iron, pallasite and chondrite meteorites. In contrast, [3] reported deficits in ε^{60}Ni and ε^{62}Ni of 0.24 and 0.69 epsilon units, respectively, and concluded that ^{60}Fe was injected into the Solar System just after its formation, and that ε^{62}Ni deficits reflect preservation of Ni nucleosynthetic anomalies on a planetary scale in the Solar System. Regelous et al. [5] measured small variations in ε^{60}Ni and ε^{62}Ni in irons and chondrites, concluding that the ε^{62}Ni variations are nucleosynthetic and that some of the ε^{60}Ni deficits in the irons could represent the effect of ^{60}Fe decay in metal with subchondritic Fe/Ni.

We have developed methods for separation of Ni from Fe-Ni metal and high-precision Ni isotopic analysis by multiple-collector inductively coupled plasma mass spectrometry at VUW. Fe-Ni metal from pallasites, irons and chondrites was digested and subjected to 3 different column chemistry methods to purify Ni. Ni cuts for iron meteorites Esquel, Arispe and Mundrabilla that were analysed and reported in [3] were also analysed. All irons and pallasites (with the exception of the IVB iron Chinga) have ε^{62}Ni values that only show small variations from the terrestrial standard (<± 0.1). Apart from Type IAB irons, ε^{60}Ni values for irons and pallasites are slightly negative (-0.02 to -0.19). ε^{60}Ni and ε^{62}Ni values are generally consistent with the measurements published by [2, 4 & 5] and inconsistent with [3]. Small ε^{60}Ni deficits in magmatic irons and pallasites appear to be consistent with a maximum ^{60}Fe/^{56}Fe = 4 x 10^{-7} at the time of their formation and the former presence of live supernova-derived ^{60}Fe in the parent bodies of the Solar System's oldest dated planetesimals. These data are consistent with a supernova causing the collapse of the cloud of gas and dust that triggered the formation of the Solar System.

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TEPHRA GEOCHEMICAL STUDIES IN NZ – NEW OPPORTUNITIES AND PITFALLS

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In situ geochemical analysis of glass shards produced during explosive pyroclastic eruptions is a powerful tool for: (a) constructing the chronostratigraphy of sediment records and, in particular, those used for paleoclimate and paleoceanographic studies; (b) examining chemical and isotopic variations present in magma chambers immediately prior to eruption that can be used to elucidate the petrogenetic origins of magmas and, potentially, eruptive triggering mechanisms.

New investments in analytical instrumentation in New Zealand (electron microprobe, laser ablation inductively coupled plasma mass spectrometry [ICP-MS], multiple-collector inductively coupled plasma mass spectrometry) make it possible to undertake routine high precision major element, trace element and Sr-Nd-Hf-Pb isotopic study of tephra material. We have developed analytical techniques for these chemical and isotopic studies at VUW that show that trace element and isotopic data considerably enhance the use of tephra geochemistry as a chronostratigraphic and petrogenetic tool.

Extracting the most information from these new geochemical techniques requires the New Zealand Earth Science community to develop a standardized approach to the measurement of elemental concentrations and isotopic compositions that will allow data from separate studies to be comparable. In detail we propose that:

(1) All studies undertake and report measurements of widely available (international) reference standard material broadly similar in composition to the samples being analysed, when undertaking chemical and isotopic studies e.g., MPI-DING glasses for *in situ* work and USGS rock standards for isotopic work.
(2) Laser ablation ICP-MS laboratories use the GEOREM database for obtaining the most up-to-date and reliable (e.g., isotope dilution) concentration data for standards that are used for calculating concentration data for unknowns.
(3) *In situ* laboratories carefully examine the effects of differing matrix between samples and standards to ensure that this does not result in the generation of inaccurate data.
(4) Laboratories undertaking isotopic work carefully examine the veracity of their leaching techniques prior to sample digestion to ensure they remove secondary and/or anthropogenic contamination.

As an example, inappropriate use of non-matrix-matched standards and reference values during laser ablation ICP-MS analysis results in data that are inaccurate by 10-50%. Moreover, a considerable part of the previously published Pb isotopic data for Taupo Volcanic Zone is inaccurate due to insufficient leaching to remove anthropogenic Pb prior to sample dissolution.

THE GEOCHEMISTRY OF LAKE ROTOMAHANA – AN UNDERGRADUATE PROJECT

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Lake Rotomahana, formed in 1886 as result of the Tarawera Eruption, is not only dominated by geothermal fluids which contribute about half of the dissolved salts to the lake, but also in turn dominates the composition of the geothermal waters discharging from springs and geysers in the adjoining "Steaming Cliffs". Lake Rotomahana has no overland outlet, instead discharging through a ridge into Lake Tarawera and maintaining a similar subsurface connection with "Green Lake", a small lake occupying an explosion crater to the south east of Lake Rotomahana. As in the similar situation between Lakes Rotoma and Rotoehu, subsurface flow of lake waters from a source lake to a receiving lake results in the addition of substantial quantities of phosphorus to the waters. Both receiving lakes are amongst the most eutrophic in the Rotorua District although are fed by subsurface flows from the most oligotrophic. As with Lake Tarawera, also oligotrophic, the composition of the sediment pore waters shows upwards mobilization of manganese but not iron, and the accumulation of substantial quantities of phosphorus at or just below the sediment/water interface.

GEOCHEMISTRY AND TECTONIC SETTING OF MASSIVE SULPHIDE MINERALISATION AND ASSOCIATED SEDIMENTS AND VOLCANICS IN THE MATAKAOA VOLCANICS, RAUKUMARA PENINSULA

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Volcanogenic massive sulphide (VMS) occurrences within the Matakaoa Volcanics are associated with lenses of siliceous mudstones. The Matakaoa Volcanics are part of overthrust blocks of Early Cretaceous to Oligocene sedimentary and igneous rocks of the East Coast Allochthon, and are extensively deformed by faults and steeply plunging folds. They represent the upper part of an ophiolite sequence of basaltic pillow and massive lavas and hyaloclastic breccias, locally with gabbro-textured concordant units that appear to be ponded lavas rather than sills. The lavas are tholeiitic basalts and basaltic andesites, with rare earth element and Ba, Rb, K, Th, Ta and Nb geochemical signatures indicating that they include both N-type mid-ocean ridge basalts and island-arc tholeiites. This is characteristic of basalts formed at a spreading centre in back-arc basin with a subduction zone influence. Lenses of siliceous mudstones, cherts, micritic limestone and rare volcaniclastic sandstone, ranging in size from a few metres to several hundreds of metres in length, are intercalated within the volcanic rocks, and are of Late Cretaceous and Late Paleocene to Early Eocene ages from foraminifera and radiolaria. Boström ratios (Al/Al+Fe+Mn+Cu) of the mudstones and cherts are only locally, slightly enriched in Fe, Mn or Cu, suggesting that they mainly consist of terrigenous or biogenic material with only local hydrothermal inputs. The mudstones and cherts are enriched in Ba (up to 0.69%), which is probably mainly of biogenic origin. As indicated by the covariation of K, Ti, Nb and Zr with Al, La_n/Ce_n ratios and Sc-Zr-Th relationships, the mudstones and cherts contain a significant detrital component, consistent with a back-arc basin setting adjacent to a continental arc.

The siliceous mudstones locally host some small bodies of massive sulphide and barite-sulphide mineralisation. At Sulphide Bay, a pyrite-pyrrhotite-chalcopyrite massive sulphide body is similar to the high-temperature (350 to >400^{o}C) interiors of sulphide chimneys found in basalt-hosted (ophiolite type) VMS deposits at spreading centres in the Pacific Ocean. The sulphide mineralisation is associated with andradite garnet-hedenbergite alteration (with high Ca-Fe and low Al), which is similar to that found in high temperature (400-700^{o}C) hydrothermal environments in active geothermal systems in the Philippines. A barite + pyrite + marcasite + sphalerite ± chalcopyrite ± galena ± gold occurrence at B13 creek is similar to VMS deposits found in volcanic arcs and immature back-arc basins in the western Pacific Ocean and to Kuroko-type VMS deposits. Thus a spreading centre in an immature back-arc basin appears to be the best fit for the tectonic setting of the Matakaoa Volcanics and its associated sediments and mineralisation.

CHEMISTRY OF MODERN ANTARCTIC SNOW: A PALEOENVIRONMENTAL CALIBRATION FOR ICE CORES

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Knowledge of atmospheric aerosol sources, transport and depositional mechanisms into snow is important for the correct interpretation of past changes in elemental abundances within the ice core record. The nature of such records is shown to be highly site specific. This study focuses on major and trace element concentrations in snow pit samples from 1997 to 2007 at Evans Piedmont Glacier, in the vicinity of a number of ice cores taken along the Victoria Land coast. An automatic weather station was installed at the site in 2004 allowing site specific correlation between meteorological conditions and snow chemistry. This meteorological record is extended by local Scott Base measurements, which are shown to be representative by the period of overlap between the two records. Dating of the samples is constrained by seasonal variations in stable water isotopes (δD and $\delta^{18}O$), snow pit stratigraphy, density measurements and correlation with records previously sampled in November 2004 and 2006. Analysis has been conducted for major (Ca, Mg, Na, methanesulphonate, SO_4^{2-}, NO_3^-) and trace element (Al, Fe, Mn, Ba) concentrations using both ion chromatography and inductively coupled plasma mass spectrometry (ICP-MS). Further analysis using ICP-MS is underway for heavy metals and rare earth elements such as As, Bi, Cd, Ce, Cr, Cs, Cu, La, Ni, Pb, Rb, Sb, Sr, Ti, Th, U, V, W, Y, Zn, Zr.

Preliminary results indicate the major source of marine aerosol at this site is from local frost flower formation on the surface of young annual sea ice in the Ross Sea. This is in contrast to the traditional interpretation of marine element concentrations indicating proximity or transport efficiency of marine aerosol from an open ocean source. A number of studies have demonstrated the formation of frost flowers from sea ice ejected brine which migrates to the surface. Depending on temperature, the brine is increasingly depleted in sulphate due to the formation of mirabilite (a hydrous sodium sulphate mineral) within the sea ice at cold conditions. The flowers that form are highly saline, concentrated in marine elements such as Na and Mg and depleted in sulphate relative to marine ratios. At Evans Piedmont Glacier, seasonal winter maxima of Na, associated with negative non-sea salt (nss) SO_4^{2-} values (calculated using the Na/SO_4^{2-} sea water ratio) indicate this is the dominant Na source. It is tentatively suggested that temporal changes in Na and nssSO_4^{2-} at coastal Victoria Land may be used as a proxy for new sea ice development, in particular the strength of the Ross Sea Polyna system.

CYCLIC PROCESSES AND FACTORS LEADING TO PHREATIC ERUPTION EVENTS FROM RUAPEHU CRATER LAKE

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The September 25, 2007 phreatic eruption from Ruapehu Crater Lake occurred without warning, and at a time when the lake was cool (13 °C), and the volcano seismically quiet. In this respect, the eruption was both rare and dangerous. The northerly-directed blast sent ballistics of up to 1 m diameter more than 2 km from the source. The ejecta comprised a variety of volcano-lacustrine lithologies, many showing evidence of intense hydrothermal alteration. Petrographic studies revealed numerous examples of pores/vesicles being filled with elemental sulphur, and associated anhydrite, pyrite and natro-alunite. Many ballistics exuded liquid sulphur from their pores during surface cooling at atmospheric pressure. Evidence suggests that the eruption was gas-driven, where failure of a critically-stressed, mineralised seal near the top of the vent led to explosive decompression of the underlying gas-charged hydrothermal system.

A long-recognised characteristic of this volcano is the thermal cycling behaviour of its crater lake, behaviour which has remained effectively unchanged through two magmatic eruption events in 1945 and in 1995/96. Since 2003, there have been 5 complete thermal cycles, with temperatures ranging between 13 and 39 °C. Over this period there has been good correspondence between heat and CO_2 discharge from the volcano, suggesting an overall control of the cycling by the magmatic system. C/S ratios in gas emissions have, on the other hand, varied widely, suggesting sulphur scrubbing in the vent/lake system

To better understand the chemical and physical processes operating in this very dynamic volcanic hydrothermal system, and its propensity to develop potentially dangerous hydrothermal seals, we have developed a finite-difference (TOUGH2) heat-mass transport simulation of the hydrothermal environment. The model, which is constrained by observed heat and mass flux characteristics of the volcano, demonstrates the transient nature of the heating cycles on the vent/lake system. Of particular interest is the role of CO_2 as a relatively inert, pressure-transmitting medium in the hydrothermal environment.

Seal formation was simulated using the reactive transport code X1t, which showed that condensation of magmatic vapour into a highly porous medium of andesitic composition leads to rapid formation of an elemental sulphur-anhydrite-natro-alunite mineral assemblage, and a drastic reduction in permeability. We suggest that since the 1995/96 vent-clearing eruptions, a shroud of elemental sulphur and other alteration phases has formed along the margins of the 2-phase liquid-vapour region enclosing the conduit. This effectively seals the upper portion of the vent from the adjacent, hydrostatically controlled environment, and allows for development of pressurised, vapour-static gas columns beneath the northern and central vents.

Mg/Ca OCEAN PALEO-TEMPERATURES FROM NEW ZEALAND FORAMINIFERA IN THE EOCENE GREENHOUSE WORLD

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We have developed laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) techniques to measure *in-situ* elemental ratios (Mg, Al, Mn, Zn, Sr, Ba/Ca) of planktonic and benthic foraminifera of Early Eocene age from the Mid-Waipara section (Ashley Mudstone), North Canterbury. The objective of this work is to extract ocean surface and bottom temperatures during the Eocene greenhouse world for the high-latitude South Pacific. These samples have also been analysed for $\delta^{18}O$ and TEX_{86}, permitting comparison between these independent temperature proxies and the Mg/Ca paleothermometer (Hollis et al., in press). Foraminifera have been separated from 20 samples of the calcareous Ashley Mudstone that is inferred to have been deposited at ocean depths of ca. 1000 m. Multiple individuals of up to 11 different species have been analysed from each sample.

Each foraminifer test is analysed at least three times, whereby a 25 µm laser pit is drilled into the specimen providing a trace element/Ca profile through the test. The resultant profile makes it possible to identify and avoid zones of surficial and internal contamination resulting from diagenetic coatings, mineralisation and detrital sediment. Ocean temperatures were calculated using the exponential relationship $Mg/Ca\ (mmol/mol) = A\ exp^{B\,T}$. Temperatures for planktonic species were calculated using the mean Mg/Ca – T calibration for nine modern planktonic species (A = 0.38; B = 0.09; Anand et al., 2003). Ocean temperatures for the benthic species were calculated using A and B values of 0.867 and 0.109, respectively (Lear et al., 2002) that have been determined on three modern benthic *Cibicidoides* species. Given that Eocene seawater is likely to have had lower Mg/Ca than the present day (Stanley & Hardie, 1988; Wilkinson & Ageo, 1989; Zimmerman, 2000; Dickson, 2002; Lear et al., 2002), we calculated ocean temperatures using a conservative estimate of Eocene seawater Mg/Ca as having been 35% lower than the present day value, giving minimum temperatures.

Surface dwelling planktonic foraminifera (e.g. *Morozovella crater*) from the Early Eocene Climatic Optimum (EECO) yield sea surface temperatures of 28-30˚C, whereas deep-dwelling planktonic species (e.g. *Acarinina primitiva*) yield temperatures that are 2-3˚C lower. Most benthic species (e.g. *Anomalina visenda, Bulimina subbortonica, Cibicides spp.*) have Mg/Ca ratios that correspond to bottom water temperatures of 16-20˚C that are consistent with the near surface ocean temperatures. Subtle differences in calculated temperatures from another benthic species, *Vaginulinopsis marshalli,* suggest that there are some species-specific differences in the Mg/Ca – T calibrations. These very high paleo-ocean temperatures for the southern latitude South Pacific during the EECO are broadly consistent with temperature derived from the other geochemical proxies. These results demonstrate the ability of LA-ICP-MS to recover reliable past ocean temperatures from what are less than ideally preserved foraminiferal specimens.

DON'T BLOW YOUR LID! CONSTRAINING VOLATILE TRANSFER IN AN ACTIVE CALDERA, RABAUL, PAPUA NEW GUINEA

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Gas accumulation can trigger violent volcanic eruptions, therefore, monitoring gas emission both directly and indirectly is essential: particularly volatiles H_2O, CO_2 and SO_2 which form bubbles in shallow magma chambers. Several methods have been applied to constrain volatile contents including COSPEC measurements of degassing plumes, melt inclusion analysis in phenocrysts, and more recently, isotopic measurements of ($^{210}Pb/^{226}Ra$) in pumice to infer Rn gas movement. What does this information tell us about degassing and do the different methods agree? We investigate this question using a data set from Rabaul Caldera, Papua New Guinea which has been erupting intermittently since 1994. After initial Plinian activity subsided, Rabaul commonly exhibited Vulcanian-style eruptions. However, from 1996-7 eight large Strombolian-style eruptions punctuated Vulcanian eruptions. Fifteen bombs and pumice erupted from 1994-2001 are analysed for the ^{210}Pb-^{226}Ra isotopic pair to determine timing of gas transfer. Time scales of open system gas loss are calculated for samples that displayed ($^{210}Pb/^{226}Ra$) deficits. Moreover, three samples are selected for olivine and plagioclase melt inclusion analysis. Rabaul has undergone periods of both open system gas loss and closed system gas accumulation. ($^{210}Pb/^{226}Ra$) deficits in three samples suggest open system gas loss since 1992. ($^{210}Pb/^{226}Ra$) excesses, which infer ^{222}Rn gas transfer are measured during 1994, 1997, 2000 and 2001. Melt inclusion data for phenocrysts erupted in 1997 are <1 wt% H_2O and CO_2 below detection limits suggesting these samples were extensively degassed under shallow conditions. These results differ from Roggensack et al. (1996) who found H_2O contents of 3.8 wt% and CO_2 contents of 960 ppm in olivine melt inclusions from the 1994 eruption. We compare the ($^{210}Pb/^{226}Ra$) ratios with COSPEC SO_2 data from the degassing plume. One of the more surprising results is that there is no correlation between ($^{210}Pb/^{226}Ra$), SO_2, H_2O or eruptive style. This would suggest that gas transfer in an active caldera is a complex process and the different lines of gas data we collect record separate processes.

CADMIUM ISOTOPIC FRACTIONATION AND NUTRIENT CYCLING IN THE SOUTHERN OCEAN

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Cadmium (Cd) in conjunction with phosphate (PO_4) has been used as a paleoproxy for understanding nutrient cycling in historic oceans. However, our limited knowledge of Cd biogeochemical cycling in the oceans has led to many assumptions being used in the application of the Cd/PO_4 proxy. Cd isotopes offer the potential to provide new insights into the distribution and cycling of marine Cd than can be obtained through Cd concentration measurements alone, and may in itself prove to be a reliable proxy for past and present nutrient cycling. New techniques for Cd isotopic measurement, utilizing double-spiking protocols combined with multiple-collector inductively coupled plasma mass spectrometry (MC-ICPMS) (Ripperger and Rehkamper, 2007, GCA 71, 631-642), have increased our ability to measure Cd isotopic fractionation. The simultaneous collection of multiple Cd isotopes results in high precision measurements with uncertainties at the 0.01%-level, allowing the resolution of very small isotopic fractionations that could not be previously explored. Research using these techniques has already shown a strong 0.1%-level biological fractionation of Cd in seawater, thought to be caused by phytoplankton uptake (Ripperger et al., 2007, EPSL 261, 670 – 684). Using a Nu Instruments Nu Plasma MC-ICPMS at the University of Otago, we are applying Cd isotopic measurement to a diverse selection of seawater and marine biota samples from the Southern Ocean. We propose that isotopic fractionation of Cd is very pronounced in Dredge Oysters (*Ostrea lutaria*) found off the south coast of New Zealand. These oysters have extremely high concentrations of Cd (2 parts per million) despite a lack of point source pollution in the surrounding waters. It is likely that these oysters have high levels of Cd due to bioaccumulation through filter-feeding on phytoplankton, thus further increasing the fractionation signal. These techniques will also be used to further the understanding of Cd isotopic fractionation in phytoplankton. Phytoplankton growth experiments will help to determine which other metals, such as Zn and Fe, influence the uptake of Cd by phytoplankton and also if there is a species dependent uptake of Cd and how that influences isotopic signatures. All of this information will help to determine and improve the effectiveness of the current Cd/PO_4 paleoproxy.

CONTROLS ON ARSENIC DISCHARGE FROM AN HISTORIC GOLD MINE SITE, WAIUTA, WESTLAND

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Processing of arsenopyrite-rich ore took place at the Prohibition site from 1938 to 1951 and no rehabilitation was undertaken after mine closure. Arsenic-rich processing residues (up to 40 wt%) have left a legacy of ongoing arsenic contamination, making this site probably the most acutely toxic historic mine site in New Zealand.

Arsenic was originally present exclusively as arsenolite (arsenic trioxide polymorph, As^{III}), which is a by-product of arsenopyrite roasting. Arsenolite is significantly more soluble than arsenopyrite, theoretically producing arsenite (As^{III} oxyanion) concentrations of up to12 g/L. In the surficial environment, arsenite oxidises to arsenate (As^{V} oxyanion), which is accompanied by acidification. Thus, the Prohibition site differs from historic gold mine sties where arsenopyrite tailings are the main source of arsenic and acidification.

Site run-off drains into a small wetland, which typically contains up to 50 mg/L dissolved arsenic, exceeding the NZ drinking water limit by 5000 times. Some of the dissolved arsenic from arsenolite dissolution is temporarily immobilised by the precipitation of scorodite (hydrated iron arsenate). Further downstream, effective arsenic attenuation occurs in a man-made dam confining the downstream end of the wetland. The high dissolved arsenic entering the dam decreases by over an order of magnitude, even after over 50 years of existence. The effectiveness of the dam depends on the input of acidic and carbonate deficient water, allowing for the dissolution and subsequent precipitation of Fe from the Fe carbonates in the rocks constituting the dam.

The processes controlling arsenic mobility and attenuation are dependent on the site-unique characteristics and are sensitive to modifications arising from site management. A desirable remediation option is the complete removal of arsenic-rich material to a safe disposal site. If that is not possible, the arsenic-rich site substrate and remaining arsenolite from the roaster system should be moved into the wetland and covered by an impermeable cover. The wetland cover and other material added to the site should be carbonate-free to ensure continued site acidity, on which scorodite stability and attenuation in the dam depend. Thus, the local Greenland Group rocks are unsuitable. Furthermore, any site disturbance should be accompanied by a monitoring system downstream, due to temporarily increased surface area of arsenic-rich material.

BIOMINERAL STABLE ISOTOPIC PALEOCLIMATE PROXIES: MODERN CALIBRATIONS FOR NEW ZEALAND

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New Zealand's natural history affords unique opportunities to apply stable isotopic climatic and environmental proxies to problems of global significance. Advances in stable isotopic research indicate the oxygen, nitrogen, and carbon isotopic compositions of biominerals are robust quantitative proxies for temperature, mean annual precipitation, and relative dietary significance of C3 versus C4 plant matter. These relatively new methods, particularly when coupled with traditional biomineral proxies (e.g. carbonate $\delta^{18}O$ and $\delta^{13}C$ values), have the potential to produce relatively high resolution terrestrial records of both climatic and environmental change - provided suitable pre-historic specimens are present. Application of multiple proxies to common biominerals provides the attractive advantage of allowing for the discovery of system-level responses to natural and anthropogenic mechanisms of pre-historic environmental change, advancing our ability to best anticipate how regional and local ecosystems will respond to the current period of global climate change and related environmental impacts.

However, establishing empirically derived isotopic environmental lapse rates and fractionation factors at the regional scale precludes application of biomineral proxies to ancient specimens. In an effort to evaluate the potential application of biomineral isotopic proxies to New Zealand systems, the oxygen, nitrogen, and carbon isotopic compositions of modern biominerals - collected across major environmental gradients - are currently being determined in the new University of Canterbury stable isotope analytical facility. Preliminary results of modern proxy calibration studies will be presented.

DEVELOPMENT OF A MG/CA TEMPERATURE CALIBRATION FOR THE PLANKTONIC FORAMINIFERA *G. INFLATA* FOR NEW ZEALAND WATERS

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The exponential, temperature dependant incorporation of Mg into foraminiferal calcite means Mg/Ca ratios may provide a sensitive proxy for past oceanic temperature variability, independent of global ice volume effects. However, species specific Mg/Ca temperature calibrations derived from modern foraminifera are vital for establishing and testing the reliability of these temperatures. Mg/Ca ratios can be measured at high spatial resolutions (~ 25 µm) on individual foraminifera using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The LA-ICP-MS method provides; (1) the opportunity to examine in detail how Mg/Ca is variably incorporated into individual foraminifera, and (2) the ability to critically filter analyses following detection of gametogenic/secondary calcite (anomalously high Mg/Ca) and the presence of contaminant phases (e.g. elevated Al/Ca, Mn/Ca). Our earlier studies (2007) of the benthic foraminifera *Uvigerina spp*. revealed significant test heterogeneity meaning that a reliable calibration for this species could not be established. Here we present a preliminary Mg/Ca temperature calibration for the planktonic foraminifera species *Globoconella inflata.*

Laser ablation analyses were conducted on *G. inflata* obtained from 14 core top sites spanning a range of latitudes, water depths, and modern sea surface temperatures (34ºS to 54ºS; 3000 to 400 m deep; ~ 8 to 20ºC) from different water masses east of New Zealand. Several laser ablation analyses in each *G. inflata* chamber has revealed the presence localised highly altered test regions (evidenced by significant time-resolved fluctuations in trace elemental ratio profiles) which can result in erroneous temperature determinations of up to ~37.4ºC for mid-latitude modern New Zealand surface waters. Mg/Ca ratios measured on the different chambers of an individual *G. inflata* can vary by up to ~ 30% (~ 1.6 - 2.3 mmol/mol), significantly greater than the associated analytical uncertainties (< 10%). These observations reinforce the importance of rigorously screening each analysis before applying the data to paleoenvironmental interpretations.

Single *G. inflata* chamber-to-chamber temperature determinations can vary by ~5 ºC, with the final chambers generally exhibiting higher temperatures. Preliminary results also suggest an additional complexity to Mg incorporation into kummerform and ecophenotypes.

