
Joint Geological and Geophysical Societies Conference, 2009

# PROGRAMME & ABSTRACTS

GEOLOGICAL SOCIETY OF NEW ZEALAND

OAMARU
23-27 November 2009

ISBN No. 978-1-877480-07-2
Geological Society of New Zealand Miscellaneous Publication 128A

DEPARTMENT OF

# Geology

Teaching and research carried out by staff and students in the Department of Geology at the University of Otago emphasises process-related research tied to the fast tempo of active earth sciences in the South Island, and to the evolution of our unique New Zealand biota. The Geosciences '09 meeting highlights the spectacular and scientifically inspiring geology of our local region. We hope you enjoy it as much as we do!

www.otago.ac.nz/geology

UNIVERSITY of OTAGO

Te Whare Wānanga o Otāgo

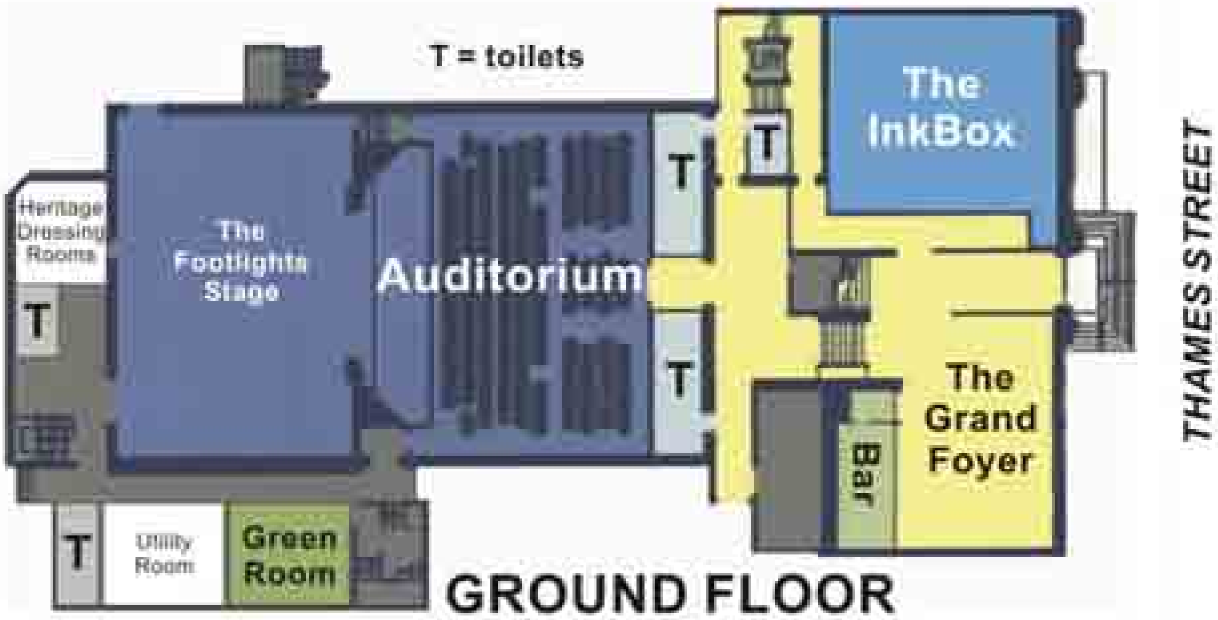
NEW ZEALAND

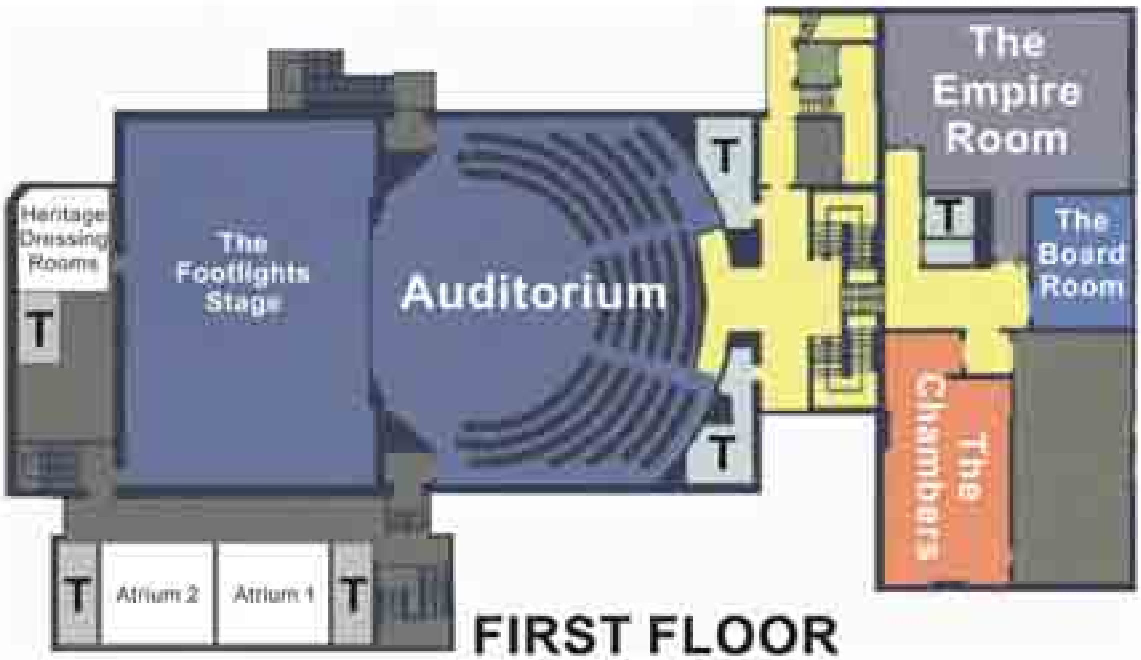
UNIVERSITY OF Otago

0800 80 80 98 | www.otago.ac.nz
txt 866 | university@otago.ac.nz

CHRISTCHURCH
Oamaru
Opera House
Kingsgate Hotel Brydone
NZ Malt Whisky Company
SOUTH HILL
DUNEDIN
Key Map
39
40
40

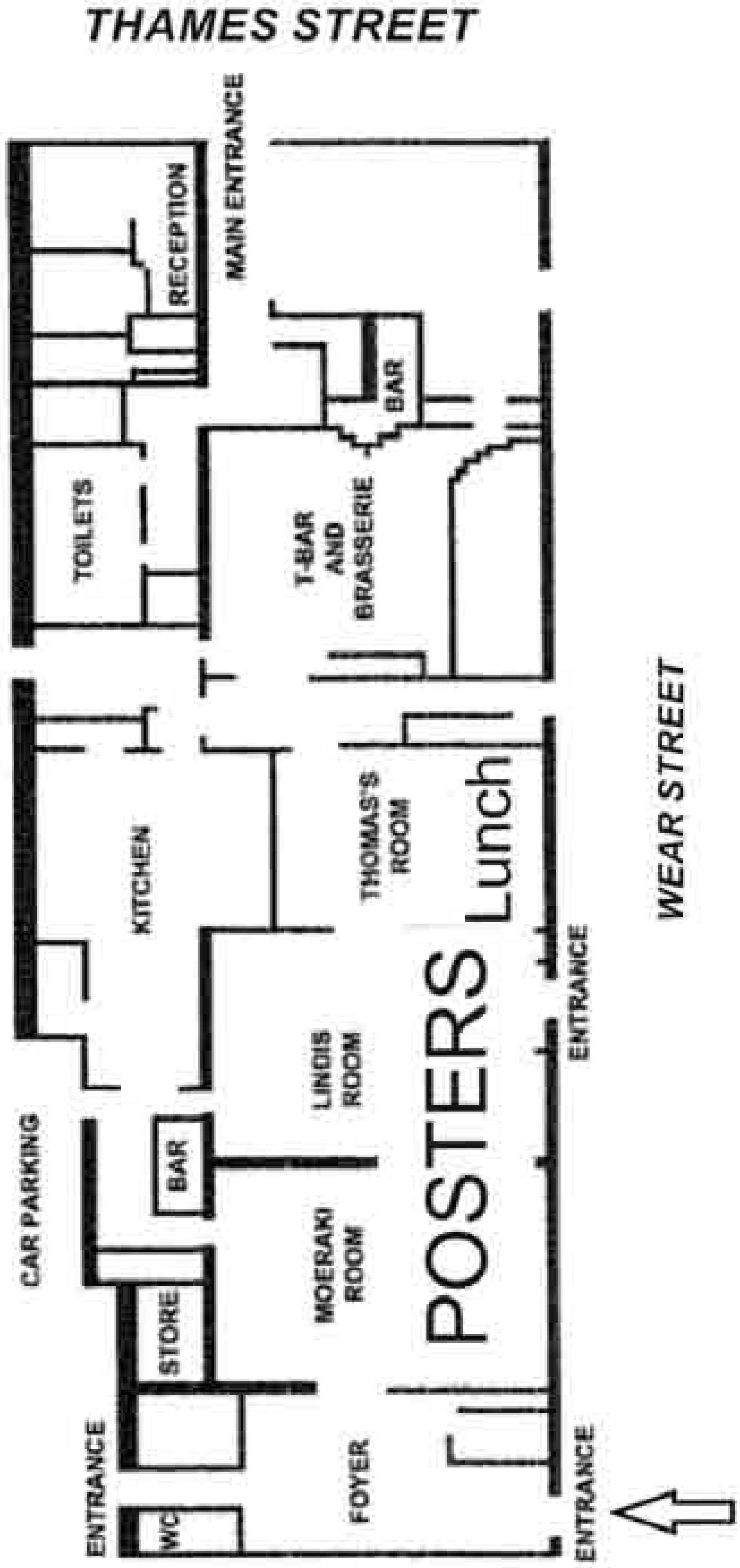
OAMARU OPERA HOUSE



**Kingsgate Hotel Brydone**

Floor plan



# GEOLOGICAL SOCIETY OF NEW ZEALAND & NEW ZEALAND GEOPHYSICAL SOCIETY JOINT ANNUAL CONFERENCE

Oamaru, 23 – 27 November 2009

# Programme and Abstracts

Edited by David Barrell and Andy Tulloch

**ORGANISING COMMITTEE**
Phaedra Upton, Virginia Toy (Conveners)
David Barrell, Jennifer Evans, Dushan Jugum, Richard Norris,
Christian Ohneiser, Andy Tulloch, Ian Turnbull, James White

**WITH ASSISTANCE FROM**
Bruce Albiston, Scott Elliffe, Richard McWha,
Hilary Norris, Glenn Ormsby, Leona Stretch

**Administration**
Janet Simes (Absolutely Organised Ltd) and Michelle Vui

**Symposium organisers**
Alan Cooper, Dave Craw, Paul Denys, Donna Eberhart-Phillips, Ake Fagereng, Miko Fohrmann, Ewan Fordyce, Phil Glassey, Daphne Lee, Jon Lindqvist, Nick Mortimer, Karoly Nemeth, Richard Norris, Mike Palin, Julie Rowland, Virginia Toy, Ian Turnbull, Phaedra Upton, James White, Gary Wilson

**Field trip leaders**
Jennifer Bannister, David Barrell, Dave Craw, Claudine Curran, Scott Elliffe, Ewan Fordyce, Uwe Kaulfuss, Dushan Jugum, Daphne Lee, Jon Lindqvist, Dallas Mildenhall, Nick Mortimer, Karoly Nemeth, Stuart Read, Jeffery Robinson, Rick Sibson, Virginia Toy, Ian Turnbull, Russ Van Dissen, James White

**Technical support**
Elly Lang, Christian Ohneiser, Delia Strong, Kay Swann, Damian Walls, John Williams

Geological Society of New Zealand Miscellaneous Publication 128A
ISBN 978-1-877480-07-2

# CONFERENCE SPONSORS

## Gold Sponsors

## Silver Sponsors

## Bronze Sponsor

## Host Organisations

## GENERAL INFORMATION

Welcome to the 2009 Joint Annual Conference of the Geological Society of New Zealand and the New Zealand Geophysical Society. With over 300 registrants, we are able to offer a very full programme including 8 scientific symposia, 5 special interest meetings and 13 fieldtrips. The conference is preceded by three pre-conference field trips, leaving from Dunedin. The conference begins with an ice breaker on the evening of Monday 23rd November, and the scientific sessions and meetings get underway on Tuesday 24th November. Wednesday 25th November is set aside for mid-conference field trips. The scientific programme resumes on Thursday and finishes with the closing ceremony at 2pm, Friday 27th November. Two post-conference field trips depart after the closing ceremony.

### Venues

The focus of the conference is the Oamaru Opera House, located at 94 Thames Street in downtown Oamaru. Presentations will be held in the Auditorium, InkBox, and Empire Rooms of the Opera House. Mid-morning refreshments will be provided in the Opera House while Lunches and Poster sessions will be held across the road at the Kingsgate Hotel Brydone. The Conference Barbeque will be held at Burnside Homestead, a short drive inland from Oamaru, while the Conference Dinner will be held at the New Zealand Malt Whisky Company in the Historic Precinct of Oamaru.

### Science Programme

The oral presentations and poster displays are grouped into eight symposia:

1) Geological and geophysical signatures of earth deformation and fluid flow;
2) Paleo-environments and basin evolution;
3) Magmatism and volcanic hazards;
4) Fiordland revealed;
5) Seismotectonics of southern New Zealand: from the Alpine Fault to the Otago shelf;
6) New frontiers and general earth science;
7) Applied geoscience;
8) Origin of the New Zealand biota.

Symposium 1 honours the scientific contributions of Richard (Rick) Sibson during his career at Imperial College – London, University of California – Santa Barbara, and most recently at the University of Otago (1990-2009). Rick is renowned for integrating structural geology, seismogenesis, and hydrothermal mineralization. Presentations in this symposium will highlight and celebrate some of the fundamental structural theories he is responsible for introducing to the scientific community.

## Registration and Help Desk

Registration is open in the InkBox of the Oamaru Opera House between 5:00 and 7:00 pm Monday 23rd November, and in the Grand Foyer from 7:30 am on Tuesday 24th, Thursday 26th and Friday 27th November.

## Satchels and abstract volume

As with last year, there is no conference satchel; please bring your own bag. Abstract and field trip volumes will be provided on CD to all participants. A printed abstract volume is provided only for those delegates that selected this additional cost option. Each registration pack includes a photocopy of this programme (without the abstracts).

Each field trip participant will receive a printed photocopy of the guide for that trip.

## Oral presentations

All oral presentations are 15 minutes (including introduction and discussion), except for plenary talks, which are 30 minutes. We recommend presenters in the non-plenary sessions aim for a presentation of no more than 12 minutes, to allow for introduction and discussion. Chair persons are asked to keep strictly to time, and in fairness to all, any presentations still running at the time the next speaker is due will be cut short.

We will only have PCs with Microsoft PowerPoint 2003, or Adobe Reader 9, available to display presentations. If your presentation was prepared using some other operating system or software version, we recommend you bring it in pdf format. Presentations for Tues 24th must be uploaded to our computers at the registration desk on Monday evening or first thing Tuesday morning. Presentations for Thurs 26th or Fri 27th should be uploaded between 7:30 and 8:15 am on that morning, directly to the computer in the theatre assigned for your presentation. Any late uploads (e.g. at the time scheduled for the presentation) will be at the expense of the 15 minute presentation slot.

The Green Room will have a 'speaker ready' area, with technical assistants in attendance and a computer available to check that your presentation works. We recommend that you use a standard font set in your presentation. If you have a movie in your talk, you must check that it works on the ‘speaker ready’ computer beforehand. Please note that there is only one projector & one screen provided in each theatre.

## Poster presentations

There are two poster sessions, Tuesday 3:00 to 5:00 pm and Thursday 3:00 to 7:00 pm, in the Moeraki and Lindis rooms of the Kingsgate Hotel Brydone. Scheduled posters will be displayed during one of those two sessions. Presenters are requested to stand by their poster for at least some of their session. Posters for display on Tuesday can be put up from Monday afternoon and must be removed by Thursday morning at 8:00 am. Posters for display on Thursday can be put up Thursday morning (covering any posters from the previous session that have not been removed) and must be removed by 1:00 pm on Friday.

Poster presentation times are given on pages xxi – xxv of this programme. Tu or Th denoting Tuesday or Thursday is followed by a board number, e.g., Tu01 = Tuesday poster session, poster board one. Posters must be no wider than 1.1 m. The poster boards are 1.2 m high, and the base of the board stands 0.8 m above the floor. Velcro dots must be used to secure the posters to the boards, as pins are not suitable. We suggest you bring your own Velcro – but we will have a back-up supply at the venue.

**Public Lecture – Monday 23rd November 8 pm, Oamaru Opera House Auditorium**

Climate change may bring wetter and warmer conditions to southern New Zealand, but we have been there before in the distant geologic past! Exquisite plant and animal fossils preserved in swamp, estuary, rocky shore and volcanic crater lake environments enable us to reconstruct changing climates and ecosystems of long ago.

Associate Professor Daphne Lee of the Geology Department at the University of Otago, will present the results of recent research on these ancient environments of Otago and Southland in a public lecture entitled: Subtropical paradise in Southern New Zealand: a story of palms, orchids, crocodiles, corals, tuatara and whitebait from Eocene swamps, Oligocene islands, and Miocene lakes.

**Field trips**

**Pre-conference trips**
*Trip 9: Miocene phreatomagmatic monogenetic volcanism of the Waipiata Volcanic Field, Otago, New Zealand.* Karoly Nemeth, James White.
Departs Dunedin Railway Station 8:45 am, passing through Dunedin Airport at 9:30 am, Monday 23rd November, 2009. Arrives at Oamaru, 6:30 pm Monday.

*Trip 10: West Coast Student Trip.* Dushan Jugum.
Departs Christchurch airport Friday 20th November, as early as possible. Arrives Oamaru, Monday 23 November, hopefully before the icebreaker event.

*Trip 11: Waitaki/Canterbury Basin.* Ewan Fordyce.
Departs Dunedin (Geology Dept, or pickup) 8:00 am Sunday 22nd November. Arrives Oamaru, Monday 23rd November, hopefully before the icebreaker event.

**Mid-conference trips**
Wednesday 25th November. These all depart from the Oamaru Opera House except for Trip 8, Victorian Oamaru, which leaves from the Oamaru i-SITE. Packed lunches are supplied for the out-of-town trips.

*Trip 1: Gold in Central Otago.* Dave Craw. Departs 8:00 am, returns 6:00 pm to Oamaru via the BBQ venue.

*Trip 2: Faults, fractures and fluid flow in basement assemblages.* Virginia Toy, Rick Sibson, Nick Mortimer. Departs 8:00 am, returns 6:00 pm to Oamaru via the BBQ venue.

*Trip 3: Coastal Otago – Oamaru to Kakanui.* Daphne Lee, Jeffrey Robinson. Departs 9:00 am, returns 5:30 pm to Oamaru.

*Trip 4: The Waihemo Fault System, North Otago.* Claudine Curran, Richard Norris. Departs 8:00 am, returns 6:00 pm to Oamaru via the BBQ venue.

*Trip 5: Waiareka-Deborah Volcanics: volcanoes of the Paleogene shelf.* James White. Departs 10:30 am, returns 4:00 pm to Oamaru.

*Trip 6: Aviemore – a dam of two halves.* David Barrell, Stuart Read, Russ Van Dissen. Departs 8:00 am, returns 5:00 pm to Oamaru.

*Trip 7: Vanished World.* Ewan Fordyce. Departs 8:00 am, returns 6:00 pm to Oamaru via the BBQ venue.

*Trip 8: Victorian Oamaru – a dramatized exploration.* Scott Elliffe. Departs 2:00 pm, returns 4:00 pm.

**Post-conference field trips**

*Trip 12: Paleobotany, Palynology and Sedimentology.* Daphne Lee, Jon Lindqvist, Jennifer Bannister, Uwe Kaulfuss, Dallas Mildenhall.
Departs Oamaru Opera House, Friday 27th November 3:00 pm, returns Sunday 29th November 5:00 pm to Dunedin Airport.

*Trip 13: Deepest Fiordland.* Mo Turnbull.
Departs Oamaru Opera House Friday 27th November, as soon as possible after the conference. Returns to Dunedin late on 3rd or on 4th December, depending on weather and swell conditions.

**Refreshments**

Morning and afternoon refreshments and lunches are provided. Morning teas will be held in the Opera House. Lunches and afternoon refreshments will be over the road in the Kingsgate Hotel Brydone with the posters and displays.

**Social Events**

***Icebreaker***

An informal "Icebreaker" function will be held in conjunction with registration in the Grand Foyer and the InkBox of the Oamaru Opera House, 94 Thames Street, Oamaru, from 5:30 to 7:00 pm Monday 23rd November. Snacks will be served. Drink vouchers can be found in your registration pack.

***Optional activities for Tuesday November 24th***

Optional activities include Victorian Oamaru – A Dramatized Heritage Experience, Whisky tasting or Wine tasting at the New Zealand Malt Whisky Company and a meal to follow. To attend you must have prepaid during conference registration. Tickets to these activities will be found in your registration pack.

***Barbeque***
A BBQ will be held on the evening of Wednesday 25th November in the grounds of Burnside Homestead, a restored Victorian mansion 15 minutes from central Oamaru. Guided tours of the homestead will be available to participants. Several of the field trips will drop BBQ participants off at the venue. Otherwise, return transport to the BBQ from Oamaru will be available, departing 5:30 pm from outside the Oamaru Opera House. To attend you must have prepaid during conference registration. Drink vouchers for participants are included in your registration pack. Bring a raincoat or umbrella in case of inclement weather.

***Conference Dinner and Presentation of Annual Awards***
The Annual Conference Dinner (theme: *Colonial Capers*, fancy dress optional) will be held on Thursday 26th November at the New Zealand Malt Whisky Company, 14-16 Harbour Street, Oamaru. Pre-dinner drinks will be available from 7:00 pm, with dinner served at 7:30 pm. The annual awards for the Geological and Geophysical Societies will be presented after dinner. There will also be prizes for the best/most imaginative fancy dress costumes.

**Meetings**

Several meetings will be held during the conference.

General Assembly: GSNZ and NZGS
A plenary-style General Assembly of the GSNZ and NZGS will take place immediately after lunch on Tuesday in the Auditorium. The organisers request that all members of these societies attend this meeting. The intention is to discuss all aspects of the proposed 2010 amalgamation. Come and hear the Executive Summary. Put your questions to the negotiating teams. Consult your newsletters for written background, as well as the proposed draft rules.

GSNZ AGM
The 55th Annual General Meeting of the Geological Society of New Zealand will be head in the InkBox, Tuesday 24th November, 5pm. See the October Newsletter for details. The agenda was printed in GSNZ Newsletter 150 (Nov 2009) and the minutes of the last meeting were printed in GSNZ Newsletter 148 (March 2009). As well as election of Officers, there will be motions on Proxy Voting, Honorarium for Treasurer and GSNZ-NZGS amalgamation. All GSNZ members are urged to attend.

Lunchtime Meetings

*1. International Scientific Drilling Partnerships (Chris Hollis)*
*Tuesday 12:15 pm, Empire Room*
This meeting will review the past year's activities relating to New Zealand's participation in the Integrated Ocean Drilling Program (IODP), the International Scientific Continental Drilling Program (ICDP) and the Antarctic Geological Drilling Program (ANDRILL), including a review of active drilling projects and proposals, and the potential role of DRILLNZ. We will discuss the rationale for belonging to international programs and will endeavour to identify priority themes and proponents

for new proposals. Options for long-term funding for membership and participation costs will also be reviewed. The meeting may attempt a live hook-up with the Canterbury Basin IODP expedition, which will be drilling on the Canterbury shelf at the time of the conference (9 November to 4 January).

*2. Historical Studies Group (Mike Johnston)*
*Tuesday 12:15 pm, The Board Room*
Among the matters to be discussed at this group meeting are the recent change in Editors of the HSG Journal, the forthcoming change in conveners, the journal and other activities the group could be involved in.

*3. Palaeontology Special Interest Group (James Crampton)*
*Tuesday 12:15 pm, The Chambers*
Among the matters to be discussed at this group meeting include; success and impact of touring exhibition: 'NZ Fossils: Dead Precious!', impending publication in February 2010 of book by James Crampton: 'Fossil Hunters Handbook'., the approach by GNS Science to public disclosure of dinosaur footprints in North Cape Formation exposures in Whanganui Inlet and any other matters arising.

*4. Deep Fault Drilling Project, Alpine Fault (Rupert Sutherland)*
*Thursday 12:15 pm, Empire Room*
This meeting will review project progress since our Alpine Fault workshop in Franz Josef in March 2009. There will be a focus on activities during the coming field season, which will set the scene for drilling. We can also talk through our longer-term strategy for logistics and funding of the main drilling experiment phases.

*5. Fossil Record File Subcommittee (Jack Grant-Mackie)*
*Thursday 12:15 pm, The Chambers*
A meeting of this subcommittee and Masterfile operators, and any others who are interested. With the new LINZ map series there are certainly issues to consider. Also there needs to be a report on the completed computerisation of the File. Any other topics can also be considered, time permitting.

**Phones, laptops and internet**

Please have mobile phones switched off during sessions, and refrain from using laptops in the conference rooms during sessions.

Limited internet is available at the conference centre. Please see the registration desk for details.

**Awards and Grants**

The announcement and presentation of annual awards for the Geological Society and Geophysical Society will be made at the conference dinner. Student awards for oral and poster presentations will be announced at the closing ceremony in the Auditorium.

Student travel grants, generously provided by the Geological and Geophysical Societies, will be distributed as cheques upon registration.

**Transport and Parking**

Transport to and from Dunedin Airport has been arranged for participants arriving on Monday 23rd November and departing on flights after 4:50 pm on Friday 27th November At Dunedin airport, you will be met by a shuttle driver who will be identified by a board saying Geosciences09. The shuttle will take you to the Geology Department, from where the buses to Oamaru will leave. We anticipate three successive trips from Dunedin to the Oamaru Opera House, the earliest leaving at 3:15 pm, once people have arrived from the 2:30 pm flight from Wellington. The second will leave sometime around 5:00 pm (to be confirmed later) and a third (a van) will take the late arrivals.

At Oamaru Airport, a shuttle bus operated by Whitestone Taxis meets all incoming flights, and can transport you to central Oamaru.

Oamaru has two taxi companies:
Oamaru Taxis (03) 434 6666
Whitestone Taxis (03) 434 1234

There are numerous metered carparks on Thames Street, outside the Conference venue, and free parking is available in most of the adjacent streets.

**Disclaimer**

The Geological Society of New Zealand, New Zealand Geophysical Society and Conference Organising Committee accept no responsibility for injury, accident, illness or death to, or financial loss by, any person attending the conference or fieldtrips, whatever the reason. All insurance is the responsibility of individual registrants.

Programme Cover photo credits: Lloyd Homer, Andrew Gorman and Ewan Fordyce

## CONFERENCE PROGRAMME

The conference programme is set out over the following pages. First authors' surnames are given. Where the presenting author differs from the first author, the presenter's name is listed in brackets. All authors' names appear in the full abstracts. ***** = student member of GSNZ, NZGS, GSAust, or GSAm. There are 3 concurrent oral sessions, with 1 plenary talk each day. Abstracts are listed alphabetically by first author name.

The symposia, and convenors, are:

**Geological and geophysical signatures of earth deformation and fluid flow:** Ake Fagereng, Julie Rowland, Virginia Toy.

**Paleo-environments and basin evolution:** Miko Fohrmann, Jon Lindqvist, Gary Wilson.

**Magmatism and volcanic hazards:** Alan Cooper, Karoly Nemeth, James White.

**Fiordland revealed:** Donna Eberhart-Phillips, Mike Palin, Mo Turnbull.

**Seismotectonics of Southern New Zealand: from the Alpine Fault to the Otago shelf:** Paul Denys, Richard Norris, Phaedra Upton.

**New frontiers and general earth science:** Nick Mortimer.

**Applied geoscience:** Dave Craw, Phil Glassey, Candace Martin.

**Origin of the New Zealand biota:** Ewan Fordyce, Daphne Lee.

# Conference Programme for Tuesday 24 November

| | | | |
|---|---|---|---|
| 07:30 | **Registration open, Oamaru Opera House** | | |
| | **AUDITORIUM** | | |
| 08:00 – 08:30 | Conference opening and notices | | |
| 08:30 – 09:00 | PLENARY - **Toshihiko Shimamoto**: Impacts of Rick Sibson on fault mechanics | | |
| | **AUDITORIUM** | **INKBOX** | **EMPIRE** |
| | ***Deformation & Fluid Flow Symposium*** | ***Magmatism & Volcanic Hazards Symposium*** | ***New Frontiers & General Earth Science #1*** |
| 09:00 – 09:15 | **Cox_SF** - Fault weakening during dissolution-mediated frictional sliding on bare interfaces at hydrothermal conditions | **Lindsay -** The age of the Auckland Volcanic Field | **Cassidy -** Archaeomagnetism of SW Pacific ceramics: a tool for geomagnetic and archaeological research |
| 09:15 – 09:30 | **Toy -** Diverse habitats of pseudotachylyte in the Alpine Fault Zone and implications for seismicity distributions | **McGee*** - Geochemical and petrographic variations and the inner workings of monogenetic basaltic fields | **Quigley -** Use of cosmogenic nuclides in tectonic geomorphology research |
| 09:30 – 09:45 | Nortje (**Oliver**) - Variable fault cohesion and reactivation on a Proterozoic fault array | **Booden*** - Genesis of the Miocene volcanic succession of the North Island in light of new isotope and trace element data | **Eccles -** Imaging through seismically attenuative volcanics: investigating below basalt in the North Atlantic |
| 09:45 – 10:00 | **Blenkinsop** - A footnote on fault reactivation | **Ilanko*** - Pyroclastic successions of a tuff ring in a monogenetic field: Barriball Road tuff ring, South Auckland | **Nobes -** Do englacial channels have a characteristic radar response and are they correlated with surface topography? Some preliminary observations |
| 10:00 – 10:30 | **Refreshments – Oamaru Opera House** | | |
| 10:30 – 10:45 | **John -** The character of oceanic detachment faults | **Stewart -** Evidence of multiple scoria cones and cone collapse at Pouerua volcano, Northland volcanic field, New Zealand | **Smith -** Biomineralisation in an urban environment: a carbonate budget for Otago Harbour |
| 10:45 – 11:00 | **Cheadle -** The structure & rheology of oceanic detachment faults: why are mylonites rare? | **Lefebvre*** - Challenges in determining the volcano-structural level of a maar-diatreme remnant: East Standing Rocks, Hopi Buttes Volcanic Field, Arizona, USA | **Macmillan*** - Comparative sedimentology and paleoecology of giant fossil oyster beds in Tertiary strata in New Zealand and Argentina |

| | | | |
|---|---|---|---|
| 11:00 – 11:15 | **Korchinski*** - Tectonic interpretation of titanium-in-quartz temperatures from high pressure rocks, D'Entrecasteaux Islands, Papua New Guinea | **Nemeth –** Morphology of glassy pyroclasts from soft substrate controlled versus open vent phreatomagmatic eruptions | **Fildes*** - Provenance studies of Miocene mass transport deposits |
| 11:15 – 11:30 | **Gillam*** - Shear bands near the mylonitic/non-mylonitic transition, Tatare Stream, South Island, New Zealand | **Murtagh*** - The Ilchulbong Tuff Cone, Jeju Island, South Korea: recent observations and development | **McKay -** Did Antarctic cooling ~3.3 million years ago help facilitate Northern Hemisphere glaciations? |
| 11:30 – 11:45 | **Fagereng*** - Incrementally developed 'dilational hydro-shears' forming at high angles to $\sigma_1$ in foliated mélange matrix | **Schipper*** - Intra-vesicular extrusions: sensitive indicators of submarine explosive conduit dynamics | **McColl*** - International summer school on rockslides and related phenomena |
| 11:45 – 12:00 | **Butler -** Thrust zone localization in poorly lithified submarine sandstones: theory and examples from seismic and outcrop | **Pittari -** Textural alteration styles and processes in volcaniclastic kimberlite deposits at the Fort à la Corne Field, Saskatchewan | **Burlinson** - Gold exploration using fluid inclusions |
| 12:00 – 13:00 | **LUNCH - Kingsgate Hotel Brydone** | | |
| 12:15 – 13:00 | Lunchtime Meeting: Paleontology Special Interest Group - THE CHAMBERS | Lunchtime Meeting: Historical Studies Group - THE BOARD ROOM | Lunchtime Meeting: International Scientific Drilling Partnership - EMPIRE ROOM |
| | **AUDITORIUM** | | |
| 13:00 – 13:45 | **GSNZ & NZGS GENERAL ASSEMBLY** | | |
| | **AUDITORIUM** | **INKBOX** | **EMPIRE** |
| | ***Deformation & Fluid Flow Symposium*** | ***Magmatism & Volcanic Hazards Symposium*** | ***New Frontiers & General Earth Science #2*** |
| 13:45 – 14:00 | Benson (**Stern**) - Crustal and upper mantle structure of the Central North Island from the MORC Survey, 2005 | **Doyle -** Temporal and spatial changes of evolving and coalescing lahars at Semeru, Indonesia | **Adams -** Mind the gap: investigating some apparent stratigraphic breaks in Permian, Triassic and Jurassic successions of the Torlesse and Waipapa terranes using detrital zircon ages |
| 14:00 – 14:15 | **Browne -** Mineralogical signals of fluid flow in geothermal systems | **Moebis*** - Characterisation of highly fragmented ash derived from Ruapehu and Ngauruhoe, New Zealand | **Jugum*** - A continuation of the Jurassic Waipapa-Aspiring Terrane in the Otago Schist: Evidence from detrital zircons |
| 14:15 – 14.30 | **De Ronde -** Hydrothermal systems of intraoceanic arcs - a 10 year odyssey of exploration | **Jolly -** Waveform modelling for repeating earthquakes at Ngauruhoe volcano in Tongariro National Park | **Ireland -** Geochronology of granulites from the Kakanui Mineral Breccia |

| | | | |
|---|---|---|---|
| 14:30 – 14:45 | **Leary -** Catching up with Rick Sibson at the outcrop: computing fracture-fluid interactions in the crust | **Zernack*** - Hot zone development beneath a long-lived andesite stratovolcano: magmatic evolution of Mt Taranaki, NZ | **Waterhouse –** Stratigraphy of the southeast Torlesse |
| 14:45 – 15:00 | **McLellan -** Spatial and numerical analysis of ancient and modern epithermal systems | **Seebeck*** - Dike intrusion and displacement accumulation at the intersection of the Okataina Volcanic Centre and Paeroa Fault zone, Taupo Rift, New Zealand | **Rattenbury -** The transition from Otago Schist to Alpine Schist, Haast region |
| | **KINGSGATE HOTEL BRYDONE** | | |
| 15:00 – 17:00 | **POSTERS** | | |
| | ***Deformation & Fluid Flow Symposium*** | ***Magmatism & Volcanic Hazards Symposium*** | ***New Frontiers & General Earth Science*** |
| | | **INKBOX THEATRE** | |
| 17:00 – 18:00 | | **GSNZ AGM** | |

# Conference Programme for Wednesday 25 November

| | | | |
|---|---|---|---|
| | **ONE DAY FIELD TRIPS**<br>All field trips depart from the Oamaru Opera House, except Trip 8, which leaves from the Oamaru i-SITE | | |
| **DEPARTS** | **TRIP NUMBER** | **TITLE** | **LEADERS** |
| | | | |
| 08:00 | **1** | **Gold in Central Otago** | Craw |
| 08:00 | **2** | **Faults, fractures, and fluid flow in basement assemblages** | Toy, Sibson, Mortimer |
| 08:00 | **4** | **The Waihemo Fault System, North Otago** | Curran, Norris |
| 08:00 | **6** | **Aviemore - a dam of two halves** | Barrell, Read, Van Dissen |
| 08:00 | **7** | **Vanished world** | Fordyce |
| | | | |
| 09:00 | **3** | **coastal Otago - Oamaru to Kakanui** | Lee |
| | | | |
| 10:30 | **5** | **Waiareka-Deborah Volcanics: volcanoes of the Paleogene shelf** | White |
| | | | |
| 14:00 | **8** | **Victorian Oamaru - a dramatised experience** | Elliffe |
| | | | |
| 17:30 | Buses depart from Oamaru Opera House for barbeque at Burnside Historic Homestead, 527 Burnside Road, Enfield | | |
| 18:00 | **Barbeque** | | |

# Conference Programme for Thursday 26 November

| | | | |
|---|---|---|---|
| 07:30 | **Registration open, Oamaru Opera House** | | |
| | **AUDITORIUM** | | |
| 08:15 – 08:30 | Notices | | |
| 08:30 – 09:00 | PLENARY **- Robert DeConto**: Plio-Pleistocene variations of the Antarctic Ice Sheet: implications for future sea level | | |
| | **AUDITORIUM** | **INKBOX** | **EMPIRE** |
| | ***Deformation & Fluid Flow Symposium*** | ***Paleo-Environments & Basin Evolution Symposium*** | ***New Frontiers & General Earth Science #3*** |
| 09:00 – 09:15 | **Berryman -** Progress towards deciphering a c. 7kyr record of surface ruptures on the Alpine Fault | **Nodder -** Temporal variability in organic and inorganic carbon vertical flux to the deep ocean, and implications for paleoceanographic reconstructions | **Herzer -** Seafloor spreading in the Tertiary backarc basins north of New Zealand - new results |
| 09:15 – 09:30 | **Cochran -** Linking an off-fault paleoenvironmental record to surface-rupturing earthquakes on the Alpine Fault | **Troup*** **-** Sedimentology and petrology of Miocene cold-seep carbonates in southern Hawke's Bay: Geological evidence for past sea-bed hydrocarbon seepage | **Leonard -** Episodic, shifting volcanism and rifting in central Taupo Volcanic Zone: results from QMAP Rotorua and new geochronology |
| 09:30 – 09:45 | **Norris -** Fluid evolution during uplift of schist in the hanging wall of the Alpine Fault: evidence from oxygen isotopes | **Naish -** The stability of the Antarctic ice sheets during the early Pliocene climatic optimum | White_P (**Tschritter**) - The Taupo Volcanic Zone in three dimensions |
| 09:45 – 10:00 | **Ninis*** - The Wellington Fault - Holocene displacement and slip rate at Emerald Hill, Wellington | **Kolodziej*** - Reconstruction of sea surface temperatures in the eastern Tasman Sea over the last 480,000 years | **Johnson*** - A high-resolution benchmark of spatial variations in seismic anisotropy around Mount Ruapehu volcano |
| 10:00 – 10:30 | **Refreshments – Oamaru Opera House** | | |
| 10:30 – 10:45 | **Malin –** FΦ | **Hollis -** Ice in the greenhouse: New Zealand's evidence for Antarctic glaciation in the Late Paleocene | **Williams_S*** **-** Numerical models of TVZ with mixed Neumann and Dirichlet boundary conditions |
| 10:45 – 11:00 | **Townend -** States of stress in the crust and at plate boundaries: what do small and large faults feel? | **Figueira*** **-** Preliminary results of salt marsh foraminiferal proxy records of sea-level rise in the South Island, New Zealand | **Kennedy_B -** Torturing volcanic rocks until they tell us everything they know |

| | | | |
|---|---|---|---|
| 11:00 – 11:15 | **Miller -** Fluid-driven aftershocks and controls on Omori decay rates | **Hannah_J -** Mean sea level changes around New Zealand as estimated from JASON 1 and TOPEX altimetry data, and from GPS and tide-gauge time series data | **Kroeger -** 3D heat-flow regimes in the Taranaki Basin |
| 11:15 – 11:30 | **Nuechter -** Dynamic and complex states of stress related to the seismic cycle | **Ohneiser*** - Magnetostratigraphic records, Eocene-Miocene equatorial Pacific, IODP321-322 | **Nicol -** History of the Marlborough Sounds during the last 5 million years |
| 11:30 – 11:45 | **Savage -** Automatic shear wave splitting, with application to time-varying stress | **Lilly –** Defining past volume of grounded ice in the Ross Sea | **Marx_R*** - Late Miocene volcaniclastic deposits at Kaiaua Bay and Marau Point, East Coast Basin |
| 11:45 – 12:00 | **McSaveney -** The answer is "elastic-strain energy", but what are the questions? | **Barrett** - NZ geosciences contribution to 5th IPCC Assessment Report | **Duffy*** - Indonesian geodynamics and paleoceanography revealed in an exhumed Pliocene forearc basin, Timor Leste |
| 12:00 – 13:00 | **LUNCH - Kingsgate Hotel Brydone** | | |
| 12:15 – 13:00 | Lunchtime Meeting: Fossil Record File Subcommittee - THE CHAMBERS | | Lunchtime Meeting: Deep Fault Drilling Project - EMPIRE ROOM |
| | **AUDITORIUM** | **INKBOX** | **EMPIRE** |
| | ***Deformation & Fluid Flow Symposium*** | ***Paleo-Environments & Basin Evolution Symposium*** | ***Fiordland #1*** |
| 13:00 – 13:15 | **Sibson -** Coupled VMS/lode-gold mineralizing scenarios associated with intra-arc compressional inversion in NE Honshu, Japan | **Lee -** A window into Early Miocene New Zealand: a progress report on research on the Foulden Maar | **Allibone -** The Median Batholith in southern New Zealand after QMAP |
| 13:15 – 13:30 | **Poulson -** Gold "breaks": Southern Abitibi Greenstone Belt, Canada | **Ryan*** - A 210 ka terrestrial palynomorph record from a marine sediment core, West Coast, South Island | **Jongens -** Ross-Delamerian Orogen in Fiordland revisited |
| 13:30 – 13:45 | **Wilson_C -** Fault control on gold mineralisation in the central Victorian portion of the Lachlan fold belt, Australia | **Bland_K -** An allostratigraphic framework for the Cretaceous-Recent fill of Taranaki Basin: insights from the Kupe area | **Tulloch** - Autochthonous inheritance of zircon in the Arthur River Complex, Fiordland, New Zealand |
| 13:45 – 14:00 | **Barker -** Variations in fluid flow pathways and fluid pressures during crustal shortening: examples from the Taemas Vein Swarm, NSW, Australia | **Fohrmann -** Intra basinal erosion through time: the 4D Taranaki Project | **Milan -** Complexity of U-Pb-Hf isotope patterns in zircon during arc magma genesis: evidence from a high-P, Cretaceous granulite / eclogite facies arc root, Fiordland, New Zealand |

| | | | |
|---|---|---|---|
| 14:00 – 14:15 | **Nuriel*** **-** Timing and mechanism of calcite-filled vein formation in a contractional strike-slip setting, the Dead Sea Fault | **Baur*** - From source to sink: visualization of a west-flowing Miocene slope channel mega-system, Taranaki Basin | **Cooper -** Arc magmatism on the Gondwana margin: Borland Road, Southland |
| 14:15 – 14:30 | **Ilg -** Relationships between normal faults and gas migration in South Taranaki, New Zealand | **Lindqvist -** Puysegur Group deepwater lacustrine turbiditic facies, southwest Fiordland: evidence of hyperpycnal flow processes & implications for the preservation of organic matter in New Zealand mid-Cretaceous rift basins | **Daczko -** Metastable persistence of pelitic assemblages during high-P granulite facies metamorphism of intermediate-mafic orthogneiss, Fiordland, New Zealand |
| 14:30 – 14:45 | **Gale -** Natural fractures in shales: timing, mechanisms of formation, and relevance for shale-gas reservoirs | **Ghisetti -** Modulation of the Westland foredeep through ongoing compressional inversion | **De Paoli*** - The eclogite - granulite transition: mafic and intermediate assemblages at Breaksea Sound, Fiordland |
| 14:45 – 15:00 | Weinberger (**Mortimer**) - Formation of systematic joints in metamorphic rocks due to release of Cretaceous residual strain, Otago Schist, New Zealand | **Jones -** A tool for creating an interactive chronostratigraphic framework | **Powell -** Metamorphism and deformation in southern Fiordland: correlation with northern and eastern Fiordland |
| 15:00 – 17:00 | **KINGSGATE HOTEL BRYDONE** | | |
| | **POSTERS** | | |
| | ***FIORDLAND SYMPOSIUM*** | ***PALEO-ENVIRONMENTS & BASIN EVOLUTION SYMPOSIUM*** | ***APPLIED GEOSCIENCE SYMPOSIUM*** |
| | ***SEISMOTECTONICS SYMPOSIUM*** | ***NEW ZEALAND BIOTA SYMPOSIUM*** | |
| 19:00 | **CONFERENCE DINNER - The Barrel House, NZ Malt Whisky Co., 14-16 Harbour St., Oamaru** | | |