NON-ANTHROPOGENIC SOURCES OF CO_2 IN THE GLOWWORM CAVE, WAITOMO

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A requirement of tourist cave management is that the partial pressure of carbon dioxide (P_{CO_2}) is kept below levels that are hazardous to human health or potentially corrosive to speleothems. In the Glowworm Cave at Waitomo the maximum P_{CO_2} level is set at 2400ppm (based on findings of McCabe, 1977) which showed drip water P_{CO_2} of about 3000ppm. Occasionally this level is exceeded which results in the closure of the cave. Ten years of monitoring at Glowworm Cave have shown that most of the variation in P_{CO_2} can be attributed to CO_2 respired by tourists and the mixing of cave air with lower P_{CO_2} outside air. Occasionally there have been periods when P_{CO_2} has risen to near maximum conditions whilst the cave has been closed to tourists. We have attempted to identify and quantify non-anthropogenic sources of CO_2 to the cave atmosphere. Two sources have been monitored. The Waitomo Stream flows through the cave, ponds and sumps. The P_{CO_2} of the Waitomo Stream water has been measured by equilibrating air within a closed loop which passes continuously through an infrared gas analyser (IRGA). The chemistry of the water has also been monitored with daily samples analysed for major ions and stable isotopes. Freshets driven by rainfall events result in pulses of high P_{CO_2} and low $\delta^{13}C$ water in the stream.

The second source, stalactite drip waters has much lower flow rates but displays much greater variability with peaks in P_{CO_2} exceeding 5000ppm and coinciding with rainfall events. Coincidence of these P_{CO_2} peaks with periods of rainfall suggest that root respired CO_2 trapped by saturation of the soil surface is responsible for both peaks.

VANADIUM ISOTOPES: EXPECTATIONS, DIFFICULTIES AND FIRST RESULTS

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Stable isotope variations of light elements such as hydrogen and oxygen have provided unprecedented insights into the formation of our Sun and planetary system through to quantifying past changes in the Earth's climate reservoirs. New analytical technologies, principally the development of plasma-source mass spectrometry, have made it possible to examine small stable isotopic variations of heavier elements expanding the field of stable isotope chemistry to much of the Periodic Table.

Much effort in the new field of "heavy stable isotope" systems has focused on elements that occur at various redox states in planetary reservoirs as redox state plays a major role in defining an element's physical and chemical properties, which may be recorded in the geological record as stable isotope variations. Detecting such variations is crucial for establishing the geochemical cycles of redox sensitive elements that can give us unprecedented insights on fundamental geological processes such as planetary differentiation, mantle melting or Earth's oceans oxygenation. However, available heavy elements isotopes systematic suffer from limitations due to abundance problems (e.g. molybdenum) or excessive oxidation (e.g. iron is mostly in trivalent form at Earth's surface). Therefore, new tools must be developed to investigate such matters.

Because vanadium occurs at multiple redox states and is abundant in all planetary reservoirs, it is likely to yield new insights into planetary geochemistry. However, vanadium only has two isotopes and with one isotope being particularly small and susceptible to isobaric interferences, establishing the required analytical methodology is challenging. Here, we will present the insights expected from this new isotope system to the geochemical cycle of redox sensitive elements, develop the analytical difficulties associated with measurement of vanadium isotopes and, finally, present the first results obtained on a variety of different rock samples.

FINGERPRINTING OF VOLCANIC GLASSES UNRAVELS THE VOLCANIC HISTORY OF NGAURUHOE VOLCANO, NEW ZEALAND

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Mt Ngauruhoe is frequently cited as one of the world's most active volcanoes. This reputation stems from direct observations of vulcanian and strombolian eruptions (VEI 1&2) that occurred over the 130 years prior to 1975. However, a realistic understanding of possible future eruption styles requires a detailed knowledge beyond the historical record. We present the first results of a tephrochronological/geochemical record of the entire history from Mt Ngauruhoe. This allows us to identify and quantify the eruption frequency and magnitude of eruptions during the onset and subsequent development of this stratovolcano.

The major obstacle in elucidating the pre-history of Mt Ngauruhoe is to untangle a complex sequence of tephra layers from other nearby sources. We use volcanic glass to distinguish Mt Ngauruhoe deposits from its nearest neighbour, Mt Ruapehu. With the help of this unique fingerprint we are able to identify the oldest tephra from Mt Ngauruhoe at 3470 ± 20 yr B.P. (NZA 30052) – thus defining the "birth" of the stratovolcano.

The subsequent volcanic history of Mt Ngauruhoe can be subdivided into three distinct eruption phases:

1. An initial phase, which lasted ca. 300 years, included the eruption of three VEI 3 (ca. 2.5×10^{-2} km^3) and at least 50 VEI 2 (>3×10^{-3} km^3) events. This eruption phase deposited three distinctive tephra packages, separated by two short (<50 years) breaks.
2. Phase 2 lasted 350 years and involved one VEI 3 (ca 2.5×10^{-2} km^3) and 14 relatively large VEI 2 (> 5×10^{-3} km^3) vulcanian/sub-plinian eruptions. These events were erupted in three distinctive periods separated by intervals of ash-soil accumulation of VEI 1 and VEI 2 events ($\leq 1\times10^{-3}$ km^3). Interestingly, the duration of these low-magnitude eruption intervals steadily increased from 40 to over 350 years.
3. Phase 3 began after the 1850 B.P. eruption of the Taupo Ignimbrite (from Taupo Caldera, ~60 km NE from Mt Ngauruhoe) and continues to the present day. In contrast to the earlier phases, this period contains no evidence for larger (VEI 3) sub-plinian eruptions.

Frequency distribution curves show a constant decrease in eruption volume from VEI 3 and larger 2 eruptions within the first 900 years of Ngauruhoe's life, and small volume eruptions (VEI 0- small 2) over the last 2500 years.

By reconstructing Ngauruhoe's tephrochronological evolution, a new hazard assessment for this volcano can be made showing changes in the level of hazard over time.

EVIDENCE FROM MELT INCLUSIONS FOR SMALL-SCALE HETEROGENEITIES IN THE SOURCES OF MONOGENETIC VOLCANOES ON THE IZU PENINSULA, JAPAN

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The Izu Peninsula, central Japan, is at the northern end of the Izu-Bonin-Mariana Arc system (IBM) where it abuts the Japan Arc. The Peninsula consists of a basement of Miocene submarine deposits upon which a number of polygenetic and monogenetic volcanic centres have erupted. Along the eastern coast of the Izu Peninsula over 70 monogenetic volcanoes, produced over the last 300 ka and covering 350 km^2, form the Higashi-Izu Monogenetic Volcano Group (HIMVG). The field also extends offshore into Sagami Bay where a further 50 monogenetic volcanoes form the Higashi-Izu Oki Submarine Volcano Group, and where the most recent activity (in 1989) was located. The monogenetic activity is associated with a change in the local stress field as the Izu block collided with Honshu. The HIMVG are mostly basaltic, but towards the centre there are a number of dacitic cones.

In order to better understand the sources of the HIMVG, and this area of the IBM, we are undertaking a study of glassy melt inclusions that occur in crystals within scoria produced by the monogenetic volcanoes. Such inclusions enable magma compositions to be accessed prior to the widespread crustal assimilation and differentiation processes that have affected other subaerially erupted volcanic rocks in the IBM. Initial work has focused on inclusions from two coeval basaltic volcanoes, Takatsukayama and Sukumoyama, located at the northern edge of the HIMVG. Major (measured by EPMA), trace (LA-ICP-MS) and volatile (FTIR spectroscopy) element data show that the inclusions exhibit a bimodal compositional distribution: high alumina (14.89 to 18.81 wt.% Al_2O_3) and low alumina (11.02 to 13.73 wt.% Al_2O_3). The low alumina inclusions from Sukumoyama appear to be less fractionated versions of the high alumina melts. However, the Takatsukayama low alumina inclusions cannot be related so easily to the high alumina series, and instead require a different source. As single host crystals from the Takatsukayama scoria contain both types of inclusion this suggests that heterogeneities in its source occur on a very small scale.

ELEMENT EXCHANGE ACROSS THE SEDIMENT-WATER INTERFACE IN THREE LAKES OF DIFFERING TROPHIC STATUS

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The Taupo Volcanic Zone in North Island of New Zealand contains many lakes of volcanic origin which differ greatly in their trophic status and limnological characteristics. As part of my Ph.D. research I have been working on five lakes in the TVZ, three of which are presented here. Lake Tarawera (82 m) is an oligotrophic lake which bottom-waters remain oxygenated through stratification. Lake Okataina is mesotrophic trophic with the lower hypolimnion becoming anoxic just before winter mixing. Two sites were sampled on Okataina as it has two main basins of which the southern basin (75m) experiences a longer period of anoxia during stratification than the northern basin (65m). Lake Ngapouri (25 m) is a eutrophic lake which has a strongly anoxic hypolimnion for most of the stratified period, resulting in strongly reducing conditions and porewaters high in ammonium, phosphate and iron. Sediment samples were taken monthly in the central basins of each of these lakes and analysed for nutrients and trace elements.

In oligotrophic lakes, oxygen penetrates well below the sediment-water interface, reducing the mobility of iron and, to a lesser extent, manganese. Phosphorus mobility is directly related to the mobility of these two metal cations. High concentrations of bound phosphorus often tend to accumulate near the sediment surface in oligotrophic lakes. As lakes become more eutrophic, oxygen concentrations in the bottom waters become progressively reduced during seasonal stratification and may eventually be reduced to zero. The reducing zone migrates up through the bottom sediments during seasonal stratification, allowing iron and manganese to be mobilised and release other metal ions and phosphate into the overlying waters. In all of the lakes the dominant inorganic nitrogen compound within the sediments is ammonium ions. Ammonium concentrations increase in the sediment when the lakes are stratified over the summer months. With seasonal mixing in winter, oxygen-rich water diffuses into the sediment, oxidizing manganese and iron, which in turn results in adsorption of phosphorus. Denitrification may occur at the sediment-water interface if there is sufficient oxygen supply to have first oxidized ammonium to nitrate, followed by reduction of nitrate with seasonal stratification following the loss of oxygen.

5500 YEARS OF PALAEOENVIRONMENTAL RECORD FROM LAKE ROTORUA

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A palaeolimnological study has been carried out on a high-resolution, 7.62 m-long core (RU188-07) from northern Lake Rotorua, North Island. The core consists predominantly of olive diatomaceous ooze, laminated in places, and contains five tephras including Tarawera (1886 A.D.), Kaharoa (c. 1314 A.D.), Taupo (c. 233 A.D.) and Whakatane (c. 5500 cal. years B.P.). Radiocarbon dates were systematically too old. The laminations were found to be irregular combinations of diatomaceous ooze and thin, dark detritus. Following the Whakatane and Waimihia eruptions and up to approximately 3000 cal. years B.P., the catchment surrounding Lake Rotorua was rather unstable. A notable feature of the record is two phases of stability, the first following the Taupo eruption (from c. 1700 cal. years B.P. to c. 630 cal. years B.P.) and the second from c. 580 cal. years B.P. to c. 300 cal. years B.P. The latest, most significant event in the catchment history of Lake Rotorua was the settlement by Polynesians. The sediment chemistry and erosion profiles obtained here, from the northern part of Lake Rotorua, indicate that although there may have been some early clearing in the northern catchment for tracks or buildings, large-scale clearing in the area probably did not occur until c. 300 cal. years B.P. Also contained within the sediments are three layers of reworked tephric material that probably originate from the transfer of coarse grained tephra from shallow to deeper water during large storms at c. 1300 cal. years B.P, c. 520 cal. years B.P, and c. 220 cal. years B.P. Each event coincides with storm events inferred from records from Lake Tutira in eastern North Island and probably represent very large cyclonic events. Significant peaks in phosphorus concentrations indicate that throughout the accessible history of the lake the flux of phosphorus has been high enough to maintain a high trophic index.

MANGANESE REMOVAL FROM NEUTRAL MINE DRAINAGE THROUGH A TRIAL SCALE PASSIVE TREATMENT SYSTEM

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Design of passive treatment systems to remove manganese from water is difficult because manganese is highly soluble in acidic and circum-neutral waters. We present results of trial systems for the passive treatment of Mn rich, reduced, neutral mine drainage from a non-operational gold mine. The discharge has a pH ~ 6, alkalinity ~150 ppm, dissolved oxygen (DO) <1 ppm and elevated Fe, Mn, As and Zn. Interpretation of the NMD indicates four important factors: (1) the dissolved Fe concentration is ~20 ppm and is all Fe(II), (2) Fe(II) is controlled by saturation with respect to siderite ($FeCO_3$), (3) remaining Fe is all colloidal $Fe(OH)_3$, and (4) Mn concentration is saturated with respect to rhodochrosite ($MnCO_3$).

Equilibrium of Fe and Mn concentrations with minerals means that dissolved concentrations are stable and a treatment system can be optimised to the water chemistry. A pilot scale passive treatment system has been installed that includes an oxygenation cascade, a settling/reaction pond and a slag leaching bed. The system treats Fe(II) by oxidation to Fe(III) followed by precipitation and settling of $Fe(OH)_3$. While this reaction is net acid producing, the high alkalinity prevents acidification, and release of dissolved CO_2 causes the pH to increase. Manganese is removed by precipitation of Mn oxides and oxy-hydroxides in the slag leaching bed at elevated pH and high DO. Zinc and As are removed through adsorption onto $Fe(OH)_3$.

The oxygenation cascade and settling/reaction ponds remove 82-96% of the Fe, 10% of the Mn, 89% of the As, and 59% of the Zn. The slag leaching bed removes 99% of the remaining Mn. Increase in DO concentrations through the cascade of V-notch weirs closely matches predicted values, and oxidation rates of Fe(II) through the reaction chambers relate well to iron oxidation kinetics.

THE MINERALOGY AND GEOCHEMISTRY OF BEDLOAD SEDIMENTS, TAIERI RIVER, SOUTH ISLAND, NEW ZEALAND

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There are many geochemical studies focusing on dissolved and suspended loads in global river systems, whereas bedload sediments are often neglected and have received minimal attention. Existing studies indicate that the chemical compositions of suspended and bedload sediments are different enough that they should not be considered the same material or assumed to be affected by the same processes. This study is investigating the mineralogy and geochemistry of bedload sediments of the Taieri River. The Taieri River, located in East Otago, is New Zealand's fourth longest river and drains an area of 5650 km^2. The bedrock geology of the drainage basin is dominated by Otago Schist, with other less extensive units including the Waipiata and Dunedin Volcanics as well as sediments of Cretaceous to Quaternary age. The aims of this study are to quantify the mineralogy of the Taieri River bedload sediments, look at patterns of elemental transport, use Sr and Nd isotopes as provenance indicators and thereby determine the relationship between the bedrock geology and sediment geochemistry. Sample locations were chosen based on the bedrock geology, river morphology and previous studies. Each sample was sieved to produce six grainsize fractions (4-2 mm, 2-1 mm, 1-0.5 mm, 0.5mm-355 µm, 355-63 µm and <63 µm). Bulk and clay mineralogy of the different size fractions were determined by XRD, major elements were analysed by XRF, and trace elements by LA-ICP-MS. All size fractions at all locations contain quartz, albite, muscovite and chlorite, with less frequent epidote and clay minerals. Clay mineral separates consist of chlorite, illite, illite-chlorite ± vermiculite, with two samples also having kaolinite. The presence of montmorillonite in one of these samples, located in an area draining Dunedin volcanics, reflects the influence of bedrock geology on bedload sediment composition. Major element data demonstrates an inverse relation between SiO_2 and Al_2O_3 which reflects the continuum between quartz rich coarser grainsize fractions and the phyllosilicate rich fine fractions. The material of the fine grain fractions is of similar composition to average upper continental crustal values.

^{26}AL-TO-^{26}MG DATING PLANETARY FORMATION AND DIFFERENTIATION IN THE EARLY SOLAR SYSTEM

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Magnesium has three isotopes (24, 25 & 26), one of which can be produced by the short-lived decay of ^{26}Al ($t_{1/2}$ = 0.73 Myr). Since the demonstration of the former presence of ^{26}Al in calcium-aluminium-rich inclusions (CAIs) [1], the ^{26}Al-to-^{26}Mg chronometer has been used to date the relative timing of CAIs and chondrules as well as the formation of some basaltic meteorites [e.g., 2,3]. Recent application of multiple-collector inductively coupled plasma mass spectrometry (MC-ICPMS) to Mg isotope analysis has potentially opened up a new range of dating opportunities. However, in order take advantage of these opportunities it is necessary to resolve δ^{26}Mg* anomalies with a precision and accuracy of the Mg isotope measurements of ca. ±0.005‰, and it is also crucial to investigate the initial distribution of ^{26}Al and Mg isotopes in the early Solar System. This is especially of importance as it has been shown that there are significant nucleosynthetic variations in the neutron-rich isotope ^{54}Cr in chondrites (undifferentiated meteorites) that are a magnitude greater than δ^{26}Mg* anomalies that have been reported for achondrites (differentiated meteorites) [4]. If a homogeneous distribution of ^{26}Al and Mg isotopes in the early Solar System can be demonstrated, small δ^{26}Mg* excesses or deficits in meteorites and their constituents that are now resolvable might allow isochron or model age dating of material that was previously impossible to date.

We have developed procedures designed to achieve Mg yields from samples of > 99.5% with > 99.5% purity. For most samples, we routinely apply a 5-step column separation procedure to produce high purity Mg separates. Mg isotope ratios are measured on a Nu Plasma MC-ICPMS at Victoria University of Wellington. Multiple analyses of samples routinely result in weighted means with uncertainties that are ≤ ±0.006‰ (2 se).

We have measured Mg isotopes in nearly all major classes of meteorites including all groups of chondrites and most achondrites where small δ^{26}Mg* excesses (angrites, eucrites) and deficits (pallasite olivines, ureilites, aubrites) have previously been reported [e.g., 5]. We found the total range of δ^{26}Mg* anomalies in chondrites to be an order of magnitude lower than the variations reported for ^{54}Cr and the anomalies generally correlate with Al/Mg ratios, indicating an initial homogeneous distribution of ^{26}Al throughout the planet forming region. Very small δ^{26}Mg* deficits in pallasites, samples from the core-mantle boundaries of planetesimals, constrain mantle-core formation to the first million years of the Solar System. δ^{26}Mg* excesses in various basaltic meteorites date igneous crust formation of different planetesimals to 2.9 to 4.8 Myr after Solar System formation.

References:

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SPECTROSCOPIC STUDIES OF SILICIC ACID INTERACTIONS AT THE METAL OXIDE-WATER INTERFACE

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Silicic acid (H_4SiO_4) has been shown to have significant effects on several properties of metal oxides in geochemical and industrial systems. In this study Attenuated Total Reflectance Infrared Spectroscopy (ATR-IR) was used to study the structures of surface species formed from the reaction of silicic acid at the metal oxide-water interface. Initially the ATR-IR spectrum of H_4SiO_4 in aqueous solution was measured and bands assigned as a single Si-O asymmetric stretching mode at 939 cm^{-1} and a weaker broad Si-O-H bending mode at 1090 cm^{-1}. On an iron oxide surface at low silicic acid surface coverage ATR-IR spectra indicated a monomeric silicate is formed via a bidentate linkage. As surface coverage increases a discrete oligomeric silicate species becomes increasingly dominant. This species was tentatively considered to be a cyclic tetramer. A small amount of polymeric silicate is also observed at high surface coverage. The percentage of monomer present for iron oxide samples approaching equilibrium with solid phase Si/Fe mole ratios of 0.029, 0.040, 0.083 and 0.15 were estimated as 84, 51, 26 and 5 % respectively. The remainder was oligomer apart from 1 to 2 % polymer at the two highest Si/Fe mole ratios.

HIGH-RESOLUTION SEA LEVEL RECONSTRUCTIONS FOR THE LAST INTERGLACIAL PERIOD: U-SERIES CONSTRAINTS FROM WESTERN AUSTRALIA

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For the past two million years, the Earth's climate has oscillated between warm interglacials and cool ice ages with a periodicity of about 100,000 years. The present climate forms part of an interglacial regime, but during the last ice age about 21,000 years ago, temperatures were a few degrees cooler, ice sheets were considerably larger, and sea-levels were about 130 m lower than at present. Superimposed on these glacial-interglacial changes are abrupt climate reorganizations that occur on millennial to decadal timescales. Understanding the mechanisms underlying these abrupt climate shifts is essential to address emerging societal concern about the magnitude and rate of future climate change in the presence of global warming.

Western Australia's fossil coral reefs contain a wealth of information on processes driving Earth's natural climate cycles. Coral reefs are important archives of past climate change because they grow close to the sea-surface, providing valuable information on both sea level and temperature fluctuations, especially during warm interglacial periods when reefs grow prolifically. Previous work carried out on fossil coral reefs that line the Western Australian coast identified the timing and magnitude of the Last Interglacial sea-level high-stand occurring ~125,000 years ago (Stirling et al., 1995, *EPSL*, v.135, p.115; Stirling et al., 1998, *EPSL*, v.160, p.745), which has been emphasized as a slightly warmer analogue of the present interglacial period. We have set out to extend the scope of this previous work and date additional samples from various locations in the Cape Range National Park using uranium decay series (U-series) chronologies to better characterize the timing of sea level oscillations associated with the Last Interglacial.

We will present initial results from samples collected during the 2007 field season. U-series measurements have been acquired at the ANU and the University of Otago using multiple-collector plasma-source mass spectrometry (MC-ICPMS). U-series data acquired using the MC-ICPMS instrumentation at Otago, adopting new-generation 'multiple-Faraday' protocols for very high-precision measurement of the U-series isotopes, will be highlighted. In 125,000 year-old samples, the multiple-Faraday approach allows events separated by 200 years to be adequately resolved, compared with the >800 year resolution offered by conventional MC-ICPMS methods. Such high precision is essential for constraining the timing and magnitude of abrupt climate excursions occurring on centennial timescales, and has not been achieved previously for Last Interglacial samples. These data will supplement conventionally-derived U-series observations defining millennial-scale episodes of Last Interglacial reef growth along the Western Australian coastline (Dutton et al. 2008, *AESC Conference*, Perth).

PRODUCTION OF MARKETABLE SODIUM SULFATE FROM REFINERY WASTE RESIDUES

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"Waste to waste" technology brings together two waste streams to form a product that is less hazardous than the precursor wastes. Acidic jarosite waste, produced during the hydrometallurgical refining of zinc, and caustic 'red mud' waste, produced during the Bayer process of refining alumina, are two environmentally hazardous materials currently requiring costly disposal methods. As part of the zinc refining process, iron impurities are removed from the zinc-rich solution by addition of thenardite (Na_2SO_4), precipitating jarosite group minerals dominated by natrojarosite, $NaFe_3(SO_4)_2(OH)_6$. In addition to its high acid producing potential, jarosite waste contains high concentrations of potentially toxic metals and metalloids, including lead and arsenic, in soluble form. It has been shown that mixing acidic jarosite waste with caustic red mud waste results in a neutralised product (referred to as JRMM), at the same time sequestering the metals and metalloids in highly insoluble forms within the JRMM. The production of JRMM obviates the disposal problem of each waste stream, resulting in a single stable, non-toxic waste, and making this an attractive environmental remediation process.

In order to add a further economic and environmental incentive to institute JRMM on an industrial scale, it would be beneficial to create one or more marketable products from the JRMM material itself. We note that the aqueous solution separated from JRMM has high concentrations of sodium (Na^+) and sulfate (SO_4^{2-}), and is therefore a potential source of sodium sulfate. Hence, the purpose of this project is to develop the methodology to produce thenardite from JRMM aqueous solution via low temperature fractional crystallisation. The ratio of jarosite waste to red mud waste and controls on fractional crystallisation will be optimised to produce the largest amount of pure sodium sulfate possible. When applied on an industrial scale, the sodium sulfate crystals may be harvested and recycled into the jarosite precipitation process of zinc refining.

GROWTH AND EVOLUTION OF THE ANTARCTIC CONTINENT FROM ZIRCON GEOCHEMISTRY AND GEOCHRONOLOGY OF THE CIROS-1 CORE

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Antarctica is one of the world's hardest continents to study due to its isolated position and ice cover. Because of the current extensive ice sheet, indirect methods must be used to study its geology and geologic past. One of these methods is the study of sediments eroded off the interior and deposited on the more accessible periphery of the continent. The CIROS-1 drill core consists of a sequence of such sediments deposited into the Ross Sea during the late Eocene to Early Miocene.

Twenty samples are being processed to obtain zircon crystals from a variety of stratigraphic levels in the core. Cathodoluminescence imaging is used to reveal internal compositional zoning within individual zircons, which are then analysed by laser ablation inductively coupled plasma mass spectrometry using an Aglient 7500CS ICP-MS with NewWave 193 µm solid-state YAG laser at Victoria University of Wellington. For each 25 µm spot analysis 26 trace elements are measured, including ^{206}Pb, ^{207}Pb, ^{232}Th, ^{235}U and ^{238}U for age calculations, using NIST 610 as the calibration standard. $^{207}Pb/^{206}Pb$ values obtained from zircon standards AS3 and Temora-2 yield ages within error of published ages. Additionally, 23 other elements, including rare earth elements, are measured to give insights into zircon provenance. Reproducibility of our trace element concentrations has been established by multiple measurements on AS3 and Temora-2 standards. A preliminary study from sediment at 249 m depth yields zircon age populations of 500 Ma through to Archaean age. This sample was deposited during early Miocene times when Antarctica was arguably ice-free and therefore gives us early insights into the lithologies eroded during ice-free periods.

Age spectra and trace element data of zircon allow the provenance of the sediment to be constrained for the age range of the core. Using this information the source lithologies can be determined and compared to known lithologies in Antarctica or other continental blocks that were once proximal to Antarctica, including Australia, North America and New Zealand. This will allow insights into the position of continents within Rodinia and the timing of continental break-up. Zircon age populations that cannot be tied to know lithologies can be presumed to have been eroded from East Antarctic lithologies, giving unique insights into the little-known geology underlying the East Antarctic ice-sheet. Finally, as the sediments were deposited during a variety of climatic conditions a variance in zircon provenance during ice-house and ice-free periods may be established, reflecting varying erosional routes and mechanisms. These variations in provenance can then be used as a proxy for the presence or absence of ice in parts of the core where the extent of ice is uncertain, allowing us to gain valuable insights into Antarctica's climate in an important window in Earth's climatic history.

GEOCHEMISTRY OF PLIO-PLEISTOCENE VOLCANIC ROCKS FROM THE NORTHERN FLANKS OF MOUNT MORNING, WEST ANTARCTIC RIFT

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Mount Morning is a large and complex shield volcano 120 km south-east of Mount Erebus in the West Antarctic Rift. Much of the volcano is covered by snow and ice but the summit, which rises to 2723 metres is marked by a small (5 km) slightly elliptical caldera and fissure eruptions have produced an extensive field of scoria cones and lava flows across the northern flanks. Scoria cones and related flows and dykes are primarily associated with NE trending faults and range in composition from dominantly basanite on the lower slopes to phonolite higher on the mountain. The lava field ranges in age from 3.5 Ma to virtually the present day but are mostly considered to be Pleistocene in age (Paulsen & Wilson, *in press*). It unconformably overlies Miocene trachytes and trachyandesites exposed on the lower slopes.

On Riviera Ridge on the lower northern slopes of the volcano, the lava field is exposed in scoria cones, lava flows and domes, dykes, and vent-filling breccias. The scoria cones are predominantly made up of near vent scoria and agglutinate units produced by Strombolian explosive activity and Hawaiian style, lava fountaining. They contain distinctive agglutinate beds which have formed lava flows as lapilli and spatter horizons have accumulated on the flanks of cones close to source.

The dominant rock-type is porphyritic olivine and clinopyroxene basanite with minor trachyandesite and rare trachyte. Basanites range from primitive high-MgO (11.4 wt%) to more evolved types (MgO = 3.4 wt%). All basanites have steep, fractionated rare earth patterns with strong relative La enrichment and Yb depletion. The trachyte has relatively higher total rare earth abundances, distinct Eu depletions and flatter, less fractionated heavy rare earth abundances. The geochemistry of the trachyte is consistent with its derivation by crystal fractionation from one of the more evolved basanites or by partial melting of young, under-plated crust.

Mount Morning rocks have Pb, Sr, and Nd isotopic compositions that are indistinguishable from those of Erebus volcanics and similar to those of intraplate basaltic rocks from southern New Zealand and the subantarctic islands. Intraplate basalts of this distinctive SW Pacific isotopic domain has been interpreted to have derived from a metasomatised lithospheric mantle source that was generated 500-100 Ma ago (Panter et al., 2006).

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THE GEOCHEMICAL EVOLUTION OF ANTARCTIC MELTWATERS IN VICTORIA LAND

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Important processes influencing the geochemistry of terrestrial meltwater ponds and lakes in inland Antarctica include the geological terrain, proximity to open seawater, evaporation (or ablation), freeze concentration and the degree of biological productivity. As many of these factors are influenced by climate, climate change might also be expected to have an effect on meltwater composition. As part of the Latitudinal Gradient Project (LGP), in which latitudinal change is used as a proxy for climate change, a comparison has been made of meltwater geochemistry at 72°S (Cape Hallet), 77°S (Bratina Island and Wright/Victoria Valleys), and 80°S (Darwin Glacier) in Victoria Land, and of the processes influencing the geochemical evolution of meltwaters at these sites.

The processes controlling major element concentrations appear to be broadly independent of latitudinal change, being more a function of catchment geology, proximity to the coast, and the degree of evaporation or freeze concentration that has occurred in the history of the feature. Coastal proximity is a major factor determining whether fresh ice melt evolves into a nitrate-rich (inland), or nitrate-poor (coastal) saline brine. This is evident as a gradient of increasing NO_3:Cl in meltwaters, with increasing distance from open seawater.

The concentrations of trace elements; Fe, Mn, As, Cu, Pb, Zn, Ni, Cd, Cr, U and Mo (or a partial suite thereof) have been determined for many of the meltwaters studied at latitudes 77°S and 80°S. Trace element concentrations in fresh ice melt may be initially influenced by catchment geology, but the ability of these elements to form insoluble mineral salts during brine evolution, or to substitute for major ions in other salts, determines their eventual concentration in a meltwater feature. Trace element mineral formation processes were modelled using PHREEQC, which identified pH, and dissolved O_2 and H_2S concentrations as critical factors in the formation of the oxide, hydroxide, carbonate, sulphate and/or sulphide minerals controlling trace element solubility. These three critical parameters are themselves influenced by the degree of biological productivity, which provides a direct linkage between latitudinal change and climate conditions, as they affect productivity, and trace element concentrations. This is particularly evident in a comparison of trace element concentration profiles in the large stratified lakes at 77°S (Lake Vanda) and 80°S (Lake Wilson). Thiophylic trace elements in particular are affected by the development of anoxia and presence of sulphide; conditions favoured by higher levels of biological productivity. Should climate change result in higher levels of biological productivity in terrestrial meltwaters systems (as expected), more effective removal of thiophylic trace elements during evaporative and freeze concentration processes would likely occur as a consequence.

PALEOVEGETATION- AND MATURITY-RELATED MOLECULAR CHANGES IN THE ORGANIC MATTER OF NEW ZEALAND COALS, AND THEIR APPLICATIONS TO OILS

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Coaly source rocks and associated oils in New Zealand basins have previously been shown by selected biomarker ratios to display a marked change in the relative contributions of gymnosperm and angiosperm vegetation from the Late Cretaceous to the Eocene. The main purpose of this study is to define this change in source vegetation more reliably by using a broader suite of appropriate biomarkers, while a second, related objective is to improve the quantification of oil maturity based on calibration of selected molecular maturity parameters using coals of known rank. Better definition of source paleofloral inputs and oil maturities will ultimately help improve the resolution of oil-source rock correlations in New Zealand basins. Molecular hydrocarbon distributions have been obtained by GC-MS analysis of solvent extracts from 38 Late Cretaceous–Pleistocene coals and of c. 80 primarily terrestrial-sourced oils, from most of the main New Zealand basins. The coals are mostly from within the New Zealand Coal Band, hence comprise a relatively restricted range of coal types, and range in rank (~ maturity) from Rank(S_r) 0 to 12 and R_o c. 0.25 to 0.80%; i.e., from peats to high-volatile bituminous coals at or near the onset of oil expulsion.

Suitable ratios to express the evolution from gymnosperm- to angiosperm-dominated plant communities utilise aliphatic and aromatic diterpenoids (gymnosperms) and triterpenoids (angiosperms). This vegetational evolution is reflected most obviously in the distinct decrease of gymnosperm biomarkers. Although these ratios are also influenced by facies variations, they are ascertained to be more robust than other parameters based only on a few selected compounds. However, due to differences in biomarker composition between oils and coals a limited range of compounds (isopimarane and aliphatic oleanane/ursane/lupane types), identified in both coals and oils, have been used to compare the changes in molecular distribution patterns from the Late Cretaceous to the Tertiary.

Most established hopane maturity parameters show progressive rank-related increases for the early mature study coals, but have already reached equilibrium in a majority of the studied oils. In contrast, the tri- and tetramethylnaphthalene ratios TMNr and TeMNr are applicable over a broader maturity range and, especially for coals above Rank(Sr) 8 (Ro c. 0.5%), show clear increases with maturity. The same is true for the alternative TeMNr II (1,2,6,7-TeMN instead of 1,3,6,7-TeMN). In diagrams of TMNr versus TeMNr or TeMNr II, the coals plot at the low maturity end but the most mature coals match with the low mature oils. A new study of a more comprehensive set of coaly source rocks that extends throughout and below the oil window and containing a more diverse range of organofacies will provide an improved basis for calibration of oil maturities and higher resolution oil-source rock correlation.

SYMPOSIUM: GEOLOGY

A GENERAL SESSION TO CELEBRATE THE 150TH ANNIVERSARY OF HOCHSTETTER'S AND HAAST'S WORK IN NEW ZEALAND

Wednesday 26th November

Soundings Theatre

Geology 1: 9:00 – 10:30
Geology 2: 11:00 – 12:30
Geology 3: 13:30 – 15:00
Geology 4: 15:30 – 17:00

Plenary: Wednesday 08:30 (Soundings Theatre)

Posters: Tuesday 1530 - 1700

PROVENANCE OF GOLD IN MESOZOIC MESOTHERMAL MINERAL DEPOSITS IN NEW ZEALAND

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Mesozoic mesothermal gold occurrences are widespread in New Zealand, extending as very minor occurrences in the Wellington area at the south of the North Island, through the South Island in Marlborough and Canterbury Provinces, to the more substantial (and commercial) deposits in Otago. Detailed Rb-Sr metamorphic, and U-Pb detrital zircon provenance ages of the gold host –rock metasediments of the Haast Schist (and its protolith Torlesse Supergroup) indicate that they are invariably of Late Triassic stratigraphic age, and all within the Torlesse (Permian to Cretaceous) composite terrane.

The detrital zircon age patterns in these host-rock metasediments, and those of their adjacent terranes, suggest that all the sediments have an ultimate source in northeast Australia. However, the Late Triassic Torlesse depocentres in particular had sediment sources restricted to the central part of the present-day eastern Queensland i.e. Townsville-Charter Towers region. This may thus suggest that gold-bearing Torlesse sediments of New Zealand may have originated within the classic Paleozoic gold-fields region of Charter Towers. Significantly, other New Zealand terrane sediments, that probably originated north and south of this region, do not host Mesozoic gold.

SHALLOW COSEISMIC FAULT ROCKS OF THE ALPINE FAULT

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The quasistatic coefficient of friction is independent of applied normal stress for a wide range of geological conditions and materials (e.g., Byerlee, 1978). The extent to which the frictional strength of rocks is rate-dependent, however, has only recently been tested with modern high-rate experimental apparatuses (e.g., Di Toro et al., 2006). These experiments show a dramatic reduction in the dynamic coefficient of friction (>3-fold) during shearing at a strain rate $\geq 1\ s^{-1}$. Indeed, fault resistance to slip is a fundamental parameter in models of earthquake rupture propagation and seismic efficiency.

The rheology of coseismic fault rocks depends on whether deformation occurs under constant volume or constant stress conditions. During constant volume deformation, pore fluids support much of the confining stress and the material deforms under dramatically reduced stresses. During constant stress conditions, the response to strain is governed by: (1) the rate at which pore fluids escape into adjacent material and (2) the variation in grain concentration with time. If the principal slip surface is anhydrous, or if porous material ($k \geq 10^{-17}\ m^2$) juxtaposes the fault plane, frictional heating can form pseudotachylyte; alternatively, other types of granular fluidisation may occur in the absence of melt.

Preliminary results obtained from coseismic fault rocks on the Alpine Fault at Gaunt Creek and Hare Mare Creek suggest that under low confining stresses, cataclastic deformation processes dominate the rheological behaviour of the principal slip zone (PSZ); there is no evidence of frictional melting. At these localities, the principal slip surface comprises finely comminuted rock 1-70 cm thick. All rocks are calcareous and thin calcite laminae are present indicating calcite mineralisation. We discuss how PSZ petrology, particle size distribution, and stable isotope data from the calcite can be integrated to elucidate the role of fluids in the rheological behaviour of these materials.

BOULDER CONGLOMERATES AND BRECCIAS AT THE BASE OF THE DEVONIAN BEACON ROCKS SHED NEW LIGHT ON THE INITIATION OF THE TAYLOR GROUP BASIN, TRANSANTARCTIC MOUNTAINS

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Until now it has been generally accepted that the Devonian Taylor Group sediments of the Beacon Supergroup were a consequence of passive subsidence and burial of a surface of low relief, the Kukri Erosion Surface. Recent work has identified at least eight localities where coarse or extremely coarse conglomerates and sedimentary breccias rest on the basement surface. The coarse deposits occur both in the base of the Windy Gully Sandstone and in the base of the overlying New Mountain Sandstone where this rests directly on basement. The localities are spread along the strike of the unconformity for at least 80 km.

The coarse deposits mantle sloping basement surfaces and are from 1-5 m in thickness. In some cases they appear to represent a single event, but in others, at least two different conglomerate layers are present. The occurrence of these deposits in the base of two formations suggests repeated episodes of breccio-conglomerate formation. Some of the large clasts, particularly the granitoids, appear to be sub-rounded and may have been partly weathered when deposited. Others, particularly vein quartz and quartzite, are angular. Sub-rounded clasts up to 2 m in diameter and angular blocks > 3 m across occur. The surface on which the deposits rest is irregular on a vertical scale of at least 10 m, with gradients of up to 25^0 observed on the basement surface below. The coarse deposits that mantle these surfaces must have been derived from steeper slopes. At one locality the shape and scale of the blocks suggests that they may have fallen directly from cliffs.

Blocks of these dimensions cannot be eroded from, or transported across, a surface of low relief and the coarsest deposits are consistent with rock falls or rock avalanches. These deposits suggest local very steep (though not necessarily high) relief. Although it is likely that a regional scale Kukri Erosion Surface with low relief was cut across Cambrian and older rocks, the coarse deposits require that the surface was severely modified in the Early Devonian. Possible explanations range from local steep slopes due to contemporaneous faulting to the marine erosion of shoreline cliffs, or a combination of both of these processes.

TECTONIC AFFILIATION OF METABASITE IN MESOZOIC TECTONOSTRATIGRAPHIC TERRANES OF THE OTAGO SCHIST

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The origin and amalgamation of the Otago Schist has been a subject of considerable research and debate. Minor, but widespread metabasite horizons within three tectonostratigraphic terranes of the Otago Schist provide additional data to address these issues. In this study, metabasite horizons in the Harris Saddle Formation of the Caples Terrane and Rakia (older Torlesse) Terrane near Ophir were examined in detail and compared with data obtained previously from metabasites of the Aspiring Lithologic Association (Aspiring Terrane) from the Matukituki Valley area. Relict pillow lavas are present in the sampled Aspiring metabasites, but not in the sampled horizons from the Caples or Torlesse terranes.

Whole-rock major (XRF) and trace element (LA-ICP-MS) data were obtained for samples taken along and across strike of the metabasite horizons. Mobile major and trace elements (Na_2O, SiO_2, LILE) show some scatter as expected for low-grade metamorphism under water-rich conditions (seafloor ± accretionary wedge). Concentrations of less mobile trace elements (REE & HFSE) are relatively uniform within and between analysed horizons. Normalised trace element plots indicate that the majority of analysed metabasites from all three terranes have OIB-like characteristics. The Caples and Torlesse metabasites have very similar trends. Aspiring metabasites do not share the relative depletion in Ta and Nb or enrichment of La exhibited in the other two terranes. Aspiring metabasites are depleted in HREE in contrast to the Torlesse and Caples samples.

The geochemical data obtained for the metabasites place important constraints on their igneous protoliths. The Aspiring metabasites appear to represent either potentially far-travelled ocean islands/seamounts accreted from a subducting plate or near-trench alkalic basalt lavas/sills produced in response to localised flexure of a subducting plate. The Caples and Torlesse metabasites probably also originated as ocean island or near-trench alkalic basalts. However, remarkable similarities in trace element patterns occur with the Karoo (South Africa)-Ferrar (Antarctica) large igneous province (LIP). This may imply that the Otago Schist metabasites have a similar mantle source as the Karoo-Ferrar LIP.

PLANKTON, OCEANS AND CLIMATE IN THE PALEOZOIC – THE GRAPTOLITE EVIDENCE

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The distribution of graptolites in time and space can be used to help constrain models of ocean circulation and climate in the Ordovician. We use the time-calibrated composite sequence of 1446 species of Ordovician to early Devonian graptolites, built by the constrained optimisation procedure (CONOP) from 256 measured sections worldwide representing the outer shelf to slope isograptid biofacies, to derive the precise age ranges of species. The mean duration of 72 species confined to the offshore, deep water, isograptid biofacies is 2.19 m.y., significantly shorter than the mean duration of the 82 species assigned to the shallow water epipelagic zone – 4.42 m.y., indicating a significantly higher extinction probability (p = <0.001). The difference between groups cuts across families, morphological types, and pandemic/endemic distributions. An environmental influence is strongly suggested and although both groups were planktonic, they were unlikely to have shared the same habitat in the water column. The new duration measurements therefore are interpreted as favouring the depth-stratification hypothesis of graptolite habitats in the water column, with largely separate, shallow (epipelagic) and deep (mesopelagic) biotopes. This in turn supports ocean stratification models that include a widespread deep water dysaerobic, high productivity zone beneath which is a dense, anoxic greenhouse ocean, for most of Ordovician time. Climatically-driven perturbations disrupted the long-term stability of the density structure of the ocean and the chemocline. This resulted in the periodic decay of the dysaerobic zone and with it, the deep-water graptolite biotope, thus providing a mechanism for the higher extinction probability of the deep-water graptolites.

MAKING TIME

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The geological timescale provides the framework and context for all studies of the history of the Earth and its life. New Zealand has its own highly refined geological timescale that has been age-calibrated and correlated with the international geological timescale (Cooper 2004: GNS monograph 22).

As part of on-going refinement of the New Zealand geological timescale, we are in the process of implementing an on-line, digital version of the timescale using the free software TimeScale Creator, written by A. Lugowski and J. Ogg (TSCreator, see: http://www.tscreator.com/). Using a professional version of this program, we are creating New Zealand data packs that will then be made freely available to the wider community.

TSCreator allows one to quickly and simply create publication-quality, vector-format timescale and stratigraphic charts for user-specified intervals of time in user-specified formats. These charts can optionally incorporate a wide range of existing information, including formal divisions of the timescale, biozonations, bioevents, sequence stratigraphic and sea-level information, the geomagnetic polarity timescale, geochemical and lithostratigraphic data, etc. Graphics can be included, such as paleogeographic maps and photographs, and it is possible to display lithostratigraphic panels. When used interactively on-line, supplementary information can be displayed by hovering the cursor over items of interest.

TSCreator is, therefore, a wonderful tool for the presentation of the New Zealand and international geological timescales. In addition, however, it provides the means to create, store, manipulate and present information that has a time- or stratigraphic dimension for any chosen basin or region. In this way it is possible to create client-specific data packs that can be used in the context of a particular study.

In this talk we will give an overview of TSCreator, demonstrate the facilities and datasets that are currently available, and outline planned future development of the New Zealand data pack(s).

MAPPING THE ALPINE FAULT ZONE ALONG THE WAITANGI-TAONA RIVER: SOME PRELIMINARY RESULTS

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The Alpine Fault is the onshore portion of the Pacific-Australian plate boundary and runs along the West Coast of the South Island of New Zealand where it accommodates ~70% of the relative plate motion. The sense of motion on the Alpine Fault is dextral reverse oblique slip with 23–25 mm/yr strike slip and up to 10mm/yr of dip slip. The Alpine Fault at the surface is replaced by a shear zone at depth. Rapid exhumation and erosion has exposed this mylonite (shear) zone in the hanging wall of the fault.

Mapping the Alpine Fault Zone presents some interesting problems. Most of the western side of the Southern Alps, where outcrop is expected, is covered with dense bush. This, combined with the effects of landslides, limits the exposure typically to the deeply incised river valleys that cut through the mountains. River sections provide essentially 1-D profiles through the fault zone. Feeding into the Waitangi-taona River, a series of closely spaced creeks cut across and expose the Alpine Fault Zone. This presents a unique opportunity to study and map the Alpine Fault Zone in 2-D and characterise the lateral variations at this scale.

We present the results from preliminary mapping of the Fault Zone along the Waitangi-taona River. The preliminary mapping shows that some structural and lithological features can be linked across the sections exposed and with previous mapping in the area (e,g. Gaunt creek:V. Toy). One of these important features is a surface trace of a fault that is not only exposed directly in one of the creeks, but also marked by a 20-30m bench running along the hillside. This fault trace runs parallel to the basal thrust zone of the Alpine Fault and appears to represent a local partitioning of near surface displacement. Continuity of lithological changes within the mylonites can also be examined, together with changes in microstructure along strike. It is hoped that, with additional study, the Alpine Fault Zone can be further characterised at this scale, and this will have implications for tectonic processes occurring at a range of depths in this setting.

ON THE RECENT EMERGENCE OF PAEKAKARIKI

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Marine erosion of the low seacliff south of Paekakariki has recently provided unusually good exposures of the diverse post-glacial terrace deposits on which the town sits. They have been studied by Cotton (1918), Adkin (1950, 1951), Leamy (1955), Fleming (1965), Davidson (1988), McFagen (1997) and, since 2001, the writer. Collation of the available data yields the following provisional chronological stack:

1) Modern buildings constructed, ~1938 onwards.
2) Dunesands stabilised by planting lupin, ~1909.
3) Middens within young aeolian dunesand (Adkin 1950).
4) Middens within Old Waitarere dunesand, 300 to 400 years old (McFagen 1997).
5) Paleosol, well developed, at the base of Old Waitarere dunesand (McFagen 1997).
6) Dunesand with variable recycled pumice content (Motuiti phase dunesand).
7) Midden ~700 years old (Davidson 1988, possibly also Adkin 1950).
8) Fluvial pumice dunesand (Taupo phase dunesand).
9) Fluvial sandy gravel (fan from Te Paripari) or, laterally, dunesand (Foxton phase?).
10) Fluvial silty sand bed, thin but widespread (Foxton phase sand-plain?).
11) Marine beach sand and gravel with sea-rafted pumice (Waimihia?).
12) Disconformity, age of the erosion unclear (~2500 or ~4000 years ago?).
13) Marine beach sand and gravel.
14) Disconformity, age of the erosion unclear (~2500 or ~4000 years ago?).
15) Marine beach sand and gravel with a thin parting of sea-rafted pumice (Waimihia?).
16) Paraconformity?, non-erosive event, age & significance unclear (~4000 years ago?).
17) Marine beach sand and gravel, ~5140 yr BP near top (Fleming 1965).
18) Obscured interval (modern storm beach).
19) Greywacke rock platform (here slightly raised relative to modern sealevel).

There are still some important ambiguities and uncertainties to be resolved about this regionally significant terrace deposit. The most important of these are to establish the ages of items 10, 12, 14 and 16. Precise leveling of the key horizons would be the next.

The content and nature of the above, as yet inadequately dated, sequence indicates that it primarily results from a complex balance between episodic tectonic uplift and sediment accomodation. The base of the oldest non-marine sediment (item 10), is 5 to 6 metres above the top of the rock platform, implying an average post-glacial tectonic uplift rate of a metre or so every thousand or so years.

GPS time series measurements made over the last eight years at the top of the post-glacial seacliff immediately behind Paekakariki township show a pattern of slow westwards movement with only minimal vertical change (www.geonet.org.nz). Given their similar geographic location, a comparison between the geological and GPS records has the potential to reveal significant information about the tectonic activity of the underlying continental crust and (at present locked) subduction zone.

EARLY RADIATION OF BALEEN WHALES REVEALED BY NEW ZEALAND FOSSILS

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Living baleen whales (Mysticeti) are large filter-feeding marine mammals whose early toothless ancestors appeared in the Oligocene. New Zealand fossil baleen whales are some of the globally oldest reported species reported. There is a significant history of study, with key fossils collected by McKay (1880s) and Marples (1940s). Since the 1980s, many new specimens have been recovered, including well-preserved highly informative skulls and associated elements from single individuals. As a result, the record from the Waitaki Valley and nearby now includes:
1, stem-Balaenidae, right whales (slow-swimming skim-feeders): one fossil from lower Kokoamu Greensand (~28 Ma). The incomplete specimen represents a small species inferred to have a short deep skull and probably an arched rostrum (upper jaw).
2, stem-Balaenopteridae, rorquals (fast-swimming gulp-feeders): multiple specimens from Kokoamu Greensand and Otekaike Limestone. One new juvenile fossil represents an informative second specimen of the widely cited but enigmatic *Mauicetus parki*.
3, Eomysticetidae, dawn-baleen whales (narrow-skulled animals of structure, and presumably ecology, unlike any living group): multiple specimens mainly from Kokoamu Greensand. These include species named by Marples and long ascribed to *Mauicetus*, but actually representing a new genus.
4, Toothed stem-Mysticeti (archaic or basal forms): no firm records for Aetiocetidae or Mammalodontidae, but an Oamaru "protosqualodontid" mentioned by Keyes is likely a toothed mysticete close to the late Eocene Antarctic larged toothed whale *Llanocetus* (Llanocetidae).

Unsurprisingly, given the generally patchy fossil record of whales, no two species are known from the same bedding plane. Nevertheless, the stratigraphic distribution through the Kokoamu Greensand and Otekaike Limestone suggests that baleen whale groups 1-3 above were sympatric 23-30 Ma in extensive southern continental shelf waters.

These fossils greatly expand Oligocene baleen whale diversity, and are thus significant on the global scale. They resolve the identity of the widely cited New Zealand genus *Mauicetus* - long thought to represent the oldest baleen whales. The local fossils include early representatives of some modern (crown) groups, providing important tie points for molecular clocks. More broadly, the record is consistent with the idea of an earlier (>30 Ma) explosive radiation of baleen whales, and also of echolocating dolphins and toothed whales between ≥34.5 Ma and 30 Ma. Such a radiation is linked temporally with the opening of the Southern Ocean and change from greenhouse to icehouse earth, suggesting that tectonic (physical, "bottom up") processes ultimately drove major aspects of whale evolution. The search for fossils from the key early Oligocene interval, in the strata below the Marshall Unconformity, continues.

SECRETS OF THE SANDS: INVESTIGATING AUCKLAND'S TURBIDITES

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The East Coast Bays Formation (Waitemata Group) is mainly made up of Miocene bathyal turbidite deposits, which are often faulted and folded. This deformation has led to serious problems in the study of the Auckland area, because the rocks generally lack marker beds. So far, the only method that has been successful in correlating beds is detailed mapping in the field. This is very time-consuming and often produces ambiguous results, so there are large areas of Auckland where no detailed stratigraphy exists.

The Milford to Murrays Bay area of Auckland's North Shore is a ~5km stretch of semi-continuous sea-cliff and shore platform exposure. This area was studied as part of an MSc thesis, which aimed to create a stratigraphy for the area, to develop a methodology for correlating beds, and to interpret the data collected in terms of depositional processes, environment, and controls.