# Conference Programme for Friday 27 November

| | | | |
|---|---|---|---|
| 07:30 | **Registration open, Oamaru Opera House** | | |
| | **AUDITORIUM** | | |
| 08:15 – 08:30 | NOTICES | | |
| 08:30 – 09:00 | PLENARY - **Bruce Hayward**: Natural experiments in the dispersal and evolution of deep sea biota following the Messinian extinction in the Mediterranean Sea | | |
| | **AUDITORIUM** | **INKBOX** | **EMPIRE** |
| | ***Fiordland #2*** | ***New Zealand Biota Symposium*** | ***Applied Geoscience Symposium*** |
| 09:00 – 09:15 | **Richards*** - U-Pb ages of detrital zircon from Eocene-Oligocene sediments in Te Anau Basin and provenance implications | **Stein*** - A subtropical biota from a Late Oligocene rocky shore, Waimumu, Southland | **Onacha -** Do earthquakes generate electromagnetic signals? |
| 09:15 – 09:30 | **Sutherland -** Exhumation history of Fiordland, southwest New Zealand, during subduction initiation, with implications for thermochronologic analysis strategies | **Marx_F*** - Climate, critters and cetaceans - Cenozoic drivers of the evolution of modern whales | Rhodes (**Van Dissen**) - It's Our Fault: re-evaluation of Wellington Fault conditional probability of rupture |
| 09:30 – 09:45 | **Upton -** Upper crustal hydraulic conductivity between Lake Manapouri and Doubtful Sound, Fiordland | **Fordyce -** New Zealand shark-toothed dolphins (Family Squalodontidae) | **Semmens* -** It's Our Fault: geological and geotechnical characterisation of the Wellington central commercial area |
| 09:45 – 10:00 | Davies (**Dykstra**) - The evolution of Milford Sound - a temperate fiord on a transform plate boundary | **Thomas*** - Evolution of the humeral plexus in penguins | **Grenfell -** Holocene evolution of the tectonically-active Wairau coastal area |
| 10:00 – 10:30 | **Refreshments – Oamaru Opera House** | | |
| | ***Seismotectonics Symposium*** | ***New Zealand Biota Symposium*** | ***Applied Geoscience Symposium*** |
| 10:30 – 10:45 | **Langridge -** Late Holocene paleoseismicity of the Alpine Fault at the Toaroha River, West Coast: preliminary results | **Scofield -** Rapid somatic expansion causes the brain to lag behind: the case of the brain and behaviour of New Zealand's Haast's Eagle (*Harpagornis moorei*) | Mogren (**Al-Jasser**) - Detailed environmental and geophysical study of Wadi Hanifah in central Saudi Arabia |

| | | | |
|---|---|---|---|
| 10:45 – 11:00 | Herman (**Cox_SC**) - Low-temperature thermochronology and thermo-kinematic modeling of deformation, exhumation and development of topography in the central Southern Alps, New Zealand | **Tennyson -** The Miocene St Bathans fauna: an update | **Pillans -** The Gravestone Project - weathering rates from the dead |
| 11:00 – 11:15 | **Dougherty -** Paleoseismic insight gained by augmenting LiDAR with GPR | **Kaulfuss*** - A preliminary account of the fossil arthropod fauna and insect-plant relationships in the Foulden Maar (Early Miocene, Otago) | **Orpin –** Resource evaluation, exploration and current prospecting interests of West Coast ironsands, North Island, New Zealand |
| 11:15 – 11:30 | **Carne*** - Development of deformational bulges along the active strike-slip Wairarapa Fault, New Zealand | **Homes -** Preliminary review of Late Cretaceous and Cenozoic fern macrofossils from South Island, New Zealand | **Reid_N* -** Downstream variation in mineralogy of bedload sediment, Taieri River: an application of quantitative XRD |
| 11:30 – 11:45 | **Bell -** Hikurangi Margin tsunami earthquake generated by slip over a subducted seamount | **Maciunas*** - *Phormium* and *Asteliaceae* macrofossils from New Zealand: using leaf cuticular details to determine phylogenetic affinities | **McCann*** - Gold and platinum deformation, aeolian deformation and toroid development in beach placer deposits, Southland |
| 11:45 – 12:00 | **Reyners -** Putting earthquakes in their (right) place: new insights into seismotectonics of the South Island | **Conran -** A review of the New Zealand macrofossil monocot flora | **Craw -** Mineralogy and geochemistry of antimony at Reefton and Macraes gold mines, South Island, New Zealand |
| 12:00 – 13:00 | **LUNCH - Kingsgate Hotel Brydone** | | |
| | **AUDITORIUM** | **INKBOX** | **EMPIRE** |
| | ***Seismotectonics Symposium*** | ***New Zealand Biota Symposium*** | ***New Frontiers & General Earth Science #4*** |
| 13:00 – 13:15 | **Fry -** A multiple-discipline approach to understanding the Mw=7.6 Dusky Sound earthquake of 2009 | **Bannister -** A review of the flora of the Foulden Diatomite | **Crowley*** - Explosive volcanism in the Chatham Islands: origin of the Rangiauria Breccia |
| 13:15 – 13:30 | **Power -** The Fiordland 2009 tsunami: observations and interpretation | **Mildenhall -** Newvale Mine, seam W6 - palynomorphs from a tree-fall depression in a Late Oligocene-Early Miocene autochthonous swamp forest, southern New Zealand | **Hikuroa -** Realising New Zealand's energy potential: a kaitiaki approach to geothermal development |
| 13:30 – 13:45 | **Beavan -** Coseismic and early postseismic slip distribution of the 15 July 2009 Dusky Sound earthquake | **Jordan -** Conifers: once and future kings? | **Kayani -** Identifying a meteorite ablation debris near village Lehri in Potohar region of Pakistan |

| | | | |
|---|---|---|---|
| 13:45 – 14:00 | unassigned | **Carpenter -** New and remarkable Proteaceae leaf fossils from southern New Zealand | **Skinner -** A strange occurrence of pyrite-coated granitic cobbles at Lee Bay on Stewart Island |
| 14:00 – 14:15 | **AUDITORIUM - CLOSING CEREMONIES** | | |

## CONFERENCE POSTERS LISTED BY SYMPOSIUM & BOARD NUMBER

***Symposium 1: Geological and geophysical signatures of earth deformation and fluid flow***

| | |
|---|---|
| Tu02 | **Caldwell** - Conductivity structure of the Ohaaki geothermal system: insights from magnetotelluric measurements |
| Tu04 | **Crispini** - Gold-bearing veins in Northern Victoria Land (Antarctica): structure, hydrothermal alteration and implications for the paleo-Pacific margin of Gondwana |
| Tu06 | **Little** - How were the world's youngest eclogites (D'Entrecasteaux Islands, Papua New Guinea) exhumed? |
| Tu05 | **Mountjoy** - Relationship between out-of-sequence upper plate thrust faulting and interplate coupling on the central Hikurangi margin |
| Tu03 | **Rowland** - The Coromandel to Taupo Volcanic Zone transition: quasi-predictable structural control on ascending hot water |
| Tu01 | **Seward** - P-wave travel time residuals across the western North Island: implications for variations in thickness of the mantle lithosphere |

***Symposium 2: Paleo-environments & basin evolution***

| | |
|---|---|
| Th22 | **Arthur*** - Sedimentation in the Waicoe Formation (Middle Miocene, Southland): local tectonics or orbital cycles? |
| Th19 | **Doughty*** - Using computer models to quantify New Zealand glacier fluctuations over the past 13,000 years |
| Th25 | **Fox*** - A Miocene terrestrial sediment core from Foulden Maar, Otago |
| Th18 | **Fraser*** - The extent of ice on Campbell Island at the Last Glacial Maximum |
| Th20 | **Hannah_M** - Palynomorphs recovered from the ANDRILL SMS sediment cores provide first proximal environmental characterization of the Middle Miocene climatic optimum |
| Th23 | **Hicks*** - Ecological and sedimentological evolution of the volcanically active Eocene-Oligocene continental shelf, northeast Otago, New Zealand |
| Th28 | **King*** - Paleomagnetic environmental record of MD152-2991 core, offshore West Coast South Island, New Zealand |
| Th30 | **Lennon*** - Geophysical investigation of shallow basin-margin structures east and west of Stewart Island |
| Th27 | **Lurcock*** - A palaeomagnetic study of the Fairfield Quarry section, Otago |
| Th29 | **Nelson*** - Magnetite grain-size trends, Challenger Plateau, New Zealand |
| Th21 | **Sabaa** - Causes of evolution and extinction of deep-sea benthic foraminifera in the Indian Ocean |
| Th24 | **Samuel*** - Depositional history of Paleogene strata in the Canterbury Basin |
| Th26 | Tinto (**Dagg**)* - The Marshall Paraconformity in the Tengawai-1 drillcore, South Canterbury: erosion and deposition associated with early development of the Antarctic Circumpolar Current |
| Th31 | **Wilson** - Use of gravity data to characterise geological structures beneath the sea floor, New Harbour, Antarctica |

***Symposium 3: Magmatism & volcanic hazards***

| | |
|---|---|
| Tu08 | Al-Damegh (**Mogren**) - Geophysical investigations on the active Al-Ais area of Saudi Arabia |
| Tu17 | **Ashwell*** - Playing Vulcan: re-creating the subterranean conditions that spawn rocks |
| Tu20 | Auer (**White_J**) - Sedimentary response to debris avalanche & eruption - stream-plain deposits on the slopes of Mt. Ruapehu |
| Tu26 | **Baines*** - Miocene detrital zircon megacrysts from East Otago |
| Tu09 | **Bennie** - Magnetotelluric imaging of the Tongariro volcanic system, New Zealand: preliminary results |
| Tu13 | **Brenna*** - Evolution of a monogenetic basaltic magma batch: comparison of Crater Hill, Auckland Volcanic Field and Udo tuff cone, Jeju Island, South Korea |
| Tu10 | **Hill** - Structure of the Mount St. Helens magmatic system: insights from magnetotelluric imaging |
| Tu21 | **Gorny*** - Snaebylisheidi, Iceland: lava-hyaloclastite sheet of a voluminous subglacial eruption |
| Tu23 | **Kilgour** - Magma residence beneath Mt Ngauruhoe from fluid inclusions |
| Tu12 | **Le Corvec*** - Structural controls on monogenetic basaltic volcanism |
| Tu19 | **Lube** - Capturing the secrets of a lahar wave |
| Tu15 | **May*** - The Rotomahana eruption of 1886: a basaltic fissure eruption through an intensely active geothermal system |
| Tu22 | **Mazot** - Gas geochemistry of New Zealand volcanoes: previous work and future perspectives |
| Tu16 | **Pardo*** - Plinian to subplinian eruptions of andesitic volcanoes: from lithofacies to eruption dynamics |
| Tu18 | **Phillips*** - Forecasting the consequences of the failure of the eastern rim of Crater Lake, Mt Ruapehu - a research outline |
| Tu11 | **Smid** - DEVORA: Year 1 of determining volcanic risk in Auckland |
| Tu14 | **Sorrentino*** - Quantifying vesicularity on semi-consolidated and altered Paleogene surtseyan deposits, Chatham Islands, New Zealand |
| Tu24 | **Turnbull_R*** - Construction and evolution of a mafic-felsic magma chamber: an example from Stewart Island |

***Symposium 4: Fiordland revealed***

| | |
|---|---|
| Th03 | **Sagar*** - High-grade gneisses & granitoids of the Glenroy & Granite Hill complexes, West Coast region |
| Th02 | **Smillie*** - Provenance of quartz-rich sandstones in the Cenozoic basins of Western Southland |
| Th01 | **Turnbull_I** - QMAP Fiordland |

***Symposium 5: Seismotectonics  of southern New Zealand***

| | |
|---|---|
| Th08 | **Bassett_D*** - 3-D velocity structure of the northern Hikurangi margin: implications for crustal growth |
| Th05 | **Bland_L** - Scientific response to the Dusky Sound earthquake, July 15th 2009 |
| Th10 | **Boese* -** Microseismicity in the central Southern Alps |
| Th15 | **Boulton* -** Creating coseismic fault rocks |
| Th13 | **Bruce*** - Characterisation of an active offshore coast-parallel fault system on the shallow southeast continental shelf of the South Island, New Zealand |
| Th11 | Cox_SC (**Strong**) - Insights to crustal fluid-flow near the Alpine Fault: monitoring experiments at Copland warm spring |
| Th14 | **Curran* -** Investigating Trotter's Gorge and offshore Shag Point: understanding the Waihemo Fault |
| Th12 | **Davey -** Crustal seismic reflection profile across the Alpine Fault and coastal plain at Whataroa, South Island |
| Th16 | **Easterbrook* -** The Alpine Fault Zone along the Waitangi-taona River: mapping in 3D and AMS in fault gouge |
| Th09 | **Ellis -** Short-term interactions between strike-slip faults across a plate boundary zone at the transition from subduction to collision: comparison to the Marlborough Fault System, New Zealand |
| Th07 | **Karalliyadda*** - Deformation mechanisms in the South Island: implications from shear-wave splitting of local S waves |
| Th06 | **Ristau** - Three years of regional moment tensor analysis in New Zealand |

***Symposium 6: New frontiers & general earth science***

| | |
|---|---|
| Tu35 | **Bassett_K -** Provenance of the Devonian Taylor Group, Lower Beacon Supergroup, Antarctica |
| Tu29 | **Begg** - QMAP Rotorua - what's new besides volcanoes? |
| Tu46 | **Behr* -** Love and Rayleigh wave phase velocity maps of New Zealand obtained via cross-correlation of ambient seismic noise: updated national models and preliminary estimates of radial anisotropy |
| Tu44 | **Bilderback* -** The role of deep-seated landslides in the evolution of the Waipaoa sedimentary system |
| Tu36 | **Black -** Bathymetry of the Ross Sea and adjacent Southern Ocean |
| Tu37 | **Chambord*** - Position of New Zealand, Australia and Antarctica during the Paleogene and Late Cretaceous |
| Tu30 | **Heron -** The QMAP 1:250 000 Geological Map of New Zealand |
| Tu39 | **Jacobs* -** Temporal evolution of earthquake sequences (swarms) in the Central Volcanic Region |

| | |
|---|---|
| Tu31 | **Lukovic** - A seamless 1:250 000 geological dataset |
| Tu33 | **Pledger*** - Structure, faulting and gas accumulation, southeast Wanganui Basin, New Zealand |
| Tu34 | **Sadaf*** - Characterisation of the Waipawa Formation, East Coast Basin, New Zealand |
| Tu45 | **Syuhada*** - Seismic attenuation anisotropy in the southern part of Taupo Volcanic Zone |
| Tu48 | **Tenzer** - A compilation of the detailed map of atmospheric correction to observed gravity (case study for New Zealand) |
| Tu28 | Tonkin (**Barrell**) - A geomorphic history of the Lower Waitaki Plain, interpreted from loess and soil stratigraphy |
| Tu32 | **Townsend** - The QMAP 1:250 000 geological map of the Hawke's Bay area: new features and updates |
| Tu47 | **Unglert*** - Crustal cracks in areas of active deformation: correlation of GPS and seismic anisotropy |
| Tu41 | **Wang** - Slow rupture of the March 1947 Gisborne earthquake suggested by tsunami modelling |
| Tu43 | **Welch** – Evaluating tsunami threats |
| Tu40 | **Williams_C** - The effects of material inhomogeneity and topography on the predicted surface deformation for Hikurangi slow slip events |
| Tu38 | **Wysoczanski** - Morphology and structure of the southern Kermadec Arc - Havre Trough |

***Symposium 7: Applied geoscience***

| | |
|---|---|
| Th43 | **Ashenden** - GeoNet hazard monitoring - the continuous GPS and seismic networks |
| Th47 | **Cross*** - Greenhills Complex dunite: mineralogy, geochemistry and potential for carbon sequestration |
| Th44 | **Dykes*** - Seismic detection of iceberg calving at Tasman Glacier, New Zealand |
| Th45 | **Forsyth** - Planning on a retreating coastline: Oamaru, North Otago, New Zealand |
| Th46 | **Johansen** - Groundwater potential of the Te Onepu Limestone, central Hawke’s Bay - an unconventional source |
| Th42 | **Page** - GeoNet: monitoring New Zealand's natural hazards |

***Symposium 8: Origin of New Zealand biota***

| | |
|---|---|
| Th34 | **Beu*** - Castlecliffian-Haweran marine molluscan biostratigraphy and climate change at the MIS scale at Wanganui |
| Th35 | **Collins*** - Preliminary stratocladistic study of New Zealand crassatellid bivalves |
| Th36 | **Hiller** - Brachiopods from the *Ostrea* bed (Broken River Formation), Upper Cretaceous of North Canterbury |

| | |
|---|---|
| Th37 | **Kennedy_E** - New Zealand's floral origins and the Oligocene land crisis: a work in progress |
| Th40 | Morrison (**Simes**) - National Paleontological Databases programme achievements |
| Th39 | **Ortega*** - Early Miocene dolphins from Awamoa Beach, North Otago |
| Th38 | **Reid_C** - Following in Darwin's footsteps in Van Diemen's Land |
| Th41 | Simes (**Terezow**) - The National Paleontological Collection - a virtual tour |
| Th33 | **Van Kerckhoven*** - Paleocene-Eocene evolution of deep-sea benthic foraminifera |

**ABSTRACTS**

in alphabetical order by first author

The bibliographic reference for abstracts is:

Author, A.N. (2009). Title of abstract. *In*: Barrell, D.J.A., Tulloch, A.J. (eds.). Programme and abstracts, Geosciences 09 Conference, Oamaru, New Zealand. Geological Society of New Zealand Miscellaneous Publication 128A: p.x

**MIND THE GAP: INVESTIGATING SOME APPARENT STRATIGRAPHIC BREAKS IN PERMIAN, TRIASSIC AND JURASSIC SUCCESSIONS OF THE TORLESSE AND WAIPAPA TERRANES USING DETRITAL ZIRCON AGES**

**C.J. Adams[1] & H.J. Campbell[2]**
[1]GNS Science, Private Bag 1930, Dunedin
[2]GNS Science, PO Box 30368, Lower Hutt
argon@gns.cri.nz

Fossils are sparse and often poorly-preserved and not time-diagnostic throughout the terrigeneous clastic sedimentary successions of the Torlesse and Waipapa terranes. However, despite a long history of geological mapping throughout these terranes, there still appear to be several stratigraphic breaks: in the Early Permian, Early Triassic and Middle-Early Jurassic in the Torlesse Composite Terrane, and in the Early-Middle Jurassic in the Waipapa Terrane.

Using K-Ar and Rb-Sr metamorphic ages to provide a minimum stratigraphic age for Torlesse and Waipapa metasediments, and detrital zircon ages in greywackes to provide age maxima, several large tracts of unfossiliferous rocks in central North Island and North Canterbury fall in the time interval Middle-Early Jurassic. This is termed the Kaweka Terrane and the greywacke zircon age patterns are characteristic of the Torlesse Terrane.

A large area in the lower-grade part of the Marlborough Schists in the eastern Marlborough Sounds are also probably Middle-Early Jurassic in age, but have a detrital zircon age patterns that are more characteristic of the Waipapa Terrane.

In East Otago, unfossiliferous metasediments adjacent to the Otago Schists, and close to a Late Carboniferous limestone unit, have detrital zircon age patterns that indicate possible maximum late Early Permian ages in greywackes above, and younger, Early Triassic ages in greywackes below this unit.

It is therefore concluded that the Torlesse and Waipapa Terranes contain more continuous Permian-Cretaceous sedimentary successions than previously thought.

**GEOPHYSICAL INVESTIGATIONS ON THE ACTIVE AL-AIS AREA OF SAUDI ARABIA**

**K. Al-Damegh[1] & S. Mogren[2]**
[1]KACST, Riyadh, Saudi Arabia.
[2]King Saud University, College of Sciences, Geology & Geophysics Department, PO Box 2455,Riyadh 11451, Saudi Arabia
smogren@ksu.edu.sa

Al-Ais is part of the Cenozoic Harrat of western Saudi Arabia which is one of the largest basaltic provinces in the world. It is located in Al-Madinah region west of Saudi Arabia and has experienced unusual seismic activities during the past few months. The activity started in early April, 2009 with a series of micro earthquakes that later culminated in a larger event in May with a magnitude of 5.7. This earthquake occurred at an epicenter: 25.34 North, 37.78 East, and had a focal depth of about 3 km. This event, by far, was the largest ever recorded event within Saudi Arabia. It was followed by few sizeable aftershocks and thousands of smaller than 3 events. Within a radius of about 150 km of the May 19 epicenter and according to the local seismic networks as well as the USGS, only 15 earthquakes with magnitudes ranging from mb = 4.1 – 5.4 have occurred since 1979 till April. This provides an idea on the level of the current activity. Off course the instrumental records are available only for the last 30 years or so; consequently, it is difficult to anticipate the long-term seismic status.

A local network of 15 portable broadband short period seismic stations was deployed around the activity region. The earthquake activity northwest of Al-Madinah occurs in the volcanic province of the Arabian shield that is regarded as one of the largest igneous provinces in continental regions of the world. This volcanism is believed to be an outcome of spreading activity under the Red Sea, as a result of which, the Arabian plate moves north-northeast. Localized volcanic activity in Al-Madinah region is also reported from historical records, when the Holocene lava flows erupted in “Harrat Lunayyir” about 1000 years ago. Whether it is related to regional tectonic processes that activated a local magma, or purely a local magma movement, the region is still active and people living there are concerned. Based on available gravity, magnetic and the seismicity data, precise 3D subsurface models were constructed for the volcanic magma showing detailed geological structures under the active Al-Ais volcanic region.

# THE MEDIAN BATHOLITH IN SOUTHERN NEW ZEALAND

**A.H. Allibone[1], I.M. Turnbull[2], R. Jongens[2], A.J. Tulloch[2]**
[1]Rodinian, PO Box 1970, Queanbeyan, NSW2620, Australia
[2] GNS Science, Private Bag 1930, Dunedin
rodinian@msn.com

A key contribution of the now complete QMAP geological mapping program is a much improved understanding of the Median Batholith in Fiordland and Stewart Island. The batholith in these areas comprises more than 100 larger plutons and numerous smaller intrusions emplaced during the Cambro-Ordovician (c. 500 Ma), Devonian-Carboniferous (c. 375-305 Ma), and Triassic-Early Cretaceous (c. 230-105 Ma). The batholith straddles the boundary between the NZ Western and Eastern Provinces. Western (inboard) parts of the batholith intrude Western Province metasedimentary rocks whereas eastern (outboard) parts occupy the area between the Eastern and Western Provinces. Cambro-Ordovician rocks in western and central Fiordland are the oldest plutonic rocks in the Median Batholith.

Plutons intruded between c. 375-305 Ma include at least six suites of S, I and A-type plutonic rocks. S-type granitoids are confined to the inboard part of the batholith, whereas A and I-type rocks of the same age extend into the outboard part. Correlatives of the c. 370-368 Ma S-type Karamea Suite in Nelson and Buller are absent from the southern part of the batholith, although younger plutons with a similar chemistry were emplaced in westernmost Fiordland at c. 350 Ma.

Mesozoic parts of the Median Batholith include the LoSY Darran Suite (c. 230-125 Ma), I/A-type alkaline syenogranites in eastern Fiordland (c. 161-130 Ma), HiSY Separation Point Suite and Western Fiordland Orthogneiss (c. 125-105 Ma), and granitic rocks in SW Fiordland similar to the Rahu Suite north of the Alpine Fault (c. 130-118 Ma). Darran and Separation Point Suite plutons occur in both the eastern and western parts of the batholith. Plutons of the Western Fiordland Orthogneiss (WFO) are restricted to the inboard part of the batholith. The location and polarity of subduction zone(s) related to Mesozoic plutonism remain unclear.

Individual plutons and belts of related plutons generally trend N-NNE throughout Fiordland, regardless of their age and chemistry. This persistent preferred orientation is the most prominent structural feature of the Fiordland basement. Ductile fabric development and amphibolite, granulite, or eclogite facies metamorphism affected parts of the batholith between c.123-100 Ma. The boundary between inboard and outboard parts of the batholith west of Lake Te Anau is marked by intrusive contacts between the Lake Hankinson Complex (inboard), Lake Roxburgh Tonalite (outboard) and Murchison Intrusives (Outboard), implying an autochthonous relationship between the two parts of the batholith. A westward, gradational increase in metamorphic grade within the plutonic rocks also characterises this contact. Early Cretaceous shear zones near the inboard/outboard boundary elsewhere in Fiordland and Stewart Island are large intra-arc transpressional faults. To date no ultramafic rocks which might be the remnants of a closed oceanic basin have been found anywhere along these faults.

**SEDIMENTATION IN THE WAICOE FORMATION (MIDDLE MIOCENE, SOUTHLAND): LOCAL TECTONICS OR ORBITAL CYCLES?**

**K.L. Arthur**
Dept. of Geology, University of Otago, PO Box 56, Dunedin
kristina.arthur@yahoo.co.nz

The Waicoe Formation is a ubiquitous mudstone member of the Waiau Group in the Waiau and Te Anau Basins, western Southland, New Zealand. Dominated by a massive, variably calcareous, grey, hemipelagic mudstone, the Waicoe Formation formed as the "background" sedimentation of the basins through the middle Miocene (12 – 16 Ma). A relatively high and uniform sedimentation rate of approximately 20-25 cm/kyr allows for detailed high resolution studies through the unit, particularly in unbroken sections such as the Bryce Burn, the area of interest for this project.

The Waiau Basin is a fault-bounded basin which developed under close influence of the developing Alpine Fault and the adjacent Moonlight Fault System to the west. Published work on sediments and associated fossils suggests that the Waicoe Formation was deposited in a semi-enclosed neritic environment. The Waicoe Formation is predominately mudstone, suggesting a distal or low energy environment. Of note, Norris et al. (1978) suggested displacement along the Moonlight Fault caused mass-flow of coarser sediments closer to the sedimentary source in the basin. Further, thickness of up to ~3 km indicates substantial input of terrigenous material.

Macrofossils are scarce in the section, and unrevealing about depositional settings, but foraminifera have proven useful in past studies of basin history. The data set collected for this project includes 122 samples from the Bryce Burn at a stratigraphic interval of ~1 m (~4 ka). The foraminiferal assemblages - with a large proportion of benthic foraminifera and either juvenile or generally small-sized planktic foraminifera - support the notion of an enclosed basin. Some samples are calcareous and well-preserved, but others are pyritic, suggesting anoxic bottom conditions. The assemblages also indicate a warm water influence, leading Field et al. (2002) to suggest that Tasman Sea currents may have affected the Southland basins.

Foraminiferal results (census counts, stage determinations) are being integrated with sedimentological, paleomagnetic and isotopic data to determine whether local tectonic signals, ice-volume signals, orbital variation, or a combination of these, can be recognised as the driver of variations within the data set across the middle Miocene climatic shift.

Field, B.D., et al. (2002). The early Middle Miocene paleoenvironmental setting of New Zealand. Revista Mexicana de Ciencias Geologicas, 19 (3), 242-251.

Norris, R.J., et al. (1978). Cainozoic sedimentation in basins adjacent to a major continental transform boundary in southern New Zealand. Journal of the Geological Society, 135 (2), 191-205.

## GEONET HAZARD MONITORING - THE CONTINUOUS GPS AND SEISMIC NETWORKS

**Caroline Ashenden & GeoNet team**
GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand
c.ashenden@gns.cri.nz

The GeoNet project was established by GNS Science in 2001 enabling real-time monitoring and data collection of earthquake, volcano, landslide, and tsunami hazard events in New Zealand. The majority of the network consists of continuous GPS (cGPS) and seismograph stations distributed around New Zealand, with GNS currently managing 127 cGPS monuments and 146 continuously recording seismic stations. The planned expansion of the network for this year includes another 20 cGPS monuments and 18 seismic stations.

The GeoNet monitoring network covers all of New Zealand including installations on Raoul and Chatham Islands, with more focused monitoring at the surface expression of the Hikurangi subduction margin as well as the Taupo Volcanic Zone, Mt Taranaki, and the Auckland Volcanic Field. All data are transmitted in real-time to GNS Science for analysis. If an event is likely to result in damage to people or infrastructure, the Ministry of Civil Defence and Emergency Response is notified and in tern will instigate an emergency response.

Much of the data collected by the GeoNet project is available online (geonet.org.nz) for public use. This data facilitates a variety of research leading to a greater understanding and mitigation of geological hazards. Data from the seismic and cGPS networks complement each other as they express different types of plate movement. Seismic data show plate movement due to earthquakes, whereas cGPS data are used to identify coseismic and post-seismic movements associated with earthquakes, and aseismic slow slip events. These ‘silent’ events can be used to model the build up or release of stresses on faults.

## PLAYING VULCAN: RE-CREATING THE SUBTERRANEAN CONDITIONS THAT SPAWN ROCKS

**P.A. Ashwell[1], B. Kennedy[1], F. von Aulock[1], K. Buchanan[2], D. Drabble[2] & J. Cole[1]**
[1]Department of Geological Sciences, UoC, Private Bag 4800, Christchurch 8140
[2]Department of Mechanical Engineering, UoC, Private Bag 4800, Christchurch 8140
paa37@student.canterbury.ac.nz

The design and creation of a new high pressure hydrothermal vessel for the analysis of porosity and permeability at volcanic temperatures and pressures of up to 1000$^o$C and up to 100MPa is currently underway at the University Of Canterbury, Christchurch. The improved design now includes the ability to facilitate experimentation on pre-existing cm-scale bubbles and crystals. As well as having full manual control over the pressure and temperature environment inside the sample chamber, the apparatus will include regulatory systems that allow sample induced changes in temperature and pressure to be measured (such as latent heat production during decompression driven crystallisation). The medium used for pressurization will be an isotopically tainted water vapour, allowing us to distinguish between the vapour and water already dissolved in the sample. The apparatus will also incorporate an adapted acoustic monitoring system, which will be used to detect real time crack formation associated with bubble growth.

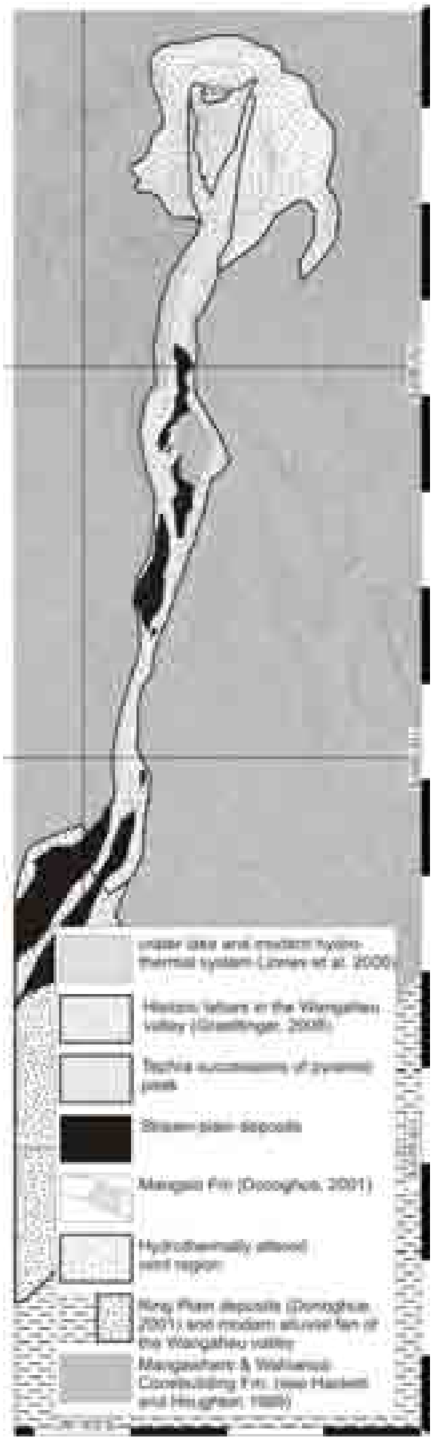
The project will focus on samples taken from Ngongotaha Dome and Tarawera Dome near Rotorua, the Te Herenga Formation on Ruapehu, and deposits from the 1665AD eruption of Taranaki. The experimental work will be compared to field insights into porous and permeable layers within the dome systems as well as field density measurements. The field work will allow GIS models of porous and permeable areas in the domes to be created which will also include faults and fractures that might have facilitated fluid and gas flow.

This research hypothesizes that: 1) The solubility of water at low temperatures (<700$^o$C) and pressures (<100MPa) has been underestimated by previous empirical models; 2) Associations between permeability, porosity and volatile content in samples from conduits, plugs and domes can be explained by crack development and healing, and bubble growth and collapse; 3) Microlite crystallization will induce latent heat increases in the range of 100$^o$C and pressure increases of 0 – 5MPa when the sample is allowed to decompress.

## SEDIMENTARY RESPONSE TO DEBRIS AVALANCHE & ERUPTION – STREAM-PLAIN DEPOSITS ON THE SLOPES OF MT. RUAPEHU

**A.Auer[1], J.D.L. White[1], V.Manville[2]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]School of Earth and Environment, University of Leeds
james.white@otago.ac.nz

Mt Ruapehu is the southernmost active volcano in the central North Island, and a source of multiple volcanic hazards. Here we investigate the sedimentary response to the volcano's last debris avalanche ca. 4600 years ago (Donoghue, 2001) and an accompanying eruption in the Whangaehu valley on the eastern side of the mountain. The preserved record comprises up to 30 m of thinly bedded volcaniclastic deposits that are notably finer-grained and better sorted than most lahar deposits in the valley, typically comprising coarse ash or fine lapilli. They are dominated by a single population of fresh vesicular volcanic fragments that are inferred to have been produced by an eruption that followed release of the Mangaio Formation debris avalanche, plus/minus hydrothermal sediment. In the uppermost (preserved) part of the unit, beds show typical characteristics of hyperconcentrated flows. The unit overall was deposited across the full width of the valley floor, and feeds onto the large alluvial fan where the Whangaehu River extends into the Rangipo desert. It is preserved now as large bar-shaped remnants predominantly shielded behind valley-floor topographic obstacles, and is deeply incised by the currently active stream paths. We infer that deposition of this unit was a direct response to the Mangaio debris avalanche and accompanying eruption. This avalanche completely filled up the former stream channels, leaving a broad valley bottom floored by the low-relief surface of the avalanche's extremely clay-rich uppermost flow unit. This broad depositional surface was then inundated by the deposits of unconfined to poorly confined flows and sheetfloods that distributed newly formed debris from the associated eruption in a low relief in-valley fan, which ultimately extended onto the volcano's surrounding ring plain. When the supply of fresh volcaniclastic sediment was expended, the River quickly incised the deposit, returning to the steep and narrow streampath active today.



## MIOCENE DETRITAL ZIRCON MEGACRYSTS FROM EAST OTAGO

**Alun Baines & J. Michael Palin**
Department of Geology, University of Otago, PO Box 56, Dunedin
alunb@slingshot.co.nz

Detrital zircon megacrysts are found in rivers and placer deposits of East Otago. The zircons occur with abundant magnetite, lesser quantities of various spinels, olivine, diopside, kaersutite and in some places gem corundum (sapphire).

Sub- to euhedral detrital zircon megacrysts from the Shag River near Palmerston yield a U-Pb age of 16.7 ± 0.3 Ma as determined by LA-ICP-MS. These zircons have distinctive trace element compositions (low P and Ti, no Eu anomaly) that match those of detrital zircon megacrysts recently reported by Sutherland et al. (2009, NZJGG) from Glenore (near Milton). The Glenore zircons have an age of 19.1 ± 0.2 Ma and are well-rounded. Both zircon ages fall with the range for alkaline basalts of the Dunedin Volcanic Group (Coombs et al., 2008 NZJGG).

Detrital zircon megacrysts in association with gem corundum are a rare, but widespread feature of the eastern Australian and Asian continental margins. They are thought to represent xenocryst and xenolith material carried by alkali basaltic magmas to the surface. The well-preserved crystal faces of the Shag River zircons contrast with those of the rounded Glenore zircons and may indicate a more direct petrogenetic relation with their inferred hosts.

## A REVIEW OF THE FLORA OF THE FOULDEN DIATOMITE

**Jennifer Bannister[1], Daphne Lee[2], John Conran[3], Dallas Mildenhall[4]**
[1]Department of Botany, University of Otago, PO Box 56, Dunedin
[2]Department of Geology, University of Otago, PO Box 56, Dunedin
[3]School of Earth & Environmental Sciences, The University of Adelaide, Australia
[4]GNS Science, PO Box 30-368, Lower Hutt
jennifer.bannister@xtra.co.nz

Six years of collecting fossils in the Foulden Diatomite has yielded many hundreds of plant macrofossils including ferns, fungi, conifers, and a wide range of angiosperms. Cuticles have now been prepared for over 550 individual leaves. Many, but not all, can now be assigned to families and genera, although none represent living species. The flora now includes representatives of two fern families, Schizaeaceae and Davalliaceae. Fertile fronds of *Davallia* carry the form spore taxon *Polypodiisporites radiatus*, making it possible to associate the dispersed spores with the foliage. One conifer, a very large-leaved *Podocarpus* is closer to modern Queensland species than to present-day New Zealand species of totara. Leaves of at least seven genera of monocotyledonous plants are present, including the oldest definitive records to date for the Orchidaceae.

The majority of plant fossils are well-preserved individual leaves of dicotyledonous angiosperms. These include representatives of at least 12 families including Araliaceae, Cunoniaceae, Elaeocarpaceae, Euphorbiaceae, Myrsinaceae, Myrtaceae, Proteaceae, Sapindaceae and Sterculiaceae, although the majority of leaves (about 40%) are from several genera and species of Lauraceae. These include *Cryptocarya, Endiandra* and *Litsea*, and confirm that this was a Lauraceae-dominated forest, something not determinable from the pollen record, as Lauraceae pollen are fragile and rarely preserved. No *Nothofagus* leaves have been identified. We now have at least four flowers, including an insect-pollinated species with *in situ* pollen, described as *Fouldenia staminosa* (family uncertain). A male inflorescence with *in situ* pollen of *Nyssapollenites endobalteus* (McIntyre) is provisionally identified as *Mallotus* (Euphorbiaceae). Fruits and seeds are common throughout the diatomite, but many are pyritised or poorly preserved. Large endocarps of Menispermaceae are present, and numerous small seeds and capsules scattered on particular bedding planes probably represent Myrtaceae. Wood-rotting fungi on bark, saprophytic fungi as spores and perithecia within cuticular envelopes, and some epiphyllous fungi are present.

There are still many well-preserved but as yet unidentified plant macrofossils, and a large number of new pollen types are yet to be described. The flora indicates that the maar lake was surrounded locally by a subtropical, seasonally-dry, evergreen forest of trees, shrubs and lianes. Pollen representing several species of *Nothofagus* and podocarps may have rained in from a distance.

# VARIATIONS IN FLUID FLOW PATHWAYS AND FLUID PRESSURES DURING CRUSTAL SHORTENING: EXAMPLES FROM THE TAEMAS VEIN SWARM, NSW, AUSTRALIA

**S.L.L. Barker[1,2]** & **S.F. Cox[1]**
[1]Research School of Earth Sciences, Australian National University, Canberra, ACT
[2]Dept. of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia V6T1Z4, Canada
sbarker@eos.ubc.ca

The Taemas Vein Swarm (TVS) is composed of calcite ± quartz veins, hosted in a series of faults and fractures, which extends over an area of approximately 20 $km^2$ in the Eastern Belt of the Lachlan Orogen, in New South Wales, Australia. The vein swarm is hosted in mid-Devonian interbedded limestones and shales, which are folded into a series of upright, open to close folds, likely deformed during mid-late Devonian crustal shortening. This vein swarm provides an opportunity to explore how fluid flow pathways changed during fold and fault growth.

Crosscutting and overprinting relationships demonstrate that vein growth was synchronous with folding, with different vein types related to different fold mechanisms at various stages of fold growth. Flexural slip folding led to the development of bedding-concordant veins. Flexural flow in semicompetent to incompetent beds caused en echelon extension vein arrays to grow. Decoupling between beds and dilatancy at fold hinges led to significant vein growth. In addition, fold lock-up led to limb-parallel stretching, and the growth of bedding-orthogonal extension fractures. Vein growth is inferred to have occurred in a compressional tectonic regime (i.e. $\sigma_3$=vertical). Oxygen isotope quartz-calcite thermometry suggests that veins formed at temperatures of 100–200 $^{o}$C. The depth of vein formation may have been between about 5 and 8 km.
Vein textures indicate that growth of veins occurred during multiple cycles of permeability enhancement and destruction. Subhorizontal extension fractures, and faults at unfavourable angles for reactivation, imply that fluid pressures exceeded lithostatic levels during the growth of some veins, while coexisting extension and shear fractures imply that differential stress levels varied over time. Flexural slip continued throughout folding at Taemas, despite some fold limbs being at angles extremely unfavourable for reactivation ($\theta > 60^{o}$). As folds approached frictional lock-up, flexural slip continued to occur when supralithostatic fluid pressures were developed. Therefore, large, bedding-discordant faults were not developed to accommodate strain during folding, explaining a deficiency of larger faults in the TVS.

Infiltration of overpressured fluids occurred into the base of the Murrumbidgee Group, and was channelled into a distributed mesh of small faults and fractures. At the point that a connected 'backbone' flow network developed in the TVS, high-pressure fluids would no longer be available to allow continuing flexural slip on fold limbs approaching lockup. Thereafter, larger faults would develop, which would adjust the fault population in the TVS to a more 'typical' displacement-frequency distribution. This had not occurred in the Taemas area by the time crustal shortening ceased. An abundance of small faults, and fracturing driven by invasion of overpressured fluid, implies that the TVS formed via an 'earthquake swarm' process.

## NZ GEOSCIENCES CONTRIBUTION TO 5TH IPCC ASSESSMENT REPORT

**P.J. Barrett**
Antarctic Research Centre and NZ Climate Change Institute, Victoria University of Wellington, PO Box 600, Wellington
peter.barrett@vuw.ac.nz

The IPCC is primarily an organisation of governments to help them address the global problem of climate change collectively and separately. They have done this by developing a process for experts to review the state of knowledge every 5-6 years, and publish the results of these assessments. These comprise reports on 1) the physical basis of climate science, ii) the effects and consequences of changes already observed and iii) the best options for mitigating the effects (essentially ways of reducing greenhouse gas emissions) and for humanity adapting to the future consequences. The most recent assessment in 2007 has included a Synthesis Report (see www.ipcc.ch )

Geosciences barely figured in the first three assessments in 1990, 1995 and 2001, which focussed largely on compilation of recent and historical observational data on climate and its effects and on modelling for making future projections. However in the last two decades huge advances in both chronology and proxy measurements of climate on geological time scales have opened up opportunities for paleoclimate archives to be used to investigate likely drivers of climate change and the consequences of global warming for the physical and biological world. This was recognised in the 4th IPCC Assessment Report in 2007 with its inclusion of a Paleoclimate chapter, though limited largely to late Quaternary archives.

The chapter outlines for the 5th Assessment Report has now been approved. That for Working Group 1 includes a chapter on Paleoclimate Archives along with separate chapters and ice sheets and oceans
(see http://www.ipcc.ch/meetings/session31/doc19.pdf). Research on effects and consequences of change in the polar regions and the world's oceans will also be reviewed separately in the report from Working Group 2
(see http://www.ipcc.ch/meetings/session31/doc20-rev1.pdf . Significant new advances in geological history and understanding of the NZ and Ross Sea regions will have much to contribute to both of these reports.

NZ geoscientists can help in two ways

i) by publishing top quality research in a timely way in peer-reviewed journals, noting that for this assessment round reviewers can consider only papers published or in press by late 2012;
ii) by participating as authors and/or reviewers. Countries will be asked to nominate authors in early 2010, and a workshop organised by the Royal Society of New Zealand will be held in Wellington on December 8, 2009, to provide background information for those interested.

## 3-D VELOCITY STRUCTURE OF THE NORTHERN HIKURANGI MARGIN: IMPLICATIONS FOR CRUSTAL GROWTH

**D. Bassett[1], R. Sutherland[2], T. Stern[1], S. Henrys[2] & A. Benson[1]**
[1]Victoria University of Wellington, PO Box 600, Wellington
[2]GNS Science, PO Box 30368, Lower Hutt
dangbassett@gmail.com

Travel-time observations from a 3-D onshore-offshore dataset comprising 81 receiver-gathers are integrated with multi-channel seismic reflection profiles to constrain a 3-D P-wave velocity forward model for the northern Hikurangi margin, New Zealand.

Forward models resolve a >10 km increase in Moho depth and a >20 km increase in basement thickness between Raukumara Basin and the Raukumara Peninsula. Low-velocities (3.0-5.0 km/sec) within a triangular prism localised beneath the topographic crest of the East Cape Ridge are interpreted as underplated sedimentary and crustal strata. We suggest that the relative buoyancy of subducted sediment is sufficient for it to escape from the subduction channel near the base of the crust and drive local rock uplift. Southwest along East Cape Ridge, both the locus of underplating and the topographic crest migrate arcward, concomitant with the increase in Moho depth, which suggests the underplating process is modulated by exiting forearc crustal structure. A northwest migration of the Neogene Raukumara Basin depocentre is inferred to track the progressive growth of East Cape Ridge and the Raukumara Peninsula, and a net increase in volume of the forearc wedge.

Trench-slope subsidence rates have been used to estimate global fluxes of forearc material into the mantle. Vertical rock trajectories are assumed and the retention of material via lower crustal underplating is generally not accounted for. Based on our new estimates of underplated volume from the northern Hikurangi margin, we suggest that global rates of subduction erosion are systematically overestimated. The rates of lower crustal underplating (10-25 $km^3$ $Myr^{-1}$ $km^{-1}$) calculated in this study may explain the discrepancy between published estimates of continental creation and destruction at subduction margins.

# PROVENANCE OF THE DEVONIAN TAYLOR GROUP, LOWER BEACON SUPERGROUP, ANTARCTICA

**K.N. Bassett[1], J.M. Palin[2], G. Gilmer[1], J. Savage[1], T. O'Toole[1], M. Bradshaw[1], J. Bradshaw[1]**
[1]Dept of Geological Sciences, University of Canterbury, Christchurch
[2]Dept of Geology, University of Otago, Dunedin
kari.bassett@canterbury.ac.nz

The Devonian Taylor Group, southern Victoria Land, Antarctica, is separated from the basement by a regional nonconformity, the Kukri Erosion Surface. A second localized unconformity in the north of the basin called the Heimdall Erosion Surface separates the New Mountain Sandstone and older units from the younger Altar Mountain Formation. The Sperm Bluff Formation has been correlated to the Altar Mountain Formation yet rests unconformably on the converged Heimdall-Kukri Erosion Surface that truncates local basement indicating it was deposited on the outer margins of the basin. The basement complex includes three plutonic suites, Dry Valley (DV) 1a, DV1b and DV2 of the Granite Harbour Intrusives that intrude Neoprotoerozoic metasedimentary rocks of the Koettlitz Group. DV1a suite was emplaced 499 - 505 Ma; DV1b suite was emplaced 488 - 531 Ma and DV2 suite was emplaced 455 - 489 Ma.

The detrital zircon age spectra for all samples from the Altar Mountain and New Mountain Sandstones have a single broad peak from 490 to 560 Ma in common that correspond to the range of crystallisation ages of the Granite Harbour Intrusives suggesting that the sediment was all locally derived. Inherited cores observed in the zircons could be the source for minor older age peaks; although age peaks could be due to minor influx of sediments from an older source, such as the Koettlitz Group. Zircon dates also show that the source of the sediment for the New Mountain and the Altar Mountain Formations is the same and did not change across the Heimdall Erosion Surface even though there was a break in sedimentation. The uniformity of trace elements (particularly REE + Y) in the zircons also suggests local derivation with little input from other sources with more anomalous trace element signatures from East Gondwana. The uniformity indicates an extremely pure source, most likely DV1 suite.

Detrital zircon data from the Sperm Bluff Formation also give a strong 500 Ma peak in all samples, characteristic of DV1 or 2, with few other peaks. The dominance of a single age peak is highly suggestive of local derivation. Rhyolitic clasts from the conglomerates have compositions typical of highly evolved subduction related rocks, although they have undergone post-emplacement silicification. Petrographic analysis suggests they are components of a silicic magmatic complex. Chemically the volcanic clasts appear to represent a single magmatic suite and are clearly related to the Dry Valley Plutonic Suites. Although clasts are not constrained beyond doubt to one suite, DV2 is the best match.

Sequence stratigraphic analysis of the Taylor Group suggests multiple Transgressive to Regressive Systems Tracts leading to intervening unconformities and rejuvenation of the relatively low-lying landscape. This brought about a periodic influx of feldspar in the sediments overlying the unconformities. However, the source itself never changed through time as indicated by the detrital zircon ages and clast geochemistry suggesting that tectonic uplift was not the mechanism for landscape rejuvenation.

## FROM SOURCE TO SINK: VISUALIZATION OF A WEST-FLOWING MIOCENE SLOPE CHANNEL MEGA-SYSTEM, OFFSHORE TARANAKI BASIN

**J. Baur**[1, 2]**, P. King**[1]**, B. Leitner**[3]**, T. Stern**[2]**, C. Uruski**[1]
[1]GNS Science, PO Box 30368, Lower Hutt 5040
[2] SGEES, Victoria University of Wellington, PO Box 600, Wellington
[3]Origin Energy, Coronation Drive, Milton, 4064, AU
j.baur@gns.cri.nz

New Zealand's present-day sedimentary systems are marked by multiple large marine channels that serve as conduits between terrestrial to near shore sediment sources and deep-water environments. Using a basin-wide grid of 2D and 3D seismic reflection data in Taranaki Basin, we reconstruct the development of an analogous Miocene contributory and distributary slope channel network in a retro-arc foreland setting. The system evolved from relatively localised channel and fan deposition in the early-mid Miocene to a fully-fledged channel mega-system that transported material westwards from a sediment staging area on the Miocene shelf in the vicinity of present-day Cook Strait to the head of the New Caledonia Basin (NCB).

We use interpreted and phantom horizons to extract single and multi-trace attributes from a regional network of 2D and 3D seismic reflection data. Derivative attribute maps are correlated with available well data and biostratigraphy to infer age and lithology of morphologic features. Attributes of 3D data sets are used to visualize detailed depositional development in the central part of the basin. This detailed information is then integrated with single and meta-attribute maps gridded from 2D data to characterize the regional character of the depositional system.