The field area was typical of the East Coast Bays formation, having flat-lying and undeformed areas in close proximity to intensely deformed zones, and included both the more common dm to m thickness turbidites and a thick (10-20m) volcaniclastic bed of the type generally referred to as "Parnell Grit". The Parnell Grit bed was particularly difficult to place in the stratigraphic succession, because the thickness of the bed is approximately equal to cliff height, and each outcrop is bounded either by areas of structural complexity or by areas of no outcrop.

In an attempt to overcome the structural complexity of the section and produce a complete stratigraphy, several different correlation methods were trialled, including some that have not been widely used in this area, such as X-ray fluorescence (XRF) and magnetic susceptibility. Conventional methods were used first: the area was mapped at a scale of 1:10,000, with around 50 1:100-scale logs. XRF and magnetic susceptibility techniques were then attempted on selected samples, with interesting results. In particular, it was found that XRF data could give insights into provenance and mixing of the sediments. The sediment mixing suggested by the XRF data is supported by thin-section work, which shows a compositional range from mafic volcanic lithic-rich to quartz-rich. In short, initial findings suggest that these methods could greatly assist correlation and interpretation of the East Coast Bays Formation sediments, and should perhaps be used more widely.

PYROCLASTIC PROXIES FOR DISENTANGLING SEA LEVEL FLUCTUATIONS FROM GRABEN DEVELOPMENT IN AN ACTIVE VOLCANOTECTONIC SETTING, BAY OF PLENTY, NEW ZEALAND

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A series of Quaternary-aged pyroclastic flow and fall deposits were exposed in steep stream valleys and coastal cliffs behind the small seaside town of Matata on the Bay of Plenty coast, following debris flow events that occurred on May 19, 2005. The pyroclastic units, 8 of which have recently been dated and correlated with volcanic sources in the Taupo Volcanic Zone, are interbedded from the bottom to the top of a complex sequence of alternating marine and terrestrial sediments. As such, the ages and position of the pyroclastic units within the sequence can be used as chronostratigraphic proxies for disentangling responses in sedimentation due to the rise and fall of the sea compared with the land moving up and down.

The exposed stream valleys and coastal cliffs are part of an uplifted horst structure on the western shoulder of the Whakatane graben, a major volcanotectonic feature of the Taupo Volcanic Zone. The sedimentary sequence is pinned to a composite global sea level curve at the young end by the age of the Matahina ignimbrite (322 ± 7 ka) which directly overlies shallow marine to shoreline deposits. In other words, the Matahina which is now 300 metres above sea level was deposited at sea level at approximately 320 ka. The oldest datable tephra in the sedimentary sequence is 661 ± 7 ka and was deposited in a terrestrial environment where soils were forming. Plotting these and other new Ar/Ar age dates on the compilation sea level curve, combined with our stratigraphic data, we can begin to approximate whether the marine vs. terrestrial depositional environments in the cliffs behind Matata are a function of sea level, tectonics or both.

FLOW DYNAMICS OF BLOCK-AND-ASH FLOWS

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Gravitational lava dome collapse and collapse of lava flow fronts generate small-scale, short-lived pyroclastic flows, known as block-and-ash flows. These flows usually comprise three components, a high-density ground-hugging basal avalanche, a low-density ash cloud surge component and an elutriating ash cloud.

Generally the basal avalanche is valley- or channel-confined whereas the overlying surge has the ability to detach from the dense basal part (decoupling), to overtop topographic barriers and to travel greater distances than the basal avalanche, hence posing the larger hazard to surrounding communities.

Decoupling can be initiated any time and is often accentuated by topographic obstructions causing blocking or deflecting of the basal avalanche. These processes have been observed at several volcanoes, e.g. Unzen (Japan), Merapi (Indonesia) or Soufriere Hills (Montserrat), resulting too often in the loss of lives.

To derive reasonable interpretations of the generation of ash cloud surges from the dense basal avalanche and their ability to decouple and accurately apply these to digital models, we need a better understanding of the processes involved, e.g. how gas release from fragmentation processes influences the formation and further behaviour of the surge or the effects of fragmentation pressures on the ash cloud surge for detaching from the underlying dense flow and travelling across larger topographic irregularities.

Currently laboratory flume experiments are being undertaken to examine the factors initiating and influencing the decoupling processes of block-and-ash flows. A better understanding of the flow dynamics of a moving block-and-ash flow and of the interaction with the underlying substrate and topographic irregularities will provide better hazard zone delineation maps for the future.

IN SEARCH OF FORAMINIFERAL EVIDENCE FOR HOLOCENE SUBSIDENCE OR UPLIFT ON EITHER SIDE OF COOK STRAIT

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Over the last three years we have we have undertaken reconnaissance field work and coring throughout the Marlborough Sounds down to Nelson, in the lower Wairarapa Valley and around Pauatahanui Inlet, in the search for evidence of vertical land movements during the Holocene. If rates and timings of displacements can be established they will be useful additional input for tectonic instability models in the Cook Strait region. Our field work has involved probing, gouge auger coring, vibracoring and hydraulic piston coring in the search for intertidal sediment records in which the elevation-related foraminiferal zones are displaced with respect to late Holocene sea level.

The supply of fine sediment to the intertidal zone throughout the Marlborough Sounds in the Holocene has been low. In most places the intertidal is represented by gravel beaches that are unsuitable for coring. At five locations, we have found sufficient depth of penetrable finer sediment to take vibracores up to 7.5 m deep – Nelson Haven, Tennyson Inlet, Havelock, Shakespeare Bay, Anakoha Bay. Foraminiferal samples have been analysed for the 13 cores taken and indicate: relatively stable conditions at the first two, more southern localities; slight Holocene subsidence (~1 m) at Havelock; and perhaps several metres of Holocene subsidence at Anakoha Bay in the north. We await radiocarbon dates to constrain these tentative conclusions.

In the Wairarapa we have taken a north-south transect of five vibracores and piston cores from half way along Lake Wairarapa to the north shore of Lake Onoke. Intertidal marine sediments were found underlying fluvial and/or aeolian sediments in the three northern cores; this confirms previous research showing the Lake Wairarapa area was a shallow marine embayment until the mid-late Holocene. No sudden vertical displacement events have been recognised but progressive slow subsidence is indicated. This could be a result of compaction of the underlying soft sediment, slow sustained tectonic subsidence or a combination of both.

Several cores at the head of Pauatahanui Inlet suggest Holocene stability with sediment accumulation as a result of early Holocene sea-level rise. One vibracore on the western, upthrown side of the Ohariu Fault on the north side of Pauatahanui Inlet, indicates a sudden uplift event of 3-5 m which may have been associated with one of the last two rupture events along this sector of the fault. Radiocarbon dates are also awaited to constrain these tentative conclusions.

DID HOCHSTETTER PLAGIARISE HEAPHY'S MAP OF AUCKLAND VOLCANOES?

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Publication of the English translation of Hochstetter and Petermann's Geological explanation to their atlas of New Zealand in 1864 ignited public dispute between former friends Charles Heaphy and Ferdinand von Hochstetter, over authorship of the geological maps of Auckland district and province. In a footnote in this publication, Hochstetter wrote that the map exhibited in London in 1861 under Heaphy's name "was entirely a copy and combination of my maps and surveys, without any acknowledgment of my authorship." He also claims that the map of Auckland's volcanoes published by Heaphy in the Quarterly Journal of the Geological Society of London in 1860 "is a very incomplete copy of my observations and maps …" to which Heaphy has added "his own observations … made previous to my arrival in NZ, but without possessing even the most elementary knowledge necessary ...". Heaphy and colleagues in Auckland responded with a series of letters and editorials in the local papers. An editorial in the New Zealander (27 Aug 1864) summed up the counter-claims stating "we have received satisfactory demonstration that not only are these charges untrue, but the worthy doctor (Hochstetter) has himself been the plagiarist and the copier. … We could not have believed that our German acquaintance has allowed himself to fall into such a depth of falsification, for the sake of gratifying a very gratuitous spleen." Hochstetter's reaction to these responses were conveyed in a letter to Julius von Haast (20 Nov 1864) "The last letters brought me Heaphy's despicable actions, lies from beginning to end."

We have compared the various maps and descriptions of Auckland's volcanoes made by Heaphy and Hochstetter in the 1850s, in an endeavour to determine the truth of the matter. We conclude that Heaphy deserves credit as the first to map Auckland's volcanoes and that Hochstetter did not adequately acknowledge Heaphy's intellectual input into his subsequent, more professional map. In today's climate of collaboration Hochstetter's widely acclaimed map of Auckland's volcanoes would be cited as Heaphy and Hochstetter's map of Auckland volcanoes.

PALAEOECOLOGY OF THE MACRO BENTHOS OF THE UPPER JURASSIC (KIMMERIDGIAN) IN THE KANTON JURA, NORTHERN SWITZERLAND

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The aim of this study was the taxonomic classification and palaeoecological analysis of an Upper Jurassic marine macro benthic fauna from the Banné Marls near Porrentruy, northern Switzerland. The habitat of potential palaeo-communities of the macro benthic organisms was reconstructed, and related to environmental parameters such as salinity, substrate consistence and water depth. The bulk samples for the study of the fossils and their habitat were collected at "La Combe de Vâ tche Tchâ", in the western Swiss Tabular Jura, northern Switzerland. The broader setting represents a shallow epicontinental marine depositional environment with a periodically fluctuating sea level. The slightly nodular Banné Marls comprise grey dm-thick layers of marlstone, calcarenitic marls and marly limestones with a rich fauna of bivalves, gastropods, some brachiopods, nautilids, echinoids and vertebrate remains.

The content of nine horizons (about 6,5 m stratigraphic thickness) was enumerated, prepared, studied taxonomically and analysed statistically. Thin sections of the profile were studied for habitat aspects (componentry, hard- or soft ground, bioturbation, reworking of fossils, e.g. by storm events, autochthonous or allochthonous environment, etc.). Thereafter, a complete benthic faunal list, consisting of five classes (bivalvia, gastropoda, brachiopoda, annelida and echinodermata), was compiled and the respective individual taxa assigned to 17 different ecotypes.

Cluster analysis showed that the benthic macroinvertebrates represent one association (*Nanogyra nana-Integricardium bannesianum*), consisting of two subassociations (*Nanogyra nana-Sellithyris subsella* and *Nanogyra nana-Mactromya concentrica*). All three are quantitatively characterised and their environments as well as feeding habitats determined. The association and the two subassociations represent bivalve-dominated, filter-feeding groups of similar structure. Diversity (Shannon-Weaver diversity index) and evenness (index after MacArthur) were quantified to help discriminate habitats. Comparing the results of the two methods reveals a largely similar correlation of the data. A similarity between the data of the evenness and the structure of the subassociations was also conspicuous.

Analyses reveal a soft ground, bivalve-dominated, infaunal, filtrating autochthonous fully marine benthic palaeocommunity. Apart from some individual fluctuations of low diversity taxa the environment was nearly stable. This stability can be explained by the higher abundance of *Nanogyra nana*, which characterizes declining or changing habitat conditions.

Correlations of Australasian biotas, especially of New Zealand and New Caledonia with the international scheme and the classical European sites has met with some difficulties because of remoteness and the biogeographic differences, derived partly from that remoteness and from isolation.

FERDINAND VON HOCHSTETTER AND JULIUS VON HAAST

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Hochstetter and Haast met the first time in Auckland in Dr. Fischer's garden on the 22nd of December 1858. Hochstetter had just stepped off the Austrian frigate Novara starting his 9 1/2 months of science explorations in New Zealand, laying the foundations for regional geological mapping and the geological survey in the young colony. Haast also had just arrived in New Zealand from Germany. Haast became Hochstetter's inseparable travel companion in New Zealand, friend and pupil, continuing Hochstetter's geological work long after Hochstetter's departure. Their lifelong friendship is well documented in the letters Hochstetter wrote to Haast[1]. Here examples are presented of the geological collaboration between the two scientists.

One example is taken from Hochstetter's 5th and only surviving New Zealand – Australian diary, covering the last month Hochstetter spent in New Zealand in the Nelson area (6th Sept. – 2nd Oct. 1859)[2]. Given the limited time Hochstetter had in the Nelson province, Haast helped Hochstetter by investigating separately Queen Charlotte Sound, the Wairau and Awatere valleys. Haast reported his observations back to Hochstetter who noted them down in his diary. The notes on earthquake damage along the Awatere and Wairau valleys suggest that the Berefelds Pass fault trace is probably related to the 1855 earthquake rather than the 1848 one[3]. Hochstetter left on the 2nd October 1859 on the Steamer Prince Alfred bound for Sydney. He spent another seven weeks in Australia before returning to Vienna via Mauritius, Suez and Triest. His visit to Australia forms the main part of Hochstetter's 5th diary and has been published by Darragh 2001[4].

Other examples presented in this talk show Haast's hand-drawn topographic and geological manuscript maps and sketches he sent to Vienna[5], used by Hochstetter to compile the first regional maps of the South Island of New Zealand[6].

[1] Nolden S., 2007: The Letters of Ferdinand von Hochstetter to Julius von Haast. Diss. Univ. Auckland.
[2] Hoke L. & Nolden S., in prep.: Ferdinand von Hochstetter's Nelson diary (6th of September to 2nd of October 1859).
[3] Grapes R. and Downes G., 1997: The 1855 Wairarapa, New Zealand Earthquake - Analysis of Historical Data. Bull. N.Z. Nat. Society for Earthquake Engineering 30, 273-373.
[4] Darragh T., 2001: Ferdinand von Hochstetter's Notes of a Visit to Australia and a Tour of the Victorian Goldfields in 1859. Hist. Rec. of Australian Science 13, 383-437.
[5] Watercolours, manuscript maps and sketches by Julius von Haast, sent to Hochstetter, Dr. Albert Schedl Collection, Vienna, presently shown in the Ferdinand von Hochstetter exhibition at the Auckland City Libraries, curated by Dr Sasha Nolden.
[6] Geological map of the province of Nelson by Ferdinand von Hochstetter 1985 and Julius Haast 1860. In: Hochstetter and Petermann, Geologischer und Topographischer Atlas von Neu-Seeland, Gotha: Justus Perthes, 1863.

HAAST'S WEST NELSON SURVEY OF 1860 - WHAT DID IT ACHIEVE?

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Julius Haast (1822-1887) accompanied Ferdinand Hochstetter (1829-1884) on his geological surveys of Auckland and Nelson provinces in 1859. In Nelson Province, a shortage of time resulted in Haast being deputised by Hochstetter to recover Moa bones from a cave on the Aorere Goldfield and then to geologically survey the northeast of the province, soon to become part of Marlborough. Following Hochstetter's departure for home in October 1859 after two months in the province, Haast remained in Nelson preparing the Moa bones prior to their shipment to Vienna. He was then engaged by the Nelson Provincial Government to complete a topographical and geological survey of the rugged southwest of the province, which included the Buller and most of the Grey catchments. The survey commenced on 8 January and finished on 28 August 1860. Haast was accompanied by colliery engineer and surveyor James Burnett (1826-1872), former manager of the Motupipi Coalmine in Golden Bay. Others in the party were European and Maori field hands, but the total involved in the survey rarely exceeded five.

While the survey party endured many hardships, it was not venturing into totally unknown territory as Thomas Brunner (1821-1874), Charles Heaphy (c.1820-1881) and others had explored the West Coast of the South Island over a decade earlier. At the time of Haast's survey, John Rochfort (1832-1892) was surveying for the provincial government the Grey Valley and the cousins Alexander and James MacKay (1831-1912) were also in the area, the latter primarily to purchase, on behalf of the Crown, land from Maori. Nevertheless, the survey accomplished much and allowed Haast to fill in the southwest portion of Hochstetter's acclaimed geological map of Nelson Province that was published in 1863. This paper briefly deals with some of the scientific highlights of Haast's 1860 survey. The survey also has a permanent memorial in that during it Haast named many mountains and other topographical features in honour of prominent scientists.

COMPARISON BETWEEN TWO VOLCANIC CRATERS – FOULDEN MAAR (SOUTH ISLAND, NEW ZEALAND) AND THE ECKFELD MAAR (VULKANEIFEL, GERMANY)

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Maar lake sediments are of outstanding importance for the reconstruction of continental paleoecosystems. Their organic sediments yield exceptionally well-preserved fossils which make it possible to study the development of the local and regional flora and fauna, and they also provide data for paleoclimate research. In some cases, their laminites are varves that document annual or even seasonal variations.

Here, we give an overview of the results of studies of the Middle Eocene Eckfeld Maar (original diameter 800 – 1000 m; depth ~ 200 m), Germany, located near the southern edge of the Tertiary High-Eifel Volcanic Field. The bituminous laminites (varves) of the central lake facies contain a large number and great variety of well preserved terrestrial, amphibious and aquatic fossils ranging from complex organic molecules to mammals, including early horses. The fossil record documents a highly diverse terrestrial flora and fauna, whereas the aquatic biota is rather poor in species. However, sedimentological, geochemical and taphonomic data gathered in more than 20 years of excavation make it possible to reconstruct the lake development and to decipher the biostratinomical processes that in the meromictic lake Eckfeld controlled the composition of taphocenoses and their variation through time.

The Early Miocene sediments of Foulden Maar (diameter ~ 1000 m) were deposited in a similar maar structure within the Waipiata Volcanic Field. In two small pits, 15 m of finely laminated freshwater diatomites with interbedded gravity flow beds are exposed. Initial seismic reflection surveys indicate that the overall thickness of diatomite may exceed 100 m. Recent sedimentological studies have shown that the lamina couplets of the diatomite exposed at Foulden Maar are indeed varves. A preliminary spectral analysis of couplet thickness revealed that the lake productivity was controlled by annual (seasonal) as well as longer-term cycles. Although no continuous excavation has yet taken place, a wide variety of well-preserved angiosperm leaves as well as rare flowers with *in situ* pollen represent a diverse flora. The fauna discovered so far comprises freshwater sponges, galaxiid fish, scale insects and a winged wasp-like insect. More fossils are expected to be found in an ongoing research project that will focus on the maar lake sediments, the structure of the maar crater, and paleoecology. With its annually laminated sediments and well preserved fossils, the Foulden Maar is providing a wealth of data on an Early Miocene terrestrial ecosystem as well as the paleoclimate of southern New Zealand, and has the potential of becoming a Southern Hemisphere counterpart of localities like Eckfeld or Messel.

PROTECTING THREATENED KARST SITES IN NEW ZEALAND

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Karst entries in the New Zealand Geopreservation Inventory are in the process of being updated. The Inventory is a computerised database maintained by the Geological Reserves Subcommittee of the Geological Society of New Zealand. It lists and describes the scientifically, educationally and aesthetically most important examples of the wide diversity of natural physical features and processes that together characterise each part of New Zealand. The Geopreservation Inventory website can be searched alphabetically, or under regional or map sheet categories (http://www.geomarine.org.nz/).

The Inventory is particularly weak in some categories, especially in the coverage of many landform types. One of the most poorly represented categories is surface karst landforms. It is also one of the landform types most under threat of being damaged by development, subdivision, harvesting of ornamental boulders, and even normal farming activities, such as farm road construction and use of tomos as farm dump sites.

These fragile karst landforms require urgent identification, documentation and mapping. The information can then be communicated to the appropriate land management authorities so that the required level of protection or management can be selected and put in place. Following this rationale, areas of karst, natural arches and pseudo-karst throughout the country that require protection are now being updated and mapped.

Names of surface karst, caves and arches entries currently printed out in the 12 published Regional Inventories can be searched in the website above. Those entries, together with over 40 new and 20 amended sites, are listed on the poster.

Problem sites – Some surface karst sites, already listed in the Inventory or planned for inclusion, are still poorly described. These problem sites are:
*Annadale (Mt Cookson) field of dolines (Inland Waiau-Kaikoura Road, Canterbury); *Blowhard Range karst in Te Waka Limestone (Kaweka Ranges, inland Hawkes Bay); *Forest Hill extensive area of small dolines (Winton Hill and Forest Hill blocks, near Winton, Southland); *Haurangi Hairpin limestone pavement, SSW of Martinborough, Wairarapa (Wellington Region); *Helena Bay basaltic proto-karst, Mimiwhangata, Northland; *Maraetotara Plateau karst, Hawkes Bay; *Moawhango-iti extensive doline field developed on gently southeast-sloping high Pliocene limestone plateau (SE of Waiouru, north of Napier-Taihape Rd, Wanganui); *Mount Cass karst, Canterbury; *Ruakokopatuna Gorge, Wellington.

Assistance from Conference delegates with any knowledge of these landforms would be most welcome.

JAFfA – JUST ANOTHER FAULT FOR AUCKLAND – DEVELOPMENTS IN HYPOTHESES OF REGIONAL FAULTING

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Since the last Geological Society Conference (Tauranga 2007), where the possibility of block faulting across the Auckland region was proposed, reinterpretation of the orientation of some of these faults has led to new ideas about the tectonic history of the region. The block faulting was inferred using offsets of the only marker horizon in the region that can actually be followed – Les Kermode's "late Miocene" eroded peneplain surface on Waitemata Group rocks.

Progress in this study has been enhanced by sporadic supplementary data gleaned from an ongoing analysis of boreholes drilled through post-Miocene material into Waitemata Group sediments beneath. The pre-existing Waitemata landscape hidden by this material has been partially mapped, although some areas have yet to be investigated. The exposed and concealed Waitemata surface forms the topographic background to the new fault interpretation depicted in the poster presentation.

In the northern half of the region, the landscape is dominated by a series of east- to northeast-trending ridges, often slightly arc-shaped, with steep south-facing gradients and gentle northern slopes. They appear to fan out from an area just north of Albany, which corresponds to the area reached by the toe of the southward-sliding Northland Allochthon. The ridges are inferred to be the topographic expression of arc-shaped sub-horizontal faults, formed in the mid to late Otaian by catastrophic sub-seafloor slope failures of the mid Waitemata Group semi-lithified sedimentary pile, as a result of being "nudged" by the toe of the Allochthon. Arcuate asymmetric ridges fan outwards more than 30 km from Albany as far as Henderson in the southwest and Howick in the southeast, suggesting affects of the Allochthon have penetrated further south than previously anticipated. Within deformed packets of dislocated Waitemata Group sediments, widespread asymmetric folds verge mainly south; further south they verge east. This evidence corroborates the postulated southward migration and fanning outwards of Allochthon-related sub-seafloor slumping into the Auckland area.

The southern half of the region is considered not to be affected by the southward nudge of the Northland Allochthon. ENE-trending faults in this region are post-early Miocene horst and graben features now concealed by Plio-Pleistocene sediments – their existence extrapolated in the past using borehole analysis and geophysical measurements. They are inferred in this study to be eastward extensions of the splay faults from offshore west coast.

South-directed imbricate slope failures and the ENE-trending block faults have been truncated by north- to NNW-trending normal faults, most of which are down-thrown to the west. They are thought to be related to the NNW-trending regional normal faults (such as the Drury, Wairoa and Waikopua Faults), inferred to have been initiated in the middle to late Miocene, and to the NNW-trending Hauraki rift zone to the east.

GEOTHERMOMETRY IN THE ALPINE AND OTAGO SCHISTS: IS TITANIUM-IN-QUARTZ THE ANSWER?

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The Alpine and Otago schists of New Zealand are considered one of the 'classic' metamorphic sequences. They form a contiguous metamorphic belt comprising rocks ranging texturally from zone IIA to IV, and mineralogically from pumpellyite-actinolite to amphibolite facies. The timing of metamorphism and deformation are contentious, but appear to include episodes in the Jurassic, Cretaceous and Cenozoic. Unfortunately, the bulk rock compositions and hence mineralogy of the schists do not lend themselves to application of conventional geothermometry, and consequently their metamorphic history is not fully understood.

This study has re-examined the Haast River section of the Alpine Schist and the Lake Hawea section of the Otago Schist using the recently calibrated titanium-in-quartz (TitaniQ) geothermometer (Wark and Watson, 2006). Quartz is present throughout the schists and allows comparison of temperature records between metamorphic grades, deformation phases and microtextural domains. The samples examined range in grade, from the pumpellyite-actinolite through garnet-oligoclase zones, and exhibit quartz veins and segregations associated with five phases of deformation.

Titanium and selected other trace elements in quartz were analysed directly in polished rock sections using LA-ICP-MS. The results reveal a strong correlation between the concentration of titanium in quartz (range = 0.2 to 40 ppm Ti) and metamorphic grade. Calculated titanium-in-quartz temperatures represent minimum values because the schists contain titanite and ilmenite (estimated a(TiO_2) = 0.6–1) rather than rutile. Nonetheless, the temperatures obtained correlate well with independent estimates given by previous garnet-biotite geothermometry and metamorphic phase relations. Within individual mineral zones, quartz associated with each deformation phase exhibits discrete temperature signatures, indicating retention of titanium concentrations through the subsequent thermal and deformation history. These results suggest that titanium-in-quartz geothermometry may be more robust and precise than conventional methods with the possibility of resolving previously unrecognised aspects of the thermal history of the Alpine and Otago schists.

VARIANCE IN JUVENILE ACCRETIONARY PYROCLASTS OF THE X-RAY KIMBERLITE, ONTARIO, CANADA: IMPLICATIONS FOR INTERPRETATION OF VOLCANIC PROCESSES FROM DRILL CORE

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Kimberlite volcanoes contain juvenile accretionary pyroclasts (JAPs), which are spherical aggregates of ash. Their characteristics can be useful in the interpretation of volcanic depositional processes, especially when the interpretation is limited to drill cores only. Detailed descriptions of accretionary pyroclasts in kimberlite literature are rare. Most of the existing detailed studies and experiments are restricted to extra-crater deposits of non-kimberlitic volcanic systems and not from within a pipe where processes are very complex.

Jurassic kimberlite pipes in the Attawapiskat Kimberlite Field, located in the James Bay Lowlands, Northern Ontario, Canada, were emplaced into karstic Ordovician to Devonian age strata of the Moose River Basin. The environment at the time of volcanic activity was likely a deltaic coastal plain. JAPs were identified during detailed core logging and petrography of the X-Ray kimberlite, which contains some of the best preserved examples of JAPs within the Field.