Early Miocene uplift of the hinterland in response to convergence across the Australian-Pacific plate boundary is evidenced on seismic by the onset of shelf progradation and local fault activity in south-eastern Taranaki Basin. Depositional directions of Early-Mid Miocene channel and fan deposits (Moki Formation) outline the basin morphology and subsidence loci during the early stages of foreland basin development. Depositional directions and channel azimuths changed during continued uplift of the hinterland and northwest shelf progradation. Regional base-level fluctuations and local fault activity can be inferred from varying morphometrics of successive channel generations. Subsequently, a vast sinuous and braiding channel network developed, transporting sediment off the shelf in present day areas of Northwest Nelson, Marlborough Sounds, and Wanganui Basin, across Western Platform and into the deep-water part of Taranaki Basin (head of the NCB). The system can be traced and visualized over a distance of more than 500 km and represents a past equivalent to present-day systems such as the Hikurangi or Bounty channels. The characterisation of this system is of significance for paleogeographic and paleo-oceanographic reconstructions of wider New Zealand as well as quality of Miocene sandstone petroleum reservoirs.

**COSEISMIC AND EARLY POSTSEISMIC SLIP DISTRIBUTION OF THE 15 JULY 2009 DUSKY SOUND EARTHQUAKE**

**J. Beavan, S. Samsonov & N. Palmer**
GNS Science, PO Box 30368, Lower Hutt, New Zealand
j.beavan@gns.cri.nz

The Dusky Sound earthquake, with magnitude variously estimated between MW 7.6 and 7.8, was well recorded geodetically. Eight continuous GPS (cGPS) stations recorded displacements of more than ca. 10 mm, with a maximum of more than 300 mm. Some of the cGPS sites show postseismic deformation of up to 20% of the coseismic signal, presumably due to afterslip on and near the fault rupture surface. We surveyed 27 campaign GPS sites 5 weeks after the earthquake; these showed maximum displacements of more than 800 mm. A number of post-earthquake L-band Synthetic Aperture Radar images have been collected by the PALSAR instrument on the Japanese Space Agency's ALOS satellite. We have (so far) processed three of these, two ascending and one descending, collected on 15 July, 23 July and 13 August. We have combined them with pre-earthquake images to form differential interferograms of ground displacement during and following the earthquake.

Both geodetic and seismic data indicate that the earthquake occurred on the Fiordland subduction interface. Assuming the shape of the subduction interface as estimated from microseismicity, we have inverted the geodetic data to form images of the coseismic slip distribution during the earthquake, and during the early postseismic period. The major slip occurred on a patch of about 30 km by 30 km centred near 20 km depth with maximum slip of about 4.5 m. The slip direction is unusual for a subduction earthquake in that there is as much right-lateral strike slip as thrusting. The slip direction becomes more strike-slip deeper on the interface and closer to thrusting at shallower depths, but generally remains within 20º of the slip direction predicted by Pacific-Australia relative plate motion. We expect that the data are good enough to be able to invert separately for the coseismic (together with very early postseismic) and postseismic slip distributions on the plate interface. We may also be able to reliably image the upper (offshore) edge of the slip distribution.

**QMAP ROTORUA – WHAT'S NEW BESIDES VOLCANOES?**

**J.G. Begg[1]; G.S. Leonard[1]; C.J.N. Wilson[2]**
[1]GNS Science, PO Box 30368, Lower Hutt, New Zealand
[2]Victoria University of Wellington, PO Box 600, Wellington, New Zealand
j.begg@gns.cri.nz

QMAP Rotorua covers ca. 24,800 km$^2$ of the Bay of Plenty and eastern Waikato regions. Broad features include Mesozoic basement rocks in the west and east, with late Early Cretaceous to Paleogene cover deposits in the southeast. Neogene marine sediments are exposed in the southeast and Middle Miocene to Pliocene volcanics in the northwest. Quaternary volcanic deposits of the Taupo Volcanic Zone (TVZ) mantle older units in the central part of the map. Densely spaced, active normal faults of the Taupo Rift are associated with extension and a series of active dextral-normal faults of the North Island Fault System lies east of, and are truncated by the Taupo Rift.

The relationship between Manaia Hill Group (Waipapa composite terrane) and Torlesse composite terrane is obscured by volcanics of the TVZ. Torlesse composite terrane comprises Kaweka terrane in the west, a poorly fossiliferous, quartzo-feldspathic sandstone-dominated unit that includes broken formation and melange zones and is probably late Jurassic in age. In the east, Pahau terrane (Waioeka petrofacies) comprises alternating volcaniclastic sandstone and mudstone with rare melange and broken formation, and is of Early Cretaceous age. Whakatane Melange, sandwiched between these terranes, comprises melange, broken formation and coherent and variably deformed blocks, probably of Kaweka and Pahau terrane derivation. Emplacement age presumably post-dates deposition of Pahau terrane. A series of elongate melange units, the Oponae Melange, slice Pahau terrane and in places grade to coherent, fossiliferous (Urutawan to Motuan) siltstone and sandstone, intermediate in dip between Waioeka petrofacies and cover beds. Faults bounding Oponae Melange are associated with overturned folds with sub-horizontal hinges in the underlying Pahau terrane, suggesting a common tectonic origin.

Unconformably overlying, gently dipping late Early Cretaceous to Late Cretaceous Matawai Group cover rocks are sandstone and siltstone-dominated and comprise a series of individual unconformity-bound units in the southeast corner of the map area. Tinui Group siltstone and sandstone, and Mangatu Group mudstone, limestone and sandstone rest unconformably on underlying units.

Marine deposits of the Miocene Tolaga Group and mainly Pliocene Mangaheia Group are found in the Waikaremoana and Ruatahuna basins. Tolaga Group unconformably overlies older units, and unconformities may be present within the Miocene and Pliocene sequence.

The map represents the first attempt to portray all TVZ volcanic deposits, particularly rhyolitic deposits, from eruptive centres through ignimbrites to distal tephra on a single map. Results of substantial new mapping and 60 new age determinations are incorporated. See Leonard et al. (this volume) for discussion of new results from the volcanic rocks.

## LOVE AND RAYLEIGH WAVE PHASE VELOCITY MAPS OF NEW ZEALAND OBTAINED VIA CROSS-CORRELATION OF AMBIENT SEISMIC NOISE: UPDATED NATIONAL MODELS AND PRELIMINARY ESTIMATES OF RADIAL ANISOTROPY

**Yannik Behr[1], John Townend[1], Martha K. Savage[1] & Stephen Bannister[2]**
[1]Institute of Geophysics, SGEES, Victoria University of Wellington
[2]GNS Science, PO Box 30368, Lower Hutt 5040
yannik.behr@vuw.ac.nz

Continuous seismic records at frequencies below 1 Hz largely consist of ambient noise. It has been known since the 1950s that surface wave information can be extracted from such ambient seismic noise using correlation techniques. In the last decade, the increased availability of data storage space and computational power has made it feasible to apply this method to large datasets.

We present 2D Love and Rayleigh wave phase velocity maps for New Zealand, inferred from ambient noise cross correlations. In order to increase the path-coverage, we merge seismic data from four temporary deployments (CNIPSE - Central North Island Passive Seismic Experiment; SAPSE - Southern Alps Passive Seismic Experiment; NORD - Northland Deployment; Marlborough Deployment) with data from 51 permanent stations operated by GeoNet.

We calculate ambient noise cross-correlations for all three components (north, east, vertical) between every pair of seismographs in the amalgamated dataset and then measure Love and Rayleigh wave phase velocity dispersion curves for the fundamental mode. The results are inverted for 2D phase velocity maps at discrete periods between 5 and 25 s. These maps exhibit strong correlations with known geological features. By comparing Love and Rayleigh wave maps, which are dominated by the horizontal and vertical shear velocity structures respectively, we then estimate the 2D distribution of radial anisotropy.

Finally, we employ the Neighbourhood Algorithm, a direct search method, to calculate 2D velocity-depth profiles from dispersion curves measured between two station pairs of the temporary deployment NORD on the Northland Peninsula. The results for Rayleigh waves are in good agreement with previous studies in this area. We attribute systematic differences in the results for Rayleigh and Love waves to the presence of radial anisotropy in the lower crust and estimate its magnitude to be between 5 and 10%.

# HIKURANGI MARGIN TSUNAMI EARTHQUAKE GENERATED BY SLIP OVER A SUBDUCTED SEAMOUNT

**R.E. Bell[1], X. Wang[1], W.L. Power[1], G.L. Downes[1] & C. Holden[1]**
[1]GNS Science, PO Box 30368, Lower Hutt
r.bell@gns.cri.nz

In March and May 1947 two subduction interface earthquakes with long rupture durations produced anomalously large tsunami with maximum inundation heights of ~10 m along the coast near Gisborne, on the east coast of the North Island, New Zealand. Seismic reflection data reveal a subducted seamount in the region of the March 1947 earthquake, which correlates with an area of deeper stronger geodetic coupling. Surrounding the seamount is a zone of high-amplitude reflectivity, interpreted to be the result of underthrust sediments, which lies in a transition region from strong to weak geodetic coupling and undergoes slow slip. There is some evidence that the May 1947 earthquake is similarly located on or near a seamount and surrounding underthrust sediments. Here, we propose a source model for the March 1947 earthquake involving rupture nucleation within the strongly coupled subducted seamount asperity, and slow rupture propagation into the surrounding zone of frictional conditional stability. We perform 3 simple models to determine nearshore inundation heights for A) an instantaneous uniform slip source model, B) an instantaneous variable slip model based on our proposed variably coupled source model and C) consider a variably coupled source model with slow rupture speed. We compare the modelled tsunami nearshore inundation heights for these three source models with eye-witness observations.

The proposed variably coupled source model, considering the likely slow rupture speed (Model C), generates anomalously large tsunami due to; 1) the subducted seamount providing a mechanism for shallow rupture, 2) concave uplift over the seamount focusing tsunami waves, and 3) slow rupture velocities, similar to the tsunami propagation speed, causing water pile-up and tsunami amplification. This study supports the growing literature that tsunami earthquakes are the result of rupture on asperities within zones of frictional conditional stability. This presentation will be accompanied by a poster investigating in further detail how rupture patterns affect tsunami energy distribution and maximum tsunami height.

## MAGNETOTELLURIC IMAGING OF THE TONGARIRO VOLCANIC SYSTEM, NEW ZEALAND: PRELIMINARY RESULTS

**Stewart Bennie[1], Graham J. Hill[1], T. Grant Caldwell[1], Hugh M. Bibby[1] & Harry Keys[2]**
[1]GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand
[2]Department of Conservation, Turangi, New Zealand
s.bennie@gns.cri.nz

The Tongariro Volcanic system, a composite andesitic cone complex, is located at the southern end of the Taupo Volcanic Zone in the central North Island of New Zealand south of the rhyolitic caldera forming volcanism that characterise the Taupo Volcanic Zone to the north. Here we use data from 22 broad band magnetotelluric soundings to image the magmatic structure along a single profile adjacent to Mount Ngauruhoe, the most recently active vent of the Tongariro system. Phase tensor analysis indicates that the data response is quasi-2D for most of the profile, although the response in the area adjacent to Mount Ngauruhoe has a significant 3D component. 2-D inverse modelling of the MT data show a narrow (1 km), vertical conductive zone located under Mount Ngauruhoe which is interpreted to represent the ascent path of magmatic fluids from a deeper source region located ~10km below the volcano.

# CRUSTAL AND UPPER MANTLE STRUCTURE OF THE CENTRAL NORTH ISLAND FROM THE MORC SURVEY, 2005

**Adrian Benson[1], Tim Stern[1] & Stephen Bannister[2]**
[1]Institute of Geophysics and SGEES, Victoria University, Wellington
[2] GNS Science, PO Box 30368, Lower Hutt
tim.stern@vuw.ac.nz

In 2005 a Marsden-funded project undertook to explore the crustal structure of the Taupo Volcanic Zone (TVZ) along a 120 km-long line from the Napier-Taupo road in the east to Bennydale in the King Country in the west. 700 seismic receivers were distributed along the roadside and in farmers paddocks, and nine shots ranging from 600 to 1300 kg of dynamite were detonated in 50 m deep holes. MORC (Mantle OR Crust ?) was a designed to specifically test differing ideas about what are crust and mantle features deep beneath the TVZ. Much of the controversy was fuelled by the fact that the volcanic regions of the central North Island are notoriously difficult to acquire quality seismic data, because the volcaniclastic rocks of the upper crust are vigorous scatters of seismic energy. A key feature of the data are the apparent arching up of the base of the greywacke crust (5-6 km/s) beneath the TVZ to a depth of about 16 km. Beneath 16 km seismic P-wave velocities increase rapidly until a velocity of about 7.3 km/s is detected at a depth ~ 23 km. The exact depth is difficult to determine without prior knowledge of seismic velocity variation within the crust. Moreover, strong seismic anisotropy in the central North Island complicates the problem of determining seismic velocities in the lower crust and upper mantle. Nevertheless, we interpret the 6.8-7.3 km/s rocks between 16 and 24 km as underplated new crust that merges into an anomalous upper mantle. The most distinctive feature of the whole MORC data set is a strong reflection that comes in at about 10 s two-way travel time and is limited in its lateral extent. Our initial interpretation was that the reflecting surface for this event is situated at about 30-35 km depth in the upper mantle. However, for a reasonable range of crustal velocities the reflector could be as shallow as 25 km, which would put it in the crust to upper mantle transition zone. When migrated to its true position the strong and deep reflector appears to be only about 20 km wide and located beneath the eastern side of the TVZ. The strong amplitude of this reflector, its position beneath the geothermal regions and its limited lateral extent, all point to the possibility that it represents a region of partial melt. Other interpretations are, however, possible and will need to be tested with amplitude modelling using wave equation codes.

# PROGRESS TOWARDS DECIPHERING A C. 7KYR RECORD OF SURFACE RUPTURES ON THE ALPINE FAULT

**K. Berryman[1], K. Wilson[1], U. Cochran[1], & G. Biasi[2]**
[1] GNS Science, PO Box 30-368, Lower Hutt, New Zealand
[2] University of Nevada, Seismological Laboratory, Reno, NV 89557, USA
k.berryman@gns.cri.nz

Two field campaigns, more than 100 radiocarbon ages, paleoenvironmental analysis, stratigraphy, and geochemistry, represent an increasingly robust dataset with which to evaluate the alternating alluvial and pond margin deposits exposed in stream-bank sections at Hokuri Creek, south Westland. These stratigraphic sections occur within 100 metres of the recent trace of the Alpine Fault, which, in this area is upthrown to the northwest. A remarkable feature of the Hokuri Creek site is the continuity of the stratigraphy. Many sedimentary horizons can be followed in outcrop for over 350 m and there are very few channels and unconformities.

For a period of about 7kyr, recurrent surface rupture on the fault appears to have resulted in temporary blockage of Hokuri Creek, with consequent changes in environmental conditions in the alluvial sequence, essentially characterised by alternating pale grey silts, and sands and rare gravel units, with dark brown to black organic silts and peats. Pale, silt-dominated sediments are interpreted as clastic alluvial sediment and the dark coloured organic silts and peats are interpreted as units with a much higher component of locally-derived sediment.

We interpret the clastic dominated units as flood deposits resulting from ponding of the stream due to the formation of a fault scarp barrier across the outlet, concomitant with increased alluvial input as a result of earthquake shaking in the catchment (Cochran et al, this meeting). Thus, the changes from “peat” to “silt” are interpreted to be event horizons of Alpine Fault rupture. Sixteen couplets of “silt and peat” occur in the interval between about 1000 cal BP and 8000 cal BP. Preliminary results from one section suggest the oldest 4 intervals average ~307 yrs, the middle 8 intervals average 478 yrs, the most recent 4 intervals average 270 yrs. The most recent event identified in the sequence so far has an age of about 700 AD. Further refinements are anticipated as we incorporate and correlate the results from three other dated sections. The major goals of the project are to (i) determine the variability of major earthquakes on a major plate boundary fault and (ii) refine the seismic hazard associated with the Alpine Fault, including the statistical likelihood of rupture in the forseeable future.

## CASTLECLIFFIAN-HAWERAN MARINE MOLLUSCAN BIOSTRATIGRAPHY AND CLIMATE CHANGE AT THE MIS SCALE AT WANGANUI

**A. G. Beu**
GNS Science, PO Box 30368, Lower Hutt
a.beu@gns.cri.nz

Biostratigraphical indices of Castlecliffian-Haweran marine isotope stages (MIS) at Wanganui are summarised, remembering that only interglacial periods are represented by strata. Few indices seem likely to apply over the whole of New Zealand. Exceptions are the arrival of *Argobuccinum* in MIS 7 and its appearance throughout New Zealand in terrace faunas from MIS 5e, and the extinction of *Anadara trapezia* after MIS 5e.
Useful events within Wanganui Basin include:
1. The extinction of *Maoricrypta profunda, Xymene expansus* and *Mactra carteri* in MIS 19 and their replacement by *Xymene plebeius* and *Mactra ordinaria* in MIS 17;
2. The restriction of *Buccinulum caudatum* and *Aeneator delicatulus* to MIS 25-17 (offshore siltstone facies);
3. The restriction of *Ponderia zelandica* and *Stephopoma roseum* to Tainui Shellbed (MIS 13); and
4. The appearance of *Pecten novaezelandiae* in MIS 19 (identifying the Brunhes-Matuyama transition), well after its appearance in eastern New Zealand at around MIS 31.

Speciation within New Zealand genera continued throughout Castlecliffian-Haweran time at a low background rate (0-2 new species per MIS), whereas appearances of warm-water taxa in Wanganui Basin and extinctions were both more frequent after the Mid-Pleistocene Transition (after MIS 21) and reached a peak in MIS 9-7. Subtler evidence of temperature change (*Pelicaria vermis* forms and *Stiracolpus* "*waikopiroensis*" at Castlecliff) indicates a relatively cool MIS 23-19, represented by offshore siltstone facies, and a warmer MIS 17, represented by shallow-water shellbeds of Kupe Formation. Appearances in Wanganui Basin of species from northeastern New Zealand or the Southwest Pacific during interglacial periods provide the major indications of warm periods. Numbers increased steadily from MIS 29 (1 species) to MIS 9 (9 species), but then dropped dramatically, as a result of the lack of a faunal record (lack of uplift) rather than of cooling climate.

However, numbers of warm-water species are highest in near-shore shellbeds, and do not simply reflect temperature; the faunal record at Wanganui resulted from the interplay of depositional environments and temperature change.

**THE ROLE OF DEEP-SEATED LANDSLIDES IN THE EVOLUTION OF THE WAIPAOA SEDIMENTARY SYSTEM**

**E.L. Bilderback[1], J.R. Pettinga[1], N.J. Litchfield[2] & M. Quigley[1]**
[1] Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch
[2]GNS Science, PO Box 30368, Lower Hutt
eric.bilderback@pg.canterbury.ac.nz

Deep-seated landslides are pervasive in the non-glacial Waipaoa River catchment, Gisborne Region, New Zealand and are an indication of a landscape in transition. Since the Last Glacial Maximum (LGM) the upper reaches of the Waipaoa and its tributaries have incised up to 120 m into the soft, mainly Tertiary marine sedimentary rocks that underlie the catchment (Berryman et al., 2000). We have documented the progressive adjustment of hillslopes in the catchment during the Late Pleistocene and Holocene to channel incision through rotational, translational and earthflow deep-seated mass movement. Our research is focussed on investigating the spatial and temporal relationship between river incision and deep-seated landslides in the catchment and to quantify the volume and timing of sediment delivery in this rapidly changing landscape.

In the Waipaoa, and for much of the eastern North Island, the shift from the LGM to the current interglacial climatic regime resulted in Late Pleistocene-Holocene catchment-wide channel incision (Berryman et al., 2000; Litchfield and Berryman, 2005). The sediment flux from this postglacial incision has been calculated from river terrace reconstructions by Marden et al. (2008) and compared with postglacial offshore sediment storage in Poverty Bay. The result is that only ~25% of the total postglacial sediment yield is accounted for by postglacial channel incision; this implies that as yet unquantified hillslope erosion processes are massive contributors to the total Waipaoa sediment flux.

Two geologically and geomorphologically distinct study areas have been chosen as representative of the deep-seated landslide processes in the 2500 sq. km Waipaoa River catchment. A 44 sq. km eastern catchment tributary area is characterized by moderate relief and is underlain by Miocene to Pliocene mudstones, fine sandstones and, in places, low-strength tectonic melange. A 75 sq. km western catchment tributary area is, in contrast, relatively high relief and is underlain by allochthonous Eocene to early Miocene mud and limestones. Air photo interpretation and field work in these two areas show that post incision deep-seated landslides can occupy over 20% of the surface area of portions of the catchment. Many of these slides show evidence of multiple “nested” failures, landslide reactivation, and the preliminary analyses of tephra cover shows that hillslopes have continued to adjust to channel incision into the late Holocene. Even though landslides occupy a large amount of the surface area in the catchment, preliminary 3-D geomorphic reconstructions in the eastern study area indicates that the volume of sediment derived from deep-seated landslides is likely to be less than 15% of the volume calculated for postglacial river incision. Deep-seated landslides are a major contributor to sediment delivery and the geomorphic evolution of the Waipaoa River catchment, but preliminary work indicates that these discrete features may not account for the apparent on-shore source-area deficit in the calculated sediment budget.

# BATHYMETRY OF THE ROSS SEA AND ADJACENT SOUTHERN OCEAN

**J. Black, S. Henrys, V. Stagpoole, D. Woodward & F. Davey**
GNS Science, PO Box 30368, Lower Hutt
j.black@gns.cri.nz

The morphology of the seafloor is a fundamental boundary condition that is essential for a wide range of research including physical oceanography, geology and marine ecosystems. Accurate high resolution bathymetric data is a necessity, even for geographically remote areas such as the Ross Sea and the Southern Ocean south of New Zealand.

We compile all available bathymetric data for the whole of the Ross Sea region. This includes modern bathymetric surveys which use multi-beam technology, providing a swath of detailed bathymetric data along the survey tracks that are well controlled spatially by GPS or DGPS navigation. Gaps and holes in the ship-borne data are filled with an inversion of satellite derived gravity data. Modern gravity data is available at a high resolution (1 minute) from satellite altimetry. Combining these two datasets enables us to generate a high quality bathymetric map of the Ross Dependency.

We present a bathymetry map for the Ross Sea and adjacent Southern Ocean combining bathymetry and gravity inversion data. We also present examples of detailed structures.

## AN ALLOSTRATIGRAPHIC FRAMEWORK FOR THE CRETACEOUS-RECENT FILL OF TARANAKI BASIN: INSIGHTS FROM THE KUPE AREA

**K.J. Bland, K.F. Kroeger, D.P. Strogen & M. Fohrmann**
GNS Science, PO Box 30368, Lower Hutt 5040
k.bland@gns.cri.nz

As part of GNS Science's 4D Taranaki Project, an allostratigraphic framework is being developed for Taranaki Basin. This allostratigraphic scheme uses sequence stratigraphic principles to develop a framework that can be applied across the basin regardless of lateral and vertical changes in stratigraphic nomenclature, lithofacies, or age. As a consequence, the fundamental tectonic and depositional signals can be better elucidated, and not be masked by lithostratigraphic or lithological "noise".

The offshore Kupe mapping area covers ~3900 $km^2$ of southern Taranaki Basin, immediately south of Hawera, and is the first of seven offshore regions to be mapped as part of the 4D Taranaki Project. Recent seismic interpretation, biostratigraphic re-evaluation and seismic attribute analysis has revealed in greater detail the geological evolution of this part of the basin. However, several conflicting stratigraphic schemes for this part of the basin are already in use. They have resulted in confusion over stratigraphic correlations, and the magnitude and timing of many significant tectonic and depositional events. The new allostratigraphic framework uses a terminology that is largely independent of lithofacies or pre-existing lithostratigraphy.

Each allostratigraphic boundary is designated with an alpha-numeric code, which purposefully removes any immediate lithostratigraphic connotation or bias. Allostratigraphic boundaries identified within the Kupe mapping area typically represent significant erosion or flooding surfaces, and bound sequences of 2nd to 3rd order duration. The most prominent and widespread surfaces typically correspond to lithostratigraphic group boundaries, reflecting significant changes in deposition and paleoenvironments in the basin.

The allostratigraphic framework initially developed here for the Cretaceous-Recent succession in the Kupe mapping area can be applied to other parts of Taranaki Basin, and also has relevance for interpreting large-scale tectonostratigraphic events elsewhere in New Zealand. Future developments of allostratigraphic frameworks for other basins may allow easier correlation of regional tectonostratigraphic events.

# SCIENTIFIC RESPONSE TO THE DUSKY SOUND EARTHQUAKE, JULY 15TH, 2009

**L. Bland[1], N. Welch[1], S. Cox[2], R. Jongens[2], N. Palmer[1], J. Beavan[1], K. Wilson[1] and the GeoNet Team[1]**
[1]GNS Science, PO Box 30368, Lower Hutt
[2]GNS Science, Private Bag 1930, Dunedin
l.bland@gns.cri.nz

At 9:22pm on July 15th 2009 a magnitude 7.6 earthquake, the largest to strike New Zealand in 80 years, occurred underneath Resolution Island in Dusky Sound, Fiordland. The earthquake was felt widely across the country, generating considerable interest from scientists, media, and the public.

An important tool in the distribution and collection of information about the earthquake following its occurrence was the GeoNet website (www.geonet.org.nz), which was visited by over 47,000 individual users on July 15th - ten times the daily average for the preceding week. As at September 2009 over 1000 aftershocks have been analysed, although many of these have been minor, and only 35 were reported as having been felt.

On July 16th a response team was dispatched from Wellington to deploy temporary seismographs to record the earthquake's aftershock sequence. Six portable instruments were deployed in southwest Fiordland to supplement the existing GeoNet stations at Puysegur Point and Deep Cove. A landslide reconnaissance team had already departed to do a preliminary fly over of the area, looking for any new activity on Fiordland's slopes generated by the earthquake. The team identified 187 new slips from Doubtful Sound to Preservation Inlet, the majority of which were minor, with estimated volumes of under 1000$m^3$. A GPS campaign to measure co-seismic deformation and a tsunami deposit/coastal uplift investigation were also conducted in subsequent weeks. The GPS campaign revealed up to 800mm of horizontal movement toward the southwest, and 200mm of subsidence near Resolution Island. The tsunami deposit/coastal uplift investigation found evidence of tsunami run-up at Passage Point and Goose Cove, and showed possible support for coastal subsidence of up to 200mm.

The seismic response is ongoing; four of the six temporary seismographs were collected in September, and the final two will be left recording onsite until December 2009. The data recorded by these seismographs will allow the precise location of events in the earthquake's aftershock sequence, which in turn will be used to infer local fault structure and provide insight into the Fiordland subduction zone.

# A FOOTNOTE ON FAULT REACTIVATION

**T.G. Blenkinsop**
SEES, James Cook University, Townsville QLD 4811, Australia
thomas.blenkinsop@jcu.edu.au

Conditions for cohesionless fault reactivation on planes containing the intermediate principal stress $\sigma_2$ can be expressed in terms of the ratio between the maximum and minimum principal stresses, R' = $\sigma_1/\sigma_3$ (Fig. 1a; Sibson 1985). Reactivation can also be considered in terms of Slip Tendency $T_S = \tau/\sigma_n$ (Fig. 1b; Ferrril and Morris 1996). This approach includes the effect of $\sigma_2$, allowing calculation of the reactivation potential on planes of arbitrary orientation. Furthermore, a normalized value $T_s'$ can be derived, which depends only on the stress ratio $\Phi = (\sigma_2\text{-}\sigma_3)/(\sigma_1\text{-}\sigma_3)$, the coefficient of friction $\mu$, and the orientation of the plane relative to the principal stresses (Lisle and Srivastava 2004). This formulation is especially useful for analysing paleostress.

Many faults contain infill that testifies to a component of dilation during slip, and that the effective normal stress on the fault was tensile. The concept of Dilation Tendency ($T_D$) is proposed here as a measure of the propensity for dilation during reactivation. The normalized Dilation Tendency $T_D'$ (Fig. 1c) depends only on the orientation of the reactivated plane and the stress ratio, and includes the effect of $\sigma_2$. Dilation tendency analysis can be carried out on planes of all orientations for any stress ratio, just like slip tendency.

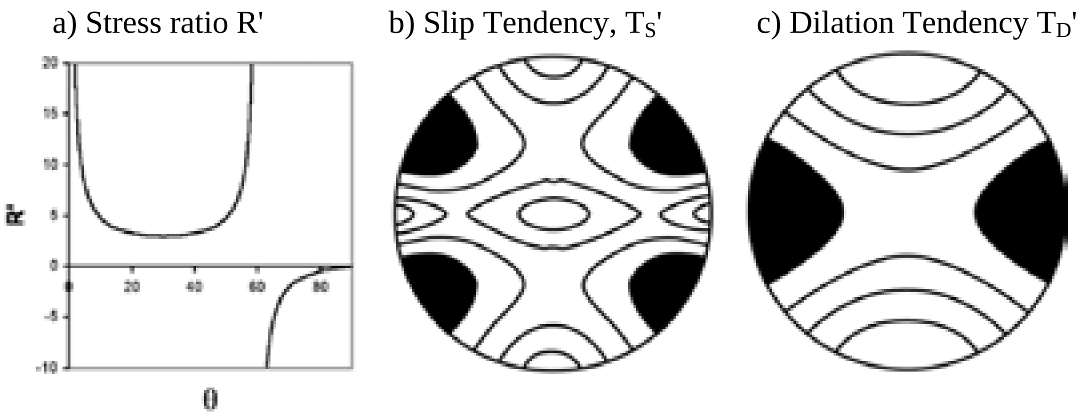



Fig. 1. Three noteworthy aspects of reactivation for ⎞ = $\tan^{-1}\mu = 30°$. a) Stress Ratio R' vs. angle between fault plane and $\sigma_1$ ($\theta$), for planes containing $\sigma_2$. b) and c) Lower hemisphere, equal area projection of contours of $T_S'$ (b) and $T_D'$ (c) at poles of planes for √ = 0.3 (close to the average crustal value). $\sigma_1$ horizontal and NS, $\sigma_2$ vertical. Contours at 0.2, 0.4, 0.6, 0.8; black for orientations with values >0.8.

Faults with infill may have significant cohesion, which is also recognised in laboratory experiments at high normal stresses. It can be shown that the addition of cohesion has no effect on normalized slip or dilation tendencies, further enhancing their application to the geological record.

## MICROSEISMICITY IN THE CENTRAL SOUTHERN ALPS

**Carolin Boese, Mark Henderson, Tim Stern**
SGEES, Victoria University of Wellington, PO Box 600, Wellington
boesecaro@myvuw.ac.nz

We are currently studying microseismicity in the central section of the Alpine Fault using data from the Southern Alps Microearthquake Borehole Array (SAMBA). This network consists of 10 stations with short period seismometers in shallow boreholes which were installed between November 2008 and June 2009. The deepest hole is situated in the vicinity of Franz Josef, approximately 2 km north-west of the surface trace of the fault, and has a depth of 98m.

The data of a few months have been analysed and locations and depths of earthquakes have been determined. At the moment, we are using a one-dimensional velocity model to locate events; however we aim to develop a 3D crustal velocity model using seismic tomography.

At the moment, between 1 and 10 earthquakes with magnitudes $M < 3.7$ are detected every day. Seismicity occurs in clusters in similar regions where they have been observed in previous studies. In these studies, the detection of small events was limited to a magnitude of $M_L$=1.6 due to a high background noise level in this region. We are currently able to resolve events down to magnitudes of $M_L$= 0.8. First results of focal mechanisms will be shown. We report about a work in progress and further investigations will focus on events occurring close to the surface trace of the fault in depths between 2 and 5 km.

## GENESIS OF THE MIOCENE VOLCANIC SUCCESSION OF THE NORTH ISLAND IN LIGHT OF NEW ISOTOPE AND TRACE ELEMENT DATA

**M.A. Booden, I.E.M. Smith, P.M. Black and J.L. Mauk**
School of Environment, University of Auckland, PB 91029, Auckland
m.booden@auckland.ac.nz

Subduction-related volcanism in the North Island began in the latest Oligocene and continues to the present, but although activity was continuous, significant changes in the style of volcanism occurred. The earliest volcanism, concentrated in the Northland Arc, formed andesitic stratovolcanoes and massive basaltic shield volcanoes. Subsequent Middle- to Late-Miocene volcanism in the Coromandel Volcanic Zone (CVZ) was marked by andesitic volcanism, the absence of significant basaltic activity, and the advent of explosive caldera-forming silicic activity, which eventually became dominant in the current Taupo Volcanic Zone (TVZ). New geochemical and radiogenic isotope data on 300 rocks from this Miocene volcanic succession shed new light on the genesis and interrelationship of the different rock types. In the Northland Arc (ca. 25-16 Ma), a principal difference exists between western belt rocks of the Waipoua, Manukau and Hukatere centres, and eastern belt rocks from the North Cape, Whangaroa, Whangarei Heads and Parahaki centres. Western belt rocks are predominantly porphyritic plagioclase + pyroxene basalts and basaltic andesites that show no rare earth element (REE) indication for amphibole fractionation and show minimal isotopic evidence for crustal involvement. These features help to explain why compositions remained relatively primitive. In contrast, eastern belt rocks are predominantly plagioclase + pyroxene + amphibole andesites and dacites. REE behaviour in eastern belt rocks is consistent with amphibole fractionation. Eastern belt rocks also have higher $^{87}Sr/^{86}Sr$ and lower $^{143}Nd/^{144}Nd$ values, consistent with stronger crustal involvement, relative to western belt rocks. The differential development of western and eastern belt rocks could reflect a thinner crust underlying the western belt and is probably no indication of the polarity of subduction underneath the arc. The andesites and dacites of the CVZ (ca. 18-2 Ma) are petrographically and geochemically comparable to eastern belt Northland Arc rocks, showing a distinct arc trace element signature, REE behaviour consistent with amphibole fractionation and isotopic evidence for substantial crustal involvement. Amphibole disappears as a phenocryst in CVZ andesites after 10 Ma, but REE behaviour and overall geochemistry are unchanged and we speculate that amphibole was more efficiently resorbed at low pressure in the later magmas because they were hotter. Explosive silicic activity in the CVZ after 12 Ma produced rhyolites with arc signatures, which have $^{87}Sr/^{86}Sr$ values that are commonly comparable to those of coeval andesites and lower than those of country rocks, suggesting an origin cognate with the andesites. We postulate that silicic magmas were ultimately primarily derived from the amphibolites that initially formed during andesite differentiation. Remelting of the amphibolites was possibly induced by an increased rate of basaltic intrusion into the lower crust, consistent with the sporadic eruption of basalts after 9 Ma and a consequence of increased regional extension from 12 Ma onward. This process could be analogous to and contiguous with the current 'unzipping' of the TVZ. In contrast, a low rate of extension apparently inhibited silicic activity before 10 Ma, even though amphibole-rich restites, i.e. potential sources of rhyolites, formed from the earliest Miocene in the Northland Arc and the CVZ.

## CREATING COSEISMIC FAULT ROCKS

**C. Boulton and T. Davies**
Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch
cjb205@student.canterbury.ac.nz

A custom-built annular shear apparatus (rheometer) in the Department of Geological Sciences at the University of Canterbury can shear fault gouge at velocities experienced during earthquake slip (~ 1 $ms^{-1}$). The rheometer comprises a 5 mm-thick annular channel of granular material that undergoes shearing at strain rates exceeding 200 $s^{-1}$ over typical displacements of 10 m. Experiments can be conducted at normal stresses ranging between 1 and 10 MPa.

During shear displacement, a LabJack UE9 data acquisition device records data from 3 strain gauges at 10 kHz. While the strain gauges accurately measure vertical load and torque, the rheometer requires additional instrumentation to measure vertical strain. An innovative design using sacrificial shear cells enables us to retrieve the experimentally-produced fault gouge for microstructural analysis.

Experiments on Alpine Fault gouge collected at Gaunt Creek were conducted under normal loads of 0, 4, and 8 MPa. The Alpine Fault gouge exhibited constant frictional resistance to shear at 0 MPa normal load, but underwent weakening at a normal load of 4 MPa. Weakening resulted in a 2-fold reduction in the coefficient of friction at a critical slip distance of 6 m. The experiment conducted under 8 MPa normal load failed because of gouge extrusion; the rheometer is undergoing modifications to eliminate extrusion.

Future experiments on the rheometer will produce fault gouge with microstructures formed at known sliding velocities and strain rates. Comparison of these experimentally produced fault gouges with those collected from natural exposures of the Alpine Fault will provide new insights into the nature of faulting and strain accommodation along this seismically active plate boundary. These experiments have important implications for understanding seismic efficiency and the mechanics of granular flow.

# EVOLUTION OF A MONOGENETIC BASALTIC MAGMA BATCH: COMPARISON OF CRATER HILL, AUCKLAND VOLCANIC FIELD AND UDO TUFF CONE, JEJU ISLAND, SOUTH KOREA

**M. Brenna[1], S.J. Cronin[1], I.E.M. Smith[2], Y.-K. Sohn[3] & K. Németh[1]**
[1]Volcanic Risk Solutions, Massey University, Private Bag 11222, Palmerston North
[2]SGGES, The University of Auckland, Private Bag 92019, Auckland 1142
[3]Dept. of Earth & Env. Scie., Gyeongsang National University, Jinju, South Korea
m.brenna@massey.ac.nz

Detailed stratigraphic sampling of the Udo Tuff Cone, Jeju Island, South Korea has allowed investigation of the evolutionary processes that affected the composition of the basaltic magma batch that fed the eruption. These are compared and contrasted with the model proposed by Smith et al. (2008, Contributions to Mineralogy and Petrology 155, 511-527) for the magmatic evolution of the Crater Hill monogenetic centre in the Auckland Volcanic Field.

The first erupted magma is in both cases the most evolved with lowest MgO and highest concentration of incompatible trace elements. The erupted magma became more primitive as the eruptions proceeded. However, at Crater Hill the eruption terminated with extrusion of the most primitive magma whereas at Udo the last magma to erupt shifted back to an intermediate composition. In addition, whereas at Crater Hill the chemical compositions show one uninterrupted spectrum, at Udo the eruption sequence can be subdivided into lower and upper tuff stages separated by a small MgO gap from c. 8.0 to c. 9.0 wt%. Further, the lower tuff has very limited evolution (all samples have MgO c. 8.0 wt%), whereas the upper tuff shows a "boomerang" evolutionary trend from MgO c. 9.0 wt% to MgO c. 10.5 wt% and back to MgO c. 9.0 wt%.

Fractionation processes at Udo can be modelled similarly to those of Crater Hill. A primary magma generated in garnet peridotite at c. 2.5 to 3 GPa underwent mainly clinopyroxene ± spinel fractionation at c. 1.5 GPa. Slightly enriched LREEs in the Udo magma (compared to the Crater Hill) suggest that crystal fractionation possibly occurred in the presence of residual amphibole in the upper mantle.

The Crater Hill model can be applied at Udo, but in addition, the two stages of Udo were likely separated by a short eruptive break. The magma batch was fractionating at depth when the conditions changed, resulting in the first stage of the Udo tuff cone. A short break was followed by eruption of the rest of the magma batch with a more primitive composition. The end of the eruption is characterized by a shift back to more evolved composition, probably indicating that the last erupted magma consisted of more fractionated material that remained near the conduit walls and was squeezed out due to the closure of the magma feeding system.

This comparison is useful in extending the previously proposed model of magma generation for small volume basaltic volcanism.

**MINERALOGICAL SIGNALS OF FLUID FLOW IN GEOTHERMAL SYSTEMS**

**Patrick Browne**
IESE and School of Environment, University of Auckland, PO Box 92019, Auckland
prl.browne@auckland.ac.nz

Huge volumes of fluids move within geothermal reservoirs during their usually long lifetimes. As they do so, the fluids leave mineralogical signals along their pathways. The signals include:

- The sequential and progressive replacement of primary, or earlier formed, minerals. The new hydrothermal minerals are products of individual fluid /mineral reactions occurring on a micro-scale. In many cases these reactions are non-equilibrium and are most readily recorded in volcanic rocks.
- The deposition of hydrothermal minerals directly into open spaces such as veins. This occurs where fluids are subject to change and is largely independent of the ambient lithology. The changes result from processes such as heating (e.g. deposition of anhydrite) or cooling (e.g. deposition of quartz) of the fluid or loss of 'dissolved gases' due to effervescence or boiling.
- The presence of fluid inclusions.

Boiling is a common and, for a fluid, a traumatic process in high enthalpy geothermal reservoirs. However it is self-limiting, as loss of $CO_2$ means a boiled (residual) liquid is no longer on the boiling point for depth curve appropriate for its dissolved $CO_2$ content. (Boiling will slightly increase the salinity of the residual liquid but this would raise its temperature of subsequent boiling by only a trivial amount). After the steam and some of the gases separate the residual liquid ascends to a depth, and thus effectively onto a different boiling point $H_2O$-$CO_2$ /depth curve, where it again boils, degasses and stops boiling. The process is repeated multiple times over a wide range of depths as an ascending fluid boils, degasses and cools. Thus the depths of first boiling in a geothermal reservoir are controlled not only by pressure and temperature but also by the amount of $CO_2$ dissolved in the ascending fluid. It follows also that the gassiest fluids boil at the lowest temperatures. Mineral signatures of boiling are the occurrence in veins of:

- Calcite, which deposits as a result of loss of $CO_2$, according to the reaction: $Ca^{2+} + 2HCO_3^- \Rightarrow CaCO_3\Downarrow + CO^{2\Uparrow} + H_2O$
  (For reasons that are difficult to understand this calcite has a bladed morphology.)
- Adularia, deposited as a result of the residual liquid becoming slightly more alkaline.
- Quartz, deposited as a result of cooling.
- Hydrothermal minerals hosting two-phase fluid inclusions.

## CHARACTERISATION OF AN ACTIVE OFFSHORE COAST-PARALLEL FAULT SYSTEM ON THE SHALLOW SOUTHEAST CONTINENTAL SHELF OF THE SOUTH ISLAND, NEW ZEALAND

**C. Bruce[1], Z. Reid-Lindroos[1], A. Gorman[1], S. Preskett[2], and R.J. Norris[1]**
[1] Dept of Geology, University of Otago, PO Box 56, Dunedin, NZ
[2] School of Surveying, University of Otago, PO Box 56 Dunedin, NZ
bruca012@student.otago.ac.nz; reizo955@student.otago.ac.nz

The Akatore Fault is a NE trending high-angle active reverse fault that is mapped onshore, for ~65 km, to the south of Dunedin on the east coast of the South Island of New Zealand. It is the easternmost onshore leading edge in a series of reverse faults resulting from the tectonic inversion of a former basin and range system. This system extends across most of the width of the South Island and accommodates some of the oblique motion resulting from the collision of the Pacific and Australian Plates. The Akatore Fault is inferred to continue offshore to the NE and is associated with several other offshore coast parallel faults that are proposed based on limited shallow controlled-source seismic data. Several earthquakes, such as those in 1974 and 1989 are attributed to movement on these faults.

In February 2009, a high-frequency detailed offshore seismic survey was undertaken to the north of the onshore exposure of the Akatore Fault. Single channel Chirp and electro-acoustic (boomer) data were recorded and also interferometric side scanning sonar (C3D). These data were collected along 31 lines, most of which ran from just outside the surf-zone in water depths of ~10 m to about 4 km offshore in water depths of ~60 m; the spacing between these lines was about 250 m. Boomer data image the sub-seafloor sediments and other features to depths of 20-60 m.

Seismic lines in this region are characterised by distinct, continuous, southwest dipping reflections that correlate to the Cretaceous – Tertiary sequence that outcrops onshore. The boomer dataset has very good penetration, which is only limited in areas by the occurrence of seafloor multiples. In some areas, more rugged seafloor features are imaged that may relate to metamorphic basement rock, volcanic extrusives, eroded igneous intrusions, or established seafloor communities. There is limited Quaternary cover in this area of the Otago shelf.

The survey did not image the Akatore Fault directly and, due to modern sedimentation associated with a river estuary and variable onshore geology, the return of the Akatore Fault onshore was not located. However, the data do constrain the Akatore Fault to within 1 km, between the beach and the surf-zone. Preliminary analyses suggest a displacement of ~30 m on the Akatore Fault. In contrast, the survey consistently images the Green Island Fault, a high-angle, offshore, reverse fault that runs parallel to the Akatore Fault about 3.5 km offshore. The Green Island Fault is interpreted to have a displacement of 200-250 m. Preliminary interpretations of the sub-bottom data tie five Tertiary sedimentary units mapped on land to recurring reflectivity patterns observed in seismic data. At least one other fault structure is observed on two regional lines. These shore parallel features, if active, need further characterisation to better constrain their combined seismic hazard.

## GOLD EXPLORATION USING FLUID INCLUSIONS

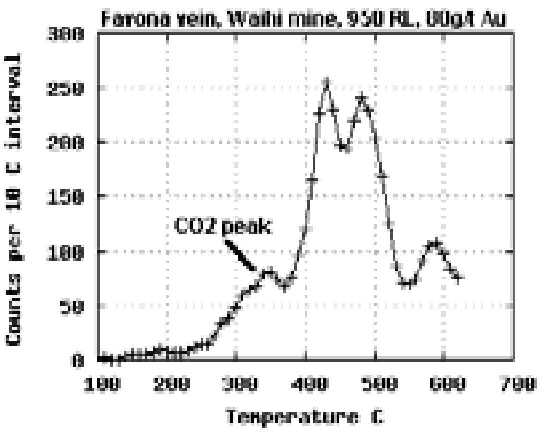
**K. Burlinson**
Burlinson Geochemical Services, PO Box 37134, Winnellie, NT, Australia
kingsley@burlinson.id.au

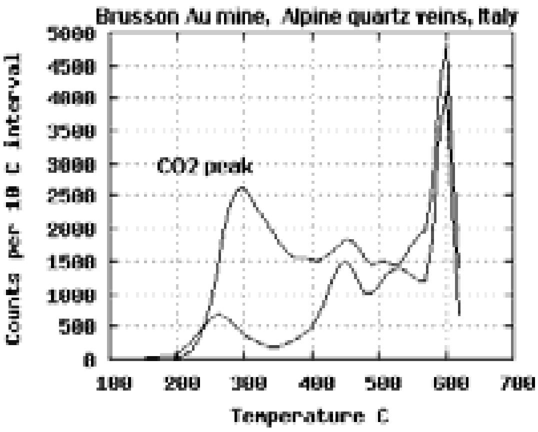
Despite our extensive understanding of fluid inclusions and the importance of fluid systems in the formation of many economic mineral deposits, there is negligible use of this important data as an exploration tool. The traditional methods of fluid inclusion study are tedious, slow and expensive and are unsuitable for routine field data collection. However, by using baro-acoustic decrepitation we can rapidly and economically collect very useful inclusion data, albeit not as pedantically precise as is used in research work. This decrepitation data is particularly useful in identifying the presence of $CO_2$ rich inclusion fluids, which are well known to be commonly associated with Au mineralisation. Gas-rich fluid inclusions give a distinctive low temperature decrepitation peak because these inclusions have high internal pressures at room temperature and when heated, the pressure increases linearly with temperature in accordance with the gas law. In contrast, aqueous fluid inclusions have a condensed liquid phase and do not generate high internal pressures until temperatures above their homogenisation point.

Samples from the Waihi epithermal gold deposit, NZ, have been analysed and they show low overall decrepitation intensities, as expected from epithermally formed fluid inclusions, but they clearly show low temperature decrepitation indicating the presence of $CO_2$ rich fluid inclusions. There is a useful correlation between the Au content of the samples and the observed low temperature $CO_2$ decrepitation measurements.

The Brusson mine in Italy is an alpine quartz vein which has been mined since Roman times. Samples from this mesothermal deposit have much more intense decrepitation and a prominent low temperature $CO_2$ peak, as well as multiple other inclusion populations.

Baro-acoustic decrepitation can give valuable fluid inclusion data to use in mineral exploration. Many mineral deposits are "fossilized" fluid systems and we can surely benefit by using fluid inclusion information when exploring for them, not merely for forensic analysis of the deposits we have already found.



## THRUST ZONE LOCALIZATION IN POORLY LITHIFIED SUBMARINE SANDSTONES: THEORY AND EXAMPLES FROM SEISMIC AND OUTCROP

**R.W.H. Butler**
Geology and Petroleum Geology, School of Geosciences, University of Aberdeen, Aberdeen AB24 3UE, UK
rob.butler@abdn.ac.uk

Analytical strategies for thrust systems commonly simplify fault zones to narrow surfaces with the folding of surrounding rocks explained by combination of fault shape and displacement gradients alone. Consequently thrust-associated folds are classified into behaviours (detachment, fault-propagation, fault-bend) with discrete thrust surfaces and prescribed stratal relationships and offsets. These models have been used to predict fault zone properties and stratal juxtapositions that impact directly on predictions of fluid transmissivity – especially for hydrocarbons. In recent years however, many oil exploration wells in anticlines in deepwater fold and thrust belts have failed, revealing greater complexity, especially in forelimb structure, than predicted by theory. These issues are explored here using well-imaged seismic examples from deepwater fold and thrust belts. While in some settings stratigraphic cut-offs against inferred faults are crisply imaged, in others there are significant zones, up to 1km wide, within which there is substantial amplitude loss. In many instances (e.g. deepwater western Niger delta) these represent zones of closely-spaced subsidiary faults separating fault-bounded slices of strata together with distributed strain. Adjacent stratal reflectors may be deflected into the fault zone. These deviations from the description of faults as very narrow structures make different predictions for structural development, the evolution of horizon dips (and hence the geometry of growth strata), and for the connectivity of the fault zone itself. The broader zones of structural damage may be mapped out using various seismic attributes and coherency volumes - showing rapid lateral variations in thrust zone geometry and localization behaviour. These seismic studies are contrasted with outcrop analogues of deformed turbidite sequences, from the French Alps, Northern Italian Apennines and the Waitemata sequences of New Zealand. All sites illustrate the importance of dispersed deformation, local buckling and soft-linked thrust zones. For the pre-kinematic succession, individual strata experience the same horizontal shortening, this may be localized heterogeneous from layer to layer. These variations increase the probability of sand-on-sand juxtaposition – reducing sealing potential of thrusts. Fine-scale connectivity can be enhanced by sand injections and fractures. Distributed strain (and structurally-enhanced compaction) impact on reservoir properties and imply that significant proportions of the bulk contraction may be accommodated by deformation other than the seismically imaged thrust-fold structures.

The seismic examples come from the Virtual Seismic Atlas (www.seismicatlas.org), a freely accessible community resource for sharing the geological interpretation of seismic data. CGGVeritas are thanked for providing data for the VSA.

# CONDUCTIVITY STRUCTURE OF THE OHAAKI GEOTHERMAL SYSTEM: INSIGHTS FROM MAGNETOTELLURIC MEASUREMENTS

**T. Grant Caldwell[1], Graham J. Hill[1], Stewart Bennie[1], Wiebke Heise[1], Ed Mroczek[2] and Greg Bignall[2]**
[1]GNS Science, Lower Hutt, Wellington, New Zealand
[1]GNS Science, Wairaki, Taupo, New Zealand
g.caldwell@gns.cri.nz

The Ohaaki geothermal system in the Taupo Volcanic Zone currently supports a 100 Mw power station and has long history of geophysical investigation using electrical methods since its first delineation by DC resistivity mapping. Although the shallow (<1 km) resistivity structure is well known from detailed DC resistivity mapping using long-wire Schlumberger resistivity surveys and from long-offset tensor bipole-dipole surveys little is know about the deep structure of geothermal system below the deepest wells, ~ 3km. At these depths the geothermal reservoir is contained in the meta-sedimentary basement rocks (greywackes) which have very poor permeability. Magnetotelluric (MT) studies at the Rotokawa geothermal field about 15 km to the southwest, suggest that the deep high temperature part of the geothermal system (also hosted in greywacke) is anomalously resistive. Here we report the findings from a 20 km long profile of 28 broad-band MT measurement stations through the centre of the Ohaaki geothermal system. Although the near-surface low-resistivity anomaly marking the Ohaaki system is a 3-D feature, phase tensor analysis of the MT data show that at longer periods the MT response is quasi 2-D. 2-D inverse modelling of the MT data identify a narrow (~600 m) near vertical (dyke-like) zone of high conductivity on the south-eastern side of the geothermal field. The geochemistry of the gas from samples taken from this side of the geothermal field has a distinct volcanic signature suggesting that we may be imaging the source of these volcanic gases.

**DEVELOPMENT OF DEFORMATIONAL BULGES ALONG THE ACTIVE STRIKE-SLIP WAIRARAPA FAULT, NEW ZEALAND**

**R.C. Carne and T.A. Little**
SGEES, Victoria University of Wellington, PO Box 600, Wellington
rachel.carne@vuw.ac.nz

The Wairarapa Fault is a major active strike-slip fault in the North Island of New Zealand. Its highly segmented surface trace cuts through the Last Glacial Maximum (LGM) "Waiohine" aggradation gravels, ~100-400 m east of the Tararua and Rimutaka range front. Rapid deposition of Waiohine gravels after the LGM overwhelmed the active Wairarapa Fault by ~12 ka, burying much of its scarp and covering the underlying Cenozoic and Mesozoic 'basement' rock. Subsequently, the fault has dextrally displaced geomorphic features incised into the Waiohine surface laterally by ~130 m and warped that surface into deformational bulges. Using aerial photographs and field work, we have mapped a central section of the Wairarapa Fault trace, including a series of bulges associated with stepovers between segments of that fault. We collected detailed topographic data across two particularly well expressed pressure bulges using a Real-Time Kinematic (RTK) Global Positioning System (GPS), from which bulge volume calculations were made. The currently active Wairarapa Fault is inferred to be an immature splay that has only recently (<100-250 ka) propagated upward to its current location on the surface from a northwest-dipping master fault at depth, perhaps in response to topographic loading by the ranges to the west. The near surface Wairarapa Fault geometry is characterised by a hierarchy of *en echelon* fault segments. The longest (Type A) segments are separated by the largest (250-350 m) fault stepover widths (associated with Type A bulges), and have fault convergence depths that we calculate to be ~100-260 m. Our data indicate that Type A segments converge into the main Wairarapa Fault well below the base of the Waiohine gravels, and in basement. We infer that Type A faults and bulges began forming in basement rock prior to Waiohine gravel deposition. By contrast, the convergence depths for the much shorter Type B *en echelon* fault segments, separated by smaller stepover widths (30-150 m) and associated with Type B bulges, are calculated to be ~1-18 m. Type B fault segments are thus thought to converge into a single fault segment at or near the base of the Waiohine gravels, representing distributed deformation in the Waiohine gravels since they buried the fault. The *en echelon* pattern of surface faulting resembles that predicted by analogue models of the deformation of a previously unfaulted, non-cohesive overburden above a strike-slip to oblique-slip basement fault. In the natural case of the Wairarapa Fault, however, the *en echelon* fault segments strike at a smaller angle (2°-18°, average of ~6°-7°) to the average strike of the main fault at depth, and the Wairarapa Fault zone is much narrower (350 m wide), than is predicted by these models (strike angle of 10°-30° and fault zone width of 1-2 km). We interpret these differences to reflect the (in part) gravel-controlled shallow fault convergence depths at the Wairarapa Fault in comparison to the typically much more thickly "sedimented" analogue models. The obliquity of convergence and the northwest dip of the Wairarapa Fault plane are reflected by the asymmetry of the surface structures along the fault, including the triangular shape of the pressure bulges in plan view, and the across-strike asymmetry of the *en echelon* fault segments in profile, associated with the partitioning of slip components between the two fault strands that bound each pressure bulge.

# NEW AND REMARKABLE PROTEACEAE LEAF FOSSILS FROM SOUTHERN NEW ZEALAND

**R.J. Carpenter[1], J.M. Bannister[2], G.J. Jordan[3] & D.E. Lee[4]**

[1]School of Earth & Environmental Sciences, University of Adelaide, South Aust. 5005
[2]Department of Botany, University of Otago, PO Box 56, Dunedin 9054, NZ
[3]School of Plant Science, University of Tasmania, Private Bag 55, Hobart, Tas. 7001
[4]Department of Geology, University of Otago, PO Box 56, Dunedin 9054, NZ
raymond.carpenter@adelaide.edu.au

Proteaceae provide a clear example of a plant group that the fossil record shows has undergone a massive decline in diversity in New Zealand: only two species are found today, and these are essentially limited to the North Island. Although it has long been known that there is an extensive record of fossil pollen types, and recent evidence of diverse cuticular fragments that conform to the family, the New Zealand record of well-preserved leaf fossils is surprisingly scant. Here we show that at one site in southern New Zealand, the Oligo-Miocene Newvale mine, at least seven species of Proteaceae co-occurred, including the distinctively Australian genus *Banksia*, and two species related to *Toronia* and the Australian genus *Persoonia*. Leaf fossils that conform to the New Caledonian *Beauprea* have also been recovered, and at least three other unidentified taxa. These species were probably part of local vegetation that had some taxonomic and ecological similarities to extant sclerophyllous heathlands of wet, acid, infertile substrates in Australia and New Caledonia. We also report on the only Proteaceae leaf so far found from the Miocene Foulden Hills diatomite. It has the large, lobed form typical of several warm rainforest taxa of eastern Australia.

# ARCHAEOMAGNETISM OF SW PACIFIC CERAMICS: A TOOL FOR GEOMAGNETIC AND ARCHAEOLOGICAL RESEARCH

**J. Cassidy[1], F. Stark[2], M.J. Hill[2], J. Shaw[2] & P.J. Sheppard[3]**
[1]School of Environment, University of Auckland, Private Bag 92019, Auckland
[2]Dept. of Earth & Ocean Sciences, University of Liverpool, UK
[3]Dept. of Anthropology, University of Auckland, Auckland
j.cassidy@auckland.ac.nz

Establishing an archaeomagnetic record for the SW Pacific has the potential to provide critical data for geomagnetic studies and to open new doors for Pacific archaeological research. A paucity of data on geomagnetic field behaviour in the Pacific region over recent millennia, especially of archaeointensity variations, has been a serious shortcoming in modelling the global field and related geodynamo processes. Preliminary archaeointensity measurements on well-dated ceramics from a broad region of the Pacific reveal significant new information on geomagnetic field strength variations over the last 3000 years. These data will be used to construct a reference curve of variations that could provide the basis for dating. This will be especially valuable for dating the pottery artefacts of the Lapita peoples, the first colonisers of Oceania, whose migration patterns are a source of much debate. Because these artefacts are mostly found in inter-tidal zones they lack an undisturbed context (and entrained carbon) and therefore cannot be dated effectively by conventional means.

High quality archaeointensity data using a state-of-the-art microwave system (MWS) have been obtained for 50 samples from Fiji and Vanuatu. The MWS has the advantage of reducing magneto-mineralogical alteration during demagnetisation experiments since the bulk samples are not heated as in traditional thermal based techniques. To cross check the MWS results, complementary Thellier-type experiments have also been conducted, with results corrected for anisotropy and cooling rate, and give good agreement. The new data are broadly consistent with current global field models (CALS3k.3 and ARCH3k) between 400 AD and 1500 AD, but with a 20% higher field between 1100 and 1300 AD. The majority of data prior to 250 AD exhibit lower intensity than predicted by the global field models, with an apparent intensity minimum at 250 BC reaching as low as 50% of the present day field strength. These preliminary results imply that the geomagnetic field has a greater range of variability than predicted and show that establishing an archaeomagnetic reference curve for dating SW Pacific ceramic artefacts is feasible.

**POSITION OF NEW ZEALAND, AUSTRALIA AND ANTARCTICA DURING THE PALEOGENE AND LATE CRETACEOUS**

**A.I. Chambord[1, 2], R. Sutherland[1] & E.G.C. Smith[2]**
[1]Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand
[2]S.G.E.E.S., Victoria University of Wellington, New Zealand
a.chambord@gns.cri.nz

The region of oceanic crust between New Zealand, Australia and Antarctica plays a key role in global tectonic reconstructions: it was created by the only non-destructive major plate boundary linking the Pacific plate to the rest of the world. In spite of many studies since the 1960s, its detailed history for times older than the Hawaii-Emperor bend (40-85Ma) has yet to be defined.

By reinterpreting all available published magnetic profiles, and by considering alternative interpretations of these profiles, we get an improved understanding of the region.

Some new, good quality magnetic profiles allow us to fill gaps in the geographical distribution of the magnetic anomalies. However, some areas of the Marie Byrd Land oceanic crust still have no data which enable identification of any magnetic anomaly. Consequently, some ridge segments cannot be reconstructed by traditional ways. We propose a new approach to calculate the relative paleoposition of a plate in case of highly asymmetric data distribution.

# THE STRUCTURE & RHEOLOGY OF OCEANIC DETACHMENT FAULTS: WHY ARE MYLONITES RARE?

**M.J. Cheadle[1], B.E. John[1], L. Hansen[2]**
[1]Dept. of Geology & Geophysics, University of Wyoming, WY, USA
[2]Dept. of Geology and Geophysics, University of Minnesota, Minneapolis, MN, USA
cheadle@uwyo.edu

Oceanic detachment faults/shear zones are complex structures ranging from 1 to >200m thick, comprising a network of thin anastomosing faults, exhibiting a progressive down-temperature continuum in deformation from amphibolite (and locally granulite), to sub - greenschist facies. They form in thin lithosphere, with high geothermal gradients, and deform both gabbroic and ultramafic rock types. There is a significant variation in structural style between detachment faults from individual oceanic core complexes, likely a function of differences in magma supply, thermal structure, depth of seawater penetration and spreading rate. Variations in these parameters can lead to different depths of interaction between a detachment fault and magma. Cold, magma-starved ridges likely support deeply rooted (up to 10km), short-lived faults (5-10km slip), whereas 'warm' ridges with reasonable magma supply, are likely to have shallow rooted (4-6km), large offset (10-100km) faults. Peridotite-hosted detachment faults are characterized by talc-, tremolite- and chlorite bearing 'fault schists', derived from ultramafic or mafic protoliths. In contrast, detachment faults hosted in gabbroic rocks only rarely host mylonites, and in many cases comprise thick zones of cataclasite with lesser gouge.

The high temperature deformation history of these faults is dominated by olivine and feldspar rheology, with an intimate association with magmatic accretion. Rheologic analysis, using LPO-deduced deformation mechanisms and geothermometry to construct deformation mechanism maps, suggests strain rates for amphibole-bearing gabbros, gabbronorites, and peridotites of $10^{-10}s^{-1}$, $10^{-12}s^{-1}$, and $10^{-13}s^{-1}$ respectively. Crosscutting undeformed diabase dikes and peridotite mylonites intruded by gabbroic dikes, and Fe-Ti oxide microstructures indicative of melt-present deformation, suggest that detachment faulting was often coeval with magmatism. The strain rates and thermal gradients at mid-ocean ridges together with the rheological properties of the ocean lithopshere limit the development of thick mylonitic shear zones. Under these conditions, the brittle-plastic transition for 'dry' gabbro (700-750°C) has a very similar temperature to the solidus of evolved gabbro (800-850°C), so in many cases fault-related deformation transitions from the magmatic regime to the semi-brittle domain. We suggest that extensive mylonitic shear zones may only form if the footwall gabbroic rocks are 'wet' leading to the suppression of the brittle-ductile transition for plagioclase (500-600°C), thereby increasing the temperature window (~300°C) formation of mylonitic shear zones.

Once formed, the faults are likely conduits for hydrothermal circulation. The presence of mixed gabbro/peridotite rock types leads to enhanced, moderate temperature (up to 450°C) alteration, which dominates the "low-temperature" history of the fault system. Resulting serpentine, talc and chlorite-bearing 'fault schists' are sufficiently weak to facilitate long-term, aseismic slip on these faults.

**LINKING AN OFF-FAULT PALEOENVIRONMENTAL RECORD TO SURFACE-RUPTURING EARTHQUAKES ON THE ALPINE FAULT**

**U. Cochran, K. Wilson, K. Berryman, & R. Langridge**
GNS Science, PO Box 30-368, Lower Hutt, New Zealand
u.cochran@gns.cri.nz

About 18 m of Holocene sediments have accumulated over a 7000 year period within 100 m of the Alpine Fault at Hokuri Creek, south Westland. Berryman et al. (this meeting) are using these sediments to extract a long surface rupture earthquake record for the Alpine Fault. This paper explores how we interpret the off-fault sedimentary record with respect to surface rupture on a major plate boundary fault.

We have explored the use of sedimentology, high resolution photography, x-ray imaging, paleomagnetism, geochemistry and pollen and diatom analysis to define major unit types. Some of the above techniques are then used to reconstruct past depositional environments for each of the main sediment types. Diatom analysis indicates that the study site was an aquatic environment throughout the 7000 years represented in the stream-bank outcrops. Paleoenvironments range from shallow pond and swamp settings where deposition was predominantly of in-situ organic material with mm-scale influxes of silt, to flowing water and deep pond settings that received predominantly catchment-derived silt. At the decimetre to metre scale the presence of organic – non-organic couplets is pervasive throughout the sections. Alternation between the two main modes of deposition (in-situ organic versus transported silt) occurred approximately 16 times during the 7000 year period represented in the exposed sections.

The cause of the transitions from in-situ (predominantly organic) deposition to transported (predominantly clastic) deposition is no doubt related to changes in hydrological regime. The phase of organic deposition requires standing water only whereas the phase of clastic deposition requires moving water. One explanation is that the latter phase represents storm-induced flood deposits. However, also requiring explanation is that there are only 16 of these units in 7000 years, they contain high concentrations of diatom microfossils that are more consistent with slowly flowing water than with storm-induced flood events, and that accommodation space appears to be created regularly because a cyclic mode of deposition, involving continuous accretion, occurs for 7000 years. Therefore, we interpret the decimetre to metre-scale episodic changes at Hokuri Creek as a response to surface rupture of the Alpine Fault over the 7000 year time period.

Geomorphic mapping shows that Hokuri Creek used to flow across the fault scarp. Therefore with each earthquake a new scarp was raised that temporarily inhibited drainage causing a “flood” and deposition at the site of catchment-derived sediment unable to bypass the normally swampy downthrown side of the fault. Such a scenario is supported by the presence of a 1-2 event scarp across the abandoned channel adjacent to the study site.

# PRELIMINARY STRATOCLADISTIC STUDY OF NEW ZEALAND CRASSATELLID BIVALVES

**K.S. Collins[1], J.S. Crampton[1, 2], M.J. Hannah[1]**
[1]School of Geography, Environment and Earth Sciences, VUW, PO Box 600, Wellington
[2]GNS Science, PO Box 30368, Lower Hutt
katiesusannacollins@gmail.com

Stratocladistics is a development of traditional cladistics that incorporates stratigraphic data into phylogenetic analyses, and which provides opportunities to consider older fossil taxa as ancestral to younger fossil or extant taxa. In stratocladistics, assumptions of non-preservation to explain gaps in the fossil record are scored as 'stratigraphic debt' for each tree constructed, as well as the 'morphologic debt' of traditional cladistics, which is incurred by homoplasy. The most parsimonious tree is that with the minimum combined morphologic and stratigraphic debt. Using both morphological and stratigraphic data, it is hoped that more accurate phylogenies can be generated than by the use of morphology alone.

Much debate still surrounds the value of this method, and studies have produced both positive (e.g. Bodenbender & Fisher, 2001) and negative (e.g. Adrain & Westrop, 2001) evaluations. As stratocladistics relies on the reliability of the fossil record, it is best used on younger datasets of well-preserved, common species, preferably from smaller ranges.

For this study, both traditional cladistic and stratocladistic analyses of the bivalve genus *Spissatella* and the other crassatellid genera known from New Zealand (*Eucrassatella*, *Salaputium*, *Talabrica*) will be undertaken in order to test which produces the most parsimonious results. *Spissatella* is known only from New Zealand, with the exception of one species from Australia and two possible species from Argentina, and it is restricted to the late Eocene to early Miocene. This genus is, therefore, an ideal test dataset for the stratocladistic method. Previous studies that dismiss stratocladistics (e.g. Adrain and Westrop, 2001) have used datasets from much wider ranges and earlier time periods (e.g., all Laurentian trilobites) and, perhaps unsurprisingly, turned up disappointing results.

This poster will present the results of a preliminary stratocladistic and cladistic study of New Zealand crassatellid species performed in order to test the principle points of the analysis. Software used will include MacClade, Mesquite and Strata-Phy.

## A REVIEW OF THE NEW ZEALAND MACROFOSSIL MONOCOT FLORA

**John Conran[1], Jennifer Bannister[2], Daphne Lee[3]**
[1]School of Earth & Environmental Sciences, The University of Adelaide, Australia
[2]Department of Botany, University of Otago, PO Box 56, Dunedin
[3]Department of Geology, University of Otago, PO Box 56, Dunedin
john.conran@adelaide.edu.au

Although monocots are generally considered to be uncommon in the fossil record worldwide, New Zealand appears to be an exception, as there are a number of fossil sites with abundant monocot specimens representing a wide range of families. Many of these are now more abundant elsewhere and/or indicate Australian and South American links. For example, the Foulden Diatomite includes leaves from at least seven genera of monocotyledons, including new species of *Astelia* (*kowharawhara*), *Cordyline* (cabbage tree), *Luzuriaga* (lantern berry), *Ripogonum* (supplejack) and *Typha* (bullrush). Orchids belonging to *Dendrobium* and *Earina* represent the first organically preserved orchid leaves, the first fossil records of subfamily Epidendroideae, and the first Southern Hemisphere records for the Orchidaceae.

Palms are well represented in the New Zealand fossil record, indicating a previously much richer flora, with Miocene *Cocos*-like (coconut) fruits, as well as abundant leaves and reproductive structures from *Phoenicites* and *Rhopalostylis* (nikau). Another palm stem from Nevis Valley contains diagnostic phytoliths. In addition, Late Eocene *Nypa* (mangrove palm) fruits and *Calamus*-like (rattan) spiny leaves and scaly fruits are known, suggesting a much warmer climate, as their modern counterparts all have tropical to subtropical distributions.

Organically-preserved leaves (and seeds) of iconic New Zealand monocots such as *Phormium* (flax) are known from the Late Oligocene–Early Miocene Gore Lignite Measures. There is also an inflorescence with buds and spent flowers that closely matches the renga lily genus *Arthropodium.* Silcrete and other impression fossils include palms, *Ripogonum*, *Cordyline* and Zingiberales (banana/ginger?) from Landslip Hill and other localities, and there are also extensive monocot-dominated beds at presumed fossilised swamp and lake margin sites such as the Kaikorai Leaf Beds deposit.

This high diversity includes the earliest global records for several families, some of which are no longer present in New Zealand. The identity of the specimens and the filling of obvious gaps in the NZ monocot record (e.g. sedges, grasses, irises) remain high priorities and the focus of ongoing studies.

**ARC MAGMATISM ON THE GONDWANA MARGIN: BORLAND ROAD, SOUTHLAND**

**Alan F. Cooper and J. Michael Palin**
Geology Department, University of Otago, Dunedin
alan.cooper@stonebow.otago.ac.nz

The Borland Road, Western Southland provides one of the best exposed and most accessible sections through the Eastern Fiordland segment of the Gondwana margin. The basement section extends from the hydrothermally altered Cuthbert Fault zone at Borland Saddle in the west, to the Borland granite pluton in the east, where it is nonconformably overlain by platform-margin sediments of the Tertiary Waiau Basin.

The local, fault-channelled hydrothermal alteration in the west is superimposed on a suite of lithologically diverse schists and gneisses of previously unknown parentage, intruded by small (<1 km diameter) stocks of diorite (of high Sr, low Y = HiSY character). Gneisses are entrained within a titanite-porphyritic orthogneiss of HiSY composition and all units are cut by garnet-bearing granite pegmatite and aplite dykes that increase in abundance eastwards towards the contact with the HiSY Borland pluton.

Zircons separated from the various units yield the following U-Pb ages: quartzofeldspathic gneiss, dominant population 147.6 ± 2.1 Ma interpreted as an intrusive age, with low Th/U rims dated at 127.2 ± 2.6 Ma; the structurally overlying amphibolite gneiss has a single population at 128.1 ± 1.5 Ma, interpreted as the intrusive age of a HiSY magma, imposing contact metamorphic recrystallisation on the country-rock quartzofeldspathic gneisses; titanite-bearing HiSY orthogneiss, broad single population 126.1 ± 3.0 Ma; locally pegmatitic diorite, dominant population 117.4 ± 1.2 Ma with some older grains, 127-138 Ma, interpreted as representing inheritance. The Borland granite yields an age of 119.9 ± 1.3 Ma, with an Ar/Ar biotite age from associated pegmatites of 117 ± 1 Ma (Scott et al. 2009, Tectonics). Previous dates on the adjacent Titiroa pluton by Muir et al. (1998, J. Geol. Soc.) and Bolhar et al. (2008, Contr. Min. Pet.) of 120.9 ± 1.8 and 122.5 ± 1.9 Ma respectively, coupled with a common HiSY chemical composition, suggests that the Titiroa and Borland exposures form part of the same Separation Point Suite pluton.

Previous work by Scott et al. (2009, Tectonics) on a garnetiferous pelite layer interlayered with the Borland quartzofeldspathic gneiss indicates detrital zircon populations with Archean, Proterozoic, Cambrian, Ordovician, Devonian, Permian, Triassic, and Jurassic ages with low Th/U metamorphic overgrowths at 145.4 ± 2.6 Ma, indistinguishable from the intrusive age of the enclosing quartzofeldspathic orthogneiss. P-T conditions of metamorphism, assessed by garnet-biotite-plagioclase-quartz thermobarometry, are 4.2 ± 1.2 kb and 639 ± 25°C.

Collectively the field relationships, geochemistry, geochronology and thermobarometry suggest that the Borland Road exposures represents a shallow to mid-crustal section of an accreted volcanic arc terrane, that differs significantly in its provenance and subsequent Mesozoic geological history from the Western Fiordland Gondwana segment exposed west of the Grebe Mylonite Zone.

# INSIGHTS INTO CRUSTAL FLUID-FLOW NEAR THE ALPINE FAULT: MONITORING EXPERIMENTS AT COPLAND WARM SPRING

**S.C. Cox & D.T. Strong**
GNS Science, Private Bag 1930, Dunedin, New Zealand
d.strong@gns.cri.nz

Rapid uplift and strong erosion of the Southern Alps on the eastern side of the Alpine Fault has perturbed the thermal structure of the upper crust, leading to geothermal activity and a number of warm springs. Elevated topography locally drives convective circulation and cooling from the surface, whereas rapid uplift and conduction drive buoyancy driven circulation from depth. The effects of this geothermal system on Alpine Fault earthquake nucleation, rupture propagation and seismic hazard are unclear. High geothermal gradients and high fluid pressures are expected to reduce the effective normal stress on the fault and suppress velocity weakening, promoting stable sliding rather than stick-slip (earthquake) processes. Because the seismic cycle is fundamentally controlled by fluids and fluid circulation, improved knowledge of hydrothermal circulation in the shallow crust is paramount to understanding earthquake processes. Establishing the regional permeability structure of the Southern Alps is a critical parameter for numerical modelling of fluid flow in and around the Alpine Fault. A series of experiments is currently underway to develop our understanding of shallow hydrothermal circulation and heat flow in the Southern Alps.

New geochemical, stable and radiogenic isotope samples have been collected from spring waters, travertine deposits, fault-rocks and veins throughout the alps for the purpose of characterising fluid sources, ages and flow-paths. At Welcome Flat, Copland Valley, thermal mapping at depths of ~0.7 m has defined a 3,300 $m^2$ anomalous zone where ground temperature is elevated consistently above mean annual air temperature. Ground temperatures reach 56°C adjacent to an upwelling spring and decay to 45°C at a distance of ~2.5 m, and 20°C at ~10 m. The spring discharges strongly effervescent $CO_2$-rich water into a pool, then down a single channel at 6 ± 1 litres/sec. At ~0.7 m depths, anomalous ground temperatures reflect heating from both the upwelling spring and surficial crossflow. Rainfall, air and pool water temperatures have been continually monitored since March 2009, with 3.5 m of rain falling between March and Sept 2009, mostly during 13 storm events. Pool water temperatures fluctuated at background values between 57-58°C, with possible diurnal variation, but fell dramatically during episodes of heavy rainfall to as low as 38°C. Water temperature fluctuations reflect dilution of deep upwelling fluids by surficial meteoric water, with recovery to background values taking 3-5 hours after rain stops falling. A 0.9°C decay in temperature occurred in the four days following the magnitude 7.8 Fiordland earthquake of 15 July 2009. Water isotopic compositions (tritium TR = 0.30–0.34; deuterium D=-65.9 and oxygen $\delta^{18}O$=-8.99 per mil rel. to SMOW; carbon $\delta^{13}C$= -4.9 per mil rel. to PDB) are similarly affected by near-surface mixing processes. Understanding relationships between rainfall, temperature, and appropriate times for sampling enables geochemical and isotopic methods to be used to characterise fluid circulation. Work continues to model fluid-flow paths and heat-flow at Welcome Flat.

# FAULT WEAKENING DURING DISSOLUTION-MEDIATED FRICTIONAL SLIDING ON BARE INTERFACES AT HYDROTHERMAL CONDITIONS

**S.F. Cox**
Research School of Earth Sciences, The Australian National University, Canberra ACT 0200, Australia
Stephen.Cox@anu.edu.au

Bare interface sliding experiments conducted on quartz sandstone at 1200K, 300MPa confining pressure, 200MPa pore fluid pressure, and at displacement rates between $0.1\mu ms^{-1}$ and $0.9\mu ms^{-1}$, demonstrate that the friction coefficient in the presence of chemically-reactive pore water is much lower than in dry regimes. At hydrothermal conditions, dynamic friction is substantially less than the static friction prior to commencement of slip. The initiation of sliding is characterised by a large, slow stress drop and subsequent stable or unstable sliding with friction coefficients as low as 0.25. Although microstructures on slip interfaces indicate that dissolution-precipitation processes are very active during sliding at hydrothermal conditions, the development of dissolution-modified wear tracks, occurrence of stick-slip behaviour, and low rate-dependence of shear strength, all indicate that shear strength is controlled by frictional processes. At high temperature hydrothermal conditions, dissolution-precipitation reactions are interpreted to reduce resistance to frictional sliding at asperity contacts. Reactive pore fluids may be important in modifying friction processes and the stability of faults in fluid-active environments near the base of the seismogenic regime in the continental crust. The large, slow stress drop associated with slip localisation and dissolution-mediated frictional sliding at low friction coefficients may also provide a mechanism for slow earthquakes and episodic tremor and slip at some subduction interfaces, and in some continental fault zones.

**MINERALOGY AND GEOCHEMISTRY OF ANTIMONY AT REEFTON AND MACRES GOLD MINES, NEW ZEALAND**

**Dave Craw[1] , Lisa Milham[1], Tim Muller[2]& Jim McQuillan[2]**
[1] Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. of Chemistry, University of Otago, PO Box 56, Dunedin
dave.craw@stonebow.otago.ac.nz

Ore at the new Reefton gold mine formed in two stages. The first stage involved quartz veins with pyrite and arsenopyrite. The second stage involved brecciation and cataclasis of quartz veins and wall rocks, with addition of pyrite, arsenopyrite, and stibnite ($Sb_2S_3$). Processing of this ore has resulted in some Sb mobilisation in mine waters. A gold-bearing sulphide concentrate from the Reefton ore processing system is transported 700 km to the Macraes mine in Otago for final processing and gold extraction. The Macraes gold mine has no stibnite, and the little Sb that is at Macraes is in solid solution (up to 2000 mg/kg) in the abundant arsenopyrite, or in rare grains of boulangerite ($Pb_5Sb_4S_{11}$). Gold extraction from both Reefton and Macraes ore involves cyanidation after oxidation at 225ºC in an autoclave. Introduction of Reefton ore to the Macraes site increases the Sb content of the process stream. Tailings from this process have up to 3 wt% Sb dispersed through As-rich iron oxyhydroxides that are formed in the autoclave. Adsorption of Sb to iron oxyhydroxides in the tailings piles removes dissolved Sb from tailings waters. Sb contents of mine waters discharging from both mine sites are generally low (<0.01 mg/L) and dissolved Sb is less than dissolved As. However, arsenic extraction by adsorption to iron oxyhydroxides is locally more effective than Sb extraction, resulting in some waters with Sb>As. Laboratory experiments show that in solutions with mixed Sb and As, As adsorption is more robust than Sb adsorption at circumneutral pH that prevails at both mine sites.

# GOLD-BEARING VEINS IN NORTHERN VICTORIA LAND, (ANTARCTICA): STRUCTURE, HYDROTHERMAL ALTERATION AND IMPLICATIONS FOR THE PALEO-PACIFIC MARGIN OF GONDWANA

**L. Crispini[1], L. Federico[1], G. Capponi[1] & F. Talarico[2]**
[1] Dip.Te.Ris., University of Genova, Corso Europa 26, 16132 Genova, Italy
[2] Dipartimento di Scienze della Terra, Via Laterina 2, 53100 Siena, Italy
crispini@dipteris.unige.it

Here we describe a syntectonic gold-bearing vein system that occurs in northern Victoria Land (Antarctica). It represents the first signalled occurrence of gold mineralization in the Transantarctic Mountains. The gold-bearing quartz-carbonate vein system is linked to a fault zone hosted in the Bowers Terrane, in the eastern sector of the Bowers Mountains. Here the Bowers Terrane consists of greenschist to low greenschist facies metabasalts (Glasgow Formation) and metasediments with volcaniclastic components (Molar Formation) of Middle Cambrian age. The Glasgow and Molar formations are deformed by regional scale NW-SE-trending folds, with an associated subvertical axial plane cleavage. This ductile structural arrangement is linked to the Paleozoic Ross/Delamerian orogeny and is then overprinted by a dominant reverse/transpressive fault system.

The vein network is hosted mainly in the metabasalts and is surrounded by a brown-reddish hydrothermal alteration zone approximately up to 500 m wide, bounded by faults and fractures. The main vein is basically composed by quartz with minor carbonates and is up to 2 m wide and up to 250 m long; here gold was found as mm-scale nuggets and as mm- to submm-scale grains associated with silver, arsenopyrite and an iron-arsenic compound. The content of gold in analysed samples is up to 3980 ppb.

From the structural point of view the veins are associated to a brittle-ductile high strain zone where the host rocks are foliated and highly fractured. The damage zone is characterized by different types of fault rocks (foliated cataclasite, hydraulic breccia, gouge) and by widespread veining and fracturing; all these structures overprint the Ross-related regional metamorphic foliation. In the hydrothermal alteration zone the host rocks are partially to completely transformed into Fe-Mg carbonate-rich rocks with different degree of replacement of the original assemblage and texture of the metabasalt.

The features of this mineralization match most of the characteristics of the deposits commonly classified as mesothermal gold or orogenic gold deposits; hence a link to the Paleozoic Ross/Delamerian orogeny is the more feasible option. Since gold formation was a process active during the Paleozoic all along the former (more than 4000 km-long) paleo-Pacific margin of Gondwana, this finding is noteworthy to refine plate tectonics correlations. Comparisons with goldfields of southeastern Australia, Tasmania and New Zealand is still hampered by lack of geochronologic data; however, deposits with similar characteristics crop out in the Stawell Zone of southeastern Australia.

## GREENHILLS COMPLEX DUNITE: MINERALOGY, GEOCHEMISTRY AND POTENTIAL FOR CARBON SEQUESTRATION

**Anthony Cross & J. Michael Palin**
Department of Geology, University of Otago, PO Box 56, Dunedin
croan343@student.otago.ac.nz

The Greenhills Complex is a composite ultramafic to mafic layered igneous intrusion located on the Bluff Peninsula, 30 km south of Invercargill. Two principal lobes range from dunite at their base through olivine clinopyroxenite to gabbro. On the basis of crystallisation sequence, mineral composition and melt inclusion compositions (Spandler et al., 2000), the intrusion appears to have formed from primitive hydrous basaltic magmas in feeder chambers beneath an island arc volcanic complex as part of the Permian Brook Street Terrane.

Dunite of the south lobe is well exposed in the Greenhills Quarry. The dominant primary mineral is cumulus olivine with minor intercumulus chromian spinel and clinopyroxene and rare orthopyroxene and plagioclase. A series of dykes of varying composition cross cut the dunite, forming small zones of plagioclase-rich rocks. Spandler et al. (2000) also report the occurrence of platinum-group minerals (PGM) in chromian spinel at one location just south of the quarry. However, petrographic examination of chromian spinel in this study has not revealed any PGM to date.

Olivine in the dunite is fractured and partially replaced by serpentine and magnetite. XRD analysis of four alteration rims of the dunite and one white vein has identified calcite, clinocrysotile, chlorite, talc, tremolite and other rarer amphibolites and phyllosilicates. Bulk rock volatile element (CHNS) and carbonate C-O stable isotope analyses will allow the abundance and origin of low-temperature secondary minerals to be determined.

An assessment of the dunite for potential in-situ mineral carbon sequestration is being undertaken. Recent studies have shown that natural rates of carbonation of olivine-rich peridotite (Keleman & Matter, 2008) and serpentinite mine tailings (Wilson et al., 2009) are much faster than previously thought. These rates should be further enhanced in the subsurface because the carbonation reactions are exothermic and, in the case of serpentine-bearing rock, lead to increased porosity. If the dunite has sufficient fracture permeability at depth, it is conceivable that $CO_2$ could be injected at a flow rate sufficient for heating due to carbonation to balance cooling due to advection and diffusion in order to maintain an optimal temperature for rapid reaction.

References:

Keleman, PB and Matter, J. 2008. Proceedings of the National Academy of Sciences 105(45): 17295–17300.

Spandler, CJ, Eggins, SM, Arculus, RJ, Mavrogenes, JA. 2000. Geology 28: 991-994.

Wilson, SA, Dipple, GM, Power, IM, Thom, JM, Anderson, RG, Raudsepp, M, Gabites, JE, Southam, G. 2009. Economic Geology 104:95–112.

## EXPLOSIVE VOLCANISM IN THE CHATHAM ISLANDS: ORIGIN OF THE RANGIAURIA BRECCIA

**D. Crowley, K. Németh, V.E. Neall, H. Campbell, C. Wallace, R.B. Stewart**
Massey University, Private Bag 11 222, Palmerston North, NZ
debscrowley@hotmail.com

Pyroclastic debris-filled pipes of small-volume monogenetic volcanoes are commonly associated with phreatomagmatism and maar-diatreme volcanism. Although such pipes always exhibit angular unconformity with respect to the host rocks they penetrate, the mode of eruption, and the environment of eruption, is not immediately obvious from pipe geometry and internal structure. This issue is even more pronounced in cases where explosive monogenetic volcanism occurs in shallow subaqueous environments where pipes have cut through surficial country rocks that are water-saturated and/or loose (i.e. a soft-rock eruptive environment).

The current study is based on the vent/conduit remnants of a Late Miocene to Pliocene volcanic field in the Chatham Islands, mapped as the Rangiauria Breccia. The data were obtained from well-preserved sections in coastal exposures on Mangere Island and along the west coast of Pitt Island, at Waihere Head and Rangiauria Point.

Geological attributes (stratigraphy, structure) suggest that occurrences of the Rangiauria Breccia are near-vent lapilli tuff and tuff units comprising pyroclastic debris vent/conduit-filling volcanic necks. Here we present field and rock texture-based evidence of these conduit/crater-filling pyroclastic debris and immediate near-vent pyroclastic successions.

The abundance of gravel-size hornblende xenocrysts and disaggregated magma clots suggests rapid magma ascent rates and high explosivity. Significant excavation by vent/conduit processes are reflected in the presence of significant volumes of non-volcanic and volcanic-lithic country rocks. Textural consideration of the pyroclastic breccias reveals that they are primary in origin and suggest a fragmentation style triggered by magma interaction with external water. Waihere Head in particular exhibits an extensive exposure of the vent area along with proximal through to distal deposits.

A detailed picture of the sequence of events involved in the formation of these volcanoes is beginning to emerge. Given their primary, phreatomagmatic-dominated origin, they offer potential new understanding of the life cycle of a “wet” volcano (Surtseyan and/or maar-diatreme volcano).

# INVESTIGATING TROTTER'S GORGE AND OFFSHORE SHAG POINT: UNDERSTANDING THE WAIHEMO FAULT

**C. Curran[1], R.J. Norris[1], A.R. Gorman[1]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin, New Zealand
claudine_curran@yahoo.co.uk

The Waihemo Fault System is a major NW trending structural feature in the north Otago landscape. It lies at the base of the Kakanui Ranges, which are the result of an inversion regime, reactivating mid-late Cretaceous normal faulting in the late Cenozoic. The fault system merges with the Hawkdun Fault System at its northern flank, runs offshore at Shag Point, and is aligned with the southern edge of the Bounty Trough. Its relationship with similar parallel-trending faults in the Otago Schist, such as the Hyde-Macraes Shear Zone, the Rise-and-Shine Shear Zone and the Cromwell Gorge Shear Zone, is poorly understood, but it is considered to be associated with the extensional exhumation of the schist ~110 Ma.

This major crustal structure, as suggested by its lateral continuity, forms the main structural divide between the greenschist facies of the Central Otago Schist, and the prehnite-pumpellyite facies of the Kakanui Ranges. Its lateral continuity belies the fact that it is a complex structure, made up of many segments, with varying degrees of reactivation along the different strands. The greatest movement has occurred along the northern strands, whereas the amount of reverse thrusting diminishes with proximity to the coast.

Presented are the results of high-resolution seismic acquisition and side-scan sonar investigations from offshore Shag Point. These data provide an indication of the extent of movement there. This is linked with an onshore explosive seismic survey in the Trotter's Gorge area, acquired to further investigate the dynamics of this structure and the mechanics of reactivation. With indications of normal faulting offshore and substantial reverse movement further inland, this area near to the coast is critical in understanding the reverse reactivation movement in its early stages. To help with establishing movement timing within the complex strands of the fault system in this area, a revision of McMillan's (1999) GNS map is presented, as is preliminary work on establishing total offsets along the Waihemo Fault System.

The "Waihemo Fault System" fieldtrip offered during this conference will look at some of the fascinating geological features associated with this elusive and complex system.

Reference:
McMillan, S.G. (1999): Geology of Northeast Otago: Hampden (J42) and Palmerston (J43). Institute of Geological & Nuclear Sciences science report 98/25. 2 sheets + 55 p.

# METASTABLE PERSISTENCE OF PELITIC ASSEMBLAGES DURING HIGH-P GRANULITE FACIES METAMORPHISM OF INTERMEDIATE-MAFIC ORTHOGNEISS, FIORDLAND, NEW ZEALAND

**Nathan R. Daczko[1], Luke A. Milan[1], Jacqueline A. Halpin[1,2], Andrew Allibone[3] & Geoffrey L. Clarke[4]**
[1]Dept. of Earth & Planetary Sciences, Macquarie University, NSW, 2109, Australia
[2]CODES, University of Tasmania, Private Bag 126, TAS 7001, Australia
[3]Rodinian Pty Ltd, P.O. Box 1970, Queanbeyan, NSW 2620, Australia
[4]School of Geosciences, The University of Sydney, Sydney, NSW 2006, Australia
ndaczko@els.mq.edu.au

Aluminosilicate-bearing, amphibolite facies pelitic schists were intruded by diorite of the Early Cretaceous (116-124 Ma) Western Fiordland Orthogneiss (WFO) at high-P (12 kbar) in the root of the long-lived eastern Gondwana continental magmatic arc now exposed in southwest Fiordland, New Zealand. The WFO partially recrystallised to garnet granulite facies assemblages as the plutons cooled. The pelitic schists record remarkably different P-T-t histories from each other and the WFO. Integrated petrography, mineral chemistry, mineral equilibria modelling and in situ electron microprobe chemical dating of monazite shows that one pelitic sample records a Carboniferous history with peak conditions of 4-4.5 kbar at 570-590 ºC, while a second sample records a Cretaceous history with apparent peak conditions of 7.5 kbar at 650 ºC. Two other pelitic samples record mixed Carboniferous and Cretaceous histories with apparent peak conditions of 7 kbar at 650 ºC and 3-7 kbar at 640-720 ºC. Though intruded by arc magmas including the voluminous high-P WFO, much of this arc country rock lacks mineralogical evidence of the Cretaceous high-P (> 12 kbar) event. Analysis of water isopleths in a model system shows that the amount of water accommodated in the rock mineral assemblage increases with pressure. With the exhaustion of all free water, and without the addition of external water, these rocks persisted metastably within the deep arc during the high-P event. The emplacement of large volumes of diorite (i.e. the Western Fiordland Orthogneiss) into the root of the Early Cretaceous continental magmatic arc lead to the development of a narrow thermal aureole, restricted to ~200-1000 m. The voluminous magmatism did not lead to regional granulite facies metamorphism of the country rock schists, as large volumes of amphibolite facies rock metamorphosed under medium-P conditions persisted metastably in the deep arc crust.

**CRUSTAL SEISMIC REFLECTION PROFILE ACROSS THE ALPINE FAULT AND COASTAL PLAIN AT WHATAROA, SOUTH ISLAND**

**F.J. Davey**
GNS Science, PO Box 30368, Lower Hutt
f.davey@gns.cri.nz

Crustal seismic reflection data were recorded across the Alpine Fault and coastal plain at Whataroa in 1998, as part of the SIGHT experiment that investigated the deformation associated with the Southern Alps orogen. The 25 km long profile followed the line of SIGHT Transect 1. A single 636 channel recording array was deployed along the profile from just southeast of the Alpine Fault on the Whataroa River to about 5 km short of the coast. 25 kg shots were fired at 1 km intervals with intervening shots of 12.5 kg at about 250 m intervals along the profile. Record quality varied from good to abysmal. Some records showed good arrivals, but others showed little coherent signal apart from in some cases very strong low frequency ground roll and in others relatively high frequency ringing. The reflection data were processed as a crooked line and in two parts – a shallow section (0 – 4 seconds two-way time (s twt)) and a deep section (0 – 14 s twt). The long recording array allowed a simple refraction model to be produced by forward modelling of first arrivals. The south-eastern part of the shallow reflection profile (1 – 5 fold) across the Alpine Fault images a poorly defined basement at about 0.2 – 0.5 s twt depth, possibly deepening slightly to the northwest across the mapped fault trace. Refraction data shows little change in depth at this position, although side-swipe from an adjacent bluff is recorded. No reflection on the seismic section can be confidently attributed the Alpine Fault, but a distinct event on one shot gather is consistent with a steeply dipping Alpine Fault. Basement deepens sharply about 6 km northwest of the fault along the profile, and a 3 km section of probably Miocene and younger sediments is imaged along the northern end of the profile. No distinct feature corresponds to the South Westland Fault. The deeper section was produced by stacking nmo-corrected variable angle reflection data from the few good quality records of the larger shots. A distinct band of strong reflectivity occurs at a depth of about 10 s twt, the base of which is inferred to be Moho. Depth conversion, based on stacking and Transect 1 seismic velocities, gives a horizontal Moho across the whole profile at a depth of about 28 – 30 km.