The objectives of this study are: 1. To describe the different types of JAPs found in the X-Ray Kimberlite, as they can be useful in characterising a geological unit for economic purposes. 2. To compare the JAPs from X-Ray to those from well understood deposits of non-kimberlitic volcanic systems to help determine from drill core the volcanic processes that resulted in the formation of the geological units. The geological units within X-Ray that contain JAPs are characterized by different relative abundances of specific JAP types (i.e. core-type, rim-type, and armored). The JAPs generally are unevenly dispersed throughout poorly sorted, massive to crudely bedded geological units that range from less than 10 m up to 250 m thick. All JAP types have well rounded and smoothly curved morphologies, and low modal abundances. Core-type and rim-type pyroclasts typically have ratios of longest to shortest diameter of < 1.5. Rim-type pyroclasts dominantly have ratios of longest core diameter to longest diameter of entire JAP > 0.7. Seven "sub-types" were identified: 1. rim-type 1 - coarse ash core and fine ash rim; rim-type 2 - multiple rims of coarser and fine ash; core-type 1 - massive, fine ash; core-type 2 - coarse centre with slight diffuse grading to fine ash; core-type 3 - unsorted coarse ash; armored type 1 - crystal or rock fragment with a fine ash rim; and armored type 2 - crystal or rock core followed by a multiple rim of a coarse ash inner rim and a fine ash outer rim.

By comparing the X-Ray JAP characteristics to those from well studied deposit types, the following may be inferred: 1. Kimberlitic JAPs have similar characteristics to non-kimberlitic volcanic systems. 2. Some degree of movement and dilution of the original JAP layers has occurred. 3. The majority of JAPs formed by pyroclastic surges.

COASTAL UPLIFT LINKED TO SEA LEVEL CHANGES AND A RECORD OF EARLY ROTORUA-OKATAINA ERUPTIONS: CONSTRAINTS FROM NEW ^{40}AR-^{39}AR GEOCHRONOLOGY

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Exposure of interbedded volcanic pyroclastic deposits and marine sediments in coastal cliffs and valleys at Matata allows us to correlate the timing of subaerial volcanism with (a) the timing of development of the Whakatane graben (northernmost onshore Taupo Volcanic Zone: TVZ) and (b) the history of sea-level fluctuations in the area. New ^{40}Ar-^{39}Ar step-heating experiments were conducted on plagioclase separates from fallout and ignimbrite units exposed in the Matata cliffs, as well as on possibly-correlative lavas from the nearby Okataina Volcanic Centre.

We have been able to interpret ages for fourteen units, which show that the cliffs have risen as a horst or tilted block alongside the graben over at least the last 660 kyr. The sequence of age determinations reveal a complex interplay of exhumation, marine incursions and tectonics (Gravley et al., this volume). The 325 ka Matahina ignimbrite caps the 300 metre high cliffs; the ignimbrite directly overlies marine silts that now occur at up to 200 metres above sea level.

The experiments also yielded new ages from the Okataina and Rotorua volcanic centres, ranging in erupted age from 531 ka to 96 ka. This places a new older limit on volcanism in the northeastern section of the onshore TVZ, nearly twice that of the existing ^{40}Ar-^{39}Ar age for the older Okataina caldera-forming eruption. These new age data start to fill a previous apparent gap in TVZ activity between 340 and 710 ka, and suggest that significant moderate-scale volcanism occurred in this period.

This paper will also discuss the results of additional age dating experiments for Okataina Volcanic Centre that are in progress.

EARLY QUATERNARY BEETLES: STASIS OR EXTINCTION?

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Quaternary fossil beetle research is a new method in paleo environmental reconstructions in New Zealand. The fundamentals of this research are that the fossil species can be identified from the modern fauna as there has been little or no speciation throughout the Quaternary. However this is a Northern Hemisphere model that is based on thousands of beetle fossil specimens from hundreds of localities throughout the Holarctic, and this record shows only one species confirmed as globally extinct and three possibly extinct. It is thought that Quaternary stasis in beetles in continental locations was maintained by extreme glacial-interglacial climate variability where communities moved to and fro over large distances to follow favourable conditions. These multi-dispersal events resulted in the mixing and reuniting of populations which effectively reset the evolutionary clocks of species and prevented speciation and extinction. On the other hand, New Zealand's Quaternary climate oscillations were comparatively low amplitude, plus there are limited dispersal opportunities. To date Quaternary fossil beetle data indicate that pattern of stasis in New Zealand fits the Holarctic model and these data are from a number of locations ranging in age from late Holocene to around 200,000 years ago. The question of stasis or extinction remains unresolved as no early Quaternary fossils insects have been studied.

To resolve this question, fossils from three early and mid-Pleistocene sites in the Auckland region are under investigation to determine if long-term stasis occurs in an island situation and if extinction rates are dissimilar to the Holarctic pattern. It will allow for better prediction of species extinctions and survivorship during climate change.

Preliminary results show extinction occurred in some species and stasis in others. An assemblage of beetles from an organic bed underlying the Waiuku Tephra (estimated age around 1 ma yrs) has at least 18 taxa that occur in the modern Auckland fauna. These species include *Microcryptorhynchus perpusillus* (Pascoe) that live in the dead branches of trees, *Stenotrupis debilis* (Sharp) that live in tree ferns in swamps and *Dysnocryptus inflatus* (Sharp) that inhabit and feed off grasses. However, several species from this assemble are unknown to specialist entomologists and indicate possible extinctions.

SHORELINE STABILITY ON CORAL ATOLLS IN RESPONSE TO SEA LEVEL RISE AND CORAL REEF DEVELOPMENT: NIUE ISLAND

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Small reef islands in the tropics are some of the most vulnerable coastal landforms to changing environmental conditions especially sea level rise and the associated impacts of climate change. The projected 1 m rise in sea level by the end of the century in addition to more frequent tropical cyclones will cause substantial erosion on such islands and the disappearance of beaches, and most likely the drowning of numerous small Pacific Island nations.

Niue is the world's largest raised coral atoll with steep limestone cliffs surrounding the entire island. Its rocky shore limits the development of beaches and other sediment accumulation to several small isolated locations on the island. These beaches are ephemeral, disappearing and reforming as cyclonic events pass over the island. Its coast therefore has the potential to provide key information on the thresholds of sediment accumulation on tropical coasts and their likely response to future climate change and sea level rise.

Topographic transects of the reef-platforms surveyed around the island indicated that width varied from 20-130 m with 64% of Niue's shoreline bounded by < 30 m wide platforms. Beach composition varies from a mix of coral, algae and molluscs to sand consisting of foraminifera, mainly *Marginopora verterbralis, Baculogypsina sphaerulata* and *Amphistegina lobifera* with the last two being the more dominant component on the beaches of the more sheltered, West and North West side of the island. A mixture of living or recent-live foraminifera species identified at the time of sampling, suggests that prolific foraminiferal production occurs on the adjacent reef flat and platform. At other sites, such species appeared worn and scarce, implying a more distant source. This clearly demonstrates the significance of a local sediment source in the development and nourishment of beaches on the rocky shores of Niue.

GEOCHRONOLOGY OF MOUNT MORNING, ANTARCTICA

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Mount Morning is a Cenozoic, alkali eruptive centre located in the south-west Ross Sea, Southern Victoria Land (SVL), Antarctica. 17 new age determinations on Mount Morning volcanics increases the total number of age determinations from this volcano to 41, which allows division of the Mount Morning geological history into two phases that have different geochemistry. The earliest, mildly alkaline, Phase I erupted between 18.7 ± 0.3 Ma and 11.4 ± 0.2 Ma. A period of volcanic quiescence, lasting about 5.2 m.y., separates this phase from a later strongly alkaline Phase II, with an age range between 6.13 ± 0.20 and 0.15 ± 0.01 Ma. Mount Mornings' period of eruption spanning approximately 18.7 Ma, is greater than any other eruptive centre in the south-western Ross Sea, and is a period of longevity infrequently observed in eruptive centers elsewhere in Antarctica or further afield. The oldest volcanic detritus in Cape Roberts drill core, 100 km north of Mount Morning, is dated at *c.* 24.1 Ma and has geochronological, mineralogical, and environment of eruption indicators that are very similar to the Phase I volcanics on Mount Morning. The oldest Cenozoic volcanism in the McMurdo Volcanic Group is located in the southwest portion of SVL, at Mount Morning, with existing age determinations indicating that the initiation of volcanism at other eruptive centers has subsequently migrated north-west towards Mount Erebus. Cenozoic volcanics in SVL have been more or less continuously active for the past 24.1 Ma, making it of comparable longevity to volcanic activity in Marie Byrd Land, and to volcanic provinces in New Zealand, such as the Dunedin/Waipiata volcanic field.

PALEOSEISMOLOGY OF SLOW FAULTS IN SE SPAIN: FIRST RESULTS OF THE ONSHORE-OFFSHORE CARBONERAS FAULT

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SE Spain straddles by the slow convergent plate boundary between Africa and Iberia (4-5 mm/yr) which is characterised by a 400 km wide zone of diffuse seismicity. In the Eastern Betics, this shortening is accommodated by a left-lateral strike-slip fault system referred to as Eastern Betics Shear Zone (EBSZ). The Carboneras Fault with a length of almost 50 km onshore and more than 100 km offshore is one of the longest structures of the EBSZ. Despite the very low seismicity associated to this fault, its geomorphology reveals certain young activity, suggesting long recurrence (10^4 years) behaviour as found in adjacent structures.

We present results of an integrated onshore-offshore paleoseismic study which aims to establish the seismic potential of the Carboneras Fault. Onshore, the La Serrata segment was studied using geomorphological, microtopographic, trenching and dating analyses. Offshore, high-resolution geophysical analysis, coring and dating were carried out. Marine seismic profiles show a large variability of structures along the fault zone: positive flower-structure morphologies in the shelf zone, underlapping restraining step-over in the central segment, and buried pressure ridges towards the south segment. Geometry and structure of the marine units are similar to onshore structures indicating a left-lateral movement with some reverse component.

Both onshore and offshore studies show faulted Quaternary layers and mass movements deposits related to deformation events (paleoearthquakes). Trench walls evidence a minimum of six events since the Mid Pleistocene. The four younger events occurred during the last 80 ka, suggesting a mean recurrence period of 20 ka. A faulted and buried paleochannel records a minimum of two events during the last 30 ka and constrain the last earthquake to AD 772-889. The horizontal maximum displacement observed for the paleochannel is 3 m, suggesting a minimum strike-slip rate of 0.1 mm/a for the last 30 ka. This is much smaller than the 0.6 mm/a lateral strike-slip calculated for the last 200 ka by displaced valleys across the faulted NW boundary of La Serrata. Further analysis will clarified if the 0.1 mm/a lateral strike-slip rate is underestimated or if it is the result of a decreasing slip rate through the Quaternary. On the other hand, offshore, very high resolution seismic profiles together with sedimentary analysis of marine sediments suggest a mean vertical slip of 0.14 mm/a for the last 165 ka. The study provides evidence for the seismogenic behaviour for the Carboneras fault and provides its first paleoseismological parameters, contributing to a more realistic seismic hazard value for the seismic catalogue.

THE NATIONAL PALEONTOLOGIGAL DATABASES PROGRAMME

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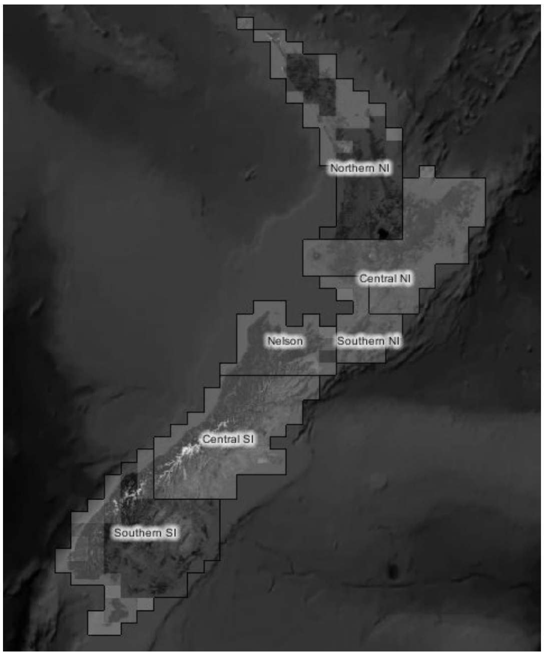
The New Zealand Fossil Record File (FRF) and National Paleontological Collection and Database (NPC) are recognised as Nationally Significant Databases by FRST and are being developed under the GNS National Paleontological Databases (PDB) programme. The programme aims to improve digital access to these databases and promote their use by both national and international researchers. This programme is now in its last year although recently announced government "backbone" funding for database maintenance should provide long-term ongoing funding for these two databases.

The most visible part of the project has been the creation of the FRED database and website (http://www.fred.org.nz) for accessing the FRF and the digitisation of the paper FRF records.



Registered users can use the FRED website to query, retrieve and download FRF data (including non-confidential fossil lists) as well as entering and submitting new data

As of September 1 80% of known FRF records have been entered into the FRED database and we are on track to complete the task by 30 June 2009. This map shows completed areas (light grey) which include the Central Sth Island, Nelson, Southern Nth Island and Central Nth Island masterfiles.
We are also working on a curation system for the NPC which will improve our management of this important collection. This new database will capture information currently held in ledgers and spreadsheets as well as allowing the storage of digital images (both photos and 3D scans). This system will essentially be for internal GNS use, but a second public website will be developed which will contains details (including images) from the *type* collections with the NPC.

The PDB programme is also funding the maintenance/development of several smaller databases including the NZ Stratigraphic Lexicon (http://data.gns.cri.nz/stratlex). Beu and Maxwell's 1990 Cenozoic Mollusca of New Zealand has now been scanned and is being turned into an online database.

EVALUATING THE *P-T* EVOLUTION OF THE ALPINE SCHIST IN THE NEWTON RANGE, SOUTHERN ALPS, NEW ZEALAND

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Results of new THERMOCALC *P-T* pseudosection calculations in the 11-component system MnNCKFMASHTO provide new insights into metamorphic *P-T* conditions that were associated with garnet growth in Alpine Schist in the Newton Range, in the Southern Alps near Hokitika.

The first appearance of garnet occurs in garnet-biotite-albite-chlorite greyschists just to the west of a large ultramafic body in the Pounamu Ultramafic belt, and about 4.5 km from the Alpine Fault.

Estimates for the metamorphic conditions have been obtained by combining results of forward modelling (*P-T* pseudosection diagrams and predicted mineral composition data) with measured compositional zoning data for garnets in greyschist rocks with varying MnO contents.

The preliminary results indicate that the prograde metamorphic *P-T* path passed through ~6.25 kbar and ~425-450 °C, with peak conditions occurring decompression through ~6.25-7.25 kbar and ~475 °C. The appearance of a second, more calcic plagioclase is associated with marked decreases in Ca in garnet and development of peristerite. This occurred late in the garnet growth history at approximately peak metamorphic temperatures. Most growth of the metamorphic minerals in these rocks probably occurred prior to the development of the modern Southern Alps, presumably in the Cretaceous.

The inferred peak metamorphic conditions and probable metamorphic *P-T* path for these rocks the Newton Range is closely similar to that reported for the McArthur Range ~6 km to the north where garnet growth in low Mn greyschists occurred during decompression at conditions near ~6.5-7.5 kbar and ~500 °C (Vry et al. 2007).

Vry, J. et al. (2007): Establishing the P–T path for Alpine Schist, Southern Alps near Hokitika, *New Zealand. Journal of Metamorphic Petrology*, 26 (1): 81-97

THE 2008 RAIN-TRIGGERED LAHARS ON MT. TARANAKI/MT EGMONT.

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On or about 30 April 2008, intense heavy rain on the upper flanks of Mt Taranaki/Mt Egmont triggered floods in most river catchments radiating from the summit. In two instances the flood discharges became hyperconcentrated and formed lahars that swept down the Little Maketawa Stream and Maero Stream. These lahars scoured out all loose sediment and vegetation cover lying in the river channels. In Maero Stream the lahar began incising a box canyon (and thus bulking the flow) into the underlying unconsolidated, block-and-ash-flow deposits. At P20/961146, about 580 m elevation, the flow failed to negotiate a corner and climbed a 6-m high cliff to then destroy a 15-60 m-wide, 0.75 km-long area of kamahi (*Weinmannia racemosa*) forest. Damage to the trunks of the few remnant trees testifies to the depth of flow and the depth of boulder scouring. Most of the missing forest, covering 2.7 ha, was swept to the margins of the flow to create a discontinuous, up to 3-m high log jam of trees with boulders up to 3.3m long entrained. Finer grained sand and fine gravel continued to flow up to 50 m through the undamaged forest at the margins. At its terminus the "jump out" flow discharged into Waiweranui Stream as a flood flow that eroded streambanks downstream of the entry point.

In Little Maketawa Stream the lahar showed superelevation on sharp corners of the river channel. Using Pierson's (1985) superelevation formulae we estimate that the Little Maketawa lahar had a peak velocity of between 11 and 16 ± 2 ms^{-1} and a maximum discharge of 1500 ± 300 m^3s^{-1} from data gathered near Maketawa Hut. In comparison at the "jump-out" pointing Maero Stream, the flow is calculated at about 10 ms^{-1}, with a maximum discharge of about 660 m^3s^{-1}. These events testify to the unstable nature of the Taranaki/Egmont cone below the 1500 m contour and the capacity of high intensity rainfall events to trigger lahars without concomitant volcanic activity.

SEDIMENT CONDUITS TO THE DEEP TASMAN: TWO CONTRASTING LARGE CANYONS-CHANNEL COMPLEXES FROM THE WEST COAST

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Large submarine canyon complexes form prominent geomorphic features that incise the continental margin and provide conduits for off-shelf escape of terrigenous material to the deep ocean. The West Coast, South Island supports two large canyon-channel complexes fed by steep, short-reach rivers that carry 29% of New Zealand's total riverine contribution to the sea (Hicks and Shankar, 2003).

Recently acquired multibeam bathymetric mapping shows four principal canyon–channel complexes make up the Hokitika/Cook system, which extends at least 700 km offshore and falls vertically >3000 m. Here, channels are locally entrenched up to 1000 m into the continental slope. Two of these conduits have prograded with sea-level rise, fed by river discharge and littoral drift where they cross the shelf and upper slope. The upper reaches of channels within the complex reach widths of 28 km and comprise multiple sinuous, ox-bowed, and meandering features. In contrast, the lower reaches of the channels are incised and erosional. The channel confluences are marked by hanging valleys, indicating that the deeper Cook channel is either the distributary system that has sustained the latest and/or at least the largest erosional 'flows'. Dependant on location, sediments within this channel system range from well-sorted, mica-rich silts and sands to coarser turbidite deposits and last glacial gravels.

The Moeraki/Waiatoto offshore canyon–channel complex to the south, has been mapped ~200 km from the coast, with the primary channel traced a further 400 km offshore to >4000 m depth. Geomorphically distinct from the Hokitika/Cook, the Moeraki canyon system is flat-bottomed and steep sided, considerably larger at 5 km-wide and incised 500-800 m into the slope. The primary canyon is fed by three near-shore features. Similarly, the Waiatoto canyon system is fed by at least four near-shore canyons at its head as well as by gravel-rich glacial outwash fans at its shoreward flank. The Moeraki canyon feeds into the Milford Basin and eventually the Haast Channel. The Moeraki/Waiatoto systems merge to form a single, entrenched, north-westerly trending channel that continues to >4000 m water depth. Sediments within these channel systems comprise mainly coarse sands and gravels, with attendant overbank mud deposits The ultimate fate of sediment in these canyon systems is presently unknown, but lies somewhere within the deep Tasman Sea.

FERDINAND VON HOCHSTETTER - FATHER OF NEW ZEALAND GEOLOGY - COMMEMORATING THE SESQUICENTENNIAL OF HIS VISIT

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When the Austrian frigate *Novara* arrived in Auckland on 22 December 1858 on its expedition around the globe this marked the beginning of a major turning point for the young geologist and physicist on board. In New Zealand Ferdinand Hochstetter found the opportunity to explore a geologically hitherto largely unexplored country in the service of the New Zealand government and as an extension of the *Novara* expedition. Although the decision to leave the expedition, at this furthest point of the journey, was not an easy one, he never regretted it later as it gave him the opportunity to spend nine months in the provinces of Auckland and Nelson, and wherever he went he was provided with generous support for his efforts and was thus enabled to make one of the most significant contributions to the results of the *Novara* expedition and at the same time accumulate collections and observations which were later to form the basis for his publications on New Zealand.

This paper provides a biographical introduction to Hochstetter and an overview of his explorations in New Zealand and goes on to look at Hochstetter's relationship with other geologists and surveyors working in the field at the time of his visit, including those who wrote to him from parts of New Zealand Hochstetter did not have time to explore in person – including James Crawford in Wellington, Octavius Carrington in Taranaki and Thomas Triphook in Napier. This will provide an insight into his relationship with the pioneer settlers in New Zealand and provide clear evidence of some of Hochstetter's sources. In closing, an overview of the geological maps and publications by Hochstetter relating to New Zealand will be given with some remarks on their genesis and development, based on archival research looking at Hochstetter's manuscripts and letters.

ALPINE FAULT KINEMATICS: HOW DOES A CREEPING SHEAR ZONE AT DEPTH LINK TO A SLIDING FAULT AT THE SURFACE?

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Oblique displacement on the Alpine Fault has led to exhumation and surface exposure of its associated deep-seated mylonite zone. Kinematic indicators from ductile and brittle fault-rocks can be compared both with each other and with surface slip. Sense-of-shear indicators in all fault-rocks show dextral-reverse shear, consistent with surface slip. Brittle-wear lineations in cataclasites and gouges within the central, most oblique-slipping, part of the fault scatter around a trend of 084°, slightly oblique to the Nuvel 1A plate vector. Shear directions derived from late-stage ductile shear bands have a mean trend of 079°. Lineations within the ductile mylonites are highly variable, ranging in trend from 220° to 080°, with a mean around 110°. In the high-strain mylonites and ultramylonites, lineations are poorly developed. In the comparatively low-strain protomylonites, the lineations mainly consist of quartz rods and streaks inherited from the protolith schist and variably rotated during mylonitisation. Microscopic mica flake lineations and X-axes of quartz c-axis fabrics have mean trends of 090° and may be considered parallel to the mylonitic stretch axis. Rotated inherited lineations also converge towards this direction. This stretching direction is oblique to both the late shear directions in the mylonites and cataclasites and to the plate vector.

A strain model is developed incorporating simultaneous simple shear parallel to the shear direction within the fault zone and pure shear perpendicular to the fault zone. A finite stretching direction trending 090° may be obtained for the shear strains recorded in the mylonites by introducing a pure shear component corresponding to a shortening of around 70% perpendicular to the fault.

Documented shortening of about 30–50% within the hangingwall schists has also affected the mylonites during thickening of the crust within the Southern Alps. Extra shortening within the mylonites may be related to the transition from a broad zone of ductile shear at depth to slip within a narrow gouge zone near the surface. This transition results in dilation within the fault zone, which can be balanced by upward extrusion of material if the fault zone converges slightly. Simple calculations indicate that a zone narrowing from 1.5 km at 25 km depth to 1 km at the brittle-ductile transition is sufficient, so that the mylonites would accumulate a shortening strain perpendicular to the fault zone of about 33% during uplift. When combined with the 50% flattening also experienced by the hangingwall, the total flattening strain in the mylonites would be around 70%, similar to that modeled for the lineations. Although small compared with the simple shear strains, this flattening is kinematically significant. The moral is that geological shear indicators may be complex and confusing even in well-constrained systems. In old exhumed mylonite zones, simply measuring the nearest available lineation may not provide a very meaningful answer!

THE EARLY QUATERNARY MARINE TO TERRESTRIAL TRANSITION OF THE SOUTHEASTERN WAIRARAPA, NEW ZEALAND

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The Hautotara and Te Muna Formations in southeastern Wairarapa provide a remarkable record of the transition from marine to terrestrial deposition as the region was uplifted during the Late Pliocene and Pleistocene. The Hautotara Formation is less than 100 m thick and consists of shallow marine, marginal marine and non marine sediments which show marked vertical and lateral variations. These are thought to record glacio-eustatic sea level changes within the context of regional tectonic uplift. The overlying Te Muna Formation is up to several hundred metres thick and entirely non-marine. It contains cyclic conglomerates, lacustrine beds, lignite layers and subaerial deposits of loess and paleosols.

We present the stratigraphy of several new exposures which challenge previous interpretations of the area. In particular, a previously unidentified and wide-spread angular unconformity between the Hautotara and Te Muna Formations shows the transition is more complex than earlier studies acknowledged. The nature and extent of this unconformity has implications for the rate and location of structural growth in the region. Furthermore, re-investigation of the numerous tephra beds within the Hautotara and Te Muna Formations, using microanalytical techniques, has allowed improved correlation between sections and better constrains the ages of the formations. By utilising advancements in East Coast tephrochronolgy provided by recent work on Ocean Drilling Program Site 1123, these Wairarapa sediments can be correlated with the marine oxygen isotope curve.

Our revised record of this marine to terrestrial transition will lead to an improved understanding of the paleogeographic setting and the nature of the cyclicity within the Hautotara and Te Muna Formations.