# THE EVOLUTION OF MILFORD SOUND - A TEMPERATE FIORD ON A TRANSFORM PLATE BOUNDARY

**T.R. Davies & J.L. Dykstra**
Dept. of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch
jesse.dykstra@pg.canterbury.ac.nz

The geomorphic and sedimentary evolution of New Zealand's Fiords reflects their unique setting. I present a potential model for the unique evolution of New Zealand fiords, supported by recent seismic reflection and high-resolution sonar data.

Fiordland lies in a temperate marine climate zone, and is bounded to the west by an active transform plate boundary, where the Indo-Australian Plate collides with the Pacific Plate. The extreme topography of the Fiordland mountains acts as a barrier to the prevailing westerly winds, resulting in extreme precipitation. During the Last Glacial Maximum (LGM), these unique climatic and tectonic conditions were favourable for the progression of tide-water glaciers, which deposited material in great fans at the edge of the narrow continental shelf. It is likely that these glaciers were relatively short-lived, but highly productive.

During the LGM, New Zealand was modestly glaciated, consequently the signature of global eustatic sea level change overrides any isostatic signature. Fiordland glaciers were likely to have retreated very quickly, starting approximately 17 ka, while global sea levels were still much lower than present day. Freshwater fiord lakes would have occupied the basins during the early stages of glacial retreat, as marine transgression was blocked by entrance sills. Headwater glaciers may have retreated very quickly, resulting in a drastic reduction in sediment production and transport. Finally, eustatic sea level rise resulted in marine transgression, with freshwater lakes becoming estuaries.

In general, this model for fiord evolution in south-western New Zealand is well supported by recent data. In fiords south of Milford Sound, laminated post-glacial marine and lacustrine sediments overly massive deposits of glacial till and landslide debris. However, interpretation of the data for Milford Sound suggests that the majority of post-glacial sediment infill has been contributed by mass wasting. High-resolution multi-beam sonar data from Milford Sound clearly shows the presence of large rock avalanche deposits, which blanket much of the fiord bottom. Early interpretation of seismic data suggests that laminated sediments are largely absent in Milford Sound. Instead, post-glacial sediment infill is dominated by massive deposits of avalanche debris.

The apparent paucity of laminated marine or lacustrine sediments at Milford Sound is in marked contrast to the proposed evolutionary model for New Zealand fiords. My talk will cover the unique evolutionary history of Milford Sound, and contrast it to that of other New Zealand fiords. I also relate the evolutionary history of Milford Sound to its' present geomorphology, and suggest implications for natural hazards and associated risk.

**THE ECLOGITE – GRANULITE TRANSITION: MAFIC AND INTERMEDIATE ASSEMBLAGES AT BREAKSEA SOUND, FIORDLAND**

**De Paoli, M.C.**[1,] **Clarke, G.L.**[1] **Klepeis, K.A.**[2] **Allibone, A.H.**[3] **& Turnbull, I.M.**[4]
[1]School of Geosciences, F09, University of Sydney, 2006, Australia
[2]Dept. of Geology, The University of Vermont, Burlington, VT, 05405, USA
[3]Rodinian Pty Ltd, PO Box 1970, Queanbeyan, NSW, 2620, Australia
[4]GNS Science, Private Bag 1930, Dunedin, New Zealand
m.depaoli@usyd.edu.au

The Breaksea Orthogneiss, a high-pressure component of the c. 126-116 Ma Western Fiordland Orthogneiss, has distinctive composite gabbroic layering and dyke structures in a dioritic host, mostly transposed into an intense shallowly dipping $S_1$ foliation. Delicate cm to m-scale layering and dyking structures are interpreted to reflect mafic sill emplacement and/or cumulate processes. Gabbroic gneiss components preserve eclogite facies $S_1$ garnet, omphacite and rutile, with or without orthopyroxene, interlayered with dioritic gneiss components that preserve granulite facies assemblages involving $S_1$ garnet, omphacite, plagioclase, antiperthite, rutile and kyanite. As both eclogite and granulite assemblages reflect peak conditions involving pressures ≈ 18 kbar and temperatures ≈ 850°C, the Breaksea Orthogneiss presents a unique natural example of the eclogite–granulite transition. The facies distinction was controlled by whole rock composition, whereby mafic, gabbroic components recrystallised to eclogite and felsic, dioritic components recrystallised to granulite. Omphacite in both components is partially pseudomorphed by post-$S_1$ symplectites of sodic–diopside and plagioclase that reflect near-isothermal decompression to pressures ≈ 14 kbar. The Breaksea Orthogneiss also occurs as pods and layers within the post-$S_1$/$S_2$ gabbroic Resolution Orthogneiss, which is distinguished on the basis of it mostly lacking garnet and being homogeneous. Along the northern shore of Resolution Island, hornblende granulite and high-pressure amphibolite facies $S_2$ assemblages involving garnet, hornblende and clinozoisite are well developed in both the Breaksea and Resolution orthogneisses. A 200 m thick, shallowly north-dipping $D_2$ shear zone forms a carapace to these orthogneiss units, and separates them from other Cretaceous orthogneiss and Palaeozoic schists that reflect lower grade conditions (pressures ≈ 12-14 kbar). The Breaksea Orthogneiss extends the thickness of the Cretaceous island arc developed off the New Zealand sector of the Gondwana margin to more than 60 km, close to the thickest of known Andean-style margins.

# PLIO-PLEISTOCENE VARIATIONS OF THE ANTARCTIC ICE SHEET: IMPLICATIONS FOR FUTURE SEA LEVEL

**R. DeConto**[1] **and D. Pollard**[2]
[1]Dept. of Geosciences, University of Massachusetts, Amherst MA 01002 USA
[2] Earth and Environ. Syst. Inst., Penn State University, State College, PA 16802 USA
deconto@geo.umass.edu

A new 3-D ice sheet-shelf model, Global Climate Model (GCM) and nested Regional Climate Model (RCM) are applied to the Antarctic region, with simulations designed to span the full range of Pliocene to modern climatic forcing. The ice sheet model simulates a dynamic West Antarctic Ice Sheet (WAIS), in agreement with new proximal sediment records from the Ross Sea Embayment (ANDRILL). Repeated, sudden retreats and readvances occur throughout the Pliocene and Pleistocene. Simulated WAIS variability in the Pliocene is dominated by 40-kyr cyclicity. Major WAIS collapses are less frequent in the Pleistocene, but do occur during a number of apparent "super-interglacials", including MIS 31. WAIS is shown to be most sensitive to changes in sub-ice oceanic melt, however changes in East Antarctic Ice Sheet (EAIS) volume driven by this mechanism are shown to be limited. Maximum equivalent sea level rise simulated by the model is ~7 m, most of which is contributed by WAIS retreat. This is significantly less than the amount required to match estimates of sea level during the Pliocene (~25-40 m) and some Pleistocene interglacials (e.g., MIS 11; 20+ m), even with an additional contribution from Greenland (~7 m). We use a nested, high resolution GCM-RCM to test the potential for an additional contribution to sea level rise via surface melt on the EAIS, but find that the combined forcing from elevated Pliocene $CO_2$ (400 ppmv), increased oceanic heat flux and reduced sea ice, warm austral summer orbits, and the loss of WAIS do not provide enough additive warming to produce significant summer ablation on the flanks or interior of the EAIS. This important model-data discrepancy implies either that the ice sheet model is lacking some critical underlying physical processes, the climate model is undersensitive to greenhouse gas forcing, or the sea level estimates during these periods are unrealistically high. We conclude by exploring the potential for more EAIS variability in the ice model by considering alternative treatments of both the conditions at the bed of the ice sheet and poorly constrained topographic boundary conditions – especially in potentially sensitive, low-lying regions of the East Antarctic margin which may have been prone to grounding line retreat and ice sheet drawdown. Finally, simulations with increased oceanic sub-ice melt rates are considered in the context of possible future Southern Ocean warming.

## HYDROTHERMAL SYSTEMS OF INTRAOCEANIC ARCS — A 10 YEAR ODYSSEY OF EXPLORATION

**Cornel E.J. de Ronde**
GNS Science, 1 Fairway Drive, Avalon 5010, Lower Hutt
Cornel.deRonde@gns.cri.nz

Since 1998, concerted efforts to locate, delineate and characterise seafloor hydrothermal systems has occurred along intraoceanic arcs. The numerous expeditions include research platforms from New Zealand, USA, Germany, Japan and Australia. These efforts concentrated firstly along the Kermadec arc, followed by surveys along the Mariana arc and southern Tonga arc, with 91 separate volcanic centers (some of which are host to more than one volcano) having been surveyed, representing ~43% of intraoceanic arcs worldwide. Initial studies focused on water column surveys of the hydrothermal plumes, in concert with detailed swath mapping of volcano bathymetry. Four dedicated plume surveys covered the Kermadec arc and part of the Tonga arc, and one along the Mariana arc. Forty three of the 91 (47%) volcanic centres of the combined Kermadec and Mariana inventory are host to active hydrothermal systems. These studies showed increasing frequency of venting along the Kermadec arc, from south to north, as the active arc front migrated from the backarc and merged with the Kermadec Ridge. By contrast, a less systematic pattern of venting frequency occurs along the Mariana arc. Projection of the frequency of hydrothermal activity found along the Mariana and Kermadec arcs to other intraoceanic arcs shows that at least 100 submarine volcanoes might be active for intraoceanic arcs worldwide. This is equivalent to ~10% of hydrothermal emissions from the global mid-ocean ridge system.

For both the Kermadec and Mariana arcs, caldera volcanoes appear twice as likely as cones to be hydrothermally active. Caldera-type volcanoes are more commonly found where the active arc front sits atop older volcanic ridges, like the Kermadec Ridge, and have more evolved lava compositions, such as dacites and rhyodacites. Hydrothermal systems hosted by caldera volcanoes are also commonly deeper than those of volcanic cones, with hydrothermal fluid discharge more focused and having hotter temperatures (up to 300°C). By contrast, the majority of cone volcanoes that host hydrothermal systems are dominated by low temperature (<120°C), diffuse venting.

Follow-up manned submersible (2) and autonomous underwater vehicle (1) cruises along the Kermadec arc, and remotely operated vehicle cruises along the Mariana arc (3) are consistent with the plume studies, showing that many of the hydrothermal system vent fluids are very acidic and dominated by magmatic volatiles, though lack significant concentrations of metals. Seafloor manifestation of these magmatic-hydrothermal systems is marked by large amounts of sulphur. Only 4 volcanic centres are known to host massive sulphide chimneys, dominated by Zn and Ba, though locally have significant Cu-Au mineralization.

# PALEOSEISMIC INSIGHT GAINED BY AUGMENTING LiDAR WITH GPR

**A.J. Dougherty,** M. Summers, D. Gravley & D. Hikuroa
Institute of Earth Science and Engineering, 58 Symonds St., Level 6, Auckland 1142
a.dougherty@auckland.ac.nz

Like many places in New Zealand, Rangitaiki Plains is a tectonically active region and consequently is the focus of several different types of geological hazards. Over the last 8,000 years deposition of volcaniclastic material has kept pace with rapid subsidence in this eastern margin of the Taupo volcanic zone. The resulting 8km wide progradational barrier records the influence of various geologic agents on its evolution within its accreting layers. Recent evolutionary studies of progradational barriers in the tectonically quiet Northland utilized ground penetrating radar (GPR) to detail their subsurface stratigraphy; within this context differences in the Rangitaiki Plain can be attributed to the influence of tectonics. Light detection and ranging (LiDAR) has recently delineated previously unmapped faults by detailing offset of surface features throughout the barrier plain (Begg et al., 2009). The malleable nature of these coastal and riverine landscapes affords the possibility of reworking the morphology, especially in the vicinity of faults where the resulting upthrown and downthrown sides could be modified differently. GPR affords the technology to extract true displacement preserved within the stratigraphy as demonstrated by the detailed image of the Edgecumbe Fault rupture in Figure 1. Geophysical mapping of subsurface fault structures, targeted from the LiDAR, replicated surface displacement within the offset of the stratigraphic beach-dune interface preserved in these young seaward dune ridges (Begg et al., 2009). This corroboration does not appear to continue in a landward direction as GPR collected over the entire width of the barrier revealed twice as much subsidence preserved within the beach-dune interface as that measured from dune morphology in the LiDAR (Begg et al., 2009). These preliminary results clearly demonstrate the utility of GPR and LiDAR in detailing paleoseismicity. Integrating these two remotely sensed techniques provides a new methodological approach to mapping previously unknown faults in areas known to be tectonically active but relatively bereft of fault data. Ultimately resolving surface and subsurface faults in these areas greatly increases the understanding of seismic hazard to the region and by implication may elucidate seismic controls and/or interactions with magmatism, volcanism, geothermal, flooding, and relative sea level (storm surge and tsunamis) as part of a much broader multi-hazard analysis.

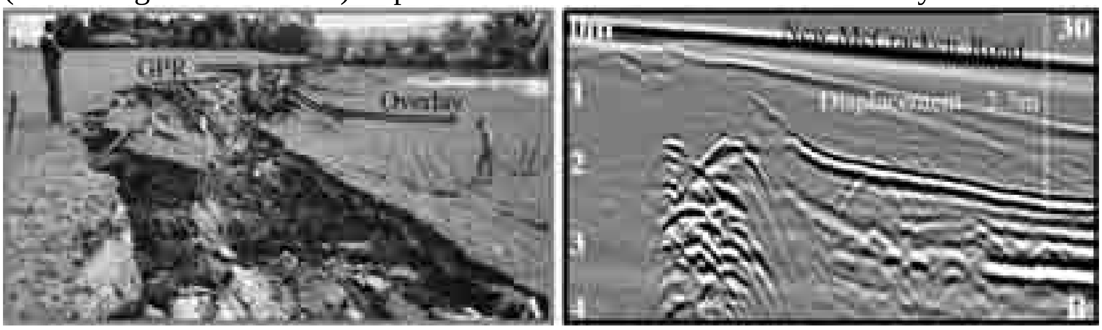



Figure 1: A) 1987 photo of Edgecumbe Fault 2.5m scarp north of McCracken Road. B) GPR detailing the rupture stratigraphy preserved under new McCracken Road.

# USING COMPUTER MODELS TO QUANTIFY NEW ZEALAND GLACIER FLUCTUATIONS OVER THE PAST 13,000 YEARS

**A. Doughty, A. Mackintosh & B. Anderson**
Antarctic Research Centre, Victoria University of Wellington, PO Box 600, Wellington
alice.doughty@gmail.com

New Zealand paleoclimate records of the past 13,000 years span a wide range of proxy records, each of which responds to a specific season and climatic component. Moraines afford the opportunity to date the age of their deposition and map past extents of the ice front. Paleoclimate reconstructions of moraine chronologies are typically represented in Equilibrium Line Altitude (ELA) fluctuations, which are then converted to temperature changes. Rother and Shulmeister (2006) report not only the importance of precipitation in glacier mass balance, but that it can be the sole cause of glacier advances in high precipitation regions. I will evaluate the effects the two variables, precipitation and temperature, have on glacier fluctuations using a combination of empirical field evidence and numerical modelling from several new sites. With the results of these tests, the available high-resolution moraine chronologies, moraine sequence positions, and further numerical modelling, I will attempt to interpret Holocene and Late Glacial climate in the Arrowsmith and Ben Ohau ranges. This unique combination of data and interpretation will allow us to constrain an envelope of possible climatic conditions necessary for the glacier to advance and stabilise at specified lengths. Because the moraines are dated, these climatic conditions can then be linked to specific times, allowing for comparisons with other local climate proxy records, such as tree ring, pollen, chironomid, and sea surface temperature records. My findings have the potential to help us identify basin-to-basin variations in climate change within New Zealand, differences between the signals coming from various proxy records, and reasons why the "Little Ice Age" in New Zealand was such a minor event compared to others during the Holocene.

**TEMPORAL AND SPATIAL CHANGES OF EVOLVING AND COALESCING LAHARS AT SEMERU, INDONESIA**

**E.E. Doyle[1], S.J. Cronin[1], S.E. Cole[1], J.-C. Thouret[2]**
[1]Inst. Natural Resources, Massey University, Private Bag 11 222, Palmerston North
[2]Laboratoire Magmas et Volcans, Université Blaise Pascal, Clermont-Ferrand, France
emmadoyle79@gmail.com

Scientific observations of active lahars are scarce. We present multi-parameter recordings of rainfall induced lahars at Semeru Volcano, East Java, using two observation sites c. 510 m apart, 11.5 km from the summit. Here the Curah Lengkong channel is composed of a 30-m wide box-valley, with a base of gravel and lava bedrock. This represents a real world flume analogy, providing vital data to better characterize and understand the processes and evolution of lahars. Instrumentation included video cameras (flow velocity, stage, and flow rheology), pore-pressure sensors, a 3-component broad-band seismometer, in addition to direct bedload and suspended load sampling. A total of 8 rainfall induced lahars were recorded, with durations of 1 - 3 hours. Observed flow types ranged 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 25-250 m3/s. The lahars were commonly characterized by a rapid onset, with surging and unsteady flow reflected in the stage records. Sediment concentration maxima lag the lahar fronts by 10-30 minutes.

The complex lahars were commonly composed of a series of partly coalesced, discrete and unsteady gravity currents, most likely originating from multiple sources. These original flows continue to behave independently as the lahar moves downstream, and are identified as ‘packets’. These individual packets can be traced between instrument sites. Those with the highest concentrations and greatest wetted areas were often located mid-lahar at our measured reach, accelerating towards the flow front. These may either be consuming the material in front of them, or forcing it to shorten and thicken. Thus, the individual packets coalesce and organization in the flow improves, forming a single mature lahar as they travel downstream. Observations of different degrees of coalescence between these discrete flow packets illustrate that a single mature debris flow may have formed from multiple dynamically independent lahars, each with different origins. Estimates of cumulative volume for a few typical events suggest that the flow is bulking during the main body of the lahar, and debulking during tail flow. This investigation indicates that the use of two closely located geophysical instrument sites provides a critical opportunity to constrain the active physical processes within these complex flows, thus furthering both our physical understanding and their numerical description, vital for the continued development of hazard mitigation tools.

## INDONESIAN GEODYNAMICS AND PALEOCEANOGRAPHY REVEALED IN AN EXHUMED PLIOCENE FOREARC BASIN, TIMOR LESTE

**B. Duffy[1], M. Quigley[1], D. Haig[2] & K. Bassett[1]**
[1]Department of Geological Sciences, University of Canterbury
[2]School of Earth and the Environment, University of Western Australia
bgd20@student.canterbury.ac.nz

The Pliocene, synorogenic Viqueque Megasequence (VM) of Timor Leste (East Timor) accumulated in a forearc basin that developed during the transition from subduction to collision of the Australian continental margin with the Banda Arc. Using the VM in its type area, we investigate the exhumation history of the island of Timor, the dynamics of arc-continent collision, the chronology of large Indonesian earthquakes, and the paleoceanographic evolution of the Indonesian Throughflow from ca. 5.5 to < 2.5 Myr ago.

The VM records an up-sequence progression of seafloor shoaling, from quiet pelagic carbonate deposition to marl deposition to interbedded marls and turbidites. Distinctive lithologies within the turbidites record the emergence of proto-Timor. The presence in the turbidites of clasts derived from the Alieu Complex, presently structurally, geographically and topographically remote from the Viqueque area, is enigmatic and must be explained by geodynamic models.

Foraminiferal studies and new U-Pb ages from detrital corals place temporal constraints on these events and permit us to tie geodynamic changes (in deformation style, earthquake-triggered turbidites) and paleoceanographic changes (in temperature and salinity) to robust chronologies. These, in turn, provide insight into the interplay between topography, tectonics and oceanography during forearc basin evolution in an active collision zone.

# SEISMIC DETECTION OF ICEBERG CALVING AT TASMAN GLACIER, NEW ZEALAND

**Rob C. Dykes[1], Martin S. Brook[1] & Gert Lube[2]**
[1]School of People, Environment and Planning, Massey University, Palmerston North
[2]Institute of Natural Resources, Massey University, PO Box 11 222, Palmerston North
r.c.dykes@massey.ac.nz

Mass loss via *calving* of large icebergs from water-terminating glaciers is a major component of glacier mass balance and the land-to-ocean transfer of ice. The effect of the calving process is a significant contribution to global eustatic sea level rise (SLR). However, the current knowledge of calving processes at water-terminating glaciers, and its impact on future SLR, is poor due its multivariate nature, and the compounding difficulties and dangers of research in such environments. Indeed, although calving accounts for ~70% of annual ice loss, the processes controlling calving rates (e.g., ice fracturing and ice flow variability) still remain enigmatic in glaciology. The main impediments to quantifying calving glacier contributions to SLR is the understanding of (1) what actually initiates calving, (2) what is the relationship between calving and glacier dynamics, and, (3) can calving retreat trigger faster ice flow, or vice versa. A central issue linking these questions is whether calving losses are the cause, or the consequence, of glacier flow (and discharge) acceleration, and the nature of the relative interplay of the physical processes involved. One conception of the relationship sees calving as the 'master', with calving losses triggering a cascade of dynamic changes up-glacier, including flow acceleration – calving being the local driving force. The contrasting view is that calving is the 'slave' of glacier dynamics, responding passively to changes in other parts of the system.

We are focusing on this problem using a novel integration of (1) passive seismological techniques (e.g., seismometers and lake-based hydrophones), coupled with (2) direct photogrammetric observations of calving, and (3) strain-net and ground-penetrating radar studies of dynamic structural changes to the glacier terminus. The aim is to provide a new acoustic insight into the 'master-slave' issue central to the calving law debate. Several studies have shown that glaciers generate seismic signals, which have been broadly termed 'icequakes'. Such seismic signals are generated during calving events, with seismograms of such events typically emergent, long lived (2-1000 s) and dominated by lower frequencies (1-3 Hz). Through the use of passive seismological techniques, such as seismometers and hydrophones, these signals can be identified and calibrated to particular ice dynamic changes and calving events.

We are currently applying these methods of passive seismological detection of calving events (in conjunction with external monitoring of glacier dynamics) to complete a detailed study of iceberg calving mechanisms at the freshwater-terminating Tasman Glacier. Such an analysis of calving into the ~250 m deep lake will provide a useful analogue for calving glaciers that act as discharge outlets from ice sheets.

**THE ALPINE FAULT ZONE ALONG THE WAITANGI-TAONA RIVER: MAPPING IN 3D AND AMS IN FAULT GOUGE**

**L. Easterbrook, R.J. Norris & V. Toy**
Department of Geology, University of Otago, PO Box 56, Dunedin
easlu898@student.otago.ac.nz

The Alpine Fault, the main onshore structure in the Pacific-Australian plate boundary, runs along the West Coast of the South Island of New Zealand, where it accommodates ~70% of the relative plate motion. The Fault accommodates dextral reverse oblique slip with 23 - 25 mm/yr strike slip and up to 10 mm/yr of dip slip. From a brittle near-surface fault, the structure continues down-dip into a continuous shear zone at depth. Rapid exhumation and erosion has exposed this mylonite (shear) zone in the hanging wall of the fault. (Norris and Cooper 2007 and references therein)

Along the Waitangi-taona River (~20km north-east of Franz Josef township), a series of closely spaced tributary creeks cut across and expose the Alpine Fault Zone. These form the area of focus for a field based project aimed at producing a detailed 3D model of the fault zone. We present some results from 2D/3D mapping of the fault zone, which illustrate how the fault becomes partitioned in the near surface.

We also present some results from a study of fabric in fault gouge, established primarily by measuring the Anisotropy of Magnetic Susceptibility (AMS). We look at AMS in faults to the south-east of the basal thrust that appear to be parallel partitions of the near surface displacement. Initial results, for one of these faults, show a planar AMS fabric at ~27º to the principal slip plane (figure 1). The likely source for this fabric is from the alignment of paramagnetic phyllosilicates (mainly clay minerals) in the gouge zone. This could come about by rotation and alignment during dextral shear (figure 1), consistent with the inferred shear sense for a parallel partition in this setting.

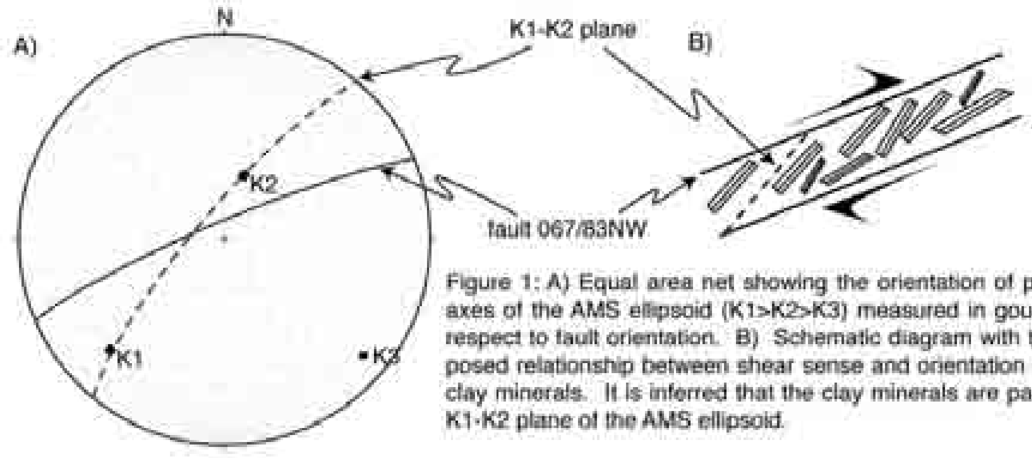



Figure 1: A) Equal area net showing the orientation of principle axes of the AMS ellipsoid (K1>K2>K3) measured in gouge with respect to fault orientation. B) Schematic diagram with the proposed relationship between shear sense and orientation of platy clay minerals. It is inferred that the clay minerals are parallel to K1-K2 plane of the AMS ellipsoid.

Norris, R. J., and A. F. Cooper (2007), The Alpine Fault, New Zealand: Surface Geology and Field Relationships, in A Continental Plate Boundary: Tectonics at South Island, New Zealand, edited by D. Okaya, T. A. Stern and F. Davey. A.G.U Monograph Series, Geophysical monograph 175, pp. 159-178

# IMAGING THROUGH SEISMICALLY ATTENUATIVE VOLCANICS: INVESTIGATING BELOW BASALT IN THE NORTH ATLANTIC

**J.D. Eccles**
Institute of Earth Sciences and Engineering, University of Auckland,
Private Bag 92 019, Auckland 1142, NZ
j.eccles@auckland.ac.nz

The North Atlantic provides classic examples of volcanic rifted continental margins. In such environments flood basalt sequences, like much of New Zealand's own volcanics, provide a challenge to seismic imaging due to their high effective attenuation and, additionally, their high seismic velocity. In the case of the North Atlantic margins, the strategy of using a large source (104 litre airgun array), low frequencies (centred on 9 Hz) and long offsets was employed. This provided some resolution of the structural and compositional features associated with magmatic continental breakup that are hidden beneath the thick (< 6 km) Paleocene basalt flow sequences across two Northwest European margins, the Faroes and Hatton Bank margins.

These margins were studied with (a) marine multichannel seismic reflection profiling (12 km single sensor streamer) and (b) long offset (< 180 km) travel-time tomography data from 170 four-component ocean-bottom seismographs. The resolution of the low frequency source was of course less than that of conventional higher frequency techniques in more tractable environments. Thus layer and grid based travel time tomography of > 70,000 top basalt converted shear (S-) wave refractions and Moho reflections was also used to determine the Vp/Vs structure of the crust. This provided additional insight into sub-basalt units such as pre-breakup sedimentary systems and the progressive intrusion of the Lewisian gneiss basement by mafic sills during continental breakup.

Can such strategies be adapted to resolve the crustal structure beneath the ignimbrites of the TVZ or offshore volcanic centres? The success and failure of the North Atlantic flood basalt case studies will be discussed in the context of challenges facing New Zealand seismologists.

## SHORT-TERM INTERACTIONS BETWEEN STRIKE-SLIP FAULTS ACROSS A PLATE BOUNDARY ZONE AT THE TRANSITION FROM SUBDUCTION TO COLLISION: COMPARISON TO THE MARLBOROUGH FAULT SYSTEM, NEW ZEALAND

**S. Ellis[1], D. Eberhart-Phillips[2,1], C. Williams[1], J. Nüchter[1], R. Robinson[1], & P. Upton[3]**

[1]GNS Science, PO Box 30368, Lower Hutt

[2]Geology Dept, Univ. Calif. Davis, Davis, CA, USA

[3]GNS Science, Dunedin

s.ellis@gns.cri.nz

We use numerical models to investigate stress interactions between semi-parallel strike-slip faults in a zone of transition from subduction to transpressive collision. The models are broadly inspired by the tectonic setting at the northern end of the South Island, New Zealand. After an initial stress-buildup period during which the faults are given a low frictional strength, the faults are locked for a specified interseismic interval. Stresses build up as a result of applied far-field and basal boundary conditions representing average plate motion. Slip along the faults is self-determined in the model as an effect of stresses built up in the initial setup stage, and is strongly controlled by the inelastic rheology. The model rheology includes elasticity, pressure-sensitive brittle yield, and thermally-controlled ductile creep.

After the setup stage we turn various fault strands "on" or "off" in order to investigate the effect on neighbouring faults in terms of stress changes. We investigate these changes for a hierarchy of models with increasing complexity in rheology, and for defined sequences of events, prescribed by unlocking certain faults in a given sequence.

As found previously for Critical Coulomb Stress elastic models, we predict that an "Alpine Fault" event will preferentially load one strand of the Marlborough Fault system (in our model, it loads the fault corresponding to the approximate location of the Awatere Fault). The inelastic rheology used in the models allows us to go further, and to investigate stress changes in subsequent interseismic steps. Postseismic creep beneath the brittle crust following an Alpine Fault-type event relieves stress in the mid-crust beneath it and loads the southern end of a strike-slip fault corresponding to the Clarence Fault. An "Awatere Fault" event unloads the shallow crust around itself and neighbouring strike slip faults, causing a stress shadow, but loads the mid-crust below, and to a much lesser extent at the northern end of the Alpine Fault. In general, events on a strike-slip fault cause a stress shadow on the slipping fault and neighbouring strike-slip faults, but have a much smaller effect on stresses on the transpressive structure (“Alpine Fault”) to the south.

The models contain many simplifications, so a detailed comparison to the Marlborough Fault system is precluded, but results do indicate that inelastic effects can help to load and unload fault strands during the interseismic period. When possible, creep and off-fault brittle yield should be taken into account when modelling stress triggering for multiple earthquake sequences.

# INCREMENTALLY DEVELOPED 'DILATIONAL HYDRO-SHEARS' FORMING AT HIGH ANGLES TO $\sigma_1$ IN FOLIATED MÉLANGE MATRIX

**A. Fagereng[1], F. Remitti[2] & R. H. Sibson[1]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin 9054, New Zealand
[2]Dip. di Sci. della Terra, Uni. di Modena, Largo S. Eufemia 19, 41100 Modena, Italy
ake@geology.co.nz

The Chrystalls Beach accretionary mélange contains an extensive fault-fracture mesh, in which mutually cross-cutting, incrementally developed, subhorizontal slickenfibre shear veins and subvertical extension veins intersect at an oblique angle of ~80º (Fig. 1). Slickenfibre shear veins commonly have multiple internal stylolitic slip surfaces subparallel to ubiquitous cleavage in pelitic mélange matrix, macroscopic 'crack-seal' textures, and dissolution selvages along the vein margins. Stylolites, internal slip surfaces, and long axes of elongate crystals within slickenfibre shear veins are inclined at a low angle (< 15º) to the vein margin. Where shear and extension veins intersect, crystal fibres within the extension vein are parallel to elongate crystals within slickenfibres. The two vein types therefore had the same crystal-growth direction and are inferred to have formed contemporaneously in the same stress field. Thus field and microstructural observations suggest that slickenfibre-coated shear surfaces in the Chrystalls Beach mélange were active at ~80º to $\sigma_1$, despite the constraint from Coulomb mechanics that new-forming faults, in cohesive, low porosity rocks, should lie at an angle $\theta_i = 45º - \phi/2$ to $\sigma_1$.

The slickenfibres appear to have formed by reactivation of subhorizontal cleavage planes, which acted as micro-transforms linking subvertical extension fractures. The reshear conditions are similar to the extensional hydrofracture criterion, but low tensile strength, low intrinsic cohesion, and localised elevated shear strain controlled by material heterogeneities and anisotropy, create a situation where shear occurs essentially by extension under local hydrofracture conditions between weak planes. The term `dilational hydro-shears' is suggested for these slickenfibre surfaces to reflect their dilational component and the requirement of the hydrofracture criterion ($P_f \gtrsim \sigma_3$) to be locally achieved for shear to occur.

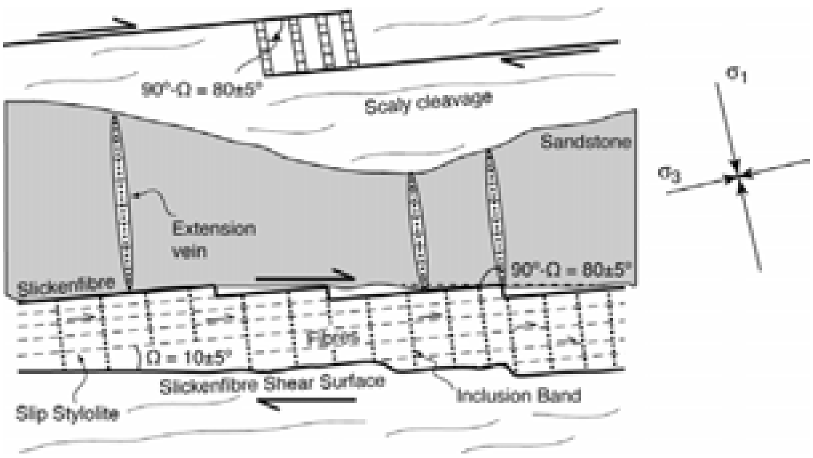



Fig. 1: Schematic diagram (not to scale) of the geometrical relationships between shear- and extension veins, and inferred compressional stress trajectories.

# PRELIMINARY RESULTS OF SALT MARSH FORAMINIFERAL PROXY RECORDS OF SEA-LEVEL RISE IN THE SOUTH ISLAND, NEW ZEALAND

**Brígida Orioli Figueira**[1], **Bruce Hayward**[2], **Hugh Grenfell**[2]
[1]Geology Department, University of Auckland
[2]Geomarine Research, Auckland
b.figueira@auckland.ac.nz

The mean global rate of sea-level rise during the last century has been estimated at ~1.8 mm $yr^{-1}$. Analyses of instrumental sea-level observations cannot fully resolve when this rate of sea-level rise commenced and whether any long-term accelerations of sea-level rise occurred in the 19th and 20th centuries or earlier. Some studies have identified sea-level accelerations around the end of the 19th century, and around 1935, while others have proposed decelerations within the 20th century. This largely Northern Hemisphere debate is of critical importance in determining whether human-induced increases in greenhouse gases and consequent global warming is, completely or partly, responsible for modern rapid rates of sea-level rise. North Atlantic Ocean studies have shown that microfossil records preserved in salt-marsh sediment can produce valuable sea-level estimates, that are in good agreement with 20th century tide-gauge observations, and can extend the record back in time through the 19th century, serving as valuable 'proxies' where tide-gauge records are not available.

The Southern Hemisphere does not have a long history of foraminifera-based sea-level research. The only Southern Hemisphere study published so far has been from Pounawea (Catlins region, South Island, NZ). In this study, salt marsh foraminiferal faunas indicate that sea level rose slowly ($0.5 \pm 0.4$ mm $yr^{-1}$) before 1900, but during the 20th century increased to $2.8 \pm 0.5$ mm $yr^{-1}$.

To better understand the New Zealand record of sea-level rise over the last 700 years, this PhD project aims to establish additional sea-level reconstructions from other tectonically stable South Island sites, at Waikawa Harbour, Southland, and Whanganui Inlet, NW Nelson. This will provide a test of the Pounawea record and allow better comparison with Northern Hemisphere studies. Using AMS $^{14}C$, $^{137}Cs$ dating, and local stratigraphic markers, a preliminary age model has been constructed for the Waikawa cores. Two modern foraminiferal transects across the salt marsh provide analogue data for the development of a tidal elevation-based transfer function. Results so far indicate that sea level was c. 65 cm below present 700 years ago. Sea level rose c. 30 cm in the next 600 years, and appears to have accelerated its rise in the late 19th century with an average rate of c. 3 mm $yr^{-1}$ for the 20th century.

# PROVENANCE STUDIES OF MIOCENE MASS TRANSPORT DEPOSITS

**C. Fildes**
Dept. of Geology, University of Auckland, Private Bag 92019, Auckland
ctfildes@hotmail.com

The study of turbidites is important in terms of understanding deepwater clastic depositional processes. Megaturbidites are geologically significant because their occurrence and individual style can be indicative of hinterland evolution, they are excellent time markers for stratigraphic and seismic correlation and they may form economic hydrocarbon reservoirs.

There is considerable debate surrounding the sandstone provenance of the Miocene Numidian Flysch turbidites of Tunisia, North Africa. These deposits consist of predominantly quartz arenite with interbedded mudstones. Heavy mineral analysis has been used to help determine the source mineralogy. This data indicates the sandstones are mineralogically mature to extremely mature with the dominant mineral complex suite being zircon, tourmaline and rutile. These minerals have an affinity to metamorphic and granitic provenance. The deposits studied have undergone multiple phases of reworking via sedimentary processes such as fluvial, deltaic and multiple turbidity flows.

Polycrystalline quartz is present in relatively high quantities within these sandstones and displays a gneissose texture. With the presence of rarer heavy minerals such as anatase, monazite and piedmontite a metamorphic source is probable. Palaeocurrent measurements are key for understanding provenance and have been well established in the Numidian Formation. Palaeocurrent data integrated with tectonic reconstructions suggest the source of these turbidites was to the northwest. Zircon ages of 514 +/- 19 Ma from the Numidian sands were the first to be recorded younger than 1750 Ma. These younger ages correspond to the 505 Ma age for augen gneiss basement rocks in the Kabylie ape zone as well as the Alpine and Hercynian age reset affects. These zircon ages suggest a deepwater flysch basin situated north/northwest of the calcareous platforms with a supply north to south. By comparing this research with previous studies from the Numidian in Italy, it is suggested that the Numidian is likely to be derived from multiple source areas related to the Pyrenean compressional event which resulted in the convergent plate boundary between Africa and Europe. During Late Oligocene-Early Miocene times, exhumation of the Greater Kabylie also provided a sediment supply for these Numidian turbidites. Two types of zircons are present within the Numidian, a prismatic elongate morphology and a more rounded crystal. These differing types of zircons may relate to multiple sources of the Numidian.

Similar methods of analysis will be employed during subsequent studies of Miocene age so called “megaturbidites” of the Waitemata Basin, New Zealand. The aim of this subsequent study is to i) characterise the hinterland of the “megaturbidites”, ii) to determine emplacement mechanics and iii) to infer chronostratigraphic significance. The foci of this latter study are the Parnell Grits and Albany Conglomerates as well as providing in sights into the rates and processes of marine arc marine sedimentary basin development at collisional plate boundaries.

# INTRA BASINAL EROSION THROUGH TIME: THE 4D TARANAKI PROJECT

**M. Fohrmann, K.J. Bland, B.R. Ilg, M.J.F. Lawrence, K.F. Kroeger & D.P. Strogen**
Institute of Geological and Nuclear Sciences, PO Box 30368, Lower Hutt, NZ
m.fohrmann@gns.cri.nz

The Taranaki Basin is located along the west coast of the North Island of New Zealand and is bound by the Taranaki Fault to the east and the deep water Taranaki Basin and Challenger Plateau to the west. It is currently the only hydrocarbon producing basin in New Zealand.

The 4D Taranaki project, currently being undertaken by GNS Science, aims to create a 4D basin model (3D + geological time) depicting petroleum generation, expulsion, primary and secondary migration and entrapment across the entire basin from the mid-Cretaceous to Recent. The goal is to improve our current understanding of the petroleum systems within Taranaki and adjacent basins (i.e. Deepwater Taranaki Basin) in ways that will reduce the uncertainties and risks associated with petroleum exploration, development, and production. As part of the 4D Taranaki project, several regionally extensive erosional unconformities have been mapped throughout the basin.

The removal of overburden as a consequence of exhumation of rocks from maximum burial depth has important implications for the prospectivity of the whole basin. The removal of overburden can affect hydrocarbon generation, migration and accumulation since it may alter 1) the duration of thermal maturation of source rock units, 2) the porosity imposed by the maximum burial depth of reservoirs, 3) the petrophysical characteristics of the cap-rock, 4) the structural evolution of traps, and 5) the hydrocarbon entrapment history. Typically, estimating the amount of "missing" rock across unconformities within a sedimentary succession has proven to be difficult and time consuming.

In order to derive a first-order estimate of erosion across angular unconformities, we use geometric and geological constraints on flattened seismic sections to derive missing sections. This technique is associated with large uncertainties, but it is a quick way to assess exhumation of sedimentary successions over a wide area. By integrating and comparing this technique with a variety of other approaches such as porosity measurements, structural restoration and sediment back-stripping, we are able to provide a valuable constraint on estimates of missing section within the Taranaki Basin.

## NEW ZEALAND SHARK-TOOTHED DOLPHINS (FAMILY SQUALODONTIDAE)

**R. Ewan Fordyce**
Department of Geology University of Otago, Dunedin 9054
ewan.fordyce@stonebow.otago.ac.nz

Squalodontids are spectacular long-jawed shark-toothed dolphins that thrived in the Late Oligocene-Early Miocene before going extinct in the Middle Miocene. Fossils are widely known from marine strata around the Atlantic, Mediterranean and Pacific margins, but most are incomplete and uninformative. New Zealand fossils include well-preserved skulls that elucidate structural and taxonomic diversity, and likely lifestyles.

Material includes skulls and associated bones of mostly unnamed species, from the Waitaki Valley and South Otago; most are in the Geology Museum, University of Otago. Key horizons are mid or outer shelf strata: Kokoamu Greensand (~29-26 Ma), Otekaike-Milburn Limestones (~26-22 Ma), and Gee Greensand-Mt Harris Formation (~22-18 Ma). Four clusters are distinguished on size, jaw shape, and tooth details. 1, Some long-jawed species have widely-separated triangular cheekteeth with small to medium-sized denticles and fine ornament. Material includes one neonate, one juvenile, and two adult skulls (~1 m long), and partial skeletons from Hakataramea, Awamoko, and Duntroon. 2, A long-jawed adult skull (~0.75 m) and part skeleton from the Milburn Limestone has cheekteeth that are close-spaced, with strongly denticulate and strongly ornamented teeth. 3, The short-jawed *Prosqualodon* (?Prosqualodontidae), is known from published fragments, and new skulls being prepared; this genus is dubiously separate from Squalodontidae sensu stricto. 4, "*Prosqualodon*" *hamiltoni* (horizon uncertain; Waitakian) has a broad-based rostrum in which maxillae roof the cheekteeth, reminiscent of the Paratethyan *Patriocetus* (Patriocetidae).

The distinctive teeth of squalodontids may reflect a snapping durophagous diet (e.g. teleosts, penguins). No two species of New Zealand squalodontids were clearly contemporaneous. Squalodontids lived in waters also inhabited by other dolphins such as *Waipatia* and *Notocetus*, early true "ocean dolphins" (Delphinida), and even relict archaocetes (*Kekenodon*). There are no structural similarities that might suggest ecological overlap between squalodontids and the latter taxa, but ecological partitioning between these groups deserves study.

Skeletal features are consistent with placement of squalodontids in the Platanistoidea (with e.g. Waipatiidae, Squalodelphinidae, and Platanistidae) and in turn within the crown Odontoceti. New Zealand fossils should help understand whether the widely-cited *Patriocetus* and *Prosqualodon* truly represent monotypic families, or better belong in a broader clade Squalodontidae.

The decline of squalodontids in the later Middle Miocene marks the start of the "modern" radiation of dolphins (Delphinoidea) and beaked whales (Ziphiidae). These 3 groups are sufficiently distinct in terms of feeding apparatus that direct competition was unlikely to be a factor in extinction; climate change might well have been the driver.

# PLANNING ON A RETREATING COASTLINE: OAMARU, NORTH OTAGO, NEW ZEALAND

**P.J. Forsyth**
GNS Science, Private Bag 1930, Dunedin
j.forsyth@gns.cri.nz

Coastal erosion is a natural phenomenon that becomes a hazard when it poses a threat to property and/or life. Erosion of the coastline around Oamaru is currently damaging or threatening property and infrastructure. Both short-term erosion events (particularly in 2007), and long-term retreat (over thousands of years) are observed. Erosion has recently affected buildings within Oamaru township and roads farther south.

The geographic and geological setting of Oamaru explains the coastal retreat. Much of the town (including the historic precinct) is built on a late Quaternary coastal terrace, consisting mainly of poorly consolidated loess and gravel and terminating in a sea cliff. Wave climate, longshore drift and the nature of the beach sediment all contribute to a sediment deficit that allows storm waves to break against the foot of the cliff at times, causing erosion. In spite of rock armouring and breakwaters, parts of the coastal terrace on which the town is built will continue to erode in the long term.

District and regional council responses to the erosion hazard include zoning, setbacks, control of new developments, hard coastal defences, and monitoring of beaches. Research organisations have studied beach sediment volume and community perceptions of natural hazards. The concept of “managed retreat” may not yet be widely accepted in Oamaru (or New Zealand), but will need to be discussed more seriously in the future. Climatic warming, with associated sea level rise, is likely to exacerbate coastal erosion. Communities and councils need to build “adaptive capacity” - the ability to adjust to erosion and cope with the costs and consequences.

Further studies could include:
- assessing the effectiveness of district and regional planning measures in this context
- monitoring the effectiveness of any mitigation measures that are adopted
- integrating all the existing sources of information to refine predictions of erosion rates
- researching the role of insurance in modifying the actions of property owners
- evaluating risk acceptance in the Oamaru/Waitaki community
- investigating international best practice for coastal management and managed retreat.

# A MIOCENE TERRESTRIAL SEDIMENT CORE FROM FOULDEN MAAR, OTAGO

**Bethany Fox, Uwe Kaulfuss, Daniel Jones, Gary Wilson*, Daphne Lee, Andrew Gorman**
Department of Geology, University of Otago, PO Box 56, Dunedin
*also at Department of Marine Science, University of Otago, PO Box 56, Dunedin
brs_fox@yahoo.co.uk

The Foulden Maar near Middlemarch, Otago forms part of the Waipiata Volcanic Group. The maar crater formed within the Otago Schist, which is the main unit cropping out at the surface today. It is approximately 1.5 km in diameter and infilled with a diatomite succession which is thought to span the Oligocene-Miocene boundary and Mi-1 climatic event. Surface pits reveal that the diatomite is laminated on a millimetre to sub-millimetre scale, with white layers composed almost entirely of diatoms and sponge spicules and dark layers composed of organic matter and resting spores. White-dark couplets are interpreted to correspond to annual variations in diatom productivity and, indirectly, in climate. Laminae extend laterally across the entire maar, and there is no evidence of bioturbation.

Seismic surveys conducted in early 2009 reveal that the stratified lake fill extends to between 200 and 300 m below the present surface. The upper ~100 m of strata are relatively flat lying but then become progressively more steeply dipping towards the base of the succession. Normal faulting thought to be associated with slumping is relatively pervasive but it is still possible to trace reflections across the basin and identify undeformed intervals. In mid 2009, Webster Drilling obtained two parallel cores from the deepest and most continuous part of the maar fill succession. The first core is ~120 m in length, and consists almost entirely of laminated diatomite. The second core is ~180 m in length, and consists of ~120 m of laminated diatomite, ~60 m of graded volcanic breccias, sands and muds, and ~4 m of basal schist bedrock. The diatomaceous interval is punctuated by a volcanogenic horizon at ~90 m depth. Recovery was 91% for the first core, 95% for the second. The basal volcanics are interpreted to be part of the diatreme of the maar.

Here we present the initial visual and physical properties logs of the core, which provide some insight into cyclicity in sediment accumulation under a mid-latitude climate spanning the Mi-1 event. Further work will use palynological, palaeobotanical and environmental magnetic parameters to correlate the record with regional and global climatic processes as well as with global drivers such as declining global atmospheric $CO_2$. A high-resolution chronology will be constructed through integration of data from magnetic polarity, cyclicity analysis, pollen analysis and $^{40}Ar/^{39}Ar$ dating of volcanic material.

# THE EXTENT OF ICE ON CAMPBELL ISLAND AT THE LAST GLACIAL MAXIMUM

**H.L. Fraser[1], A.R. Gorman[1], G.S. Wilson[1,2] & S. Preskett[3]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. of Marine Science, University of Otago, PO Box 56, Dunedin
[3]Dept. of Surveying, University of Otago, PO Box 56, Dunedin
fraser.hamish@gmail.com

Campbell Island, New Zealand's southernmost island is located about 700 km south of the South Island at 52.33˚S, 169.09˚E. In February 2009, the *R/V Polaris II* (Otago University's research vessel) travelled to Campbell Island to conduct a high-frequency seismic survey and collect sediment cores to find evidence of the Last Glacial Maximum (LGM). Campbell Island is an important site for understanding the LGM and its termination because it is situated in the mid latitudes, and therefore is more sensitive to small climatic variations than sites located at extreme high and low latitudes.

A detailed high-frequency seismic survey was conducted using electro-acoustic (boomer) sub-bottom imaging, Teledyne Benthos C3D interferometric side-scan sonar and CHIRP in Perseverance Harbour, Northeast Harbour and off the more sheltered east coast of Campbell Island. The survey was designed to target possible glacial features that are beneath present-day sea level. The survey revealed that within the harbours, U-shaped valleys have been filled with flat lying sediment with modern marine transgressional sediments at the entrance of the harbour. Six piston cores were recovered from key sites within the harbours.

Whole-core physical properties (P-wave velocity, magnetic susceptibility, resistivity, gamma-ray density and colour reflectance) of the piston cores were determined by a GEOTEK MSCL (multisensor core logger). The measured properties were used to identify variation within and between the cores and to tie the seismic data to the sedimentary record. Paleomagnetic analyses of U-channel subsamples of five of the six piston cores were conducted to establish chronological constraints. Rock magnetic experiments (determinations of temperature dependant magnetic susceptibility, isothermal remnant magnetisation, and anhysteretic remnant magnetisation) were performed on selected discrete samples, to determine changes in the magnetic mineralogy with depth.

Preliminary results suggest glacial terminal moraines extend to the mouths of the present day harbours. Sub-aerially eroded channels on the eastern shelf have been identified to depths of ~120 m beneath present day sea level, with more work being needed to link these channels to glacial processes.

## A MULTIPLE-DISCIPLINE APPROACH TO UNDERSTANDING THE Mw=7.6 DUSKY SOUND EARTHQUAKE OF 2009

**B. Fry, S. Bannister, J. Beavan, K. Berryman, L. Bland, S. Cox, G. Dellow, N. Fournier, G. Hancox, C. François-Holden, N. Palmer, W. Power, J. Ristau, R. Robinson, S. Samsonov, T. Webb, N. Welch, K. Wilson, and GeoNet Team**
GNS Science, PO Box 30368, Lower Hutt, NZ
b.fry@gns.cri.nz

The $M_w$=7.6 Dusky Sound earthquake of July 15$^{th}$, 2009, was the largest magnitude earthquake in New Zealand since the devastating 1931 Hawke's Bay event ($M_s$=7.8). The earthquake was sufficiently large to generate a tsunami measured at 1 meter by a tide gauge in Jackson's Bay. Subsequent field measurements based on surge deposits at Passage Point document an approximately 2.3 meter wave. Despite the large magnitude, this event resulted in relatively minimal damage when compared to worldwide events of a similar size. This can be explained as a fortunate combination of the sparse population of the area and the specific physical characteristics of the earthquake. We present an overview of the current research on this earthquake and provide a context for concurrent conference abstracts describing more detailed results.

Centroid Moment Tensor (CMT) solutions define the rupture surface as a low-angle plane and finite fault inversions confirm it is coincident with the known interface between the eastward-subducting Australian plate and overriding Pacific plate. The aftershock sequence has consisted of approximately 15 earthquakes with $M_w \geq 5.0$. The largest aftershocks are roughly geographically grouped into two sequences, one occurring to the north of the main shock and another located to the south. Slip distribution solutions from waveform modeling describe the main event as a rupture starting at about 30 km depth and propagating updip along the subduction interface toward the southwest, terminating at approximately 12 km depth. These models show maximum displacement of about 5.5 meters. This is in agreement with GPS and DInSAR modeling. The southwestward (oceanward) directivity likely contributed to the lower intensity of measured ground motion than might be expected for such a large, shallow event. The mature nature of the plate interface, common to most subduction thrust events worldwide, provided a low-friction slip surface that also contributed to the low amount of radiated energy. Because of the relatively small energy release, far fewer landslides were triggered from this event than from the 2003 $M_w$=7.2 Fiordland event. Coulomb stress modeling predicts the initial stress transfer decreased stress on the shallowest regions of the southern Alpine Fault (offshore) but loaded deeper regions of the southern Alpine Fault by approximately 0.8 megapascal.

# NATURAL FRACTURES IN SHALES: TIMING, MECHANISMS OF FORMATION, AND RELEVANCE FOR SHALE-GAS RESERVOIRS

**J.F.W. Gale, S.E. Laubach, P. Eichhubl & A. Fall**
Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, University Station Box X, Texas, 78713, U.S.A.
julia.gale@beg.utexas.edu

Natural fractures are common in shales, but there are several possible mechanisms for their formation. A key variable is the depth of burial, and thereby the stress state and pore fluid pressure at the time of fracture development. Examples exist across the spectrum; from veins developing before host-rock compaction is complete, to veins forming at maximum burial due to hydrocarbon generation or other mineral reactions, to late, shallow veins of gypsum formed due to pyrite oxidation in the weathering zone. This study examines such examples from several US shales, including the Devonian New Albany Shale in the Illinois Basin, the Devonian Woodford Shale and the Mississippian Barnett Shale from the Fort Worth and Permian Basins in Texas, and the Pennsylvanian Smithwick Shale from central Texas.

Of particular interest with regard to mechanism are bedding-parallel, sub-horizontal fractures sealed with fibrous cements. In the Barnett Shale in the Delaware Basin these fractures are sealed with fibrous quartz that contains two sets of 2-phase liquid-vapor hydrocarbon inclusions. Primary, liquid-rich inclusions are trapped along fibres. We interpret these as forming due to overpressure during primary cracking of kerogen to oil. Secondary, vapor-rich hydrocarbon inclusions with condensate rims are present along cross-cutting planes, sub-parallel to the fibres. We interpret these as having formed later during secondary cracking to gas. If the cracking temperatures are plotted onto a burial history curve for the samples the minimum depth of fracture formation is greater than 2 km and this presents a problem: the horizontal fractures develop when the greatest effective stress should be vertical. We examine some possible explanations for their development, including a recently proposed seepage force mechanism.

Natural fracture systems are important in shale-gas reservoirs in two different ways. In some shale reservoirs the most important effect of natural fractures is their tendency to reactivate during hydraulic fracture treatments. In other shales natural fractures are partly open and can contribute to permeability without reactivation. Degree of fracture openness and the strength of the fracture planes are related to the specific structural-diagenetic history of each fracture set and shale host rock. Shales within the Whangai and Waipawa formations in the East Coast Basin of New Zealand’s North Island may have shale-gas potential. Characterization of their natural fracture systems and the present day in situ stress would be fundamental to decisions about how to drill and complete wells.

# MODULATION OF THE WESTLAND FOREDEEP THROUGH ONGOING COMPRESSIONAL INVERSION

**F.C. Ghisetti[1,2] & R.H. Sibson[2,3]**
[1]TerraGeoLogica, 55 Mansfield Avenue, Christchurch 8014
[2]Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch
[3]Dept. of Geology, University of Otago, PO Box 56, Dunedin 9054
francesca.ghisetti@terrageologica.com

West of the Alpine Fault, Neogene shortening within the Australian plate has been largely accommodated by compressional reactivation of inherited normal faults, coupled with the propagation of new compressional structures. The tectonic signature of this Compressional Inversion Orogen includes: (i) a predominance of steep reverse faults; (ii) no regional vergence of folds and faults; (iii) an irregular time-space propagation of shortening; (iv) a complex sequence of distribution, infill and uplift of syntectonic basins; (v) lack of evidence for a deformation front migrating systematically away from the transform boundary with time.

This tectonic style is in distinct contrast to a ‘typical’ foreland fold-and-thrust belt, but independent geophysical data (e.g. the SIGHT seismic survey) are consistent with flexure of the Australian lithosphere ahead of the load imposed by the Southern Alps, and with the regional interpretation of a Miocene-Pleistocene retroarc foreland basin system west of the Alpine Fault.

We analyse migration and deformation of the Westland basins (from the Nelson offshore to Hokitika) using a series of 19 chrono-stratigraphic transects that extend from the Waimea-Alpine Fault margin to the offshore, sub-orthogonal to the NNE-SSW tectonic trends. For each transect, we use available bio-stratigraphic data from exposed sections and exploration wells to define differential mobility (in terms of subsidence, uplift and erosion) and time evolution of sedimentary basins in the last 16 Ma. Analysis of these transects, coupled to the interpretation of offshore seismic lines and to the structural setting onshore, help define the location, time shift, and progressive deformation of domains with distinct sedimentary infilling.

Our analysis shows a strong control of inherited paleogeography and basement discontinuities on the initial (16-12.5 Ma) configuration of segmented subsiding basins, followed by irregular westward and southward migration of subsiding basins and of deformed “piggy-back” basins from 12.5 to 2 Ma. Segmentation of the foredeep is characterised by re-entrants and salients of depocentral zones, controlled by compressional reactivation of discontinuous fault segments in different positions.

The tectono-stratigraphic evolution and progressive disruption of the Westland foreland basin system records the tectonic interference between progressive westward migration of shortening in the retro-wedge and localised, selective reactivation of inherited basement discontinuities that modulate the diachronous and irregular distribution of uplift and subsidence in the flexed Australian lithosphere.

# SHEAR BANDS NEAR THE MYLONITIC/NON-MYLONITIC TRANSITION, TATARE STREAM, SOUTH ISLAND, NEW ZEALAND

**B. Gillam & T.A. Little**
Dept of Geography, Environment and Earth Sciences, Victoria University, Wellington
gillam.ben@gmail.com

Slip on the Alpine Fault's central section, including in its mylonite zone, is often described as being "unpartitioned," such that both the margin-parallel and margin-transverse components of the obliquely convergent plate boundary motion are accommodated together on the same structures. One explanation for this (e.g., Koons et al., 2004) is that the very rapid rates of erosional exhumation there have caused a thermal weakening of the Pacific Plate crust; allowing plate motion to collapse into a narrow zone that simultaneously accommodates both components of motion. Although many lineations have been measured in the Alpine mylonite zone, there have been far fewer direct measurements of the ductile shearing direction in these rocks.

In Tatare Stream, near Franz Josef Glacier, the distal mylonite zone is ~300m wide. There, C' shear bands cross-cut the older non-mylonitic Alpine foliation (S), and deflect that pre-existing fabric in a dextral reverse sense. We have so far measured the geometry of this intersection precisely at 9 different outcrops as a means of determining the movement plane and direction of ductile shearing in this part of the distal mylonite zone. This analysis does not require any interpretation about the origin of a particular lineation in the mylonite zone, or the degree of simple shearing there (i.e., the kinematic vorticity number). The plane of the mean mylonitic foliation is inferred to be parallel to the Alpine Fault and has a very consistent attitude of 054/63SE. The intersection of this plane with the movement plane defined by the intersecting S and C' planes trends 108 ±6° (1σ). This calculated ductile shear direction is significantly (~37 ± 6° at 1σ) more down-dip than the predicted vector based on a fault plane projection of the Nuvel-1 plate motion (here, 071 ± 2° at 1σ). We infer that ductile shearing in this part of the central Alpine mylonite zone was "partitioned" in that slip accommodated by the shearing was more fault-orthogonal than the plate motion. That an "excess" of strike-slip motion has been accommodated by slip on neotectonic backshears farther up-section provides complementary evidence for "slip-partitioning" in the hanging wall of the central part of the Alpine Fault (e.g., Little, 2004).

In our structural transect across the distal mylonite zone we have so far conducted a detailed analysis of 412 shear bands at 16 outcrops. The mean dihedral angle between the foliation and the younger C' shear plane decreases from 31° to 24° with increased proximity to the Alpine Fault. This relationship suggests a progressive "back-rotation" of the C' planes with increasing finite strain (proximity to the Alpine Fault). A mean offset of 6.5 mm and a mean spacing of 15.7 mm were measured for the shear bands at the outcrop scale of observation. This implies a mean finite shear strain of ~0.4 ± 0.06 accommodated by the discrete offsetting of the foliation across shear bands at that scale. Our calculated ductile shear strain is only 3-4% of estimates by Norris and Cooper (2003) for the distal mylonite zone, and if representative of the entire width of the distal mylonite zone, implies a cumulative shear displacement across it of only ~62 ± 20 m. Tabular microlithons between the shear bands may account for the further strain deficit.

## SNAEBYLISHEIDI, ICELAND: LAVA-HYALOCLASTITE SHEET OF A VOLUMINOUS SUBGLACIAL ERUPTION

**C.F. Gorny[1], J.D.L. White[1], and M.T. Gudmundsson[2]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavík
carolyngorny@gmail.com

Sheets of hyaloclastite volcaniclastic debris underlain and intruded by sheets of coherent basalt are common in the Sida area of southeastern Iceland. Initially interpreted as submarine deposits, they are now interpreted as having a nonmarine subglacial origin. Source areas of the Sida units are not preserved, which has complicated interpretations of their emplacement. A broadly similar deposit, however, forms an elongate flat-topped ridge in the Snaebylisheidi area. It has a volume of a couple of tens of cubic km, similar to that of the larger Sida units. Moreover, its source area is preserved and parts of the deposit remain unlithified. Preliminary work shows that the source area is dominated by volcaniclastic deposits, and there is no evidence for significant accumulation of pillows or other lavas. Considerable coherent basalt is present in the source area, however, as extensive basal intrusions into preexisting volcaniclastic deposits, and a plexus of smaller high-level intrusions showing evidence of high viscosities. Near the source, isolated pillows and other fluidal juvenile clasts are enclosed in matrices of highly vesicular ash and lapilli, or of mixed vesicular and dense glassy fragments. Downstream in the unit, deposits are dominated by dense clasts that in places are clearly derived locally from the underlying to intruding basalt sheet. Many of the larger dense clasts are highly irregular, vuggy, and/or composite. Some appear to have been rolled up around sandy hyaloclastite matrix material. An upper subunit of the clastic part of the deposit is dominated by well-developed bedding in complex geometries with multiple internal truncation surfaces. Below the well-bedded subunit there are thick structureless to alignment-bedded layers. At the edges of the deposit many layers have been broken and tilted to sub-vertical inclinations.

From these features we infer that there was little or no pillow or sheet lava emplaced in the source area during eruption. There is, however, a large amount of basalt that was intruded into unconsolidated volcaniclastic deposits. The coherent basalt sheet inferred to extend downslope from the source area, seen in outcrop near the distal end of the unit, may have advanced as an intrusion into tephra deposited ahead of it. This tephra would initially have come from the source area, but as the intrusion advanced it also produced new fragments by interaction with the tephra host. Remobilisation of this mixture would have provided additional debris to be carried into the path of the intrusion. Depositional rates were commonly high (thick, weakly structured beds), but there is evidence for multiple depositional pulses as seen by thinner overlying beds. Marginal deformation reflects slumping of the unconsolidated deposits. Overall the features suggest a largely englacial origin. More work is now underway to better understand the source eruption, how the basalt sheet was emplaced, and depositional processes of the associated volcaniclastic deposits.

# HOLOCENE EVOLUTION OF THE TECTONICALLY-ACTIVE WAIRAU COASTAL AREA

**H.R. Grenfell[1], B.W. Hayward[1], K. Wilson[2], M.S. Morley[1], U. Cochran[2], A.T. Sabaa[1], R. Daymond-King[1]**
[1]Geomarine Research, 49 Swainston Rd, St Johns, Auckland
[2]GNS Science, PO Box 30 368, Lower Hutt
h.grenfell@geomarine.org.nz

The shallow tidal Wairau coastal lagoons, Blenheim, are an ideal location for investigating the relative roles of tectonic and eustatic sea-level in paleogeographic evolution. The Wairau Valley has been eroded along one of New Zealand's largest and most tectonically active transcurrent faults – the Wairau Fault and south of the lagoons is the active Vernon Fault.

The lagoons are unique in New Zealand for their wide seasonal and tidal salinity range, from hyposaline (10-20 psu) to hypersaline (35-54 psu). Foraminiferal and ostracod associations are recognised, using Q-mode cluster analysis, living in and around these lagoons today and detrended canonical correspondence analysis (DCCA) shows that their distributions are strongly correlated with tidal elevation and salinity. Analyses of the modern analogue faunal data combined with Holocene microfaunal data from five 2.5-9 m deep cores enables direct paleoenvironmental interpretation of the fossil faunas and elucidation of the lagoons' paleogeographic evolution.

The area was inundated by rising eustatic sea level from 8.5 ka onwards, forming a fully marine, sheltered, subtidal bay. Sediment supply outpaced local tectonic subsidence and the bay filled with mud, shallowing to intertidal by 4.5-3.5 ka, still with an open mouth to the sea. Since then sediment supply has kept pace with further accommodation space provided by 3-4 m of inferred tectonic subsidence. At ~1.5 ka the calcareous-dominated foraminiferal faunas suddenly changed to agglutinate-dominated faunas indicating a switch to a semi-closed lagoon linked to the Wairau River estuary, with highly varied salinity like today. We infer this was caused by northwards extension of the Wairau Boulder Bank across the bay's mouth in response to a sharp eustatic sea-level fall after 2 ka. Sediment supply switched to fluvially-derived sand which built a flood-delta into the lagoon dividing it into three water bodies. Relative sea-level rise in the last 600 years from earthquake- related compaction (1855 AD) and accelerating eustatic rise (0.6 m) has resulted in increased marginal erosion of the lagoons and their re-amalgamation into one linked water body.

The Holocene evolution of the Wairau coastal lagoons was influenced by the interplay between sediment supply, sea-level change, longshore drift and, in a minor way, human activities. Microfossils suggest that the two most significant drivers of geographic evolution in this locality was tectonic subsidence and eustatic changes in sea level.

# MEAN SEA LEVEL CHANGES AROUND NEW ZEALAND AS ESTIMATED FROM JASON 1 AND TOPEX ALTIMETRY DATA, AND FROM GPS AND TIDE-GAUGE TIME SERIES DATA

**J. Hannah[1], N. Dayoub[2], R. Tenzer[1]**
[1] School of Surveying, University of Otago, Dunedin, New Zealand
[2] School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne, United Kingdom
John.Hannah@surveying.otago.ac.nz

Sea level changes in coastal areas have traditionally been determined using tide-gauge records. However, tide-gauge data can detect only a relative measure or trend unless the observations are corrected for crustal and other vertical movements. Recent improvement in GPS processing strategies now makes such corrections possible. Satellite altimetry provides a direct measure of the sea surface topography and their variations with a sub-monthly temporal resolution, and with respect to the Earth's centre of mass. To date more than 16 years of radar altimetry data allow us to model the semi-annual, annual and decadal signal variations of the sea surface topography and thence to determine any sea level trends.

In this study JASON1 and TOPEX radar altimetry data along with GPS and tide-gauge time series (provided by the New Zealand GeoNet project) are used to estimate the sea level changes around the coast of New Zealand. The regionally-filtered vertical component of GPS time series are used to model the vertical tectonic velocity rates in New Zealand. The vertical tectonic velocity rates are applied to linear trends of sea level variations estimated from tide-gauge time series in order to determine the sea level rising in the coastal areas. Offshore of New Zealand, the sea level rising is determined from radar altimetry data after modeling and removing the periodic signal variations. Our estimates are analyzed and compared with the results of previous studies.

# PALYNOMORPHS RECOVERED FROM THE ANDRILL SMS SEDIMENT CORES PROVIDE FIRST PROXIMAL ENVIRONMENTAL CHARACTERIZATION OF THE MIDDLE MIOCENE CLIMATIC OPTIMUM

**Michael J. Hannah[1], J. Ian Raine[2], Sophie A. Warny[3], Rosemary A. Askin[4], Barbara A.R. Mohr[5]**
[1]Victoria University of Wellington, Wellington, New Zealand
[2]GNS Science, Lower Hutt, New Zealand
[3]Louisiana State University, Baton Rouge, USA
[4]Jackson, Wyoming, USA
[5]Museum of Natural History, Berlin, Germany
michael.hannah@vuw.ac.nz

The 2007 ANDRILL Program (AND2A), drilled from a sea-ice platform in southern McMurdo Sound, penetrated 1138.54 m sub-seafloor (mbsf) with 98% core recovery of glacially-influenced marine sediments. Biostratigraphy, magnetostratigraphy, and isotopic dating suggest that an Early and Middle Miocene section (223-1138.54 mbsf) is disconformably overlain by a Pliocene to Recent interval. The Pliocene interval (223 to 0 mbsf) contains sparse to moderate assemblages of penecontemporaneous and reworked marine palynomorphs (leiospheres, *Micrhystridium* species, and rare reworked dinoflagellate cysts). Terrestrial palynomorphs recovered in this part of the core are likely to be a result of reworking.

In general the Early – Middle Miocene interval provided low yields of low to moderate diversity mixed assemblages of marine and terrestrial palynomorphs, but within the Middle Miocene section (between 312 and 319mbsf ) an exceptional peak in palynomorph abundance was seen. This event provides climatic constraints for the Middle Miocene Climatic Optimum (MMCO) in the Ross Sea, Antarctica. Compared to levels elsewhere in the core, the event is marked by an up to 2000% increase in two species of fossil dinoflagellate cysts, a synchronous abrupt 5% increase in fresh water algae, and up to 70% increase in terrestrial pollen (especially of Podocarpaceae). Together, these sudden shifts in the palynological assemblages at about ca.15.7 Ma represent a short period of time when the Antarctic environment became abruptly much warmer. During that time, we estimate that sea-surface temperatures ranged from 0° to 11.5 °C and that land temperatures reached 10°C (January mean). That increased fresh-water input lowered the salinity during a short period of sea-ice reduction is also likely.

# NATURAL EXPERIMENTS IN THE DISPERSAL AND EVOLUTION OF DEEP-SEA BIOTA FOLLOWING THE MESSINIAN EXTINCTION IN THE MEDITERRANEAN SEA

**Bruce W. Hayward[1], Ashwaq T. Sabaa[1], Shungo Kawagata[1,2], Hugh R. Grenfell[1]**
[1]Geomarine Research, 49 Swainston Rd, St Johns, Auckland
[2]Yokohama National University, Yokohama, Japan
b.hayward@geomarine.org.nz

The deep-sea biota of the Mediterranean Sea was wiped out during the late Miocene Messinian Crisis. Following reopening of the shallow Straits of Gibraltar liveable marine conditions were quickly re-established at bathyal and abyssal depths in the Mediterranean. By what mechanism and how quickly did deep-sea-restricted organisms manage to disperse back into this enclosed sea?

In our study of a deep-sea-restricted group of elongate benthic foraminifera, we have found that only 45% (44 species) of their Pliocene global biodiversity successfully migrated into the Mediterranean Sea (ODP Sites 654, 966, 967, 975, 976) following their Messinian annihilation there. Most colonisation occurred within the first 0.8 myrs (5.3-4.5 Ma) after re-establishment of the Mediterranean-Atlantic link, with possibly a second lesser period of immigration in the late Pliocene (3.4-3.0 Ma). We infer that colonisations were fortuitous and few in number, as some common members of the group in the Atlantic never succeeded. There is no evidence of any new immigration events during the Pleistocene, implying that the present anti-estuarine circulation may have been in place throughout this period. Our studies suggest that these deep-water, low-oxygen-tolerant foraminifera survived the many periods of deep-water sapropel formation in the Pliocene-Early Pleistocene, possibly in somewhat shallower (~500 m) refuges with dysoxic, rather than anoxic conditions.

The Pliocene-Pleistocene stratigraphic record of this group is similar in the west and east Mediterranean basins. The group declined in abundance (flux) and diversity in two pulses, during the Late Pliocene (3.1-2.7 Ma) and the late Early Pleistocene (1.3-1.0 Ma) in concert with abyssal sites globally and much earlier than the single decline (1.0-0.6 Ma) in mid-lower bathyal sites around the world. All species, with one possible exception, disappeared earlier in the Mediterranean than globally. The highest occurrence of any species of this group in Mediterranean sites was 0.8-0.43 Ma, comparable with 0.7-0.2 Ma elsewhere.

Thus, despite the unusual oceanographic conditions and isolation, the deep Mediterranean Sea was neither the centre for the evolution of new species nor a refuge where species survived after they had disappeared elsewhere.

# LOW-TEMPERATURE THERMOCHRONOLOGY AND THERMO-KINEMATIC MODELING OF DEFORMATION, EXHUMATION AND DEVELOPMENT OF TOPOGRAPHY IN THE CENTRAL SOUTHERN ALPS, NEW ZEALAND

**F. Herman[1], S.C. Cox[2]& P.J.J. Kamp[2]**
[1]Earth Sciences Department, ETH, Zurich, Switzerland
[2]GNS Science, Private Bag 1930, Dunedin
[3]Dept. of Earth & Ocean Sciences, University of Waikato, New Zealand
s.cox@gns.cri.nz

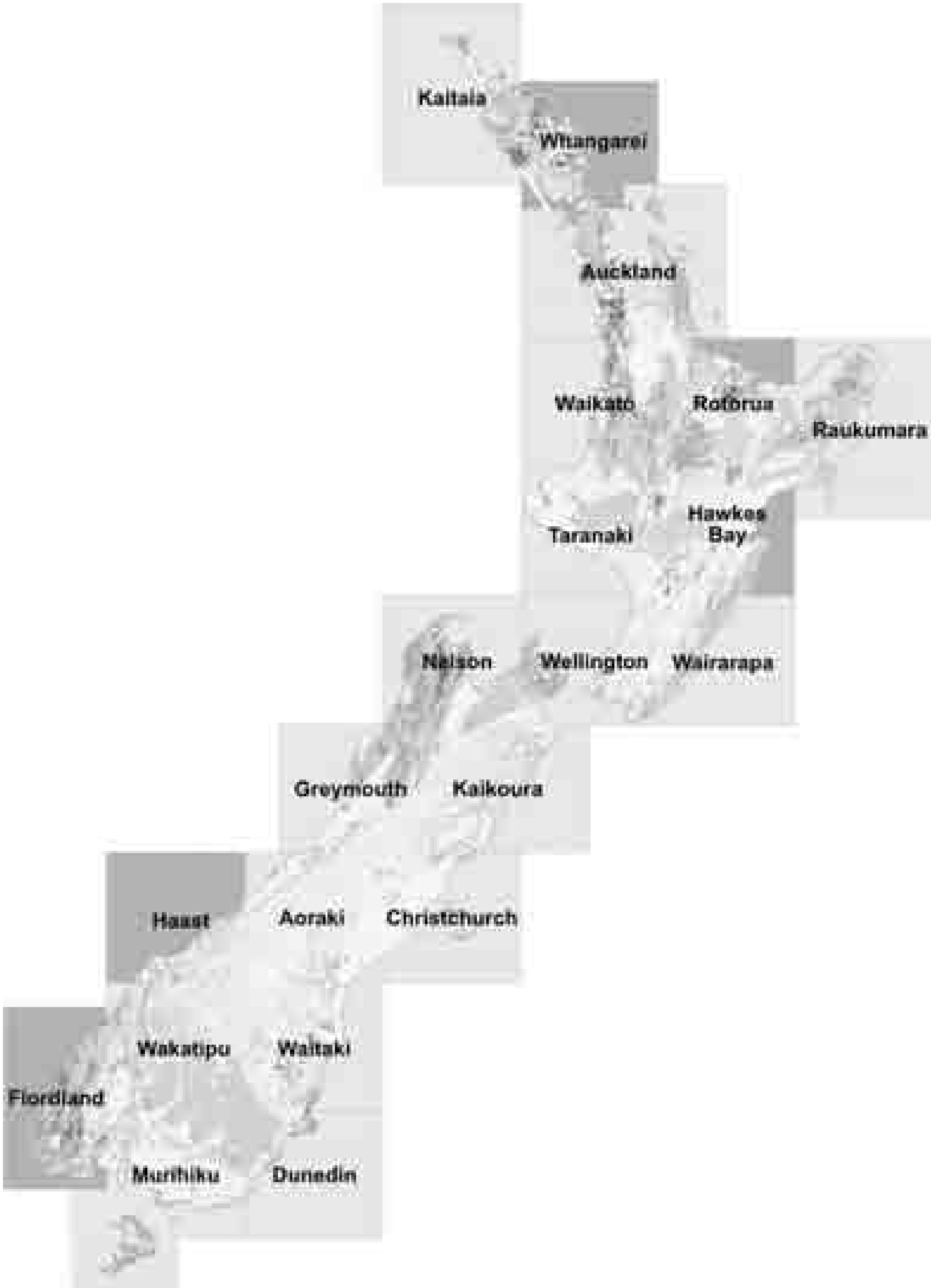
Apatite and zircon (U-Th)/He and fission track ages were obtained from ridge transects across the central Southern Alps, New Zealand. Interpretation of local profiles is difficult because relationships between ages and topography or local faults are complex and the data contain large uncertainties, with poor reproducibility between sample duplicates. Data do form regional patterns, however, consistent with theoretical systematics and corroborating previous observations: young Neogene ages occur immediately southeast of the Alpine Fault (the main plate boundary structure on which rocks are exhumed); partially reset ages occur in the central Southern Alps; and older Mesozoic ages occur further towards the southeast. Zircon apparent ages are older than apatite apparent ages for the equivalent method.

3D thermo-kinematic modeling of plate convergence incorporates advection of the upper Pacific plate along a low-angle detachment then up an Alpine Fault ramp, adopting a generally accepted tectonic scenario for the Southern Alps. The modeling incorporates heat flow, evolving topography and the detailed kinetics of different thermochronometric systems, and explains both complex local variations and regional patterns. Inclusion of the effects of radiation damage on He diffusion in detrital apatite is shown to have dramatic effects on results. Geometric and velocity parameters are tuned to fit model ages to observed data. Best fit is achieved at 9 mm/yr plate convergence, with Pacific plate delamination on a gentle 10° SE-dipping detachment and more- rapid uplift on a 45-60° dipping Alpine Fault ramp from 15 km depth. Thermo- kinematic modeling suggests dip-slip motion on reverse faults within the Southern Alps should be highest ~22 km from the Alpine Fault and much lower toward the southeast.

**THE QMAP 1:250 000 GEOLOGICAL MAP OF NEW ZEALAND**

**David Heron and Mark Rattenbury**
GNS Science, P.O. Box 30-368, Lower Hutt
d.heron@gns.cri.nz

The QMAP 1:250 000 Geological Map of New Zealand programme is within a year of completion. Sixteen maps have been published, two (Whangarei and Fiordland) are in press and the remainder (Rotorua, Hawkes Bay and Haast) are now digitally captured. There is now interim digital geological map coverage of the entire country and vector GIS data are being released on CD following data validation and quality control. Before the QMAP data can be released as a single dataset, sheet boundaries must be removed and this process has begun under the Seamless QMAP initiative.



# SEAFLOOR SPREADING IN THE TERTIARY BACKARC BASINS NORTH OF NEW ZEALAND - NEW RESULTS

**R. Herzer[1], D. Barker[1], W. Roest[2] & N. Mortimer[3]**
[1] GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand
[2] Département Géosciences Marines, Ifremer, BP 70, 29280 Plouzané, France.
[3] GNS Science, Private Bag 1930, Dunedin 9054, New Zealand
r.herzer@gns.cri.nz

Recent studies have indicated that it is likely the South Fiji and Norfolk backarc basins expanded in tandem in the Late Oligocene and Early Miocene. We present a new investigation of the spreading history and kinematics of the central part of this region using (i) a magnetic and gravity anomaly re-interpretation tied to recently published radiometric dates of oceanic crust and (ii) a multibeam bathymetric, magnetic, seismic reflection survey of the southwest arm of the Minerva triple junction. This arm links the Bounty spreading centre (the northeast arm) and the Julia Fracture Zone (the southeast arm) to the Cook Fracture Zone, which offsets the Three Kings and Loyalty ridges. Interpreted anomalies 9 to 6Cn (28-24 Ma) on either side of the Bounty spreading centre agree with radiometric dates of 26 Ma on anomaly 8r, 22 Ma on crust apparently younger than 6C in the southeast arm, 19 Ma on an off-axis seamount in the southwest arm, 23 Ma on the Cook Fracture Zone and 20 Ma in the Norfolk Basin. Blocks of crust were identified variously from magnetics, satellite gravity, seafloor fabric, crustal thickness, morphology and composition to be oceanic, continental, arc volcanic or intermediate. Oceanic blocks were removed in sequence to produce a palinspastic reconstruction which reveals a complex interplay of seafloor spreading, transform faulting and migration of rigid or semi-rigid blocks behind a constantly retreating Lau-Colville subduction zone. The southern South Fiji Basin was not investigated, but the kinematics above require seafloor spreading to have occurred there through most of the Oligocene and Early Miocene with consequent effects on the northern continental margin of New Zealand.

## ECOLOGICAL AND SEDIMENTOLOGICAL EVOLUTION OF THE VOLCANICALLY ACTIVE EOCENE-OLIGOCENE CONTINENTAL SHELF, NORTHEAST OTAGO, NEW ZEALAND

**Simone Hicks, James D.L. White, R. Ewan Fordyce, Daphne E. Lee**
Department of Geology, University of Otago, PO Box 56, Dunedin
hicsi947@student.otago.ac.nz

The Waiareka-Deborah volcanics comprise well preserved small relicts of monogenetic, intraplate volcanoes exposed in northeast Otago, South Island, New Zealand. Together with associated sedimentary and intrusive rocks, they belong to the Alma Group. The volcanics occur in a triangular area of about 180 $km^2$ with one side along the present coastline of northeast Otago. The volcanic rocks erupted around 35 to 30 Ma on the submerged continental shelf and formed small Surtseyan volcanoes with an estimated total volume of the order of a few tens of $km^3$. Through the Late Eocene to Early Oligocene, pillow lavas, hyaloclastite breccias, various pyroclastic and reworked volcaniclastic rocks were deposited in marine shelf settings while contemporaneously limestone and diatomite deposition was taking place.

The association of the mainly tholeiitic basalt with a substantial volume of mid- to high-alkaline basalt are complexly interdigitated with the bioclastic Ototara Limestone. The interfingering of biogenic and volcanogenic strata occurred throughout Kaiatan, Runangan, and earlier Whaingaroan times (~ 37 - ~ 32 Ma). The end of the Alma Group is marked by a widespread mid-Oligocene hiatus, the Marshall Unconformity, a regionally significant surface of erosion or non-deposition in the South Island.

Hicks' (PhD) research concentrates on the sedimentary rocks immediately associated with the Eocene-Oligocene volcanics, to elucidate relationships between marine organisms, sediment accumulation, volcanism, currents and paleoenvironment. Volcanism on a continental shelf produces new topography and acts also as a distributor for new sediment, both of which affect organisms living on the shelf. The new topographic highs may have been sites of enhanced biological activity and hence suppliers of biogenic sediment to the surrounding shelf. They may also have affected ocean currents in the vicinity, and thereby have played a role in development of erosional or disconformable contacts among marine units. Perhaps iron and other nutrients from erupted iron- and magnesium-rich volcanic glass fragments influenced local ocean fertility. Perhaps, also, changes in the nature of accumulating sediment affect aspects of volcanic eruption processes. A final goal of the work is to determine the timescales over which changes have taken place. This will be accomplished by determining Sr isotopic compositions and through biostratigraphic dating, particularly using foraminifera.

## REALISING NEW ZEALANDS ENERGY POTENTIAL: A KAITIAKI APPROACH TO GEOTHERMAL DEVELOPMENT


**D.C.H. Hikuroa[1], T.K.K.B. Morgan[2], M. Henare[3] & D.M. Gravley**

[1]Institute of Earth Science & Engineering, U. of .Akl., Priv. Bag 92019, Auckland, 1141
[2]Dept. of Civil & Environmental Engineering, University of Auckland
[3]Mira Szaszy Research Centre, University of Auckland
[4]Geological Sciences, University of Canterbury, Private Bag 4800, ChCh 8140
d.hikuroa@auckland.ac.nz


Maori science and commerce 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. The reputation of Geothermal Energy as renewable and sustainable makes it highly desirable to Maori – and has the potential to satisfy the quadruple bottom-line.

However to date, relatively few Maori groups have undertaken development of their resources. Furthermore, recent Treaty of Waitangi settlements have included considerable geothermal resources. A potential barrier to development has been a clear pathway that accounts for an additional responsibility that Maori decision makers have – that of kaitiaki (best translated in this context as ‘stewards’).

We will present here an update on our work to create a geothermal development model that meets both governmental consenting requirements (e.g. RMA – administered by regional councils) and also accounts for kaitiakitanga (‘stewardship’) responsibilities.

The major outcome of this project will be a geothermal development model that integrates geothermal science and engineering with matauranga and kaitiakitanga and in so doing will enable New Zealand to realise more of its sustainable and renewable energy.

# STRUCTURE OF THE MOUNT ST. HELENS MAGMATIC SYSTEM: INSIGHTS FROM MAGNETOTELLURIC IMAGING

**Graham J. Hill[1], T. Grant Caldwell[1], Wiebke Heise[1], Hugh M. Bibby[1], Darren G. Chertkoff[2], and Matt K. Burgess[3]**
[1]GNS Science, Lower Hutt, Wellington, New Zealand
[2]Crystal Prism Consulting Inc., North Vancouver, BC, Canada
[3]USGS California Water Science Center, San Diego, CA, USA
g.hill@gns.cri.nz

Magnetotelluric (MT) data from an analysis of 86 broad-band soundings from Mount St. Helens show two high conductivity zones that appear to image both the ascent path and source region of the dacitic magma currently being extruded as a lava dome at the surface. These two conductive zones can be clearly identified in the phase tensor data, while detailed inverse (2-, and 3-D) and forward (3-D) modelling show that the conductive zones are connected. Simple 3-D block modelling show that a strong asymmetry in the phase response at ~85s near the volcano is also caused by this interconnection. The ascent path or magma conduit lies at the margin of a large regional conductive zone about 15 km deep also seen in earlier magnetovariance (MV) and MT studies. We interpret this region to be the source of the silica-rich component of the magma at Mount St. Helens. Seismicity recorded at the time of the 1980 eruption and more recently, during the period of dome growth, is concentrated along the margins of the conductive zones providing independent evidence for our interpretation.

**BRACHIOPODS FROM THE *OSTREA* BED (BROKEN RIVER FORMATION), UPPER CRETACEOUS OF NORTH CANTERBURY**

**Norton Hiller**
Canterbury Museum, Christchurch
nhiller@canterburymuseum.com

The *Ostrea* bed is a 2-5m-thick, calcareous sandstone unit packed with fossil oyster shells, occurring at or near the top of the Broken River Formation. It has been traced from Broken River, in the west, eastwards to Weka Creek where it is well exposed in the stream bed and banks. This unit has been dated, on the basis of dinoflagellates, as Upper Haumurian (late Campanian – early Maastrichtian), making the *Ostrea* bed probably early Maastrichtian.

The presence of brachiopods in the *Ostrea* bed was first noted by Thomson (1920) who observed a fragment of a rhynchonellide among the molluscs. However, no mention of brachiopods was made in Wilson's (1963) bulletin on the geology of the Waipara district, although a comprehensive list of fossils from the unit was provided.

A project to investigate the occurrence of brachiopods in the *Ostrea* Bed was prompted by the discovery of several poorly preserved rhynchonellides and an unknown terebratellidine in the Robin Allan collection that had been transferred from the University of Canterbury to Canterbury Museum. The associated documentation indicated that the specimens were obtained from the *Ostrea* bed in Weka Creek, North Canterbury. To validate the locality, several exposures of the *Ostrea* bed were investigated in the Weka Pass area, and a number of additional brachiopod specimens were recovered.

The small to medium-sized rhynchonellides are the more common of the two brachiopod genera present in the oyster reef, but without well preserved crura in the dorsal valve it is impossible to provide a precise identification. Nonetheless, the combination of characters shown by the material available suggests affinity with the Superfamily Hemithiridoidea and possibly the Family Notosariidae, within which similarities are noted with *Plicirhynchia* and *Paraplicirhynchia.*

The second genus is much more difficult to place. The punctuate shell, straight hinge line and strong costate ornament would indicate a member of the Suborder Terebratellidina. The large permesothyrid foramen and attrite beak suggest Kraussinoidea or Megathyridoidea but size, lack of a dorsal, or even a ventral, median septum, and the absence of any brachidial structures are difficult to reconcile with placement in either of these superfamilies. The affinities of this brachiopod require further investigation.

Thomson, J.A. 1920. The Notocene geology of the middle Waipara and Weka Pass district, north Canterbury, New Zealand. *Transactions of the New Zealand Institute* 52: 322-415.

Wilson, D.D. 1963. Geology of Waipara Subdivision. *New Zealand Geological Survey Bulletin* 64, Government Printer, Wellington, 122 pp.

# ICE IN THE GREENHOUSE: NEW ZEALAND'S EVIDENCE FOR ANTARCTIC GLACIATION IN THE LATE PALEOCENE

**C.J. Hollis[1], L. Handley[2], K.W.R. Taylor[2], R.D. Pancost[2], S. Schouten[3], J. Creech[4], J. Baker[4], B. Andrew[5], C.S. Nelson[5], P. Lurcock[6], G.S Wilson[6], P. Schiøler[1], H.E.G. Morgans[1], E.M. Crouch[1], J.S. Crampton[1], C.P. Strong[1] & M. Huber[7]**

[1] GNS Science, PO Box 30-368, Lower Hutt, NZ
[2] Organic Chemistry Unit, School of Chemistry, University of Bristol, Bristol, UK
[3] NIOZ, PO Box 59, 1790 AB Den Burg, Texel, The Netherlands
[4] SGEES, Victoria University of Wellington, PO Box 600, Wellington, NZ
[5] Dept of Earth & Ocean Sciences, University of Waikato, Hamilton, NZ
[6] Marine Science & Geology Depts, University of Otago, Dunedin, NZ
[7] Earth and Atmospheric Sciences Dept., Purdue University, Indiana, USA
c.hollis@gns.cri.nz

The textbook history of Cenozoic climate has Antarctic ice sheets developing at the Eocene-Oligocene boundary and Arctic ice sheets developing much later in the Neogene. The Antarctic ice sheets are thought to have developed as a consequence of thermal isolation, with the opening of ocean gateways facilitating establishment of the Antarctic Circumpolar Current (ACC). Indeed, the vigorous circulation linked to this current is suggested to have caused the demise of the Paleogene greenhouse by stimulating phytoplankton productivity and accelerating the drawdown of atmospheric $CO_2$. However, this paradigm is now being challenged on all quarters. Milankovitch-scale sea level oscillations extending into the Cretaceous suggest at least periodic occurrences of significant continental ice for at least the last 100 million years. Evidence from indicators of sea ice and ice-rafted debris from the Late Cretaceous and Middle Eocene suggests ice sheets may have actually formed in the Arctic before the Antarctic. Finally, ice sheet and general circulation models indicate that Antarctic ice sheet stability is controlled by $CO_2$ not ocean heat transport.

These challenges to the "gateway theory" are of critical importance in a warming world because they imply that ocean currents may not protect the Antarctic ice sheets from catastrophic collapse if greenhouse gases increase beyond a critical threshold.

To test this theory we looked for clear evidence of Antarctic glaciation prior to the latest Eocene initiation of the ACC. In the New Zealand region, there is equivocal evidence for significant cooling pulses from middle to late Eocene, but the most pronounced episode of cooling occurs in the late Paleocene. Around 57-58 Ma, geochemical proxy data suggest that both sea surface and sea floor temperatures were only slightly warmer than today and, more significantly, markedly cooler than the tropical conditions reported for the early Eocene. At the same time, palynofacies analysis signals a distinct regression across several of New Zealand's sedimentary basins, suggesting a eustatic sea-level fall. Eastward of the main depocentres, hardgrounds, lag deposits, phosphatic layers and glaucony suggest intensification of bottom currents consistent with a proto-western boundary current flow. This episode of cooling and sea-level fall coincides with the Paleocene carbon isotope maximum, an episode of greatly accelerated carbon burial, implying that the Paleocene Antarctic glaciation may have been a consequence of atmospheric $CO_2$ falling below a critical threshold.

# PRELIMINARY REVIEW OF LATE CRETACEOUS AND CENOZOIC FERN MACROFOSSILS FROM SOUTH ISLAND, NEW ZEALAND

**Aline Homes[1], Daphne Lee[2], Ellen Cieraad[3]**
[1]School of Geography, Environment & Earth Sciences, VUW, Wellington
[2]Department of Geology, University of Otago, PO Box 56, Dunedin
[3]Landcare Research, PO Box 40, Lincoln 7640, Christchurch
aline.homes@paradise.net.nz

New Zealand fern macrofossils are a neglected group. Only a handful of studies have been undertaken since Ettingshausen (1891) published descriptions of several fossil ferns from this country. This contribution is part of a proposed study of the macrofossil history of New Zealand's pteridophytes. Cieraad (2003) briefly reviewed New Zealand fern macrofossil studies to that time, but more recent work, particularly in Central Otago has yielded new records. This preliminary review is based on published accounts and selected collections held in the Geology Department, University of Otago.

Fern macrofossils from seven South island localities are considered here, ranging in age from Late Cretaceous to Late Miocene. Some macrofossil taxa occur at more than one locality and at least three have *in situ* sporangia. Newly recognised specimens from Puponga, northwest Nelson include two species of *Gleichenia* and a possible *Sticherus*. Six different ferns are recorded from a late Eocene fossil forest site at Pikopiko, western Southland. These include fertile pinnae of probable *Todea* and *Cyclosorus.* A further species of *Gleichenia* occurs in early Miocene silcrete at Landslip Hill, Southland. Probable *Gleichenia* sporangia have been isolated from the Gore Lignite Measures.

A number of ferns occur together in Lake Manuherikia sediments at a site near Bannockburn, Central Otago. These include species of *Blechnum*, *Cyclosorus*, and fragmentary specimens that may represent *Todea*, *Marattia* and *Pneumatopteris*. Another early Miocene site at Foulden Hills has yielded sterile *Schizaea* and fertile *Davallia*. Fern fragments are not uncommon in the middle to upper Miocene Longford Formation. These include species of *Blechnum, Davallia*, *Hymenophyllum, Leptopteris* and possible tree ferns.