COSEISMIC LOADING AND POSTSEISMIC CREEP: INTEGRATION OF THE GEOLOGICAL RECORD INTO NUMERICAL MODELS

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During major earthquakes, the middle crust is exposed to coseismic loading. The imposed stress peak relaxes during an episode of postseismic creep, which is expected to contribute to surface deformation transients. Interpretation of these transients requires knowledge of the spatial and temporal evolution of seismic stress changes at depth, but such information cannot be deduced from inversion models of postseismic surface deformation, as the results are generally non-unique. An alternative source of information is provided by exhumed metamorphic rocks which are increasingly affected by stress cycling related to seismic activity during exhumation. These rocks may therefore provide insight into the processes and conditions prevailing at deeper levels of the crust during the seismic cycle. We use the record of metamorphic tensile quartz veins to calibrate numerical models on the mid-crustal seismic stress cycle. The veins are hosted by the metamorphic Styra-Ochi Unit of South Evia, Greece, which were exhumed in the footwall of a low angle normal fault. Crosscutting relationships between the veins and all syn-metamorphic fabrics of the host rock and the quartz microfabrics indicating crystal plastic deformation imply that the veins formed during exhumation, but still below the brittle ductile transition. The veins were sealed in a single stage and crystals grew into an open cavity. The veins show low aspect ratios, which requires inelastic deformation of the host rock. Fluid inclusions trapped in the vein quartz record a time series of pore fluid pressure (P_f) during progressive sealing, with low P_f at the vein walls (early stage) to high P_f in the vein core (final stage). Opening of the fractures commenced immediately after crack arrest, controlled by ductile deformation of the host rock at temperatures >300°C. For opening of tensile fractures, the minimum principal stress σ_3 acting normal to the walls must be tensile, and P_f must be similar to σ_3. If $P_f > \sigma_3$, fracture propagation would have re-initiated, resulting in a drop in P_f. The evolution of P_f is therefore interpreted to reflect a major coseismic drop in σ_3, causing a major increase in the differential stress. During the stage of sealing, σ_3 rises and the stress peak relaxes. The results of calibrated numerical models are in first-order accordance to the vein record. They show: 1) a major coseismic stress peak in the middle crust; 2) coseismic loading predominantly by a drop in σ_3 in the footwall and by an increase in σ_1 in the hanging wall by values comparable to those deduced from the veins; 3) stress relaxation by thermally activated creep during the interseismic period.

HOLOCENE SEDIMENTARY RECORD OF STORMS, EARTHQUAKES AND CATCHMENT EROSION FROM LAKE TUTIRA, HAWKES BAY

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Lake Tutira in Hawkes Bay was cored in 2003 to provide a detailed record of environmental change and controls on upper catchment sedimentation since the lake's creation 7200 cal. y BP. The 27.14 m-long core contains alternating lithotypes that are sedimentary responses to severe rainfall, drought, earthquakes and volcanism. Diatom assemblages, spore counts, sediment texture and structures, plus C and N percentages were used to indentify intra-lake and catchment-derived storm deposits and modes of lithotype deposition. The lithotypes and depositional modes are: tephras (volcanic airfall); organic-rich laminae (algal-rich lake sedimentation); massive to weakly graded, brown silty clay beds (re-deposited lake sediments); grey, graded sandy mud beds (intense storm-delivered sediment); and, thin bedded, grey clay (low intensity storm run-off). Using 11 tephra and 3 radiocarbon ages to provide a chronology, the long-term sedimentation rate is 3.3 mm/y, which increases to >10 mm/y for the European colonisation period. Having characterised and identified storm-beds over the 7200-year lake history, a hind-cast relationship infers around 53 pre-historic storms occurred, similar in magnitude to the severe Cyclone Bola event of 1988, and 7 potentially larger rainfall events. A storm event chronology indicates that storm magnitude and frequency varied throughout the record with periods of increased frequency of large storms occurring every ~300-400 years. Comparison to a number of other local, regional and distal climate proxies record conditions that are consistent with the timing and periodicity of major storms in the Tutira storm record.

Despite the prominence of storm beds, a summation of the total percent thickness of each lithotype shows that proportionally, the balance of intra-lake versus storm deposits preserved in the lake bed is 69% and 26%, respectively. As well as storms, lake sedimentation is strongly influenced by earthquakes which destabilize lake margins to generate homogenites, represented by the brown silty clay beds. These deposits tend to be thicker after a hiatus in seismic activity and after sustained periods of lake-margin loading, inferred from the occurrence of thick graded storm beds. Comparison to marine records on the adjacent continental margin suggests that in general only low-frequency, high magnitude perturbations (e.g. volcanic eruptions, European deforestation) and major shifts in the climatic (rainfall) regime are preserved across the source-to-sink sedimentary system, consistent with earlier hypotheses. Deposits from intense storms such as Bola, can be traced to the middle shelf but no further presumably in response to physical and biological mixing processes.

EVIDENCE FOR PERSISTENCE OF PART OF NEW ZEALAND'S TERRESTRIAL BIOTA FROM LATE CRETACEOUS TO PRESENT: IMPLICATIONS FOR THE 'OLIGOCENE INUNDATION' HYPOTHESIS

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It has recently been suggested (Campbell & Hutching 2007) that all of New Zealand may have been inundated during an Oligocene marine transgression. If so, the entire terrestrial biota, including those taxa hitherto regarded as 'ancient endemics', may represent the evolutionary derivatives of forms that arrived after the Paleogene.

Evidence that may shed light on whether elements of New Zealand's pre-Oligocene terrestrial biota persisted comes from the physiology and habitat preferences of those elements of the Recent biota having low transoceanic biogeographic dispersal potential. These include weta (Rhaphidophoridae, Henicidae), kiwi *(Apteryx), Xenicus* (a flightless rock-wren) and tuatara *(Sphenodon),* all of which have been regarded as 'ancient endemics' – derivatives of forms present when New Zealand separated from Gondwana.

Weta, kiwi, *Xenicus* and tuatara are all facultatively cryophilic. Development of cryophily in several unrelated taxa cannot readily be ascribed to the availability of cold niches created by Neogene tectonism or Pleistocene climatic deterioration, because this would require unusually fast adaptation in 'ancient' forms and concomitant failure of more modern ones to become similarly adapted. Cryophily in the 'ancient endemics' can alternatively and preferably be interpreted as a paleoclimatic signal reflecting the cold climate that prevailed in high-latitude Cretaceous New Zealand at the time it separated from Gondwana.

This view is supported by the fact that the ability of each 'ancient endemic' form to tolerate cold is coupled with a fine degree of adaptation allowing activity in low-light conditions. In the absence of defined predation pressures that might have enforced nocturnal behaviour, I suggest that the ability to exploit dark habitats arose simultaneously with development of cryophily, and that nocturnal behaviour and cryophily in the 'ancient endemics' probably arose in response to the prolonged winter darkness and cold that prevailed in near-polar Late Cretaceous New Zealand. After separation from Gondwana severed terrestrial biotic links, ancestral forms were marooned on a cold, dark polar archipelago, and became so fundamentally adapted that their Recent counterparts are predestined to exploit cold, dark niches.

New Zealand's weta, kiwi, and tuatara are considered by some authors (e.g. Kuschel 1975, Natusch 1967) to be bizarre oddities, a view finding ready explanation in terms of their adaptation to dark and hitherto-unrecognised shared facultative cryophily. Any suggestion that they arrived by biogeographic dispersal after Oligocene inundation and are not Gondwanan relics needs to be evaluated in light of the clear evolutionary basis set forth here for these nocturnal, facultatively cryophilic, but unrelated forms being the evolutionary derivatives of a Cretaceous Gondwanan near-polar fauna.

QUANTITATIVE GEOMORPHOLOGY: ESTABLISHED METHODS AND NEW BEGINNINGS

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The recognition that surface processes may strongly influence the orogenic evolution of mountain belts has established a greater need to acquire quantitative measures of surface process rates. Erosion rates may be determined directly using cosmogenic nuclides in bedrock and sediment, or indirectly by comparing offset datums of known age, for instance terraces or straths stranded above active stream channels. This paper presents the results of combined tectonics – surface process studies from Australia and Mexico, and proposes new methods of establishing surface process rates in the northern South Island of New Zealand. In Australia, cosmogenic ^{10}Be and ^{26}Al concentrations have been used to determine landscape response times to tectonic perturbations and distinguish active from non-active geomorphic features. In Mexico, ^{10}Be concentrations in stream channels have been used to estimate the time at which extension initiated along the Main Gulf Escarpment. In New Zealand, samples will be collected from abandoned strath surfaces and incised stream floors to quantify bedrock incision rates and test models for knickpoint migration and catchment response.

THE QMAP 1:250 000 GEOLOGICAL MAP OF NEW ZEALAND: NEW MAPS AND SEAMLESS DIGITAL GEOLOGY.

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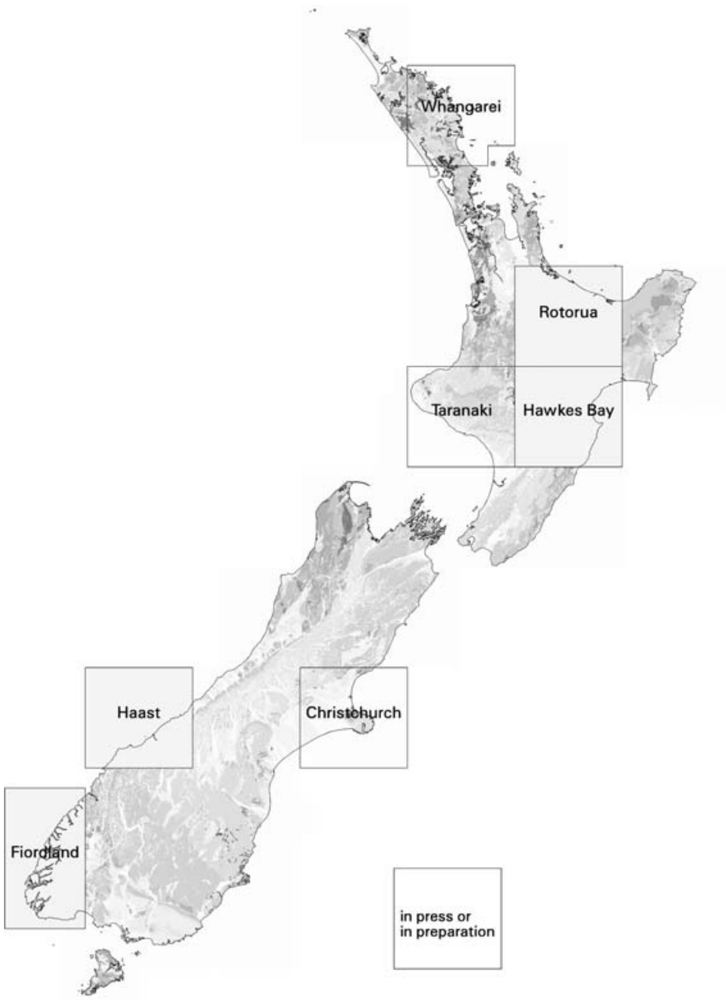
The QMAP 1:250 000 Geological Map of New Zealand programme is in a map and text production phase with all fieldwork now completed. Fourteen maps have been published, three (Taranaki, Whangarei and Christchurch) are in press and the remainder (Rotorua, Hawkes Bay, Haast and Fiordland) will be digitised over the next 12 months. A parallel project has commenced where the GIS data underpinning the QMAP geology will be made "seamless" and will involve some revision and resolution of conflicting geology across some sheet boundaries. The mismatches have resulted from new data becoming available within the period of the QMAP project. The seamless geological dataset will be served via the web. A new second edition of the 1:1 Million Geological Map of New Zealand is another parallel project now underway. This map will be available as a printed map and as digital GIS data, and will be a generalised depiction of the new QMAP geological mapping.



DISTRIBUTION OF EAST AUSTRALIAN LATE PALAEOZOIC BRYOZOANS: A POTENTIAL TOOL IN REFINING NEW ZEALAND TERRANE ORIGINS

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Late Palaeozoic rocks of Gondwana contain a variety of bryozoans that are at times abundant. Eastern Australian bryozoans reveal a distinct biota in this cold-water environment, where climatic stress produced a low diversity eurytopic fauna dominated by fenestrates and trepostomes. Within this fauna a clear trend in increased diversity and complexity is seen from the Tasmania Basin northward to the Bowen Basin, Queensland. While Palaeozoic bryozoan faunas are known from only a few localities in New Zealand, the south to north compositional trend of east Australian faunas may have important implications for determining the relative position of New Zealand terranes at the close of the Palaeozoic.

Artinskian-Kungurian limestones of Tasmania, Australia, contain abundant and often large bryozoans deposited in polar glaciomarine environments. Diversity is low and biotas are dominated by cosmopolitan trepostomes *Dyscritella* and *Stenopora,* an d the simple emshed fenestrates *Parapolypora, Polypora, Polyporella, Pseudopolyporella* and *Rectifenestella*. Rhabdomesids and cystoporates occur, but are rare. Northward in contemporaneous rocks in the Sydney Basin, where depositional environments were deep and cold-water, these same Tasmanian taxa occur and are joined by common *Laxifenestella,* and *Minilya*. The Bowen Basin rocks of Queensland also record glaciomarine environments, however glacial influence is more distal. Although bryozoan faunas here are dominated by fenestrates and trepostomes, and they also exhibit increased faunal diversity and complexity. In particular the fenestrate biota also includes the more complex mesh forms of *Alternifenestella*, *Levifenestella*, *Spinofenestella*, *Synocladia*, *Penniretepora* and *Acanthocladia*, and the rhabdomesid *Streblascopora* and the cystoporates *Fistulipora* and *Ramipora* are now common.

Although thus far poorly known, bryozoan biotas from the Parapara Group (Takaka Terrane) are like those from Tasmania Basin, with numerous simple fenestrates and trepostomes. In contrast, and based on data published in Gilmour and Morozova (1999), the bryozoan biotas from the Productus Creek Group (Brook Street Terrane) show diversity and composition more like that of northern eastern Australia. This suggests that further work on New Zealand bryozoans may be fruitful.

References

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MAPPING NEW ZEALAND'S DEEP-SEA – THE FORAM WAY

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We use census counts (59,000 specimens) of 424 species of benthic foraminifera in 264 samples to identify and map benthic soft sediment ecological regions in New Zealand's deep-sea (50-5000 m depth). Using cluster analysis (chord coefficient) of the full census data we identify seven high-level ecological associations (A-G), and 28 lower-level subassociations. Of the seven associations, two are largely restricted to abyssal depths (>2000 m), three to bathyal depths (200-2000 m) and two to mid shelf – upper bathyal depths (50-600 m). The deepest association (>3500 m) and two of the bathyal associations only occur east of New Zealand, but no associations are restricted to the west. One of the bathyal associations only occurs beneath the Subantarctic Front along the south-eastern edge of the Campbell and Bounty Plateaux. The two shallowest associations have northern and southern distributions approximating the pattern of overlying Subtropical and Subantarctic Water. Cluster analysis of presence/absence data produces similar, but not identical, ecological associations, indicating that total species composition is equally important as the relative abundance of dominant species in defining these regions. Canonical correspondence analysis indicates that the main factors that drive the faunal patterns and allow subdivision into ecological regions are depth-related (e.g. bottom temperature, bottom oxygen, organic carbon flux, carbonate corrosiveness) latitude-related (e.g. surface temperature, chlorophyll-a, surface phosphate), and bottom-current-related (mud %). Not surprisingly the resulting ecological regions' map mimics bottom topography and to a lesser extent the properties of the directly overlying water masses.

AGE AND GEOCHEMISTRY OF GRANITOIDS FROM COASTAL EXPOSURES OF THE LOWER-PLATE OF THE PAPAROA METAMORPHIC CORE COMPLEX, WESTLAND

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The Paparoa Range of northern Westland is interpreted as a metamorphic core complex (Paparoa Metamorphic Core Complex or PMCC) formed during mid-Cretaceous continental extension in the New Zealand sector of Gondwana, which preceded fragmentation of the southern supercontinent. Extensive coastal exposures of the PMCC lower-plate between Charleston and Belfast Creek include small granitic plutons and dikes whose genetic and temporal relationships to established metamorphic, deformation and magmatic events associated with the separation of New Zealand from Gondwana are largely unknown.

Foliated granitoids and amphibolite facies Charleston Metamorphic Group (CMG) ortho- and paragneiss comprise the lower-plate of the PMCC, which is separated by shallow-dipping detachment faults from the upper-plate consisting of relatively massive granitic plutons intruded into low-grade metasediments of the Ordovician Greenland Group and overlain by breccia-conglomerate of the Cretaceous Pororari Group shed off the Paparoa Range during exhumation. Three lower-plate granitoids were sampled for major (XRF) and trace element (LA-ICP-MS) geochemistry and zircon U-Pb dating (LA-ICP-MS): 1) near Charleston, a small (~200 m^2) pluton of undeformed biotite-muscovite-garnet granite (informally termed the Little Beach granite) that intrudes CMG paragneiss, 2) a syn-tectonic two-mica granitic dike (Doctor Bay dike) that cuts foliated CMG tonalite and granite orthogneisses, and 3) two-mica, locally foliated, leucocratic Redjacket Granite that intrudes CMG paragneiss at Belfast Creek.

The Little Beach granite and Doctor Bay dike yield mid-Cretaceous crystallisation ages of 112 ± 2 Ma and 108 ± 2 Ma, respectively. The Redjacket Granite is interpreted to have crystallised at 353 ± 6 Ma, synchronous with the Devonian metamorphism of the host CMG paragneiss (Ireland & Gibson, 1998). All three granitoid samples exhibit significant zircon inheritance. The zircon U-Pb ages obtained via LA-ICP-MS are consistent with those determined previously by other methods. The syn-tectonic relation of the Doctor Bay dike to its mid-Cretaceous orthogeniss host (Ireland & Gibson, 1998) constrains the timing of metamorphism and deformation to prior to ~108 Ma. The crystallisation age of the Little Beach granite is indistinguishable from that of the syn-tectonic Buckland Granite (Muir et al. 1994), indicating intrusion coeval with development of the PMCC. Mineralogy, whole-rock geochemistry (low Na_2O & moderate Sr), and zircon crystrallisation ages and inheritance patterns of the Doctor Bay dike and Little Beach granite suggest correlation with Rahu Suite granitoids, to which the Buckland Granite belongs. The Redjacket Granite is probably a member of the Karamea Suite based on its earliest Carboniferous crystallisation age, zircon inheritance pattern, and whole-rock geochemistry (high K_2O & low Sr).

FAULT CONTROLS ON THE GEOMETRY AND LOCATION OF THE OKATAINA CALDERA, TAUPO VOLCANIC ZONE, NEW ZEALAND

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Okataina Caldera is located within the Taupo Rift and formed due to collapse following eruptions at 280 and 61 ka. Gravity, seismic reflection, topographic and geological data indicate that active rift faults pass into the caldera and have influenced its location and geometry. The caldera has a minimum gravity anomaly of -50 mGal, is elongate north-south with an inferred minimum depth to caldera floor of 3 ± 0.5 km at the rift axis, and occupies a 10 km hard-linked left step in the rift. The principal rift faults (55-75° dip) define the location and geometry of the northwest and southeast caldera margins and locally accommodate piecemeal collapse. Segments of the east and west margins of the caldera margin are near vertical (70-90° dip), trend north-south, and are inferred to be faults formed by the reactivation of a pervasive Mesozoic basement fabric (i.e. faults and/or lithological contacts). The fault sets which define the caldera geometry predate it, while the step in the rift across the Okataina Volcanic Centre (OVC) is at least as old as the caldera. Within the OVC displacement on rift faults induced by gravitational caldera collapse at 61 ka exceeds tectonic displacement since this time by at least a factor of two. Collapse along pre-existing rift faults and, in particular, Mesozoic basement fabric are important for caldera formation elsewhere in the Taupo Volcanic Zone.

OUTCROP SCALE STRUCTURES AS TOOLS FOR UNDERSTANDING PROCESSES IN EPITHERMAL GOLD DEPOSITS: AN UPDATE

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Outcrop scale structural features are important controls in epithermal gold deposits, especially where the porosity and permeability of the host rocks were low during mineralisation, thus minimising the influences of lithology. Apart from elucidating the kinematics and dynamics of their formation, detailed investigations of structural conduits may provide important information on the flow patterns, deposition versus non-deposition and structural zonation within a deposit and eventually may aid in prospecting for ore concentrations at the sub-deposit scale. The purpose of this contribution is to review the inventory of outcrop scale vein structures based on the example of the Hauraki Goldfield of the Coromandel Peninsula of northern New Zealand. The mineralisation is hosted in mainly dense Late Miocene to Early Pleistocene arc/backarc volcanic rocks. The field consists of 50 deposits, including the world-class Martha Hill Mine.

The vein structures will be initially described in two dimensions, essentially as they appear to the geologist working on the outcrop, followed by an interpretation of their full spatial geometry. They range from relatively planar veins to intricate three-dimensional networks. Simple tension veins, en echelon arrays and fault/vein meshes are relatively rare, whereas simultaneous vein opening in many directions is very common. Breccia formation interacts in a complex way with vein opening. Some of the veins were open only briefly, whereas others may have existed as cave-like voids for a considerable time. The most important process appears to be reactivation of pre-existing mesoscopic structural features in a dominantly extensional regime. Strain is most commonly three-dimensional rather than planar. This is an important difference to mineral deposits formed at deeper levels of the crust.

Knowledge of the vector of opening is important in unravelling the kinematics of a vein system. Examples of the vein deflection method and the multiple marker method of determining the net slip vector of vein opening will be presented. The results indicate that oblique opening of veins may be common in epithermal gold deposits.

WHEN SEA LEVEL IS TRUMPED BY TECTONICS AND AUTOCYCLIC PROCESSES: A FIELD STUDY OF AN EVOLVING DEEP MARINE SYN-RIFT BASIN, SINAI, EGYPT

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The link between rift tectonics, surface tilting, depositional processes and resultant deposits has been investigated from a range of environmental settings including non-marine and marine. This link is particularly keenly felt in deep marine syn-rift systems dominated by sediment gravity flow processes during rift climax times, i.e. when there is maximum displacement on the bounding fault.

Conceptual tectono-stratigraphic models for marine rift basins during rift climax, predict that subsidence will outpace sedimentation resulting in mudstone-dominated systems, controlled by sea level. While useful in driving forward our understanding of such basin types, these conceptual models are yet to be validated by outcrop studies and oversimplify the structural and sedimentological evolution of rift basins.

The aim of this presentation is to use a stunning 100% exposure, three-dimensional (3D) outcrop, to document the vertical and lateral evolution of deep marine sedimentary processes and architectures in a developing hanging wall slope and basin floor system, during rift climax.

The area of study is the Early Miocene Baba Basin, located on the western Sinai Peninsula, Egypt. The syn-rift sediments within the Baba Basin have undergone significant large scale (>300m) syn-depositional deformation and rotation, forming an archetypal example of monoclinal folding above a blind normal fault.

Integrated field mapping, detailed sedimentological analysis and terrestrial Light Detection And Ranging (LiDAR) data reveals a complex sedimentary succession dominated by coarse-grained turbidites and debrites. Turbidite channels, levees and lobes are recognised and together with debrites record evidence of evolving bathymetry resulting in flow deflections, relocation of depocentres, changing flow types and clustering of remobilization events. Markov chain analysis reveals the absence of widespread vertical trends in grain size, as might be anticipated from a sea level control. Instead the variety of bed transition types and architectures is more readily explained by a tectonic and autocyclic process controls.

TIME, SIZE AND SPACE PATTERNS OF THE NZ LANDSLIDES

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We characterize time, size and space patterns of 1996-2004 New Zealand landslides. We use the GNS database i.e. 1943 landslides with location and date of occurrence. For 13% of them, volumes, ranging from $0.01m^3$ to $24*10^6m^3$, were reported. 40% of the landslides were rainfall triggered, 30% were earthquake triggered, 28% had no reported trigger and 2% were triggered by other triggers. We compare the landslide time, size and space distributions to 100 random catalogues and NZ seismicity ones.

First, we confirm that the cumulated volume distribution of the NZ landslide catalogue follows a power law with a rough 0.4 exponent, for $Vc>50m^3$. Earthquakes are found to trigger more $V>10^5m^3$ landslides than rainfall.
Second, we found that both landslide and earthquake daily rates were power law distributed over 2 orders of magnitude. The landslide interevent time distribution, which is a gamma distribution, evidences a correlation between events in time. Signal for $t<10$ days is mainly driven by the $V<Vc$ landslides. The interevent distance distribution shows that landslides are more clustered than random distributions.
Third, a significant seasonal trend was found in the rate of NZ landslide occurrences, with a peak from June to October.

The landslide catalogue is mainly driven by the rainfall triggered landslides. To reproduce the time and space correlation we observed for the New Zealand landslides, we need either the rainfall events to be correlated in time and space or the landslide response to rainfall to be delayed and/or shifted. Because the unreported trigger landslides share the same size, time and space distributions than the rainfall triggered events, it supports the rainfall triggering not to be simply bounded to a daily correlation with rainfall.

GEONET: MONITORING NEW ZEALAND'S NATURAL HAZARDS

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New Zealand is a country in motion. We face earthquakes, volcanoes, tsunami, landslides and geothermal activity. In many places where you live and work these hazards have the potential to cause devastating social and economic loss.

Operated by GNS Science and funded by the New Zealand Earthquake Commission (EQC), the GeoNet Project was set up in 2001 to provide real-time monitoring of these hazards. The project uses nationwide networks of seismograph and GPS stations to collect data on New Zealand's earthquake, strain, and deformation patterns.

The completion of these networks in the last five years has improved the timing and accuracy of incoming data, and the project's focus has now shifted to the extension of regional seismic and GPS networks, the establishment of a regional tsunami gauge network and the development of data products to promote better uptake of this valuable resource.

The data collected by the New Zealand GeoNet Project are fundamental to a better understanding of the natural hazards faced by this country and in turn, this knowledge will improve their detection and management. It is hoped that the dissemination of accurate and timely information by GeoNet will aid planning and community preparation before a disaster strikes, and facilitate effective emergency responses afterwards, speeding the subsequent recovery of affected communities.

CAUSES OF CENOZOIC EVOLUTION OF DEEP-SEA BENTHIC FORAMINIFERA

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This PhD research project is part of a wider collaborative study with the overall goal to increase understanding of the causes of global evolution and extinction in the deep sea. This is being addressed by focusing on a distinctive group of benthic foraminifera, which became extinct during the late Pliocene-Middle Pleistocene (3-0.12 Ma). Nineteen genera and 95 species belonging to three families of cosmopolitan deep-sea benthic foraminifera, were wiped out during this Last Global Extinction (LGE). All these extinct species, referred to as the "Extinction Group", shared elongate, cylindrical morphologies (often uniserial) with small, specialized apertures. The LGE was coeval with the pulsed expansion of the northern hemisphere ice cap, rendering deep-sea conditions colder and more oxygenated during increasingly severe glacials. This leads to the proposition that the LGE wiped out remnants of the Greenhouse biota, when they or their food supply were unable to cope with the large and rapid changes in the deep-sea environment.