Unlike spores which have the potential to travel long distances, fern macrofossils represent the relatively local occurrence of species. They can be used to augment information on the vascular flora to provide insights into edaphic, hydrological, and climatic conditions during the Late Cretaceous and Cenozoic in New Zealand.

# PYROCLASTIC SUCCESSIONS OF A TUFF RING IN A MONOGENETIC FIELD: BARRIBALL ROAD TUFF RING, SOUTH AUCKLAND

**T. Ilanko[1], A. Pittari[1], R.M. Briggs[1] & K. Németh[2]**

[1]Dept. of Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton

[2]Institute of Natural Resources, Massey University, P.O. Box 11 222, Palmerston North

ti10@waikato.ac.nz

Explosive phreatomagmatic eruptions are a significant element of volcanism in monogenetic volcanic fields such as South Auckland. Deposits of phreatomagmatic volcanoes usually contain abundant juvenile and country rock lithic material, and their relative ratios, textural characteristics, and vertical and horizontal variations can provide an insight into the changes in eruption style and emplacement mechanism. Barriball Road tuff ring, dated at 1.00 ± 0.06 Ma (K-Ar whole rock method), is one of about 97 eruptive centres in the South Auckland basaltic volcanic field, and consists of a tuff ring about 2 km in diameter including the rims, and a nested scoria cone. In this study the stratigraphy of a 22 m thick succession from the inner wall of the tuff ring was logged and individual facies identified. Petrographic analysis was also undertaken on bulk pyroclastic rocks and individual ballistic samples hosted in the beds. The purpose of this work is to understand the eruption and depositional processes through which Barriball tuff ring has been formed. Bedding and changes in stratigraphy are expected to reflect the transport and deposition of pyroclasts and eruption intensity. Identification of the accidental lithic components in the succession can indicate the relative depth of country rock excavation, which in turn can be correlated to the depth of magma-water interaction. Variations in texture and morphology of the juvenile pyroclasts can be associated with the magma fragmentation style, for example from purely phreatomagmatic to magmatic.

Two main facies associations have been identified in the study section. The lower facies association is 6.7 m thick and consists of moderately indurated, massive to planar bedded tuff to lapilli tuff. Individual bed thicknesses range from a few cm to 80 cm. The upper facies association (15 m thick) is finer grained with alternating beds of laminated tuff and lapilli tuff, which often pinch and swell in thickness or show cross bedding and abundant bomb sags. Ballistic lava fragments are common in both facies associations and include non-vesicular blocks and vesicular bombs, sometimes occurring along concentration zones. The main ash and lapilli sized grain components within both associations are juvenile scoria, juvenile and accidental crystals including quartz, and lithic clasts including recycled basaltic lava, white mudstone and sandstone, and shell fragments of marine fossils (e.g. *Polinices propeovatus*, *Dentalium solidum*).

The succession at Barriball Road tuff ring is interpreted to represent a predominantly phreatomagmatic eruption with alternating phases of pyroclastic surge and fall processes. The abrupt transition to the upper, probably more surge dominated, facies association may be due to an increase in the water: magma ratio. The presence of quartz and fossils suggest that the country rock involved is likely to be the Pliocene Kaawa Formation. Barriball Road tuff ring typifies some of the phreatomagmatic eruption processes that have occurred in lowland monogenetic fields such as South Auckland and Auckland.

## RELATIONSHIPS BETWEEN NORMAL FAULTS AND GAS MIGRATION IN SOUTH TARANAKI, NEW ZEALAND

**Brad Ilg, Jan Baur, Andy Nicol, Mike Milner, Miko Fohrmann & Rob Funnell**
GNS Science, PO Box 30368, Lower Hutt, New Zealand
b.ilg@gns.cri.nz

Gas plumes and normal faults are widespread within the South Taranaki Basin. Interpretation of 2D and 3D seismic reflection data together with seismic meta-attribute analysis have been used to map the locations and geometries of the gas plumes, faults, anticlines, regional seal and Cretaceous hydrocarbon source rocks. These data support the notion that normal faults can be conduits for the up-sequence migration of hydrocarbons. In particular, late-stage (0-4 Ma) normal faults carry about 70% of the observed gas plumes, many of which are elongate parallel to fault dip and actively expelled at the seafloor during the Quaternary. The remainder of plumes are vertical gas chimneys that are spatially unrelated to seismically resolvable faults. The density of these vertical chimneys is inversely correlated to Oligocene seal thickness, with most gas plumes located above source rocks which have been generating hydrocarbons since ~11 Ma. The absence of gas plumes along some faults is due primarily to their lack of contact with hydrocarbons. The faults showing the greatest evidence for gas expulsion displace the reservoir/seal rocks and appear to be contained within (and perhaps control the location of) a hydrocarbon migration pathway. The predominance of gas plumes above expelling source rocks and in culminations is consistent with a migration model in which lateral hydrocarbon flow is sub-seal and up-sequence flow occurs throughout the sequence. Gas plumes within fault zones appear to be vertically and laterally discontinuous. The locations of some gas plumes along faults are coincident with fault intersections or relay ramp zones, where relatively high densities of open fractures would be predicted, and with locally elevated dilational stresses.

# GEOCHRONOLOGY OF GRANULITES FROM THE KAKANUI MINERAL BRECCIA

**Trevor Ireland**[1], **Tony Reay**[2] **& Paul Sipiera**[3]
[1]Research School of Earth Sciences, ANU, Canberra
[2]Geology Dept., University of Otago, Dunedin
[3]Planetary Studies Foundation, Elizabeth IL, USA
trevor.ireland@anu.edu.au

The Kakanui Mineral Breccia provides samples from the lower crust and mantle under Eastern Otago. The eruption age of the unit is well constrained stratigraphically to lower Oligocene. Xenoliths of many types are found throughout the breccia.

Granulites are found in beach outcrops on the southern side of the Kakanui River Mouth. Geochemical analysis suggests that these could be derived from the main PermoTriassic sedimentary units of eastern South Island, viz. Caples Terrane or Torlesse Greywacke. We have separated and analyzed zircon and monazite from one of these granulite blocks. The zircons are small and ovoid in shape. Cathodoluminescence imaging reveals distinct igneously-zoned cores surrounded by uniform intensity zircon on the rim. The cores have been resorbed: rim boundaries cut across the oscillatory zoning of the cores. SHRIMP U-Th-Pb analysis reveals that the oldest ages in the cores are late Permian to early Triassic in age.

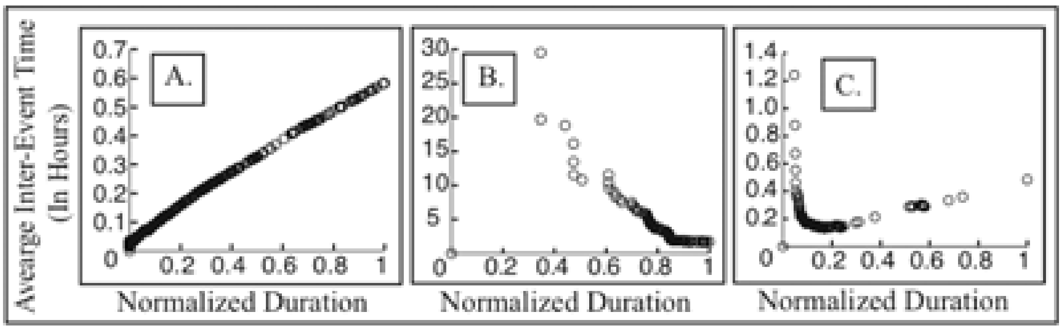
The zircon geochronology supports the geochemical interpretation that the granulites are derived from the sedimentary rocks in close proximity. However, constraining the source solely on the basis of geochronology remains equivocal. There is no indication of any older material as would be a clear indicator of derivation from the Torlesse greywacke. However, the number of analyses is relatively low and the abundance of older detrital components (500, 1000 Ma) is frequently quite low in Torlesse and so the contrary argument can not be proven (i.e. that absence of old zircon indicates Caples provenance). However, the combination of geochronology and geochemistry is most consistent with Caples derivation.

The rims on the zircons give a uniform age of around 90 Ma. The monazites separated from the granulite also give this age. This age is consistent with widespread volcanism in eastern Otago in the mid Cretaceous and suggests the dominant metamorphism of this rock occurred at this time. This event was probably regional in character. Surprisingly, there is little indication of any disturbance in zircon or monazite associated with the Oligocene volcanism.

**TEMPORAL EVOLUTION OF EARTHQUAKE SEQUENCES (SWARMS) IN THE CENTRAL VOLCANIC REGION**

**K. Jacobs, E.G.C. Smith & M.K. Savage**
Institute of Geophysics Victoria University of Wellington, PO Box 600, Wellington
katjac8@gmail.com

We examine the temporal evolution of earthquake sequences in the Central Volcanic Region as a step towards probabilistic modelling of those sequences. We characterize 257 sequences with at least four events selected from the GeoNet earthquake catalogue between 1987 and 2009 with an inferred completeness magnitude of 2.5. We categorize 14 as mainshock-aftershock (MS-AS), including four of the ten largest sequences. We analyze sequences by size (4 to 831 events), maximum magnitude (2.53 to 6.14), duration (minutes to 35 days), and other parameters including moment release with time, magnitude histories, inter-event time differences, and spatial relationships. In particular we closely examine the position and size of the maximum magnitude event and its relation to the size and development of each sequence. Sequences with mainshock magnitudes of M=5.0 or greater all have 100 or more earthquakes (5 sequences, including 3 MS-AS). Sequences with a mainshock magnitude below 3.0 have less than 20 earthquakes (60 sequences). We use average inter-event time differences to look at development of sequences in time. While there is variability between sequences they generally fit three basic patterns (Fig.). We have also searched for possible triggering of the sequences by large global (M=7.0+) and moderate New Zealand (M=6.0+) earthquakes. While some sequences follow large earthquakes closely in time, we cannot rule out the possibility that this timing is random.




Average inter-event times are plotted against time normalized to sequence duration for three sequences A) classic MS-AS sequence with decaying rate (increasing inter-event time); B) swarm whose rate accelerates towards the end of the sequence (decreasing inter-event time); C) sharp increase in rate (decrease in inter-event time) followed by steady decrease (seen for both swarm type and some foreshock-MS-AS sequences).

# GROUNDWATER POTENTIAL OF THE TE ONEPU LIMESTONE, CENTRAL HAWKE'S BAY - AN UNCONVENTIONAL SOURCE

**A.C. Johansen & S.C. Rabbitte**
EAM Environmental Consultants, PO Box 1154, Napier
alex@eam.co.nz

Increased land development across Central Hawkes Bay has resulted in the consideration of more challenging potential groundwater supply targets. A review of the geology and hydrogeology of the Ruataniwha Plains indicated an alternative potential aquifer target east of Takapau. The deep prospective aquifer is the Pliocene Te Onepu Limestone Formation, which forms the eastern boundary of the Quaternary sands and gravels of the main Ruataniwha Basin.

A pre-existing seismic interpretation report identified the presence of a highly porous and permeable limestone along the eastern margin of the basin. A Hawke's Bay Regional Council State of the Environment well was identified that intercepts the limestone at approximately 105m. An exploratory well was drilled and logged to a total depth of 231m. Limestone and interbedded sands were encountered at 108m, and extended to the base of the borehole. Initial pump testing of this well comprised a step test and a 4 day, 18L/s constant discharge test. Five water quality samples were collected from different depths. A production well was drilled to 233m depth, with the limestone encountered at 98m. A step test and 7 day, 60L/s constant discharge test were carried out. Five observation wells and the pumped well were monitored, two within the same aquifer, two intermediate and one shallow within the Quaternary gravels and a limestone spring.

Detailed well logging of the exploratory well was correlated against known geological formations. The water quality results were assessed against relevant standards. Assessment of confinement from the main Ruataniwha Basin and surface water was made by analysis of water levels within intermediate and shallow wells and the flow from a spring discharge. Constant discharge test drawdown data from the two deep limestone observation wells indicate confined conditions. Slight departure below the Theis type curve was noted which suggests interception of potential fracture flow. A maximum fluctuation of 45mm was observed during the test in the two intermediate depth wells, and a 10mm fluctuation was observed in the shallow well. No persistent declining water level trends were observed during or following cessation of pumping, and there was no apparent affect on the flow in the limestone spring. The Pukeora Oyster Shellbed and Sailsbury Gravels are seen to extend further to the east than originally shown on the earlier seismic interpretation. The thickness of the Te Onepu Limestone and Tuki Tuki Sandstone is greater than expected. The Te Onepu Limestone is separated from the main Ruataniwha Basin deposits by the 56.8m thick South Makaretu Mudstone, and is considered confined from them. This is supported by shallow and intermediate depth water level observations made throughout the duration of, and following termination of the constant discharge pump test. The water quality is good and suitable for the purpose of irrigation. The reported Transmissivity of 206.7 $m^2$/day and Storativity of 0.001 are thought sufficient to support sustainable water extraction from the limestone unit.

# THE CHARACTER OF OCEANIC DETACHMENT FAULTS

**B.E. John[1], M.J. Cheadle[1], C.B. Grimes[2], A.G. Baines[3] & J. Wooden[4]**
[1]Dept. of Geology & Geophysics, University of Wyoming, WY, USA
[2]Dept. of Geosciences, Mississippi State University, Starksville, MS, USA
[3]School of Earth and Environmental Sciences, Adelaide University, Adelaide, Australia
[4]Dept. of Geological Sciences, Stanford University, Stanford, CA, USA
bjohn@uwyo.edu

Oceanic detachment faults and associated core complexes form at intermediate, slow, and ultraslow spreading mid-oceanic ridges, and together represent a fundamental mode of crustal extension comprising up to 60% of the seafloor locally. They are characterized by corrugated, domal topography; exposures of the fault surface extend 10 to >100 km in the down-dip direction, at dips ≤15°. In contrast to continental detachment systems, these faults are non-conservative; footwall exposure is far more extensive than the hanging wall. Either addition of gabbro through magmatic activity or upward flow of mantle peridotite continuously 'casts' the footwall, during fault slip. These detachment faults are rolling-hinge type normal faults and are arguably the largest normal faults on Earth, serving as the plate boundary at the mid-ocean ridge.

U/Pb SHRIMP RG dating of zircon collected from evolved samples of gabbroic crust exposed in the footwalls to these large-offset faults provides detailed slip rates, helps calibrate marine magnetic anomalies, and provides constraints on the timing of both magmatism and denudation. Spreading rate estimates derived using zircon from Atlantis Bank (SW Indian Ridge), Atlantis Massif and the Kane (mid-Atlantic Ridge) core complexes, suggest that oceanic detachment faults form during periods of asymmetric spreading (Atlantis Bank detachment fault accommodated roughly 80% of plate spreading). Asymmetric spreading requires consequent ridge migration and thus oceanic detachment faults are intimately linked to ridge-transform evolution.

Combined Pb/U zircon dating and (U-Th)/He cooling ages delimit the depth of detachment faulting at mid-ocean ridges. Ti-in-zircon crystallization temperatures, taken with the closure temperature of the (U-Th)/He system in zircon bracket the acquisition temperature of magnetic remanence, and collectively define a cooling history for detachment footwalls over a temperature range between ~900-220°C. Time-averaged cooling rates for this interval range from $1025(^{+645}_{-330})$° C/myr. to $2110(^{+1600}_{-720})$° C/myr. Assuming the footwall was denuded along a single, continuous fault system, the time interval defined by the difference between Pb/U and (U-Th)/He ages, can be used to estimate the distance along the fault between 900° and 200°C isotherms, and therefore, the length-scale of the active fault. U/Pb zircon derived fault slip rates taken with the cooling time interval, a single, continuous fault would have a length of 6-11km between the 900º and 200º C isotherms. Using this calculated fault length with an estimated depth to the 200º C isotherm (1-2 km), and an assumed initial fault dip (50°, based on paleomagnetic data and sea floor bathymetry), implies that these faults were active to depths of up to 9 km. These significant depths for active faulting in slow spreading environments are consistent with microseismicity studies, and the existence of high temperature fault rocks from many oceanic detachment faults.

# A HIGH-RESOLUTION BENCHMARK OF SPATIAL VARIATIONS IN SEISMIC ANISOTROPY AROUND MOUNT RUAPEHU VOLCANO

**J.H. Johnson** , **M.K. Savage & J. Townend**
Institute of Geophysics, Victoria University of Wellington, PO Box 600, Wellington
jessica.johnson@vuw.ac.nz

We have created a benchmark of spatial variations in seismic anisotropy around Mount Ruapehu volcano against which to measure future temporal changes. Anisotropy in the crust is assumed to be caused by microcracks aligned preferentially with the prevailing stress field. Therefore, the polarisations of the fast quasi-shear waves are interpreted to indicate the direction of maximum horizontal stress. Mount Ruapehu is an andesitic stratovolcano in the central North Island. Its last major eruption was in 1995/1996. Changes in seismic anisotropy have been observed following this eruption and were attributed to changes in stress from the depressurising and subsequent repressurising of the magmatic system within the volcano. We deployed sixteen 3-component broadband stations as part of the SADAR (Spatial Anisotropy Deployment At Ruapehu) experiment to complement the fourteen permanent GeoNet stations that surround Mt. Ruapehu. This creates a denser overall network, improving the resolution with which spatial variations in seismic anisotropy can be observed. Using an automated shear wave splitting analysis algorithm, we examine local earthquakes from 2008 with epicentres within 100 km of Mt. Ruapehu. Preliminary results reveal a generally north-south fast polarisation, which is likely to reflect the regional tectonic stress regime. Smaller areas to the north and east of Mt. Ruapehu exhibit fast polarisations approximately orthogonal to the predominant north-south orientation. These observations generally agree with past anisotropy studies and with stress estimations from focal mechanism inversions.

# WAVEFORM MODELLING FOR REPEATING EARTHQUAKES AT NAGURUHOE VOLCANO IN TONGARIRO NATIONAL PARK

**A.D. Jolly[1] Steve Sherburn[1], Philippe Jousset[2] & Jurgen Neuberg[3]**
[1]GNS Science, Wairakei Research Centre, Wairakei
[2]Development, Planning and Natural Hazards Division, BRGM, Orleans, France
[3]SEE, University of Leeds, England
a.jolly@gns.cri.nz

Ngauruhoe volcano has produced over 19000 small repeating long period earthquakes since 2006. The earthquakes are characterised by extended codas, a small range in magnitudes (all < $M_L$ 1.5) and nearly identical waveform characteristics over long time-periods (years). These persistent earthquakes were observed to change dramatically over a two week period in January 2008. In the frequency domain, the earthquakes became higher frequency, while retaining some of the main resonant peaks (i.e. 1.2, 3.2 and 4 Hz) from the earlier period of the sequence. In the time domain, the waveform envelope retained some of their characteristic phases, but had notably higher frequencies. These changes occurred without any measurable shift in relative phase arrival times (i.e. locations), and so occurred within a small source volume.

We have begun modelling the waveform and frequency characteristics for this earthquake sequence using a 3D finite-difference (FD) modelling technique which is informed by local knowledge of the velocity structure, source properties and constraints of physical properties in volcanic systems. We obtain synthetic seismograms from the FD codes and compare these in a forward method to the observed seismograms. We will show initial tests including the effects of simple source geometries and shallow resonators (i.e., shallow magma, or hydrothermal systems). Our objective is to discover possible property changes which can produce the observed changes within the time and spatial constraints where the earthquakes are observed.

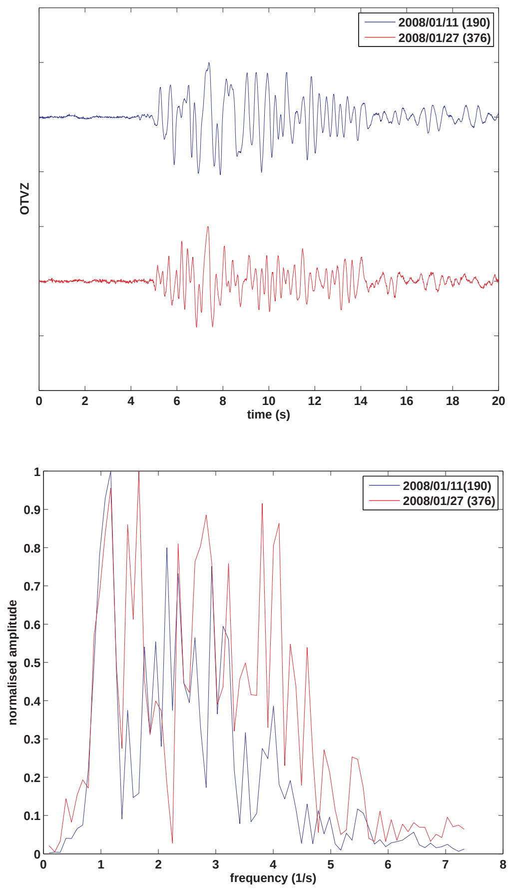



Figure: Example waveforms (top), and spectra (bottom) showing evolution of Ngauruhoe earthquakes before (blue), and after (red) January 2008.

## A TOOL FOR CREATING AN INTERACTIVE CHRONOSTRATIGRAPHIC FRAMEWORK

**C.M. Jones[1], P.R. King[1], J.S. Crampton[1], J. Ogg[2], A. Lugowski[3]**
[1]GNS Science, PO Box 30368, Lower Hutt
[2] Purdue University, Indiana, USA
[3] Computer Science Dept., Univ. Calif., Santa Barbara, USA
c.jones@gns.cri.nz

Timescale Creator (TS Creator) is a free java-based software application that has been created by the authors (J. Ogg & A. Lugowski) in conjunction with the Subcommission for Stratigraphic Information (ICS) to encourage and enable a global compilation of data about the history of Earth. The program allows users to interactively create publication-quality timescale charts using pre-packaged datasets. Here we outline new functionality developed to expand the software's capability for visualising new types of geological data, with examples using New Zealand datasets.

We recognise that a lot of important chronostratigraphic data are encapsulated in paper graphics that become out-of-date as changes are made in local and international timescales. With this in mind a set of tools has been developed within TS Creator that allows for the quick and simple digitisation of paper graphics into a format that is able to be read directly into the program. Recalibration of the graphics can then be performed, with interactive functionality in the form of pop-up boxes or hyperlinks added to enhance the information. We have used this new capability to digitally re-master, and recalibrate six chronostratigraphic transects from the Taranaki Basin region (after King et al. 1999, Institute of Geological and Nuclear Sciences folio series 1).

We have also used the graphical visualisation power of the program to display measured depth data that have not been previously used, including measured section and well sample sets, lithostratigraphic columns, biostratigraphic occurrence and abundance data, and sample analysis curves. These can now be cross-plotted against timescale data as a graphical correlation panel and events used to interpolate depth data into chronostratigraphic data on-the-fly. This provides a powerful visualisation tool for evaluating sequence stratigraphic models and the starting point for construction of new chronostratigraphic transects.

## ROSS-DELAMERIAN OROGEN IN FIORDLAND REVISITED

**R. Jongens[1], A.H. Allibone[2], I.M. Turnbull[1], A.J. Tulloch[1]**
[1]GNS Science, Private Bag 1930, Dunedin
[2]Rodinian, PO Box 1970, Queanbeyan, NSW2620, Australia
r.jongens@gns.cri.nz

A previous suggestion that an intrusive element of the Ross-Delamerian Orogeny is present in the New Zealand basement (Gibson & Ireland 1996) has been strengthened by U-Pb zircon dating of two granitoid plutons in central and western Fiordland: the Jaquiery Granitoid Gneiss and Pandora Orthogneiss. The Jaquiery Granitoid Gneiss crops out as three 5–7 $km^2$ bodies in the headwaters of Jaquiery and Florence streams and in the Townley Mountains of central Fiordland. First recognised by N. Powell's PhD mapping, this unit is a strongly foliated, fine to medium grained granodiorite or tonalite gneiss. In some parts, evidence of igneous textures is preserved, but much of the gneiss is completely recrystallised to a polygonal mosaic of grains. Xenoliths of massive to schistose amphibolite are present in the Townley Mountain body, but elsewhere xenoliths are absent. U-Pb zircon TIMS dating indicates an emplacement age of c. 493 Ma. Transposed dikes of the Jaquiery Granitoid Gneiss intrude mafic metavolcanic rocks adjacent to pluton margins. These metavolcanic rocks form part of a conformable metasedimentary sequence from which a psammitic sample in the Jaquiery Stream catchment has yielded a youngest detrital zircon population age of 501 ± 10 Ma (Scott *et al.* 2009). This age, and the intrusive relationship with the Jaquiery Granitoid Gneiss, implies the metasedimentary sequence was deposited in the Middle to Late Cambrian.

The Pandora Orthogneiss is a NNW-trending, 20 km x 2 km body of variably foliated heterogeneous tonalite, granodiorite, and monzogranite orthogneiss between Thompson and Nancy sounds in western Fiordland. The orthogneiss is generally well foliated, but retains obvious relict igneous textures in some outcrops. U-Pb TIMS zircon dating indicates an emplacement age of c. 500 Ma. The orthogneiss is flanked on either side by metasedimentary rocks, and metasedimentary xenoliths are common within the pluton's western margin. Transposed dikelets of the orthogneiss intrude the adjacent metasediments on the eastern margin, confirming an intrusive relationship, and implying these metasedimentary rocks are no younger than Cambrian in age. These Cambro-Ordovician intrusions imply a general correlation with granitoid intrusions in the Ross-Delamerian Orogen of the Transantarctic Mountains and South Australia. Granitoid intrusions of this age have not been seen in the Takaka terrane of northwest Nelson, nor in its probable nearest correlative, the Bowers terrane of Northern Victoria Land. They do, however, intrude west of the Bowers terrane, within the Wilson terrane, where metasedimentary rocks in the eastern portion appear similar in character to those seen in central and western Fiordland.

**CONIFERS: ONCE AND FUTURE KINGS?**

Greg Jordan, Tim Brodribb, Scott McAdam
Plant Science, University of Tasmania, Private Bag 55, Hobart, Tas. 7001, Australia
greg.jordan@utas.edu.au

The conifers have the best fossil record of any group of terrestrial organisms, and in this talk I will consider the success of this ancient clade by comparing and contrasting the histories of these organisms in Tasmania and New Zealand. These regions are now centres of conifers diversity and the climates and landscapes of Tasmania and at least parts of New Zealand are similar in many ways. However, the two regions have highly divergent histories.

Fossil evidence (largely from Bob Hill) clearly shows astonishing diversity of conifers in Tasmania during the Paleogene. In particular, the Early Oligocene Little Rapid River fossil site shows a diversity of conifers that is likely to be greater than any other known site fossil or living, and coeval sites indicate high beta-diversity as well. Conifers have dwindled in diversity and abundance ever since that time, even into the Late Pleistocene. This has been associated with drying climates and increased fire.

The New Zealand fossil conifer flora is not quite as well known as that of Tasmania, but published and unpublished recent work is revealing a somewhat similar story. There is certainly growing evidence that past diversity of conifers was considerably greater than at the present, especially in the Late Oligocene/Early Miocene (after the peak in Tasmania). This diversity has declined, though higher diversity has been retained in New Zealand than Tasmania. Drying and disturbance may also have contributed to this diminution.

This pattern seems straight forward, but in fact the high Paleogene diversity challenges a traditional view. Conifers are often considered to have been displaced by angiosperms because reproductive and water conducting characteristics are believed to have given angiosperms a competitive edge over conifers. However, this idea may be simplistic because the hyperdiverse Southern Hemisphere conifer floras post-date the diversification of angiosperms by tens of millions of years. In fact they co-existed with diverse angiosperm floras.

Recent work suggests that this apparent anomaly can be at least partly explained by fundamental differences in physiology between conifers and angiosperms. Apart from long-known differences in reproduction and water transport, conifers seem to have much less ability to adjust to both long- and short-term changes in atmospheric $CO_2$ concentration than angiosperms. This means that the conifers have less ability to optimise their photosynthesis in a low $CO_2$ world. This could have been an important factor in why conifers were competitive with angiosperms in the high $CO_2$ world of the Paleogene and raises the intriguing possibility that conifers may once again reach pre-eminence in the new, elevated $CO_2$ world we are facing.

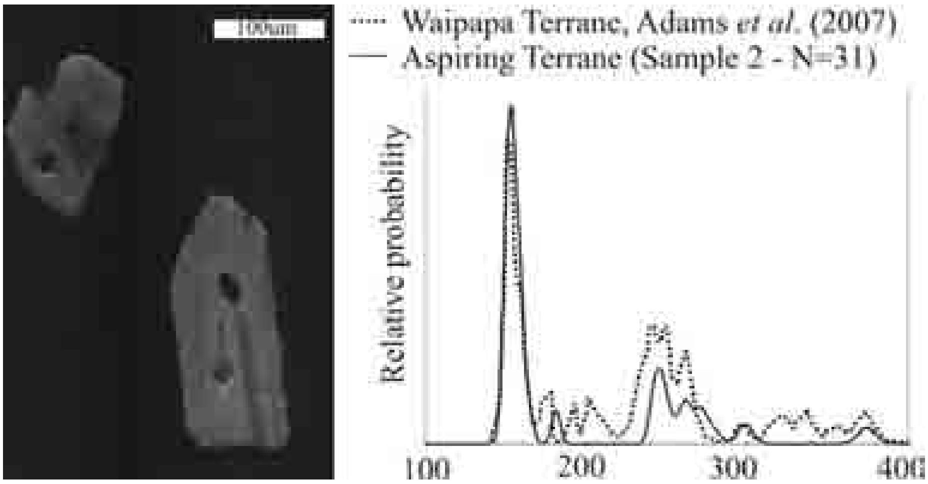
**A CONTINUATION OF THE JURASSIC WAIPAPA-ASPIRING TERRANE IN THE OTAGO SCHIST: EVIDENCE FROM DETRITAL ZIRCONS**

**Dushan Jugum, Richard Norris, J. Michael Palin, Ake Fagereng**
Geology Department, PO Box 56, University of Otago, Dunedin
dushan@geology.co.nz

Detrital zircons have been analysed in samples of the Otago Schist from the Aspiring Terrane, the Caples-Rakaia Terrane boundary and Chrystalls Beach assemblage.

The youngest zircon populations within samples of the Caples Terrane and Chrystalls Beach assemblage are Triassic in age. These samples also do not have a significant number of Palaeozoic or older zircons. Based on presently available data, the Caples Terrane and Chrystalls Beach assemblage cannot be distinguished using detrital zircons. Three samples of the Aspiring Terrane exhibit youngest zircon populations of Jurassic age (Figure). The dates represent analyses of zircon cores with typical magmatic Th/U of 0.5-1.8 making a metamorphic origin unlikely. The Rakaia Terrane samples are similar to those reported by Adams et al. (2007) with significant Palaeozoic and older zircons.

We infer the Caples Terrane and Chrystalls Beach assemblage to be derived principally from a Triassic volcanic source. The distinctly younger Aspiring Terrane lies structurally beneath the Caples and Rakaia Terranes and thus may have been subducted to some depth before it was basally accreted to the orogenic wedge. The detrital zircon pattern of the Aspiring Terrane is also similar to those obtained from the Waipapa Terrane in the North Island (Adams et al. 2007), which lies in the same relative tectonostratigraphic position on the NW side of the Alpine Fault.



# DEFORMATION MECHANISMS IN THE SOUTH ISLAND: IMPLICATIONS FROM SHEAR-WAVE SPLITTING OF LOCAL S WAVES

**S. Karalliyadda** & **M. Savage**
School of Earth Sciences, Victoria University of Wellington, PO Box 600, Wellington
karallsapt@myvuw.ac.nz

We use shear-wave splitting of local S waves to determine the three dimensional distribution of deformation on the South Island. South Island is characterized by complex deformational structures that extend over a broad region. These structures mainly result from the transpressional movement between the Australian and Pacific plates at central South Island and the subduction system that appears at the southwestern tip of South Island. Local shear wave phases recorded by land-based stations, including Geonet earthquake data and other data sets available from portable deployments in the South Island, are used to image the vertical and lateral variations of seismic anisotropy. Shear-wave splitting parameters are routinely measured using a recently developed automatic processing technique. So far, we analyzed ~20 events (Mb≥4.0) in northern South Island (NSI) and ~18 events (Mb≥4.0) in central South Island (CSI) and southern South Island (SSI) from 2004. Shear-wave splitting delay times obtained for all Geonet stations range from 0.1-0.7s. Fast polarization directions are variable and they appear to be structurally controlled. In NSI, the average delay time is 0.26s +/- 0.04s. Stations in NSI display two distinct fast polarization azimuths, ranging between 020-060$^0$ and 280-320$^0$. At stations QRZ, KHZ, NNZ and THZ, fast polarizations are subparallel to major fault traces and the strike of minor faults in the region. These results are consistent with previous results obtained from a manual method. Non-coastal stations in the SSI display a ~NNE/SSW azimuth parallel to SKS studies in the same region, and may be caused by mantle deformation. In contrast, stations on the Alpine fault in CSI and the eastern part of the SSI yield fast polarization directions that are at high angles to the SKS results and to the Alpine fault trace but are subparallel to the regional maximum compressive stress. This result may indicate a shallow source of anisotropy from cracks. By comparison with SKS splitting results, anisotropy observed from crustal and subcrustal depths above local earthquakes contributes about 25% to the total SKS splitting measurements. We plan to examine more events from 2005 to 2008 in NSI and SSI and to study the depth distribution of seismic anisotropy associated with the subdction zones.

# A PRELIMINARY ACCOUNT OF THE FOSSIL ARTHROPOD FAUNA AND INSECT-PLANT RELATIONSHIPS IN THE FOULDEN MAAR (EARLY MIOCENE, OTAGO)

**Uwe Kaulfuss[1], Daphne Lee[1], Jennifer Bannister[2], Anthony Harris[3]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. of Botany, University of Otago, PO Box 56, Dunedin
[3]Otago Museum, Great King Street, Dunedin
kauuw275@student.otago.ac.nz

Foulden Maar provides a unique window into an Early Miocene New Zealand terrestrial ecosystem. Anoxic conditions at the bottom of a deep, stratified lake and the fine-grained diatomaceous sediment allowed the preservation of a wide range of organisms that lived in or around the maar. These include a wide variety of different species of aquatic and terrestrial insects as well as spiders.

Prior to detailed research beginning at the Foulden Maar in late 2003, only six insects were reported from Mesozoic and Cenozoic strata in New Zealand. New discoveries in the past year have increased the number of fossil insects known from the Foulden Diatomite to 35.
They are preserved as chitinous compressions on light-coloured laminae, which are interpreted to represent spring-summer layers. One beetle wing scale has original structural colour preserved.

The insects discovered so far belong to four different families and some can now be assigned to genus and species level. Coleoptera are represented by adults and larvae of staphylinid beetles and at least one aquatic beetle; Hymenoptera by several ant specimens; Hemiptera by scale insects and a lace bug; and Isoptera by an isolated wing of a wet-wood termite. A species of scale insects (Coccoidea, Diaspididae) represented by fourteen individuals in life position on a large leaf of Eleocarpaceae has already been described (Harris et al. 2007).

Insects were obviously a key component of the Foulden Maar ecosystem. Many leaves exhibit insect damage structures and repair, e.g. feeding damage and galls, and some of the flowers were insect-pollinated. Additionally, some of the coprolites contain insect debris and it is likely that insects formed part of the diet of the galaxiid fish that lived in the lake.

Besides insects, a fossil spider was found at the site. The specimen is poorly preserved (pyritised) and, thus, cannot be assigned to a modern genus. It is the first fossil spider to be recognised from New Zealand.

The fossils from Foulden Maar indicate that a diverse terrestrial arthropod fauna existed in the Early Miocene of Southern New Zealand.

**IDENTIFYING A METEORITE ABLATION DEBRIS NEAR VILLAGE LEHRI IN POTOHAR REGION OF PAKISTAN**

**Saheeb Ahmed Kayani**
National University of Sciences and Technology, H-12, Islamabad-44000, Pakistan
saheebk@ceme.edu.pk

For some time locals have reported presence of a peculiar and strange looking variety of stones on a location called Pind (33°09'47"N; 73°34'09"E) approximately half a kilometer northeast of village Lehri in district Jhelum, Pakistan. For analysis purposes, representative samples were collected from different sites on the location using magnetic prospecting. Most of these samples are black in color with metallic luster. They have irregular shapes, variable thickness (0.5 to 3 cm) and are covered with rough and pitted surfaces containing depressions and shrinkage cracks.

| ***Element*** | **Composition (wt%)** | **Element** | **Composition (wt%)** |
|---|---|---|---|
| Si | 3.93 | P | 0.228 |
| Ti | 0.508 | V | 0.07 |
| Al | 0.95 | Cr | 0.324 |
| Fe | 56.28 | Ni | 0.00786 |
| Mn | 0.066 | Sr | 0.0093 |
| Mg | 0.342 | Ba | 0.367 |
| Ca | 2.69 | W | 0.024 |
| Na | 0.114 | Cl | 0.046 |
| K | 0.146 | Cu | 0.0015 |

From its unusual appearance, surface characteristics, weight to size ratio and the debris (of some natural or man made phenomenon) manner in which this suspected stone variety is scattered over a limited area, three possible origins were considered: volcanic, industrial and extraterrestrial. To determine the elemental composition and mineralogy, combined XRD-XRF analysis was performed on a sample stone (dimensions: 4.1×2.9×1.4 cm) using the facilities at Geoscience Advance Research Laboratories in Islamabad. Elemental composition (wt%) determined from XRF spectrometry is included in above table. XRD analysis detected wüstite ($Fe_{1-x}O$) and magnetite ($Fe_3O_4$) as predominant mineralogical phases in the outer crust of the tested sample stone. Magmas usually contain oxygen fugacities that are extremely oxidizing. Presence of wüstite will become very difficult to explain in terms of volcanic activity. Also volcanic magnetite tends to contain $TiO_2$ in the range of nearly 4-30 wt% where as the relatively low abundance of $TiO_2$ (0.848 wt%) detected in the tested sample helps to rule out a volcanic origin. According to local history, in past no industry associated setups (mines, storage dumps and factories) of any kind have existed on or near the said location. Also no archeological remains of any furnaces or blacksmith activity (on a commercial or industrial scale) exist in the vicinity of the location. So it is logical to assume that these stones were not deposited or transferred here as a result of industrial or human activity. Thus an industrial origin remains unlikely. The mineralogical and elemental composition of the tested sample stone is more consistent with an extraterrestrial origin. Increased relative abundance of Fe, low abundance of cosmically abundant elements such as Mn, Cr and Ti, presence of wüstite and low Ni content points towards an extraterrestrial origin by ablation of a low Ni parent meteoroid body.

## TORTURING VOLCANIC ROCKS UNTIL THEY TELL US EVERYTHING THEY KNOW!

**B. Kennedy**[1], **M. Jellinek**[2] **& K. Russell**[2]
[1]Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch
[2]Earth and Ocean Sciences, University of British Columbia, Vancouver
ben.kennedy@canterbury.ac.nz

Observations of active lava domes show that they are characterised by periodic magma supply and re-intrusion and reheating. We propose that the timescale, temperature, and water pressure of reheating control whether crack and bubble networks open or close, and whether or not gas can escape. Interpretations of historic eruptions indicate open, permeable magmatic systems favour degassing and non explosive eruptions, whereas, closed impermeable systems favour pressure build up and explosive eruptions. Despite the observations and interpretations mentioned above, the evolution of open and closed systems during reheating remains poorly understood. We reheated rhyolite dome and pumice samples under open (atmospheric pressure and dry) and closed (pressurized and wet) conditions. Open and closed porosity was measured before and after experiments by helium pycnometry, textures were examined with the Scanning Electron Microscope (SEM), and bulk water contents were measured by infrared spectroscopy during loss on ignition. Open (atmospheric pressure, 200-1100C) experiments show that (1) short timescales and low temperatures allow degassing without deformation, (2) intermediate timescales and temperatures favour bubble and crack growth, and (3) longer timescales and higher temperatures produce bubble collapse and crack healing. Closed experiments at (450C-750C and 2 and 10 MPa) show that (1) low temperatures and high pressures promote rehydration with no deformation and (2) high temperatures at all pressures allow degassing with bubble collapse. Our results indicate that during reheating of a volcanic plug, volatile content, viscosity, porosity, and permeability are very sensitive to time, temperature and water pressure. Open dry systems will degas during reheating and not deform unless temperatures of 850C are reached. Above 900C bubble collapse may result in permeability reduction and pressurisation of the volcanic system. We use evidence from remelted enclaves of rhyolite to propose that the exceptional explosivity of the 1886 basaltic eruption of Tarawera, New Zealand, may have been caused by reheating and sealing of the rhyolite plug prior to the basaltic eruption. Our experiments show closed wet systems allow rapid rehydration, and bubble collapse at lava dome temperatures and timescales. Local variation in closed wet and open dry conditions explain the large gradients in porosity seen in lava domes and conduit wall material from Mt Meager, Canada and other similar volcanoes. Additionally, we propose that our experiments have implications for the interpretation of deformation and degassing patterns at active lava dome systems.

# NEW ZEALAND'S FLORAL ORIGINS AND THE OLIGOCENE LAND CRISIS: A WORK IN PROGRESS

**E.M. Kennedy[1], D.C. Mildenhall[1], N. Mortimer[2], D.E. Lee[3], J. Palmer[4] & M.J. Isaac[1]**
[1] GNS Science, PO Box 30 368, Lower Hutt
[2] GNS Science, PO Box 1930, Dunedin
[3] Geology Dept, University of Otago, PO Box 56, Dunedin
[4] Institute of Natural Resources, Massey University, PO Box 11 222, Palmerston North
e.kennedy@gns.cri.nz

Earlier this year GNS Science and Massey and Otago universities commenced looking at the well-documented decrease in Zealandia's land area, or possibly complete submergence, in the late Oligocene (c. 27-23 Ma) and its effect on the terrestrial flora.

The project aims to find information that will lead to a better understanding of whether New Zealand completely sank below sea level or was reduced to a series of archipelagic islands. Either way, the effect on the terrestrial biota would have been devastating. It is well documented that at about this time the New Zealand flora underwent a major change with, for example, the broad-leafed southern beeches changing species dominance from *Nothofagidites matauraensis* to *N. cranwelliae*, based on pollen analysis. But was this floral change due to climate or land reduction. If land reduction was caused by climate change rather than tectonic events can we tell the difference?

Studies of lignites in Southland dated at younger than 23 Ma (e.g. Newvale Mine) show that the early Miocene flora was extremely diverse and associated with sedimentation rates that suggest a large catchment area. The flora contains precursors to the modern flora. These precursors are not necessarily direct ancestors of modern New Zealand clades. In our studies of the fossil plants we will be paying close attention to those taxa with a good fossil record and whose molecular clock has been estimated from modern native plants. The relative lack of terrestrial animal fossils precludes us from looking in any detail at the fauna but we are keen to collect freshwater hyriids to determine if any difference between pre- and post-Oligocene hyriids can be detected.

Much of the late Oligocene record is dominated by limestone but marine sandstones and some terrestrial sediments are known – Southland, Canterbury, Wellington and Northland. A number of localities have been collected for petrological analysis to determine whether trends in the maturity parameters of marine sandstones suggest presence or absence of land in the Oligocene. Analysis of these samples is underway.

We have identified a number of formations and localities that we think are of particular interest and worthy of detailed petrological and palaeobotanical study. These include Torehina (Coromandel), Pukorukoru and Ruatangata (Northland), Benneydale to Tangarakau (King Country), Pomahaka (Southland) & northern Te Anau Basin (Fiordland). If readers know of any other localities or formations that could provide clues to the geography of terrestrial New Zealand in the late Oligocene we would like to hear from you.

## MAGMA RESIDENCE BENEATH MT NGAURUHOE FROM FLUID INCLUSIONS

**G. Kilgour[1], F. Della Pasqua[2], G. Jolly[1]**
[1]GNS Science, Wairakei Research Centre Private Bag, 2000, Taupo
[2]SMG Consultants, GPO Box 3252, Brisbane, Australia
g.kilgour@gns.cri.nz

Mt. Ngauruhoe is one of the most active volcanoes in historic times. A common characteristic of the erupted deposits from the volcano are the presence of xenoliths. Ngauruhoe-derived xenoliths are mostly quartz-rich.

Fluid inclusions record the conditions (pressure and temperature) at which crystals form and as such, can be used to determine the depth of crystal formation. In this study, we analysed the fluid inclusions within xenoliths erupted during the 1975 eruption of Ngauruhoe.

We analysed $CO_2$-rich inclusions on the Laser Raman facility at Geoscience Australia, Canberra and the fluid inclusion freezing/heating stage microscope at GNS Science, Taupo. This poster shows that all of the inclusions (both primary and secondary) record a similar pressure of crystal growth. Our results indicate that country rock-magma interactions occurred between 1.5 and 3.5 km below the crater of Ngauruhoe, which implies that a network of shallow magma chambers existed (and still exists) at a similar depth.

# PALEOMAGNETIC ENVIRONMENTAL RECORD OF MD152-2991 CORE, OFFSHORE WEST COAST SOUTH ISLAND, NEW ZEALAND

**Angus King[1], Gary Wilson[2] and Helen Neil[3]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept of Marine Science, University of Otago, PO Box 56, Dunedin
[3]NIWA, Private Bag 14901, Greta Point, Wellington
1gusking@gmail.com

We conducted magnetic analyses on a piston core collected during the MATACORE voyage of RV Marion Dufresne in January 2006 along the Hokitika channel offshore the west coast of the South Island. The 33 m-long core (MD152-2991) was collected over a 20 m thick package of strata close to the northern rim of the canyon, in water depth within the Antarctic intermediate water mass (886m). The core has a generally homogenous greenish grey foraminifera rich mud, and was logged for magnetic susceptibility (κ) using the University of Otago GEOTEK Multi Sensor Core Logger (MSCL). The core was sub-sampled with 1.5 m-long U-channels that were measured for natural remnant magnetisation (NRM) and anhysteretic remnant magnetisation (ARM) with a 2G cryogenic magnetometer at the University of Otago.

The magnetic susceptibility shows $10^{-5}$ magnitude spikes at 60 cm, 188 cm and 761 cm depth below seabed. High NRM intensities were measured at 0-200 cm, 700-750 cm and 2200 cm depth below the seabed. Subsequent calculation of anhysteretic remnant magnetisation susceptibility (κARM) revealed possible fine grain magnetic minerals at 0-120 cm, 190 cm, 655-800 cm and 910 cm. When κARM was combined with κ, the result suggested the remaining core intervals were dominated by multi domain behaviour. The κ between 1000 cm and 2600 cm depth is variable, but below 2600 cm to the bottom of the core the variability diminishes. Physical properties in the core suggest some variability in sediment properties throughout, which is consistent with the site’s proximity to the north wall of the Hokitika Canyon.

The environmental cause for the high κARM values between 0 and 20 cm are likely to be related to the Holocene marine sedimentation overprinting on the high-energy, terrigenous, multi-domain magnetite that seems to dominate the rest of the core. The high κARM values between 655 and 800 cm are coincident with a 0.6 cm tephra (volcanic ash) layer at 762 cm depth and has to be investigated further to confirm any link.

This project is part of the FRST funded Paleoseismicity of the Alpine Fault and Hikurangi Margin program (C01X0801).