To test this hypothesis this particular research project extends our group's Pliocene-Pleistocene studies back in time. "Extinction Group" species in ODP Sites 689 (Southern Ocean) and 1211 (North Pacific Ocean) are analyzed to obtain a record of their occurrence and abundance through the whole of the Cenozoic, allowing the investigation of palaeoenvironmental drivers of abundance, extinctions and originations of species. Preliminary results of this research on ODP Site 689 reveal high population dynamics throughout the Cenozoic without extreme periods of high turn-over. In a second phase, the research will be focused on a detailed study of the "Extinction Group" species through the Palaeocene-Eocene warm event.

NEW TIMING CONSTRAINTS FOR EARLY METAMORPHIC EVENT(S) IN HAAST SCHISTS FROM SHRIMP DATING OF ZIRCON OVERGROWTHS

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Zircon is a common and widespread accessory mineral that has long been recognized as a "gold standard" for geochronology because it resists age resetting to temperatures as high as 800 °C. The zircon grains in metamorphosed sedimentary rocks are however inherited from the sedimentary source area, so other geochronometers are generally used to interpret the timing of tectonic event(s) these rocks record. Especially for rocks that undergo metamorphic changes at low to moderate temperatures (≤ 450-500 °C) these available alternative geochronometers are variably affected and compromised by the twin problems of inheritance and resetting, and so do not provide direct timing constraints. Only very recently has it been recognized that new zircon can grow and form overgrowths on pre-existing grains in low temperature (≤ 400 °C) metamorphic environments.

Here we report that the inherited zircon grains in rocks of the Haast Schist group can have thin (typically < 10 µm thick) overgrowths of metamorphic zircon on their rims. We show that SHRIMP U-Pb ages from those overgrowths yield precise timing constraints for the event in which the zircon grew. An episode of metamorphism and dewatering is clearly recorded at *c.* 165-170 Ma, with evidence for another event at *c.* 130-140 Ma. These events are recorded in samples of both the Otago Schist from the central arch (garnet-albite zone) of the Otago Schist belt, and from Alpine Schist in the Southern Alps near Hokitika. The results were obtained using SHRIMP equipment in Tokyo, Japan, and in Canberra, Australia.

One of the longest standing intractable problems in geology has been how to directly determine the precise timing of early tectonic events that cause rock dewatering at low- to moderate temperatures (≤ 450-500 °C). Our discovery of these dateable metamorphic overgrowths on zircon crystals from the Haast Schist group rocks of New Zealand thus represents a significant breakthrough in metamorphic geochronology. Though the overgrowths that we have found on zircon are typically extremely narrow and only rarly of a thickness that can be dated, the potential for significant gains in understanding is very high. Obtaining precise metamorphic ages for mid-crustal rocks will lead to superior insights in the timing, rates and processes involved in rock exhumation, landscape evolution and mineral deposit formation in mountain belts the world over.

SYMPOSIUM: SEEPS

NEW ZEALAND COLD SEEPS/GAS HYDRATES/METHANE-DERIVED AUTHIGENIC CARBONATES (MDACS) - PRESENT AND PAST

Wednesday 25th November

Rangimarie 1&2

Seeps 1: 13:30 – 15:00
Seeps 2: 15:30 – 17:00

Posters: Tuesday 1530 - 1700

TECTONIC AND GEOLOGICAL FRAMEWORK FOR GAS HYDRATES AND COLD SEEPS ON THE HIKURANGI SUBDUCTION MARGIN, NEW ZEALAND

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The structure and geomorphology of the Hikurangi subduction margin varies along strike primarily in response to changes in subducting crustal structure, convergence rate and obliquity, and sediment supply. New seismic reflection and multibeam bathymetric data are used to interpret the stratigraphy of the subducting sequence, the upper plate tectonic structures, and the geological framework for cold vent seep sites. The imbricated frontal wedge of the central margin is characteristic of wide (ca. 150 km), poorly drained and over pressured, low taper (~4°) accretionary thrust systems associated with a relatively smooth subducting plate, a thick trench-fill sedimentary sequence, weak basal décollement, and moderate convergence rate. This region differs from the northern, Hawkes Bay to East Cape, sector of the margin where subducting seamounts, faster convergence rate, and reduced trench sediment supply have resulted in a dramatically reduced and steeper active frontal wedge, complex deformation and uplift of frontal ridges above subducting asperities, and a tectonic regime dominated by non-accretion and tectonic erosion. Bottom simulating reflectors (BSRs) are widespread along the length of the margin.

Five areas with multiple fluid/methane seep sites, referred to informally as Wairarapa, Uruti Ridge, Omakere Ridge, Rock Garden, and Builders Pencil, typically lie in about 700-1200 m water depth on the crests of thrust faulted ridges along the mid-slope. All of these seep sites lie near the outer edge of a deforming Cretaceous and Paleogene inner foundation, at the rear of the accreted trench fill turbidites. One seep site lies in close proximity to a major strike slip fault. Another occurs directly above a subducting seamount. Beneath the seafloor seeps on ridge crests there is typically a conspicuous break in the BSR, and commonly a seismically-resolvable fault-fracture network through which fluids and gas percolate. There is a clear relationship between the seep sites and major thrust faults, which are conduits for fluid and gas migration sourced from the deeper, inner parts of the thrust wedge, and probably from subducting sediments. We consider that the Cretaceous and Paleogene inner foundation is, on the whole, relatively impermeable and focuses fluid migration preferentially to its outer edge via major low angle thrust faults and the décollement.

GEOLOGICAL IMPRINT OF METHANE SEEPAGE ON THE HIKURANGI MARGIN SEABED: RESULTS OF BOX CORE STUDIES

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During the 2007 joint German-New Zealand SONNE cruise offshore eastern North Island, New Zealand, TV-guided box cores were taken at mapped hydrocarbon seep sites in order to study sedimentologic, biotic, mineralogic and geochemical influences of methane seepage upon near-seabed muddy and sandy sediments (to 30 cm depth bsf). X-rays of 10-cm-wide slabs revealed a shelly and burrowing infauna that varied with respect to different sedimentary horizons (muds, sands, shell beds and nodular, microcrystalline carbonate bands to ~15 cm thick). Shells were collected (living, dead articulated/disarticulated, cemented) from the horizons and identified. Physical and geochemical properties of the box core carbonates and host siliciclastic sediments also were compared to seafloor seep-carbonate grab samples obtained during the cruise, with respect to carbonate content, TOC and carbon and oxygen stable isotopes.

Box core results to date indicate several burrowing morphologies within host muds, with some burrows still occupied by polychaetes or juveniles of the chemosymbiotic bivalve, *Acharax*, a low-sulfide mining specialist. One mud-only core contained large, branched, vertical burrows with wall scratch marks, inferred as decapod crustacean in origin. Vesicomyid and lucinid bivalves occur as shell beds in sandy sediments, or as scattered individuals within muddy or nodular carbonate horizons. Diverse gastropods also are present in box core muds. In one core, a dense carbonate horizon with vesicomyids is overlain by mud riddled with *Acharax* and its burrows, suggesting waning fluid flow at this site over time.

Box core mud and nodular carbonate samples vary in TOC content from 0.2 to 0.9 wt %, and yield $\delta^{13}C$ values of –50.3 to –0.6‰ PDB and $\delta^{18}O$ values of +0.77 to +3.2‰ PDB. Strongly depleted carbonate-carbon and positive oxygen values in nodular, microcrystalline aragonite bands indicate formation from anaerobic oxidation of methane in a seafloor (or very shallow subsurface) environment, possibly influenced by gas hydrate dissociation. Carbonate-carbon isotope values of the “background muds” (4-27 wt% carbonate) indicate varied carbon sources. Some mud horizons suggest derivation from marine porewaters, organic matter fractionation and/or diffuse methane seepage ($\delta^{13}C$ –37 to –7‰ PDB); others indicate a seawater bicarbonate origin ($\delta^{13}C$ –2 to +1.5‰ PDB) for the mud-sized carbonate fraction. Comparison with grab-collected carbonates in seep areas along the Hikurangi margin shows that samples with the same mineralogy (microcrystalline aragonite) display similar TOC and stable isotope signatures compared to nodular carbonate bands in the box cores.

MODELLING OF FLUID PRESSURE WITHIN THE SHALLOW GAS HYDRATE PROVINCE OF ROCK GARDEN ON THE HIKURANGI MARGIN

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The crest of Rock Garden, a shallow bathymetric expression within New Zealand's Hikurangi Margin gas hydrate province, is eroded close to the top of the regional base of gas hydrate stability (BGHS). This suggests a strong link between the gas hydrate system and slope failure.

Ten high-resolution 2D seismic lines, acquired over Rock Garden in 2006 as part of a specialised gas hydrate research cruise, reveal numerous pockets of gas close to the seafloor. They manifest themselves seismically as regions of anomalous amplitudes, and are focused mostly beneath the seismically predicted BGHS. This suggests that gas may be at least partially trapped by a permeability contrast between sediments below (free of gas hydrate) and sediments above (partially saturated with gas hydrate, reducing permeability).

The gas pockets have the potential to contribute excess fluid pressure and ultimately load pre-existing structures or intact sediments to failure. We have utilised a complex systems modelling platform (CSMP) to numerically simulate fluid flow and test the sensitivity of the system to gas pockets and to permeability contrasts. Results reveal that significant over-pressuring between the BGHS and the seafloor is plausible, especially under combined conditions of appreciable gas saturation (greater than 10%) and a permeability contrast at the BGHS. Ongoing modelling is exploring relationships between effective pressure and permeability, in an attempt to provide better understanding of timescales involved in the accumulation and dissipation of fluid over-pressure.

TESTING PROPOSED MECHANISMS FOR SEAFLOOR WEAKENING AT THE TOP OF GAS HYDRATE STABILITY, ROCK GARDEN, NEW ZEALAND

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We evaluate different hypotheses concerning the formation of a peculiar, flat-topped ridge at Rock Garden, offshore New Zealand. The coincidence of the ridge bathymetry with the depth at which gas hydrate stability intersects the seafloor has been previously used to propose that processes at the top of gas hydrate stability may cause seafloor erosion, giving rise to the flat ridge morphology. Two mechanisms that lead to increased fluid pressure (and sediment weakening) have previously been proposed: (1) periodic association and dissociation of gas hydrates during seafloor temperature fluctuations; and (2) dissociation of gas hydrates at the base of gas hydrate stability during ridge uplift. We use numerical models to test these hypotheses, as well as evaluating whether the ridge morphology can develop by tectonic deformation during subduction of a seamount, without any involvement from gas hydrates. We apply a commonly-used 1D approach to model gas hydrate association and dissociation, and develop a 2D mechanical model to evaluate tectonic deformation.

Our results indicate that: (1) Tectonics (subduction of a seamount) may cause a temporary flat ridge morphology to develop, but this evolves over time and is unlikely to provide the main explanation for the ridge morphology; (2) Where high methane flux overwhelms the anaerobic oxidation of methane via sulphate reduction near the seafloor, short-period temperature fluctuations (but on timescales of years, not months as proposed originally) in the bottom water can lead to periodic association and dissociation of a small percentage of gas hydrate in the top of the sediment column. However, the effect of this on sediment strength is likely to be small, as evidenced by the negligible change in computed effective pressure; (3) The most likely mechanism to cause sediment weakening, leading to seafloor erosion, results from the interaction of gas hydrate stability with tectonic uplift of the ridge, provided permeability strongly decreases with increasing hydrate content. Rather than overpressure developing from dissociation of hydrates at the base of gas hydrate stability (as previously thought), we found that the weakening is caused by focussing of gas hydrate formation at shallow sediment levels. This creates large fluid pressures and can lead to negative effective pressures near the sea-floor, reducing the sediment strength.

PETROLOGY OF SOME MODERN AND ANCIENT COLD SEEP-CARBONATES, EAST COAST BASIN, NEW ZEALAND

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Cold seeps mark areas of focussed methane rich fluid expulsion at the sea floor. They correspond to oases of diverse biological, chemical and geological processes, including common precipitation of carbonates from the interaction of hydrocarbon fluids with a consortium of methanotrophic bacteria and archaea.

This study is the first detailed petrographic analysis of New Zealand's cold seep-carbonates. The inclusion of both modern and ancient samples into the study allows a comparison on the effect of early diagenetic influences and overprinting of fabrics in the carbonates. Ancient samples come from Tauwhareparae, a moderate sized, middle Miocene (Lillburnian) carbonate mound 70 km inland from Tolaga Bay in East Coast Basin. Modern samples are sourced from Ritchie Ridge on the Hikurangi Margin (NIWA Collection: Tangaroa Cruise, TAN0616).

The seep carbonates range from fossil absent to fossil rich, where they include chemosynthetic species of Bathymodioline mussels and Vesicomyid clams and varying amounts of planktic and benthic foraminifera. The Tauwhareparae deposit is especially fossil rich, with abundant mussels and worm tubes. Various burrowing and boring fabrics are conspicuous in the mound-like carbonates.

Laboratory analysis of the carbonate samples included standard and cathodoluminescent petrography, carbonate percentage determinations, XRD mineralogy, and stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes.

Petrographic fabrics are often complex and there is much variation between and within samples, highlighting their dynamic paragenesis of the seep carbonates. Not uncommonly their evolution has involved several phases of carbonate-siliciclastic sedimentation, carbonate precipitation and cementation, fracturing or brecciation, fluid injection and veining, reworking and resedimentation, and diagenetic alteration or replacement.

Mineralogically, aragonite is the dominant carbonate species in both the modern and ancient samples, with subordinate calcite. Dolomite is also common in several of the modern samples, possibly due to sea floor exhumation of former subsurface deposits.

Isotopically, the carbonates fall within the range $\delta^{13}C$ -27 to -45‰ PDB, supportive of formation from thermogenic methane, which is characteristic of many seep carbonates. Positive $\delta^{18}O$ values to suggest the formation and disassociation of gas hydrates may have been implicated in the precipitation of the carbonates.

METHANE SEEPAGE ALONG THE HIKURANGI MARGIN OF NEW ZEALAND: GEOCHEMICAL AND PHYSICAL EVIDENCE FROM THE WATER COLUMN, SEA SURFACE AND ATMOSPHERE

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The concentration and carbon isotope values of dissolved methane have been determined in the water column at Rock Garden, Omakere Ridge and Wairarapa areas in the first dedicated cold seep investigations along the Hikurangi Margin. All areas are actively venting methane. The highest concentrations (up to 3500 nM) measured in water samples obtained from Conductivity-Temperature-Depth (CTD) operations were at Faure Site of Rock Garden. Here, bubbles being released from the seafloor were observed by ROV. The Omakere Ridge area is active over almost its entire length (~25 km), in particular at Bear's Paw, a newly discovered seep site. In the Wairarapa area another new seep site called Tui was discovered. With respect to the observed methane release of our study, Tui is arguably the most active site discovered so far along the Hikurangi Margin, with many methane measurements exceeding 500 nM. ADCP measurements at Wairarapa show that currents are predominantly south and depict the occurrences of bubbles associated with upward directed currents. Currents have transported a methane plume, at about 700 below sea surface, over a horizontal distance of about 20 km from the source area. The use of a METS (methane sensor) enabled us to accurately collect samples for on-board quantitative methane measurements and provide a high resolution impression of the methane distribution in the water column. Repeated CTD casts at the same location indicated that removal rate of methane in the water column along the Hikurangi Margin ranges from 11 to 19% per day (or ~38 nM/day) for concentrations < 200 nM, at depths of 1200 – 550m. No evidence was obtained from water column or sea surface measurements to indicate that methane from the seafloor is reaching the sea surface and introduced into the atmosphere. In fact, a consistent upper boundary at 500-550 m was apparent at all the sites (density barrier, maximum bubble rise height), above which methane decreased to background concentrations. A wide range of $\delta^{13}C_{CH4}$ values (-71 to -19‰, VPDB) were measured. Isotope values of samples that have the highest CH_4 concentrations reveal that the source methane had values of about -68 to -66‰. Simple Rayleigh distillation model calculations show that aerobic oxidation of methane in the water column can account for the range of concentrations and $\delta^{13}C_{CH4}$ values along the Hikurangi Margin.

OVERVIEW OF THE FIORDLAND GAS HYDRATE PROVINCE, NEW ZEALAND

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Occurrences of bottom simulating reflections – related to the presence of gas hydrates – previously have been observed over a wide-spread zone on the active continental margin associated with the incipient Puysegur subduction zone, south-east of the South Island of New Zealand. However, unlike New Zealand's other large gas hydrate province located on the active Hikurangi Margin, east of the North Island, the Fiordland BSRs have not been described in terms of their seismic characteristics or distribution. The presentation will outline the results of the analysis of five seismic reflection datasets and will introduce an area of approximately 2200 km^2, in which gas hydrates are hypothesised to be present. The BSRs identified in this region exhibit classic characteristics indicative of a reflection at the base of the gas hydrate stability zone: 1) they predominantly have a negative polarity – implying a decrease in acoustic impedance, 2) they cross-cut strata, and 3) they have a variable amplitude with offset (AVO) response – indicating the presence of free gas below the reflection. Localized regions of acoustic blanking may be observed at some points above strong BSRs. The lack of information on the sedimentary characteristics of the Fiordland Margin limits our ability to quantify the gas hydrate deposits in this province. However, a significant proportion (16%) of the mapped region contains structural and stratigraphic features that can focus upward flow of fluids and may therefore correspond to regions of increased hydrate concentrations.

GEOLOGICAL SETTINGS OF METHANE SEEP-DERIVED CARBONATES IN THE EAST COAST BASIN

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In the onshore East Coast Basin, 17 localities of carbonates formed at former sites of seabed methane seeps have so far been recognised, and research is proceeding on several aspects of these. Most are enclosed within claystone or clay-dominant mudstone of deep water facies, and ages range from Early to Late Miocene (Lw–Tt).

Eleven of these localities are located generally north of Gisborne, and all except 2 of these are of Middle Miocene age (Sc-Sl). Six localities are known in Southern Hawke's Bay in a restricted area south of Waipukurau, where all are of Early Miocene age.

Size of the carbonate bodies varies from a little over 1 m in diameter to more than 2 hectares in area, and some are known only as a series of disconnected boulders on hillsides or in stream beds.

A diverse faunal assemblage is characterised by bathymodioline mussels, similar to those found inhabiting modern seafloor hydrocarbon gas seeps, and includes at least 30 other species of bivalves, gastropods, brachiopods, polychaetes, crustacea, and corals. Whale bones are also known.

Structural settings are diverse; northern limestones occur close to or on major synclinal axes, near anticlines, or part way through fold limbs. All but one of the southern limestones lie along the western limb of the Akitio Syncline, close to the reverse-faulted eastern margin of the Whangai Range. Several present-day gas seeps occur along this fault zone.

Lithologies include dominantly micrite of dark, medium or pale grey, buff, or greenish colours. Various phases of carbonate cementation are present, as well as fibrous aragonite-lined voids indicative of fluid flow. Cross-bedding, breccia and chaotic orientation of fossils suggest deposition in part by debris flow for some deposits, perhaps off active mud volcanoes. Tubular concretions of generally small size are present within the carbonates, and larger but similar bodies are seen in the underlying host claystone or mudstone where exposed. Freshly broken carbonate has a sulphurous smell, and a scent of oil is evident if crushed or cut.

The seep carbonates indicate a long history of hydrocarbon generation and seepage in the East Coast Basin, although it is not as yet certain whether the gas was generated by thermogenic or biogenic means. Similarly the oil may have been generated directly from organic carbon within the deposits, or may be sourced from mature Upper Cretaceous to Paleocene source rocks (the Whangai and Waipawa formations) and has migrated into the carbonate.

AN OVERVIEW OF THE LATEST RESULTS OF COLD SEEP RESEARCH ALONG THE HIKURANGI MARGIN, NEW ZEALAND

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Prior to 2006, the knowledge about cold seeps around New Zealand was based mainly on accidental recovery of seep fauna or methane-derived carbonates by fishermen and the detection of flares in fish-finding sonars. Lewis and Marshall (1996; NZJGG) compiled these findings, providing the first details on 13 seep sites. Four of those are located at the Hikurangi Margin along the east coast of New Zealand's North Island.
Since then, three international cruises in 2006 and 2007 enhanced our knowledge considerably about methane seepage along the Hikurangi Margin, an area which has widely distributed and in places very strong BSR. Two cruises on the RV TANGAROA (led by GNS Science and NIWA, NZ) in 2006 focused on extensive reconnaissance work (multibeam mapping, seismic surveys, flare imaging, visual observations) as well as fauna sampling, geochemical pore water analyses and CTD casts including water sampling for methane analyses. Several new seep sites were discovered during these cruises. Using these data, very detailed investigations in four main working areas could be performed during a 10-week expedition with RV SONNE (SO191, led by IFM-GEOMAR, Germany). All research topics currently discussed in the scientific community were addressed using state-of-the-art equipment (e.g. deep-tow side-scan, TV-guided sampling, lander and ROV-deployments). Fourteen institutes from seven countries were involved (Australia, Belgium, Germany, New Zealand, United Kingdom, United States, Switzerland).

Echosounder and sidescan surveys unmistakably revealed active seep sites by detecting bubbles in the water column and carbonate precipitation at the seafloor forming massive chemoherm complexes. These complexes are associated with typical seep fauna like tube worms, bivalve mollusk species (*Calyptogena*, *Bathymodiolus*), and bacterial mats. At the fringe of these chemoherms dark sediment patches were observed which exihibit a novel seep habitat dominated by dense beds of two new species of heterotrophic ampharetid polychaetes. Bubble release was visually observed at several sites and recorded in the backscatter of various acoustic devices. At one site (680m water depth) very strong, pulsing outbursts could be observed repeatedly with methane fluxes of 20 to 25 l/min (60 to 74 mol/min). Intense CTD sampling and onboard methane analyses revealed that at least three of the areas are actively venting methane with an upper boundary at about 500 m, due to a density barrier. ADCP data indicate tide-dependent changes in current speed and direction. $\delta^{13}C$ values of dissolved methane range from -71 to -19‰, reflecting bacterial oxidation of methane in the water column, with a removal rate of 38 nM/day (or 11 to 19%/day). Equilibrator surveys, analyzing the sea surface and atmospheric methane concentrations show no significant oversaturation and fluxes for the entire studied area of the Hikurangi Margin.

Extensive pore-water measurements, including *in situ* measurements during lander deployments, were aimed at evaluating flux rates of dissolved geochemical species and free gas. These measurements revealed that the dark sediment patches represent a remarkable seep habitat because of its very high methane fluxes and total oxygen consumption rates. Detailed seismic and controlled-source electromagnetic surveys allowed quantification of gas hydrates and regional estimates of fluid-flow focusing and the impact on the gas hydrate stability and BSR occurrence. Furthermore, the geophysical data imaged fluid pathways under seeps and indicated that more seep sites could be found at the seafloor. In 2006 and 2007, 23 new seep sites have been identified and visually observed, which resulted in a total of 31 seeps sites for the Hikurangi Margin. With more cruises proposed, this number is likely to increase.

GAS HYDRATE RESOURCES ON NEW ZEALAND ACCRETIONARY MARGINS

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Analysis of bottom simulating reflections (BSRs) on multichannel seismic reflection data the southern Hikurangi margin offshore of the East Coast of New Zealand, reveals that a world class gas hydrate province extends from about 600 m water depth to the Hikurangi trench and covers an area of about 50,000 km^2. The Fiordland margin is less well explored and contains an area of about 2,500 km^2. We analyzed BSR reflection strength in grids of seismic data across both margins and found 4% (2,000 km^2) of the gas hydrate stability zone on the southern Hikurangi margin is underlain by strong BSRs that may underlie highly concentrated gas hydrate deposits ("sweet spots"); we conservatively estimate that up to 8 trillion cubic feet (tcf) of recoverable gas may be stored in these sweet spots. Mapped variations in BSR and seafloor reflection amplitude ratios and reflection coefficients reveal a strong correlation, on a regional scale, between the amplitude of BSRs and structures that promote fluid flow. Three dedicated gas hydrate surveys along the Hikurangi margin have been conducted between 2005 and 2007 on a number of potential sweet spots, many of which also exhibit known vent sites, and have succeeded in detection of highly concentrated gas hydrates. Isotope, geochemical and geophysical data from previous studies onshore point to a thermogenic origin for methane and suggest that East Coast fluids are derived from accreted, organic rich, sedimentary sources overlying the subducting slab. We therefore speculate that a widespread highly concentrated gas hydrate resource on the Hikurangi margin is supported by long-term recycling of fluids along faults that penetrate through the oldest sediments in the forearc and sole at the plate interface. Squeezed subducting sediments at the plate interface may provide a rich source of water driving this fluid recycling.

INSIGHTS INTO PARAGENETIC COMPLEXITIES WITHIN MIOCENE HYDROCARBON SEEP LIMESTONES IN EAST COAST BASIN, NEW ZEALAND

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Miocene cold seep limestones in East Coast Basin forearc, New Zealand, archive paleo-hydrocarbon seafloor seepage, and represent a previously little-documented, volumetrically small but unique and important carbonate rock type in the New Zealand stratigraphic record. They occur in two main geographic areas, one northwest of Gisborne in Raukumara Peninsula and the other east of Dannevirke in southern Hawke's Bay. The limestones are hosted within Miocene slope mudstones and are commonly characterised by chemosynthesis-based fossils, including lucinid, vesicomyid, and/or mytilid bivalves, together with non-chemosynthetic corals, gastropods, brachiopods, and worm tubes.

In outcrop the seep limestones are commonly rather bland in appearance, yet extraordinary once slabbed revealing a truly complex array of textures, fabrics, and mineralogies. Fossils, along with variable amounts of siliciclastics, are cemented by typically pristine methane-derived authigenic carbonates (MDACs) with minimal alteration and distinctly negative $\delta^{13}C$ isotopic signatures (-20 to -30‰ PDB) indicative of formation via microbially mediated, anaerobic oxidation of methane (AOM). Major textural complexities arise through a combination of sequential mineralisation episodes punctuated by multiple hydrofracturing and brecciation, recementation, and local corrosion events, which collectively dramatically altered rock fabrics and poroperm characteristics.

A host of primary and secondary mineral types formed during early (at or near seafloor) through later (burial) diagenetic phases. Many important spatial and temporal relationships are emerging despite the overwhelming fabric complexity, enabling recognition of a broadly based paragenetic sequence. Generally dark cathodoluminescent, early authigenic peloidal aragonitic micarb ("micrite") is associated with seepage inception and diffuse flow, while radiating acicular to botryoidal isopachous bands of often hydrocarbon-bearing inclusion-rich aragonite alternating with laminated microbial fabrics and digitate thrombolites formed during more advective fluid flow. Vacated worm tubes provided additional preferential conduits for aragonite mineralisation. The bacterially mediated sea bed diagenesis resulted in early lithification and local firm or hardground formation, as evidenced by burrows and bores.

Once in the burial realm, later diagenetic precipitates developed more slowly from diffuse flow forming generally brightly luminescent Mn-rich calcitic phases and recrystallised micarb fabrics, coarse variably coloured and complexly zoned red through purple late stage dentate/equant carbonate minerals often infilling skeletal pores and corrosion cavities. Authigenic quartz and possibly barite also occur.

COLD SEEPS AS METHANE SOURCES IN COOK STRAIT, NEW ZEALAND: EFFECTS OF LATERAL AND VERTICAL PROCESSES ON REGIONAL METHANE BUDGETS

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Uncertainty in the global marine methane (CH_4) budget is exacerbated by under-sampling in the Southwest Pacific Ocean. Methane is formed in the marine environment by anaerobic decay of organic matter in sediments and the water column, and in the form of gas hydrates and at cold water seeps in ocean sediments. Around New Zealand natural sources of marine CH_4 are particularly poorly constrained. Recent exploratory work at the southern end of the convergent Hikurangi subduction margin has identified high concentrations of methane in oceanic waters of the Cook Strait, with elevated concentrations in surface (maximum 500% saturation) and deep waters (>10000%). CH_4 in seep gas plumes is also highly depleted in ^{13}C (-67‰), and so is readily distinguishable from the open ocean surface signature of -45‰. In order to identify the source(s) of surface water methane in Cook Strait, surveys of methane distributions were made across the region, targeting riverine and upwelling sources, with a local cold seep site, the Wairarapa Seep in southeastern Cook Strait, studied over several voyages as a focal point for process studies. Measurements included methane distribution, ^{13}C-methane and particulate isotopes in the water column, and characterisation of the microbial methanotroph community. Gas bubble plume heights at the Wairarapa Seep site at 1050 m water depth rarely exceed 350m, and lateral currents and stratification prevented methane from the seep reaching the sea surface directly at the site. Plume morphology and dynamics, however, were observed to be affected markedly by tidal currents, and the topography and dynamic current system of the Cook Strait offers the potential for lateral transport of seep methane in deeper waters. For example, lateral advection of seep methane to canyon heads could facilitate transport into surface waters. The depleted ^{13}C-CH_4 at the surface in Cook Strait, however, was primarily associated with low salinity, suggesting a terrestrial or shallow sediment origin. These different methane sources are examined using simple isotope mixing models to determine their relative contributions, and presented in the context of a new marine methane budget for New Zealand waters.

SUBMETER MAPPING OF METHANE SEEPS BY ROV OBSERVATIONS AND MEASUREMENTS AT THE HIKURANGI MARGIN, NEW ZEELAND

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During R.V. Sonne cruise SO191-3, part of the "New (Zealand Cold) Vents" expedition, RCMG deployed their CHEROKEE ROV "Genesis" on the Hikurangi Margin. This accretionary margin, on the east coast of New Zealand, is related to the subduction of the Pacific Plate under the Australian Plate. Several cold seep locations as well as an extensive BSR, indicating the presence of gas hydrates, have been found at this margin. The aims of the ROV-work were to precisely localize active methane seeps, to conduct detailed visual observations of the seep structures and activity, and to perform measurements of physical properties and collect samples at and around the seep locations. The ROV allowed first ever visual observations of bubble-releasing seeps at the Hikurangi Margin. Seeps were observed at Faure Site and LM-3 in the Rock Garden area, at a flat to moderately undulating sea floor where soft sediments alternate with carbonate platforms. Bubble-releasing activity was very variable in time, with periods of almost non-activity (5 bubbles/second) alternating with periods of violent outbursts (190 bubbles/second). Bubbles sizes ranged from less than 5 mm to more than 20 mm. At Faure Site, bubble release was monitored over a period of 20 minutes, resulting in the observation of 6 outbursts, each lasting 1 minute at a 3 minute interval. These violent outbursts were accompanied by the displacement and resuspension of sediment grains and the formation of small depressions showing what is possibly an initial stage of pockmark formation. At the LM-3 site only some small bubbling seeps were observed near a large carbonate platform covered by *Bathymodiolus* mussels, *Calyptogena* shells and tube worms. Sediment-temperature measurements, in both areas, were largely comparable with the bottom-water temperature except at LM-3, at a site densely populated by polychaetes, where anomalous low sediment-temperature was measured. Overall, both seep areas are very confined in space and bottom-water sampling revealed that the released methane has a microbial signature.

SEEP STRUCTURES IN WAIRARAPA, HIKURANGI MARGIN: SEISMIC CHARACTERISTICS AND METHANE CONCENTRATIONS

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Cold seeps are abundant along active and passive margins. They constitute important pathways for methane from the subsurface into seawater and atmosphere. The area of Wairarapa near Cook Strait east of Northern Island, New Zealand, represents an ideal target area for detailed seep investigation. A number of extremely active seeps have been discovered within the New Vents Project in this area. Along with the acquisition of multichannel seismic lines, methane sensors (METS) were deployed together with seismic ocean bottom stations, where they stayed stationary for the duration of the seismic profiles.

The high-resolution seismic sections show a variety of seep appearances. We see seismic chimneys either characterized by high-amplitude reflections or by acoustic turbidity and faults presumably acting as fluid pathways. Acoustic blanking and bright spots provide further evidence of gas within the sediments. Seep formation in Wairarapa seems to be primarily controlled by the presence of numerous minor faults piercing the base of the gas hydrate stability zone.

The bathymetric expression of the seeps also varies, there are seeps beneath a flat seafloor as well as a pockmark and small mounds. The images of the 3.5 kHz Parasound system reveal the near-surface structure of the vent sites. While high-amplitude spots within the uppermost 50 mbsf are observed at the majority of the seeps, indicating hydrate and/or authigenic carbonate formation with a possible accumulation of free gas underneath, a few seep sites are characterized by the complete absence of reflections, indicating a high gas content without the formation of hydrates and/or carbonates.

The METS registered methane concentrations at the station sites, which are correlated with the seismic structures related to seep locations. We recorded methane concentrations differing by an order of magnitude at neighbouring stations. This large difference in methane concentration at a distance of only 300 m also demonstrates that the seeps are small scale structures and methane diffuses quickly in the water column.

The prevailing methane discharge from the seafloor is probably dominated by compaction of sediments and associated with transient, episodic events. Additionally all METS registered the bottom water temperature. Methane and temperature signals correlate with the tidal variations. The strong semi-diurnal tides contribute to the fast dilution and mixing of the discharged methane in the seawater.

SEEPS ALONG THE HIKURANGI MARGIN – A COMPARISON OF FOUR DIFFERENT SITES

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Methane plays a crucial role in the global bio-geo-system. Hence, cold seeps, where methane leaves the seafloor and enters the water column, are an important issue of present-day research. The cruise SO191-1 in 2007 to the Hikurangi Margin, east of New Zealand's North Island, was dedicated to the investigation of local and regional transport processes of methane and gas hydrate deposits east of New Zealand.

The Hikurangi Margin varies greatly along its axis. However, methane seep sites seem to accumulate on crests of thrust faulted ridges along the middle slope. Geophysical data from four different research areas reaching from Builders Pencil close to Hawke Bay to the area of Wairarapa near Cook Strait allow a comparison between seep sites, their setting and their distribution. The seep sites are analysed with regard to their seismic characteristics, their appearance on Parasound echosounder profiles, their bathymetric relief and the monitored methane concentration.

The methane, of biogenic origin, is probably captured within the sedimentary layers and transported upwards with the uprising fluids from the subduction channel or fluids from within the sediments due to sediment compaction. Fluid escape from the seafloor is partly governed by seafloor topography. In some regions, like Uruti, fluid seepage is restricted to areas of bathymetric highs. Whereas in other regions, e.g. Wairarapa and Omakere Ridge fluid escapes the seafloor at bathymetric highs, as well as along small faults through horizontally layered sedimentary sequences. Varying subseafloor structures related to fluid escape, e.g. bright spots and large fault systems, hint at different fluid escape mechanisms, regionally, as well as locally.

Along the entire Hikurangi Margin fluid escape is governed by gravitational forces, enhanced fluid escape occurs during low tides due to the smaller hydrostatic pressures.
The comparison of seep sites in different setting and different areas at the Hikurangi Margin provides valuable insight into the distribution of methane, the pathways of methane within the gas hydrate stability zone and the influence of sediments and tectonic setting on the development of seep structures.

SCHEMATIC MODEL FOR THE SUBSURFACE PLUMBING SYSTEM OF HYDROCARBON SEEPS AND METHANE HYDRATE DISSOCIATION, NORTH ISLAND, NEW ZEALAND

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Widespread occurrences of tubular carbonate concretions in Cenozoic slope mudstones in New Zealand are interpreted to represent the subsurface plumbing pathways of methane expulsion in hydrocarbon seep systems. The diverse geologic characteristics of the tubular concretions provide a unique opportunity to construct a comprehensive 4-D model of the subsurface development of such a system.

Tubular concretions are geographically widespread but occur in localized clusters in several Cenozoic sedimentary formations of the East Coast Basin and Taranaki Basin in North Island, New Zealand. They formed by precipitation of micritic dolomite and calcite cement within host mudstone, and contain 50–85% carbonate (dolomite dominated) compared to <10% carbonate in the surrounding mudstone. Several concretion morphologies occur, especially pipe, bulbous, doughnut, corkscrew, and conical shapes, and they include some of the largest examples known worldwide, ranging from 10 cm to 5 m or more in length (limited only by exposure) and 0.1 to 1 m in diameter. The concretions typically support near-central conduits ranging from 1–40 cm diameter which may be open or variably filled with sediment and/or late cements.

As well as diverse morphologic types, the tubular concretions also show, within limits, variable mineralogic, petrographic and geochemical characteristics. Additionally, some examples display association with slope instability, fault control on fluid migration, and stratigraphic placement directly below ancient seafloor seep carbonates.

Minus cement porosities (50–85%) in the tubular concretions indicate cementation took place before any significant compaction of the mudstones (0–300 m burial). $\delta^{13}C$ values of the cement range from –52 to 13‰ PDB and are interpreted to reflect carbonate precipitation from the onset of methane migration to the end of a major fluid migration event. A trend from strongly negative to strongly positive $\delta^{13}C$ values reflects extensive anaerobic oxidation of methane (AOM), which is confirmed by lipid biomarker evidence. $\delta^{18}O$ values range from -3 to 5‰ PDB suggesting an evolved fluid source influenced by cycles of methane hydrate formation and dissociation.

The resulting schematic model of tubular concretion formation is an analogue for the subsurface fluid migration system of hydrocarbon seeps along the modern Hikurangi Margin off eastern North Island, and possibly for many modern and ancient hydrocarbon seep systems in general. Additionally, they provide some spatial and temporal insight into hydrocarbon migration and gas hydrate formation/dissociation, which could assist in the evaluation of future hydrocarbon resources and any potential hazards associated with their recovery.

LIPID EVIDENCE FOR ANAEROBIC OXIDATION OF METHANE IN CONCRETIONS FROM NEW ZEALAND PETROLIFEROUS BASINS: DIFFERENCES RELATED TO CONCRETION MORPHOLOGY

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Lipid data for concretions from North Island basins reveal the presence of markers for anaerobic oxidation of methane (AOM). Archaeol is most prominent in the Cape Turnagain concretion together with pentamethyl icosane (PMI). Other pipe-like concretions from Rocky Knob and Taranaki Basin localities yielded PMI-bearing lipids in subsamples close to their central conduit. By comparison, host shales of all basins and a Taranaki 'classical' spheroidal concretion yielded only traces of either marker. PMI was confirmed at low levels in East Cape 'doughnut' concretions where archaeol is abundant. However, new lipid data for 'flowerpot' concretions from East Cape show no evidence of AOM involvement – both PMI and archaeol are absent. Further study of this phenomenon is ongoing.

Carbon-13 isotope ratios for PMI, archaeol and related putative marker compounds have so far been determined only for three samples. Biomarkers considered sedimentary in origin (early diagenetic or water-column derived) such as n-alkanes and steranes have C isotopic values typical of photosynthetic input ($\delta^{13}C$ around -25 to -35‰). Putative AOM markers crocetane (+ phytane), PMI, archaeol, DGD and MD are all very ^{13}C-depleted ($\delta^{13}C$ around -75 to -120‰) and so consistent with an AOM origin. This suggests fluids that had contacted AOM metabolic activity passed through Cape Turnagain pipes and East Cape doughnut conduits.

In a preliminary assessment of organic maturity, *n*-alkane carbon preference index (CPI) and sterane isomerisation were examined. In all of the host sediments and concretions studied CPI is >2 and sterane 20S/20S+20R ratio is <0.3. Consequently neither parameter shows any evidence of elevated temperature, consistent with a 'cold' seep origin.

Bulk carbonate C isotope compositions of the Taranaki and Rocky Knob calcitic concretions in which PMI is prominent are also ^{13}C-depleted (in some cases $\delta^{13}C$ is below –35‰), and thus consistent with an origin at least partly contributed to by anaerobic oxidation of ^{13}C-depleted methane of either thermal or biogenic origin. However, dolomitic Cape Turnagain and East Cape 'doughnut' concretions (with prominent PMI and archaeol) both show strong ^{13}C enrichment normally associated with residual bicarbonate of methanogenic origin and incompatible with AOM. Bearing in mind that lipid extraction was from powdered rather than dissolved carbonate it is possible that the fluids from which the bulk of the carbonate crystallised were different from those that introduced the lipids. Alternatively, a single fluid could have carried lipids and bicarbonate from different sources.

FOCUSSING OF FLUID FLOW AND ITS RELATION TO GAS HYDRATE FORMATION ON THE SOUTHERN HIKURANGI MARGIN – EVIDENCE FROM SEISMIC DATA

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Large quantities of fluids are predicted to be expelled from the southern Hikurangi Margin. We present seismic data that emphasize the significance of fluid-flow focussing on this margin. The data show high-amplitude anomalies beneath a thrust ridge, the Porangahau Ridge, that are most likely caused by free gas above the regional level of bottom simulating reflections (BSRs). While we cannot rule out buoyancy-driven invasion of free gas, several observations let us favour advective heat flow leading to local upwarping of the base of gas hydrate stability (BGHS) as cause for these anomalies. Estimates of advection rates suggest that the most significant source of fluids is likely to be compaction of subducted sediments. According to these estimates, on the order of 15% of predicted fluid expulsion across the margin may take place at the Porangahau Ridge.

The amplitude anomalies disappear further south and develop into a BSR gap, which we interpret as evidence for gas depletion. Such several-hundred-meter wide BSR gaps are present beneath other ridges on this margin and we speculate that they may mark locations of focused fluid flow. On regional scales, i.e., ignoring such relatively small gaps, BSR occurrence on the outer margin appears to be linked to thrusting in the accretionary wedge. Low coherency, decrease of amplitudes and possible lowering of frequencies of the seismic data are indicative of higher attenuation in the thrusted sections. Attenuation may be caused by free gas and/or scattering due to destruction of sediment fabric.

The source of methane for hydrate formation on the outer accretionary wedge is thought to be biogenic. We propose that the regional link between thrusting and BSR occurrence reflects the opening of fluid conduits that facilitate de-watering of the wedge. Upward migrating fluids “pick up” gas generated in the temperature window for biogenic methane generation in the upper ~2 km beneath the seafloor. This gas is available for BSR and hydrate formation at locations where fluids are being channelled to the seafloor, such as the thrust ridges.

MIOCENE HYDROCARBON SEEP DEPOSITS IN NEW ZEALAND: TAXONOMY AND PALAEOBIOGEOGRAPHY

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The East Coast Basin, eastern North Island, New Zealand, is one of few places worldwide that provides an opportunity to reconstruct a spatio-temporal record of long-lived (~20 Ma) hydrocarbon seepage for both onshore, exhumed accretionary prism and forearc rocks and their adjacent, offshore, modern convergent tectonic settings. Thus, their palaeontologic study can yield important insights, including assessment of evolutionary trends in the Pacific deep-sea faunae, generation of palaeobiogeographic models, and evaluation of the migration and spread of these provincial yet widely dispersed communities, of which current knowledge is incomplete. At least 16 geographically isolated ancient hydrocarbon seep deposits occur in the East Coast Basin, as discrete pods or lenses of authigenic carbonate embedded within thick Lower to Upper Miocene mudstone deposits. A preliminary checklist compiled for fossils collected from the deposits includes over 60 zootaxa in 10 phyla, and at least seven ichnotaxa, an increase in diversity from previous estimates of over 100%. Assessment of co-occurring species has allowed insights into ancient organismal interactions, such as the use of worm tubes as substrates by the acmaeid limpet *Serradonta vestimentifericola* Okutani, Tsuchida & Fujikura, 1992. Since the Late Jurassic, the most common fossils faunal groups reported from seep deposits worldwide, especially vestimentiferan worm tubes and veneroid bivalves, have modern representatives associated with chemosymbiotic micro-organisms. Similar seep-dominant taxa are also found in the Miocene deposits of this study, with its faunal composition consistent with previously reported Cenozoic seep fossils studied elsewhere around the world, and many of the taxa identified to date appear to have close affinities to modern vent–seep species.

MARINE CSEM SIGNATURES OF GAS HYDRATE AND GAS SEEPS ON THE HIKURANGI MARGIN: RESULTS FROM THE "NEW VENTS" PROJECT

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Methane seepage from the seafloor and the existence of submarine gas hydrates is known from the Hikurangi Margin on the east cost of New Zealand's North Island. Widespread BSR's have been observed in seismic data and several gas seep sites have been identified with echo sounders and video observations during expeditions on New Zealand's RV Tangaroa. The first systematic investigation of methane seepage took place in 2006 on cruise TAN0607 and culminated in the international multidisciplinary "New Vents" project in 2007 on RV Sonne cruise SO191.

Marine controlled source electromagnetics (CSEM) is an exploration method that recently gained considerable recognition in the offshore oil and gas exploiting industry. This is because the electrical resistivity derived from CSEM data is sensitive to the presence of resistive hydrocarbons such as oil, gas, and also gas hydrates. Submarine gas hydrates form in the available pore space of the sediment matrix and replace conductive pore fluid, with the consequence that the observed resistivity increases over areas, where hydrate forms in sufficient quantities.

Within the "New Vents" project it was the first time that marine CSEM has been applied within a German project as well as in New Zealand coastal waters. Four profiles have been surveyed in three target areas of active venting and methane seepage. The instrumentation used is a unique bottom-towed electric dipole-dipole system, capable to sense the seafloor to a depth of some hundred meters with a lateral resolution of about 100m. Three profiles show a strong coincidence between the location of seep sites and very anomalous resistivities. Deposits of concentrated gas hydrate at depth are likely the cause for these anomalies, but free gas may also play a role. In particular, data from the Wairarapa at the SE corner of the North Island point to considerable sources of gas hydrates in the first 100mbsf. There is one seep site where active venting, high heat flow, shallow gas hydrate recovered from cores, and seismic fault planes have been observed, but no resistivity anomaly. The reasons could be a) the gas hydrate concentration is too low, even though methane venting is evident, b) strong temporal or spatial variations, and c) the thermal anomaly indicates rather temperature driven fluid expulsion that hampers the gas hydrate formation beneath the vent. The fourth profile across Porangahau Ridge shows an anomaly over a seismic high amplitude reflection band extending from the BSR to about halfway to the seafloor, which may constitute a gas hydrate "sweetspot" above a zone of free gas.

THE LUSI MUD-VOLCANO (JAVA): CATASTROPHIC DISCHARGE OF A GEOPRESSURED SYSTEM

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The LUSI mud volcano is the surface manifestation of a geopressured geothermal system which started with an eruption of hot fluids and mud on 29.05.2006 close to a deep gas exploration well near Sidoarjo (East Java). The 2.8 km deep well encountered a sequence of over-pressured and under-compacted Pleistocene claystones between 1.3 and 1.9 km depth in a young back-arc setting. The still uncased section of the well below 1 km depth acted probably as a pressure-release shortcut. Hot water, gas (CH_4, CO_2, with minor H_2S), and hot mud ascended to the surface close to the well with quasi liquid volume flow rates > 100,000 m^3/s, close to boiling discharge temperatures. The uncontrolled discharge covered an area of c. 6 km^2 after one year and destroyed several villages. A construction programme of high dams has confined the extruding mud to most of the area covered in June 2006. The discharge is continuing almost unabated.

The composition of the liquid/mud mixture has changed with time. Initially c. 60% of the discharged volume was hot water, it decreased after one year to c. 30%. The hot mud contains at least c. 50% liquid. Heat-discharge rates on the order of c. 135 MW_{th} are indicated for the free liquid and c. 200 MW_{th} for the hot mud (2006/7 period). Chemical analyses have shown that the discharged liquids derive from deep marine pore fluids (NaCl c. 20 g/kg, i.e. c. 60% is paleo-seawater). A fast equilibrating geothermometer (K/Mg) points to deep equilibrium temperatures (T) of 100 – 120 deg C, prevailing at depths of 1.6 to 1.8 km where most of the mud comes from. Thus a high T gradient of c. 0.05 deg C/m is indicated, caused presumably by the low thermal conductivity of the under-compacted claystones. Isotope data of the surface liquids show the same anomalous $\delta^{18}O$ trend as paleo- waters in Gulf Coast (US) oil wells. A volcanic heat input is not required to explain the anomalous T setting of the pressurized LUSI fluid reservoir.

The effect of removing liquid and mud from the deep geopressured reservoir has been monitored by micro-gravity surveys during 2007/8 which indicate that the LUSI crater source lies within the eastern half of a much larger and growing residual negative gravity anomaly. It extends to the northwest and covers an area at least twice that of the present mudflats. Stresses at the margin produce shallow, clustered micro-earthquakes. The mud-water discharge has caused until now the accumulation of a c. 40 m thick, flat dome of mud near the discharge centre accompanied by a net subsidence of c. 20 m. Attempts to block or to reduce the catastrophic mud-water discharge of LUSI have failed until now.

DETERMINING GAS HYDRATE DISTRIBUTION AT PORANGAHAU RIDGE, SOUTHERN HIKURANGI SUBDUCTION MARGIN USING SEISMIC AND CONTROLLED SOURCE ELECTROMAGNETIC DATA

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Porangahau Ridge is a prominent thrust ridge inferred to contain large concentrations of gas hydrate, located within the accretionary wedge of the southern Hikurangi Subduction Margin. We have developed a very-high resolution 2D velocity model of Porangahau Ridge and surrounding geological structures using a combination of conventional techniques and horizon-based velocity analysis of 05CM-38 – a 120 km long margin-perpendicular multi-channel seismic line. Anomalous velocities in the velocity model differentiate between the presence of free gas (anomalously slow velocity) and gas hydrate (anomalously fast velocity). This high-resolution velocity model has been used to derive a preliminary acoustic impedance section, and to produce a high-quality migrated seismic section which reveals complex near-surface faulting not previously resolved, and more clearly defines a band of high-amplitude reflections above the regional bottom simulating reflections (BSRs). Interpretation of this migrated seismic section provides new insight into the nature of faulting and its relationship to fluid flow and gas hydrate formation on the margin.

Controlled source electromagnetic (CSEM) surveying is sensitive to highly-resistive gas hydrate and free gas in water-saturated conductive sub-seafloor sediments to depths of a few hundred metres below the seafloor. CSEM data acquired along a transect across Porangahau Ridge (coincident with 05CM-38 seismic profile) show anomalously high apparent resistivities above the high-amplitude reflection bands we observe. We use 1D-inversion results constrained by depth-converted seismic horizons to test a possible correlation between layered resistivity structure, p-wave velocity and reflection strength, suggesting the presence of a gas hydrate sweet spot.

SEDIMENTOLOGY AND PETROLOGY OF MIOCENE COLD-SEEP LIMESTONES IN NORTHERN WAIRARAPA: GEOLOGICAL EVIDENCE FOR PAST SEABED HYDROCARBON SEEPAGE

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This poster paper outlines the intent of MSc research that is recently underway to study the nature and origin of cold-seep limestones in deep-water mudstones of Miocene age in northern Wairarapa. The poster includes locality information, outcrop images, close up photographs of slabbed limestone specimens to convey their complexity, and petrographic photomicrographs to illustrate the paragenetic relationships amongst the primary and secondary components and fabrics building the limestones.

Along many modern continental margins there is evidence of seafloor escape of methane rich fluids. This evidence is in the form of pock marks, mud volcanoes, and carbonate build-ups. The carbonate build-ups can occur as irregular mounds or as chimney structures, and are collectively referred to as ‘methane derived authigenic carbonates’, or MDACs. The MDACs originate from the anaerobic oxidation of methane upon or near below the sea floor, a process carried out by a variety of microbes which thrive around areas of modern seafloor fluid escape.

Ancient cold-seep deposits are relatively rare, but are being discovered around the world. Several examples have been located in northern Wairarapa where the MDACs occur in slope mudstone sequences of Miocene age. To date, there has been only limited analysis of these MDACs in the field and laboratory. The proposed thesis research aims to add to the knowledge of cold-seep limestones and their origins, and to relate the ancient Wairarapa deposits to paleo-seafloor hydrocarbon seepage in the East Coast Basin of New Zealand.

As oil and gas seeps are known to occur both onshore and offshore in the eastern North Island, this study should widen understanding of the total East Coast Basin petroleum system. Comparative studies of MDACs of different ages across the region will add to our knowledge of the lateral and spatial characteristics of this petroleum system.

The main thesis objectives are:

- To document the field occurrence, distribution and geologic setting of the northern Wairarapa cold-seep limestones
- To unravel the complex evolution/paragenesis of these cold-seep limestones
- To establish the nature and origin of the seeping seabed fluids which formed the limestones
- To compare results with other national and international occurrences of cold-seep limestones
- To suggest economic ramifications arising from the study of the cold-seep limestones, particularly in relation to the petroleum exploration industry.