# RECONSTRUCTION OF SEA SURFACE TEMPERATURES IN THE EASTERN TASMAN SEA OVER THE LAST 480,000 YEARS

**Andrew Kolodziej[1], Bruce Hayward[2], Martin Crundwell[3], & Michael Hannah[1]**
[1]SGEES, Victoria University of Wellington, Gate 7, Kelburn Parade, Wellington
[2]Geomarine Research, 49 Swainston Road, St Johns, Auckland
[3]Institute of Geological and Nuclear Sciences, PO Box 30 368, Lower Hutt
andy.kolodziej@gmail.com

The aim of this project is to investigate palaeoceanography conditions of the Eastern Tasman Sea from Marine Isotope Stage (MIS) 12-1 (480 ka-present). As an island nation, New Zealand's climate is largely influenced by its oceanography. Sea surface temperatures (SST) and surface water mass location are key factors in New Zealand's climate. Therefore, in order to understand how New Zealand's climate might change in the future, it is important to learn how it has behaved in the past. One way to investigate this is to learn how oceanographic conditions have changed through time. This study uses planktic foraminifera assemblages to reconstruct sea surface temperatures and to constrain the movement of surface water masses in the Tasman Sea, west of New Zealand.

The location of the New Zealand continent in the Southwest Pacific ocean affects both local and global oceanography. New Zealand's 20˚ of latitudinal length, between 30˚S and 50˚S, spreads across two surface water masses; the macro nutrient-poor Subtropical (STW) and macro nutrient-rich Subantarctic (SAW) water masses. The boundary between these water masses is known as the Subtropical Front (STF).

Southeast of New Zealand the complex submarine topography, such as the Campbell Plateau and the Chatham Rise, partially control flow direction for both the Antarctic Circumpolar Current and Deep Western Boundary Current from the south and surface currents associated with the Subtropical Gyre from the north. The Chatham Rise has also controlled the positioning of the STF during glacial and inter-glacial periods.

West of New Zealand, the Tasman seafloor is more open with fewer bathymetric features, and therefore the STW and SAW should have been able to migrate northwards or southwards more freely during glacial and inter-glacial periods. This has implications on the location of the westerly trade winds, which affects weather patterns on land. To determine this, 137 planktic faunas have been assembled from Marion Dufrense piston core MD06-2986 to reconstruct SST's from MIS 12-1. It was cored at ~43˚S, the current position of the STF. Here, we used the Modern Analogue Technique and an Artificial Neural Network to estimate past SST at this location over the last 480 kyr. Faunal changes through the last four glacial-interglacial cycles will be discussed and our data compared with SST and faunal data through the same time interval from the east coast of New Zealand.

# TECTONIC INTERPRETATION OF TITANIUM-IN-QUARTZ TEMPERATURES FROM HIGH PRESSSURE ROCKS, D'ENTRECASTEAUX ISLANDS, PAPUA NEW GUINEA

**M.S. Korchinski[1], T.A. Little[1], & S.L. Baldwin[2]**
[1]SGEES, Victoria University of Wellington, PO Box 600, Wellington, 6140
[2]Dept. of Earth Sciences, Syracuse University, Syracuse, New York, USA
korchimega@myvuw.ac.nz

The mode of exhumation of gneiss domes that contain the world's youngest eclogites in the D'Entrecasteaux Islands of Papua New Guinea (PNG) is unclear. The domes are bounded on their NE side by NE dipping normal faults that are part of the Woodlark Rift. We measured paleo-temperatures in quartzofeldspathic gneiss with the titanium-in-quartz exchange geothermometer, *TitaniQ*, in an attempt to identify spatial differences in exhumation across the domes. There are two competing kinematic models for dome development: pure shear-dominated (symmetric) and detachment-related (asymmetric) exhumation. The former is predicted to cause a 'bulls-eye' pattern with the most rapidly exhumed rocks located in the centre of the dome. The latter is predicted to cause these rocks to occur in proximity to the bounding detachment fault. So far we have measured temperatures for seven samples of felsic gneiss along a NE-SW transect across the high-strain carapace and core of the Goodenough dome.

Our results show a steady increase in Ti-in-Quartz (minimum) temperatures towards the dome core and away from the bounding fault. These range from a low of 519 ± 20°C (2σ) proximal to the fault to the NE end to 636 ± 43 °C near the centre of the domes, and 635 ± 29 °C on the SW coast of the island. Along a similar transect, $^{40}Ar$-$^{39}Ar$ ages for white mica show an apparent inward younging trend from ~1.8 Mya proximal to the bounding fault, to ~1.6 Mya near the centre of the domes to >2.0 Ma at SW coast of the dome. Though preliminary, these apparent age gradients can be interpreted as recording an inward increase in cooling rate from ≤250 °C $Ma^{-1}$ near the dome's margins to ~290 °C $Ma^{-1}$ towards its centre (assuming a white mica closure temperature of ~400 °C).

The applicability of *TitaniQ* to metamorphic quartz is uncertain, especially the resetting effects of dynamic recrystallisation. Experimental data on Ti diffusion (and the known rapid cooling rate of the domes) indicate that solid-state diffusion would have been too slow to affect Ti concentrations. Quartz in our samples has amoeboid grain-boundary textures suggesting dynamic recrystallisation by grain boundary migration during late stages of the exhumation. Most of the gneisses are migmatitic (were once partially molten), yet the Ti temperatures are all <650 °C. We infer that these were reset by dynamic crystallization. In rocks with the fastest exhumation rates (relative to recrystallization rate), the extent of dynamic recrystallization would have been less. Quartz grains in these more rapidly exhumed rocks should be less "reset," preserving higher Ti temperatures. This interpretation is consistent with other microstructural data (Little et al., this volume) and the preliminary $^{40}Ar$-$^{39}Ar$ data.

We interpret the *TitaniQ* results to indicate that most rapidly cooled and deeply exhumed rocks occur today near the centre of the gneiss domes, indicative of a pure shear-dominated mechanism of dome formation, and not a detachment-related one.

# 3D HEAT-FLOW REGIMES IN THE TARANAKI BASIN

**K.F. Kroeger, K.J. Bland, M. Fohrmann & R.H. Funnell**
Institute of Geological and Nuclear Sciences, PO Box 30368, Lower Hutt
k.kroeger@gns.cri.nz

The changeable geological history of New Zealand is recorded in the compositionally and structurally heterogeneous basement of the Taranaki Basin. This heterogeneity influences the thermal history and hydrocarbon generation potential of the basin. Therefore, as part of the 4D Taranaki project at GNS, we have modelled regional heat-flow patterns as a basis for the ongoing investigation of Taranaki petroleum systems.

In a chemically heterogeneous crust, differences in heat generation through radioactive decay of U, Th and K are expected to influence the thermal regime within the basin. A heterogeneous crust can also control conductive heat transport. In addition, heat advection occurs through mass transfer, either as fluid flow or displacement of rock volumes, i.e. through faulting and rock uplift.

In order to predict heat-flow distribution and evolution in the Taranaki Basin from the Cretaceous to the Recent, we have constructed a 3D basin model extending from the sediment surface to the upper mantle. Earlier work on crustal composition has been reassessed based on seismic interpretation and surface analogues of deeper crustal rocks. Major differences occur between the heat generation in metasedimentary terranes and in predominantly igneous terranes. The largest difference, however, is between granodiorites and related rocks of the Median Batholith and Palaeozoic granitic rocks of the Western Platform, the latter having a 4 times higher heat productivity. In addition to compositional heterogeneities, we test potential effects of tectonic events, such as 1.) extension and crustal thinning in the late Cretaceous and Palaeocene, 2.) compression and crustal thickening in the late Palaeogene/early Neogene and 3.) Miocene and Plio-Pleistocene regional tectonic uplift resulting in exhumation and erosion of sediments. Changes in heat advection due to mantle processes are modelled by changing the boundary conditions at the base of the model.

Patterns of Neogene-Recent sedimentation and uplift and of heat generation in the upper crust explain the majority of recent surface heat-flow and well temperature data. Predicted temperature histories are also in agreement with the maturity of sedimentary organic matter as indicated by vitrinite reflectance measured on samples from various Taranaki wells. The low thermal regime in the region south of the Taranaki Peninsula can only be explained by changes in heat advection. Model results indicate that crustal thickening resulted in considerable crustal scale cooling by the uplift of colder rocks. Other parts of the basin have been influenced by mantle heat-advection related to the subduction of Pacific crust beneath the Hikurangi Margin and related magmatic and hydrothermal processes.

# LATE HOLOCENE PALEOSEISMICITY OF THE ALPINE FAULT AT THE TOAROHA RIVER, WEST COAST: PRELIMINARY RESULTS

**R.M. Langridge[1], P. Villamor[1], N. Litchfield[1], K. Wilson[1], R. Sutherland[1] & W. Ries[2]**
[1]GNS Science, PO Box 30-368, Lower Hutt; New Zealand
[2]School of Earth Sciences, Victoria University of Wellington, New Zealand
r.langridge@gns.cri.nz

A growing body of evidence points to frequent major landscape change events on the West Coast attributed to Alpine Fault earthquakes. This work needs to be calibrated with on-fault paleoseismic data from trench sites that can provide similarly precise event ages. We are taking a fresh look at an important paleoseismic site southeast of Hokitika on the true left bank of the Toaroha River. In addition to 2 trenches excavated on the Staples farm by Yetton (2000, PhD thesis, University of Canterbury), we have excavated 3 new trenches and constructed a micro-topographic map of the site in order to characterise the late Holocene rupture history of the Alpine Fault there.

Two main active fault traces exist at the site. Staples-1 trench was excavated across a broad zone of deformation associated with the NW trace (see Toy et al. 2009, Field Trip Guide. ICDP Workshop, March 2009). The c. 43 m long trench crossed a scarp of height 5-6 m in c. 2000 yr old alluvial deposits. The total structural relief on the deposits (≥ c. 3 m) cannot be assessed here due to the dominant component of strike-slip motion. Staples-2 trench was excavated across the foot of the steep, 15 m high scarp of the SE trace of the Alpine Fault. This trench revealed evidence for 3-4 earthquake ruptures post-dating the terrace deposits exposed in these 2 trenches.

Staples-3 trench, excavated across a small scarp on the NW trace provided the best record of late Holocene earthquakes. At this site, gravelly colluvium derived from the scarp of the Alpine Fault has been shed into an abandoned channel that is being translated along the fault, whilst accumulating peat. This section offers the opportunity to both correlate faulting with colluviums and to precisely date the influx of colluvium into a swamp. Preliminary results suggest 3 surface faulting events have occurred during the last 600 years (perhaps correlated with the AD 1717, 1620 and 1425 events). An earlier event is postulated on the basis of the transition from an alluvial terrace to silt-filled channel.

Although these results are preliminary they indicate that the Alpine Fault has ruptured at least 3 times during the last millennia at the Staples site - located at the NE end of the high-slip rate central segment of the fault. These results are consistent with observations in the Yetton (2000) trenches which were excavated across a low and occasionally re-occupied terrace near the Toaroha River. Future work will aim to obtain more precise event ages and vertical slip rates for the fault here.

# STRUCTURAL CONTROLS ON MONOGENETIC BASALTIC VOLCANISM

**N. Le Corvec, J. Rowland, J. Lindsay**
School of Environment, University of Auckland, Private Bag 92019, Auckland
n.lecorvec@auckland.ac.nz

Monogenetic basaltic volcanism is a widespread phenomenon around the Earth. However, whether or not it is related to tectonic activity has always been a matter of discussion. Our study firstly presents a review of different Quaternary monogenetic basaltic volcanic fields around the world: West-Eifel volcanic field, Germany; Boring Lava Field, USA; Springerville volcanic field, USA; Potrillo volcanic field, USA; Dariganga volcanic field, Mongolia; Chaîne des Puys, France; Al Haruj volcanic field, Libya; Es-Safa volcanic field, Syria; Pinacate volcanic field, Mexico; Camargo volcanic field, Mexico; Pali Aike volcanic field at the boundary between Chile and Argentina; and the Jeju volcanic Field, Korea. We have compiled satellite image analysis and published data using GIS software to inform our understanding of the relationship between regional tectonic and local structures (e.g. volcano cluster elongation, fractures, lineaments). Results show good correlations between the trends of the regional tectonic features (generally related to extensional stress fields) and the general orientations within the volcanic fields, which we suggest indicates a structural control on the localisation of magma conduits, at least in the near-surface.

The second part of our study is based on the Auckland Volcanic Field (AVF) underlying Auckland city, New Zealand. This small-scale monogenetic intra-plate basaltic system has produced about 51 small centres during its estimated 250 kyr lifetime and is one of the world's best examples of an active intraplate volcanic system. Our study provides preliminary results using field and published data on the relationship between the tectonism and volcanism affecting the Auckland city area. These results are compared with the general relationships deduced from our review of monogenetic basaltic volcanism.

**CATCHING UP WITH RICK SIBSON AT THE OUTCROP: COMPUTING FRACTURE-FLUID INTERACTIONS IN THE CRUST**

**P. Leary & P. Malin**
Institute of Earth Sciences & Engineering, 58 Symonds Street, Auckland 1142
p.leary@auckland.ac.nz

Rick Sibson is one of the early and great observers of crustal fracture and fluid processes seen in outcrop. Following on his work, numerous studies have variously speculated on the two topics of how fractures and fluids interact over long periods of time in crustal reservoirs, and over short periods of time in earthquakes. In this presentation, we discuss 4 'fractal-related' brittle-crust rock characteristics. These characteristics lead to new physical insights and means to compute Rick's outcrop rock fracture fabric and fluid flow interactions.

(1) Well logs worldwide have a unifying property: the spatial fluctuations of the physical properties of *in situ* rock have power-law spectra, $S(k) \sim 1/k$, where $S(k)$ is the Fourier power at spatial frequency $k$ from $10^{-1}$ to $10^{6}$ cycle/km (~crustal thickness to grain-scale). The power-law spectra can be understood in Biot-like thermodynamic terms if crustal rock comprises two grain-scale populations: (i) non-percolating intact grain-grain cement bonds and (ii) fractured percolating grain-grain cement bonds. The observed well-log spectra arise from long-range spatial correlations between fractured cement bonds, a 'critical state' thermodynamic state not known to Biot. Crustal fractures can be computed as spatially-correlated networks of percolating grain-scale defects.

(2) The beyond-Biot thermodynamic picture of crustal rock is supported by well-core porosity and permeability data. Clastic reservoir core sequences show that fluctuations in porosity ($\delta\varphi$) highly correlate with the logarithm of permeability ($\delta\log(\kappa)$) for thousands of core plugs over kilometres of reservoir rock. The $\delta\varphi \sim \delta\log(\kappa)$ correlation is directly understandable in terms of spatial density fluctuations in a population of grain-scale defects.

(3) Fluid flow simulation in media with permeability heterogeneity due to $S(k) \sim 1/k^{p}$ spatial-scaling distributions of grain-scale percolating fracture density reveal an interesting prediction. For exponent $p = 0$ (spatially uncorrelated 'white noise') and exponent $p = 2$ (spatially highly correlated or compartmentalised 'Brownian noise') smooth diffusion flow occurs, while in contrast exponent $p = 1$ (observed in well logs) produces temporally fluctuating diffusion flow. Fluctuating flow is a standard feature of geothermal reservoirs and is a plausible mechanism for the chemical banding pervasively observed in outcrop fracture veins and hydrothermal mineral deposits.

(4) The temporal spectra of crustal strain measured in boreholes at 15 km intervals have $\sim 1/f^{2}$ power-law trends reflecting steady crustal deformation by far-field forces. Spectral fluctuations about the $1/f^{2}$ trend are observed to be spatially coherent over tens of km, indicating crustal deformation induced by barometric fluctuations. Evidence for stress-diffusion in fractured-crust deformation phases and amplitudes can be sought in such strain-array data and can be modelled by finite element code for deformation of $1/k^{p}$-heterogeneous fracture-compliant/fracture-permeable media.

# A WINDOW INTO EARLY MIOCENE NEW ZEALAND: A PROGRESS REPORT ON RESEARCH ON THE FOULDEN MAAR

**Daphne Lee[1], Gary Wilson[1 2], Jon Lindqvist[1], Andrew Gorman[1]**
[1]Department of Geology, University of Otago, PO Box 56, Dunedin
[2]Deptartment of Marine Science, University of Otago, PO Box 56, Dunedin
daphne.lee@otago.ac.nz

The best global records of past terrestrial climates and environments come from the finely laminated sediments preserved in maar craters. The varved diatomite preserved in the Foulden Maar, near Middlemarch, Otago provides an exceptional archive of a southern hemisphere, mid-latitude, low-elevation, ocean-influenced terrestrial environment and climate record. In order to read this archive, a continuous core through the thickest and most undisturbed part of the sedimentary succession was retrieved in mid 2009 by a team from Webster Drilling.

Geophysical investigations to determine the three-dimensional structure of the basin prior to coring the maar succession included gravity, a finely sampled magnetic survey, ground-penetrating radar, and three high-resolution seismic reflection lines. The maar basin was determined to be steep-sided, with a thick laminated sediment infill that dipped gently towards the middle of the 1.5 km diameter basin.

A key part of the study is determination of the precise age and chronology of the lake archive. An $^{40}Ar/^{39}Ar$ age of 23.2 Ma from a basanite outcrop on the southwest margin of the basin closely matches radiometric dates from other nearby flows, plugs and dykes of the Waipiata Volcanic Field. Further dates that will correspond to the time of maar formation (and beginning of lake sedimentation) will be obtained from fresh volcanic breccia retrieved from the lower part of the core.

Pinstripe lamination, absence of bioturbation, and the exquisite preservation of fish, insect and plant fossils indicate that the deep lake waters and lakebed were anoxic. Discoveries from the Foulden Maar in the past year have increased the number of fossil insects known from the New Zealand Cenozoic by an order of magnitude. The study of hundreds of leaves with preserved cuticle that either fell, or were blown into the lake shows that the lake was surrounded by a forest of subtropical trees, shrubs and lianes. The diversity of plants and insects, many of them from genera now extinct in New Zealand, are helping rewrite the history of the New Zealand biota.

Preliminary spectral analysis of a selected 1.38 m interval from 15.5 m of diatomite exposed in surface pits shows a strong periodicity in varve couplet thickness of ~3-10 years that compares with Quaternary records of El Niño-Southern Oscillation variability, and suggests that the early Miocene climate was seasonal and strongly ocean influenced, as it is today.

Lindqvist, J.K., Lee, D.E.: High-frequency paleoclimate signals from Foulden Maar, Waipiata Volcanic Field, southern New Zealand: an Early Miocene varved lacustrine diatomite deposit. Sedimentary Geology (2009) doi.1016/j.sedgto.2009.07.009.

# CHALLENGES IN DETERMINING THE VOLCANO-STRUCTURAL LEVEL OF A MAAR-DIATREME REMNANT: EAST STANDING ROCKS, HOPI BUTTES VOLCANIC FIELD, ARIZONA, USA

**N.S. Lefebvre & J.D.L. White**
Dept. of Geology, University of Otago, PO Box 56, Dunedin
lefna448@student.otago.ac.nz

Maar-diatreme volcanoes comprise three volcano-structural levels: root zone, diatreme, and crater representing the lower, middle, and upper parts of the volcano, respectively. These levels are distinguished based on their depth in the volcano, size, shape and internal architecture, which reflect processes during sub-ground level emplacement of volcaniclastic products during the evolution of these volcanoes.

The East Standing Rocks (ESR) volcanic complex is situated in the monogenetic Hopi Buttes Volcanic Field in NE Arizona. The Volcanic Field, located in the SE Colorado Plateau, erupted during the late Miocene – early Pliocene into Tertiary and Mesozoic sediments. Varying degrees of country rock erosion within the Field has since exposed the pipes at different stratigraphic levels. Detailed mapping of the complex suggests that determining the level within a pipe can be complicated, even with excellent exposure. The ESR vent complex has experienced around 200 m of erosion. Deposits represent at least 3 main vents varying in size from approximately 0.8 to 32 ha, which were fed by and lie adjacent to exposed NW-SE trending dykes. The vent deposits, which crop out mostly flush with the present-day land surface, are made up of weathered volcaniclastic material, including blocks of country rock from higher and lower stratigraphic levels; overall they define circular to NW-SE trending elliptical shapes.

The middle vent deposits define a 2.2 ha ellipse. It includes an ~ 0.6 ha topographic high in the central-NW part of the vent that has many features typical of a root zone. It has a narrow, highly irregular shape, with a central zone consisting of deposits from several distinct depositional phases; they are dominated by massive volcaniclastic material cross-cut by numerous apparently intrusive bodies, some peperitic, and striking in various directions. A number of features, however, are unusual for a typical root zone: 1. The irregular central zone occurs within a larger, elliptical vent-fill deposit. 2. Localized, well defined layering is present. Commonly the layering is chaotic with variable dip directions and magnitudes, but it is locally consistent, and subhorizontal to shallow. 3. The nature of the late, apparently intrusive rocks, is highly inconsistent, changing proximally from intrusive-looking, 1-3 m thick sheets that are texturally coherent with sharp and peperitic contacts, into broader bodies several meters wide where coherent magmatic material is apparently intercalated with older tuff/lapilli tuff, or grades into fully fragmental rocks that appear to be a partially welded spatter deposit. 4. The presence of collapsed volcaniclastic and magmatic blocks in possible “debris filled cavities”. We infer from these features that the ESR may represent deposits emplaced at and just below the floor of an open crater, with magma both injected intrusively and ejected in weak magmatic to phreatomagmatic spatter jets or fountains. In volcano-structural terms, this represents a diatreme-free gradation from root zone to crater, or a root zone-crater transition above an unexposed, buried diatreme.

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

**T. Lennon**[1], **A.R. Gorman**[1] **and J.M. Beggs**[2]
[1] Department of Geology, University of Otago, Dunedin
[2] GeoSphere Ltd, PO Box 44285, Lower Hutt, NZ
lenti685@student.otago.ac.nz

Sedimentary basins developed to the east and west of Stewart Island are linked through similar tectonic and depositional processes during formation. The sediment supply and tectonic rifting phases are common, while sedimentation rates and tectonic subsidence define the unique characteristics of the basins. 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 has 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. High-resolution seismic data have been used in conjunction with existing data to further investigate the geological history and hydrocarbon potential of these basins.

On the southeast side of Stewart Island, a detachment fault associated with late Cretaceous rifting from Gondwana has recently been proposed for the region (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 seafloor morphology and shallow fault geometry. High frequency, sub-bottom images were acquired aboard the University of Otago's *R/V Polaris II*, while seismic processing and interpretation techniques have been employed to investigate the shallow geometry and location of the offshore segment of this proposed detachment fault.

On the west side of Stewart Island, a 240-km-long line of multi-channel seismic reflection data, recorded aboard *R/V Maurice Ewing* in 1996, has imaged several complex structural features along the shelf adjacent to the Solander Basin. Reprocessing of these data and further high-resolution imaging focuses on faulting that appears to outcrop on the seafloor, as well as inferred erosional features on the shelf margin. The collection of high frequency boomer data in January 2009 has improved the resolution and interpretability of these features. Direct comparison of single-channel boomer data and multi-channel reflection data has revealed several near surface features which are below the Rayleigh resolution limit of the older low frequency data, including a Bottom Simulating Reflection and turbidite / contourite erosional features.

Kula J., Tulloch A.J., Spell T.L., Wells M.L., 2007, Two-stage rifting of Zealandia-Australia-Antarctica: Evidence from $^{40}Ar/^{39}Ar$ thermochronometry of the Sisters Shear Zone, Stewart Island, New Zealand. Geology 35: 411- 414.

# EPISODIC, SHIFTING VOLCANISM AND RIFTING IN CENTRAL TAUPO VOLCANIC ZONE: RESULTS FROM QMAP ROTORUA AND NEW GEOCHRONOLOGY

**G.S. Leonard[1], C.J.N. Wilson[2], D.M. Gravley[3], A.T. Calvert[4], J.G. Begg[1], J.V. Rowland[5] & D.C.H. Hikuroa[5]**
[1]GNS Science, PO Box 30 368, Lower Hutt
[2]SGEES, Victoria University, PO Box 600, Wellington
[3]Geological Sciences, Canterbury University, Private Bag 4800, Christchurch
[4]US Geological Survey, 345 Middlefield Road, MS-937 Menlo Park, CA 94025, USA
[5]SGGES and IESE, University of Auckland, Private Bag 92019, Auckland
g.leonard@gns.cri.nz

Mapping, stratigraphic interpretation and data compilation for QMAP Rotorua, together with an ongoing Ar-Ar dating program have: (a) drawn a unified spatial-temporal picture of migrating volcanism from the waning Coromandel Volcanic Zone (CVZ) through the Tauranga-Kaimai area to the present day Taupo Volcanic Zone (TVZ); (b) further resolved episodic events within the history of the TVZ and Taupo Rift; and (c) allowed correlation of major sedimentation events to those episodes.

In the long term, from the late Miocene through the Quaternary, an episodic progression in space and time is visible from the northwest (CVZ) to the southeast (TVZ). In the shorter term the central TVZ is notable for its high frequency of caldera-forming eruptions and voluminous ignimbrite output (greater than 6,000 cubic kilometres of magma equivalent over its 2 million year history), i.e. it is an ignimbrite flare-up. The central TVZ can be subdivided into episodes of escalated volcanism followed by periods of relative quiescence. We have revised the mapped extents of major deposits between 1 and 2 Ma and have identified a burst of activity in the central to northern TVZ around 550 ka. In addition, we now separately date and map distinct deposits of the largest single episode, which lasted 120 thousand years (from ca. 350 to 230 ka) and erupted more than 3,000 cubic kilometres of magma (half of the total central TVZ output) from 7 caldera sources that, together, encompass most of the central TVZ.

We can detail a series of volcanic and tectonic events that may represent the build-up to that largest burst of activity. These are seen along the eastern Bay of Plenty coast in stratigraphic sequences, which are >200 metres thick and cover an age range from 700 to 320 ka. Sedimentation rates, when integrated with paleo-environment and sea level, show a major shift in the TVZ volcano-tectonic regime at ca. 370 ka - just prior to the 350 to 230 ka episode. The western shoulder of the Taupo Rift shifted from somewhere west of Matata to its current position bounding the Whakatane Graben. We also see a smaller change in the localised rate of subsidence and sedimentation around the ca. 550 ka volcanism.

With respect to ignimbrite flare-ups worldwide, the TVZ could help answer some of the questions posed at other large silicic systems, where controls on episodic magmatism and volcanism associated with flare-ups are not as obvious. See Begg et al. (this volume) for discussion on new non-volcanic results from QMAP Rotorua.

# DEFINING PAST VOLUME OF GROUNDED ICE IN THE ROSS SEA

**K. Lilly[1], G. S. Wilson[2,1], D. Fink[3], R. Levy[4] & C. Mifsud[3]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. of Marine Science, University of Otago, PO Box 56, Dunedin
[3]ANSTO, PMB 1, Menai, NSW 2234, Australia
[4]GNS Science, PO Box 30368, Lower Hutt
kat.lilly@otago.ac.nz

A large portion of global sea-level increase over the last glacial cycle is believed to originate from reduction in the volume of West Antarctic ice including ice grounded across the Ross Sea. The evidence for this comes from observation of glacigene sediments in the Ross Embayment, both onshore and offshore, indicating a much greater ice extent in the past. However, much of this evidence is not dated directly. Marine geophysical surveys show that the Antarctic Ice Sheet did in many locations ground out to the continental shelf edge, but it is not clear whether this happened at the Last Glacial Maximum. On land, our understanding of former ice extent in the Ross Sea region comes primarily from a glacial sedimentary deposit known as the Ross Sea Drift. The limit of these sediments has been used to define the volume of grounded ice in the Ross Sea and by further inference in the adjacent West Antarctic, representing an ice volume of some 9 million $km^3$, or 14 m sea level equivalent. However, the Ross Sea Drift is defined by common processes and facies rather than as a time restricted unit and conflicting interpretations from different locations suggest different timing and different ice configurations. The geographic area of the southern McMurdo Ice Shelf (between Black Island, Minna Bluff and Mount Discovery) is identified as a location where the reconstructions are in greatest conflict.

We present new constraints on the age of formation of these moraines from the application of cosmogenic exposure dating on 16 sandstone erratics collected from moraines on the flanks of Minna Bluff and Mount Discovery. These ice shelf marginal moraines have traditionally been included in the Ross Sea Drift. The sandstone erratics themselves are ideal targets for exposure dating as they include large blocks (> 1 m) that sit proud of the surrounding drift, they are quartz rich and are from an Eocene formation for which there is no known outcrop. While the origin of the erratics is not confirmed, each of the available reconstructions infers them to have been exhumed by advancing ice grounded in the Ross Sea. Thus we can assume that their exposure age relates to glacial erosion and deposition.

# PUYSEGUR GROUP DEEPWATER LACUSTRINE TURBIDITIC FACIES, SOUTHWEST FIORDLAND: EVIDENCE OF HYPERPYCNAL FLOW PROCESSES & IMPLICATIONS FOR THE PRESERVATION OF ORGANIC MATTER IN NEW ZEALAND MID-CRETACEOUS RIFT BASINS

**J. K. Lindqvist**
Department of Geology, University of Otago, PO Box 56, Dunedin
jonlind@ihug.co.nz

Terrestrial plant-derived organic matter is recognised as an important precursor of New Zealand's oil and gas. Although alluvial-deltaic coal-bearing formations classically described as 'coal measures' have long been considered the primary repository, deepwater lacustrine rift fills as represented by Puysegur Group in south Fiordland, and parts of Pororari Group, Westland, offer alternative prospects for petroleum source and reservoir development.

This paper presents a facies analysis of Puysegur Group, a Mid-Cretaceous (Motuan-Ngaterian) succession exposed at the entrance to Preservation Inlet and along the south coast between Puysegur Point and Gates Harbour. Earliest deposited coal-bearing alluvial plain sediments exposed on Gulches Peninsula include abundant andesite and rhyolite clasts that have yet to be traced to source. A ~750 m thick association of granite boulder conglomerate, bouldery sandstone, and graded-bedded sandstone and mudstone overlies the basin-margin facies. Individual graded sands display Bouma-like turbidite divisions, locally contain abundant plant detritus, and show a well developed thinning- and fining-upward stacking cyclicity. A further ~500 m thick cyclic succession comprising 20-50+ m thick coarse-grained sandstone bodies incised into thin-bedded silty mudstone units of similar thickness is interpreted as a series of prograding delta-slope channel and slope levee packets. Capping the succession, a ~100 m thick delta-front assemblage comprising 2-10 m thick clinoform sandstone and siltstone units, trough-cross bedded sandstone, carbonaceous shale and thin rootlet-based coals record a local shoaling phase of sedimentation.

Turbidity currents originating from river-generated hyperpycnal underflows and possibly also from failures of delta slope sediment transported clastic sediment and plant detritus into the deep lake basin. Underflow reworking within incised slope channels produced thick coarse-grained sand bodies laterally confined and overlain by thick shales. Successive pulses of coarse sediment into the deep lacustrine environment are interpreted to have been influenced by delta progradation and flooding cycles that were controlled by changes in lake level. Puysegur Group provides predictive outcrop analogues potentially relevant to interpretations of early-rift successions in offshore basins such as Hoiho Group, Great South Basin, and Taniwha Formation, Taranaki and Northland Basins.

# THE AGE OF THE AUCKLAND VOLCANIC FIELD

**J. Lindsay**[1], **G. Leonard**[2] **& E. Smid**[1]
[1]Institute of Earth Science and Engineering, The University of Auckland
[2]GNS Science, PO Box 30368, Lower Hutt 5040
j.lindsay@auckland.ac.nz

Determining magnitude-frequency relationships in volcanic regions is a critical first step in assessing volcanic hazard, particularly at long-dormant volcanoes or volcanic fields. Such analyses have been hampered in the Auckland Volcanic Field (AVF) by the difficulty in dating past eruptions from the field's ca. 50 volcanic centres: excess Ar inhibited early attempts using the K-Ar technique, and radiocarbon dating is limited to centres younger than ca. 40,000 years. The tephra record obtained from drilling Auckland's paleolakes is providing excellent interpolated ages for basaltic AVF ash layers; as yet, however, only very few ash layers retrieved from cores can be correlated to individual centres (e.g. Rangitoto ash in Pupuke core; Crater Hill ash in Pukaki core, Mt Wellington ash in Panmure core). Recent Ar-Ar dating of AVF basalts has yielded exciting results, and future dating using this technique promises to fill many of the gaps in the chronology of the field.

Here we review 179 age determinations available for the volcanic deposits from the 25 dated volcanic centres of the AVF, and group the best-estimate ages for each centre based upon reliability. The ages have been obtained through a range of methods: radiocarbon (74), K-Ar (68), thermoluminescence (14), Ar-Ar (10), Optically Stimulated Luminescence (2) and Magnetic Declination (11). Despite this large number of dates, strongly reliable age estimates can only be given for three centres: Rangitoto (0.6 ka), Mt Wellington (10 ka) and Three Kings (28.5 ka). A further 6 seem to have reliable single ages, or several reliable ages spanning a small age range: Purchas Hill (11 ka) Ash Hill (32 ka), Puketutu (30-34 ka), Wiri Mountain (27-33 ka), Crater Hill (32-34 ka) and Panmure Basin (31.5–32.5 ka). Minimum ages based on tephrochronology and sedimentation rates of core are available for 5 centres: St Heliers (>45 ka), Kohuora (>27 ka), Hopua (>29 ka), Pukaki (>52.4 ka) and Orakei (>83.1 ka). A further 15 centres have yielded conflicting ages. Twenty centres are undated, although in some cases relative ages can be determined based on stratigraphic relationships. The oldest ages have been obtained by Ar-Ar from Onepoto (249 ka) and Pupuke (200 – 260 ka).

Best-estimate radiometric ages available for the AVF display a marked clustering of possible ages between 28 and 33 ka, which corresponds well with the clustering of basaltic tephra in the same age range observed in the maar sediment cores as well as a clustering of activity during this timeframe indicated by paleomagnetism. We do, however, note that the dominance of radiometric ages in this age range most likely reflects the age limit of the $^{14}C$ dating technique rather than a real tendency for most centres in the AVF to fall within this age range. It is likely that many of the currently undated centres will be older than 33 ka. Our results have implications for any past or future statistical treatment of the distribution of past volcanism in the Auckland Volcanic Field. Past eruption timing is a common parameter in calculations of future risk.

# HOW WERE THE WORLD'S YOUNGEST ECLOGITES (D'ENTRECASTEAUX ISLANDS, PAPUA NEW GUINEA) EXHUMED?

**T.A. Little,[1] B.R. Hacker,[2] S.L. Baldwin,[3] & S.M. Gorden[2]**
[1]Victoria University, P.O. Box 600, Wellington 6040, New Zealand
[2] University of California, Santa Barbara, CA, 93106-9630, U.S.A
[3]Syracuse University, Syracuse, NY, 13244-1070, U.S.A
timothy.little@vuw.ac.nz

The gneiss domes of the NW D'Entrecasteaux Islands in the Woodlark Rift of Papua New Guinea host the world's youngest HP (eclogite-facies, 2-4 Ma) to UHP (coesite-bearing) terrane (~8 Ma). Models for their exhumation at >2 cm/yr include: 1) the rise of crustal diapirs; or 2) normal-slip on deeply penetrating faults, one variant of which invokes the inversion of a paleo-subduction zone as a result of unstable microplate tectonics. We report on structural and microstructural studies of gneisses of Goodenough and Fergusson Islands, including electron-backscatter diffraction. Relict eclogite-facies assemblages occur in boudinaged mafic dikes, but HP fabrics in the surrounding felsic rocks were overprinted in the amphibolite-facies during exhumation from the lower crust. At this time, the migmatitic rocks were deformed at 730-570°C and 7-11 kb and intruded by abundant, mostly syn-kinematic granodiorites. U/Pb ages of zircon indicate retrogression and crustal melting at ~0.5-3 m.y. after the HP to UHP metamorphism. A ~1 km-thick, high-strain "carapace" at the top of the gneisses is capped by an ultramafic sheet that did not experience HP metamorphism. Active NE-dipping normal faults cut this sheet to bound the domes on one flank.

Foliation in the gneisses defines the shape of the up to 2.5 km-high, elongate domes. Stretching lineations reveal a 3-D pattern of ductile flow. In both the carapace and upper core zone, lineations are mostly EW: subparallel to the strike of the rift and at a high angle to plate motion (from which rock flow was apparently decoupled). At greater structural depth, lineations gradationally deflect clockwise to NW-SE. The kinematics of ductile flow in the carapace included top-E shear on a regional scale. In both core and carapace, conjugate shear-band microstructures and near-orthorhombic quartz lattice preferred orientations (LPO's), and back-rotation of mantled porphyroclasts indicate a strong imprint of pure shear vertical shortening. The LPO's of the deepest rocks record the high-T prism-[c] and prism-<a> slip systems, whereas the carapace rocks record lower temperature slip systems. These data reveal that deformational temperatures of the preserved fabrics increase toward the dome centres, rather than outwardly towards any detachment fault. Quartz LPO's are remarkably weak (~2-3 times random), suggesting the activity of melt-mediated grain-boundary sliding.

The eclogites ascended nearly isothermally from mantle depths to the crust by a process that is still unclear. Our model invokes diapiric ascent of a weak, partially molten crustal "bolus" that had become detached from a foundered piece of lithosphere. This felsic body ponded in the lower crust, where it spread laterally westward and upward beneath the colder, denser, and stronger cover of ultramafics. Final exhumation involved isostatically driven upward flow of the gneisses into symmetric domes beneath extensional necks in the ultramafics. Eventually the gneisses breached their ultramafic cover as a result of normal faulting (this also tilted the domes to the SW).

**CAPTURING THE SECRETS OF A LAHAR WAVE**

**G. Lube, S.J. Cronin & J.N. Procter**
Volcanic Risk Solutions, INR, Massey University, Palmerston North
g.lube@massey.ac.nz

Lahars are among the most frequent and deadliest volcanic mass flows on Earth. Most of our current understanding of lahar waves stems from interpretations made upon their final deposits, because their hazardous nature and unpredictable timing defy all means of conventional direct probing into active flows. Previous work has indicated that during the evolution of a lahar wave, its flow kinematics, particle concentration and grain-size distribution, as well as flow rheology vary highly in the spatial and temporal domain. Quantifying the complex dynamic changes of these parameters is the key to better understanding the fundamental physical processes underlying lahar wave motion and to test and further develop existing numerical lahar models.

The March 18 2007 lake breakout lahar of Mt Ruapehu provided the hitherto missing perspective for capturing a holistic record of the space- and time-dependent flow behaviour and structure of a lahar wave during its 200 kilometre travel through the Whangaehu River channel. The here presented results are based on combining records of flow kinematical data (stage, wave and surface velocities), sediment concentration and grain-size distribution, water chemistry from more than 20 permanent and mobile lahar monitoring stations as well as data of net volume of transported sediment.

The main results of our analysis include: (I) dam breaching at 11:18 hrs into the steepest and driest part of the channel was followed by fast flow acceleration to reach the maximum wave velocity of 16 m/s over the first kilometre of travel; (II) from 1-20 kilometres, the lahar wave decelerated strongly, while moving as a supercritical flow through the steadily flattening channel; (III) up to this point the lahar volume increased logarithmically through bulking by a factor of 2.4 to reach a quasi-steady state in bulk sediment load of c. 3 x 10^6 m^3; (IV) this phase also coincides with an exponential decay in the lahar wave height, lahar front velocity and lahar peak stage velocity, and hence wave Froude number, all of which approach and maintain quasi-constant values within a stretch from 30-120 kilometres; (V) in-between 20 and 30 kilometres travel distance lahar/stream flow interaction became strong; from here onwards the lahar wave moved as a subcritical flow at a constant velocity of 3.65 m/s and displaced the slower moving stream flow to form a bow-wave; (VI) from 30 to 120 kilometres the length of the bow-wave increased steadily at a rate of c. 140 m per kilometre, while its wave height approached and occasionally exceeded that of the successive lahar proper; (VII) from 30 kilometres onwards the lahar proper took a form strongly resembling a particle-laden density current, comprising a turbulent head with a strong gradient in sediment concentration in upstream direction and followed by the concentrated body of the density current with slowly decreasing particle concentration; suspended sediment and Crater Lake water notably moved in phase for the entire lahar runout distance.

We will discuss how these new results of wave form evolution, together with data of space- and time-variant flow rheology can be used to improve numerical lahar simulations.

## A SEAMLESS 1:250 000 GEOLOGICAL DATASET

**Biljana Lukovic, Dave Heron and Dougal Townsend**
GNS Science, P.O. Box 30-368, Lower Hutt
b.lukovic@gns.cri.nz

The QMAP 1:250 000 Geological Map of New Zealand programme is almost complete and there is now interim digital geological map coverage of the entire country. Before the QMAP data can be released as a single GIS dataset, sheet boundaries must be removed and this process has begun under the Seamless QMAP GIS initiative. Data for Auckland, Waikato, Taranaki, Wellington and the Wairarapa maps have been merged into a single dataset. The original maps do not completely match across their sheet boundaries, usually due to new data and interpretation incorporated into the later maps. Updating of the border areas of older maps has been undertaken to resolve these conflicts.

The Seamless QMAP project is also increasing the richness of the geological GIS data. Stratigraphic detail (supergroup, group, formation, etc) is being added to geological unit, horizon and dike layers based on the detail held in the map legend and text. Simplified rock descriptions (e.g. Torlesse sandstone), stratigraphic ages (e.g. Triassic-Jurassic) and gross groupings (e.g. of basement rocks) are being added to make map creating using GIS simpler and also allowing more possible ways of viewing the same data.

The versatility of the structural data is being enhanced with the addition of fields that will allow users to more easily filter data on the basis of the feature measured (i.e. bedding or cleavage), and the certainty of facing.

The Seamless QMAP GIS will become the most current version of the QMAP dataset and will be updated periodically as time and need demand. The data will be made available on CD and as a web map application via the internet.

# A PALAEOMAGNETIC STUDY OF THE FAIRFIELD QUARRY SECTION, OTAGO

**P. Lurcock** & **G.S. Wilson**
Dept. of Geology, University of Otago, PO Box 56, Dunedin
pont@talvi.net

Fairfield Quarry in south-eastern Otago exposes a Haumurian-Teurian section comprising non-marine (Taratu Formation) and shallow marine (Wangaloa Formation) sands overlain by the glauconitic Fairfield Greensand and Abbotsford Mudstone units.

The location and age of this sequence makes it a potentially valuable recorder of the history of Antarctic glaciation prior to the establishment of a permanent Antarctic ice sheet, as it is well placed to respond to fluctuations in the Antarctic Bottom Water of the Southwest Pacific Deep Western Boundary Current. It seems likely that the glauconitic horizons in the sequence can be linked to variations in bottom water flow. In this study, a palaeomagnetic approach is taken to the interpretation of these strata. This poses interesting challenges, since the magnetic behaviour of glaucony is still poorly understood.

A rock magnetic investigation of the Fairfield Greensand and Abbotsford Mudstone at Fairfield is presented: around 200 oriented cores were taken with a hand-held rock drill, at sites spaced at approximately half-metre intervals throughout most of the 25-metre section; *in situ* magnetic susceptibility measurements were also taken in parallel with the drill samples at approximately 5 cm intervals.

The sampled specimens are being used for a magnetostratigraphic study to allow dating of the environmental changes recorded through the section. This involves progressively demagnetizing the oriented samples in order to recover a record of the magnetic field at time of deposition. In common with many New Zealand sediments, the specimens from Fairfield respond poorly to alternating-field demagnetization, and a thermal demagnetization study has therefore been commenced; results so far indicate that a coherent magnetostratigraphy should be possible.

Measurements have also been taken of both bulk magnetic susceptibility and anisotropy of magnetic susceptibility (AMS). Most of the AMS measurements show plausible current directions, changing gradually through the section, though a few display a vertically prolate magnetic fabric which may be the result of diagenesis.

# PHORMIUM AND ASTELIACEAE MACROFOSSILS FROM NEW ZEALAND: USING LEAF CUTICULAR DETAILS TO DETERMINE PHYLOGENETIC AFFINITIES

**Elizabeth Maciunas[1], John Conran[1], Rosemary Paull[1], Daphne Lee[2], Jennifer Bannister[3]**

[1]School of Earth & Environmental Sciences, The University of Adelaide, Australia
[2]Department of Geology, University of Otago, PO Box 56, Dunedin
[3]Department of Botany, University of Otago, PO Box 56, Dunedin
elizabeth.maciunas@student.adelaide.edu.au

Unless cuticular material is preserved, it is often impossible to determine the affinities of fossilised monocots. The affinities of two monocotyledonous fossils, thought to be close to *Phormium* (Hemerocallidaceae) and *Astelia/Collospermum* (Asteliaceae) were determined by examining the cuticular characteristics of related modern taxa in the Hemerocallidaceae and Asteliaceae. Specimens collected from the Newvale Lignite (*Phormium*) and Foulden Diatomite (*Astelia* aff.) fossil sites were measured for a range of epidermal cuticular features related to cell size, shape, ornamentation and accessory structures. These data were then compared against other species and genera within their respective families and also used to place the fossils onto phylogenetic trees derived from the leaf features. This enabled the assessment of the phylogenetic utility of the various character states which were defined (both for modern and fossil taxa), as well as to suggest possible relationships of the fossils to modern crown taxa.

This project has led to the identification and description of two fossils representative of prominent monocots in the modern New Zealand landscape and with clear southern continental biogeographic links. The analyses allow for the placement of these fossils within a phylogenetic context, the determination of their likely relatives from amongst modern related taxa. The associated biogeographic implications are also discussed. In addition, the study shows the usefulness of cuticular characteristics for identifying individual Asteliaceae and Hemerocallidaceae leaf samples to either genus or species level and the potential for identifying future fossil leaf-based taxa within these families.

# COMPARATIVE SEDIMENTOLOGY AND PALEOECOLOGY OF TERTIARY GIANT OYSTER REEFS IN NEW ZEALAND AND ARGENTINA

**Larissa C. Macmillan[1], Cam S. Nelson[1], Silvio Casadío[2], & Steve D. Hood[1]**
[1]Dept. of Earth and Ocean Sciences, Univ. of Waikato, Private Bag 3105, Hamilton
[2]Univ. Nacional de La Pampa, Uruguay 151, 6300 Santa Rosa, Argentina
lcm16@students.waikato.ac.nz

The usefulness of shell concentrations as indicators of relative sea-level changes, systems tracts, and depositional sequence and boundary surfaces has been recognised for more than a decade. Shellbeds can equally act as useful environmental indicators, such as using the orientation and packing of the shells to infer transport conditions and sclerochronological and LA-ICP-MS analysis of periodic skeletal increments to unravel aspects of their life history and growth environment.

Giant oyster reefs and shellbeds occur in Tertiary sequences in the North Island, with similar occurrences in Patagonia, southern Argentina. Study sites in the North Island include the large oysters common in the Oligocene Orahiri Limestone of the Te Kuiti Group found in the vicinity of Waitomo and the oyster beds in the Pliocene Wilkies Shellbed in the Wanganui Basin. In the Waitomo region the oyster Flemingostreini Stenzel can be found in bands up to 9 m thick within highly indurated temperate limestones. Individual specimens reach 15 cm in length, 10 cm in width and 2.5 to 5 cm in thickness. The Wilkies Shellbed, up to 15 m thick, comprises the oyster *Crassostrea ingens* within a weakly calcareous silty very fine sandstone. Individuals are up to 30 cm long, 7 cm thick and weigh as much as 2 kg. Specimens of *Ostrea patagonica* in the Late Miocene Puerto Madryn Formation, Península Valdés, Patagonia, are held in a weakly calcareous medium sandstone host. They reach 20 cm in length, 5 cm thick and weigh up to >3 kg.

Early studies suggested that the giant oysters at Waitomo lived in marginal marine conditions. Stable isotope results show $\delta^{18}O$ values from 1.40 to -2.10‰ and $\delta^{13}C$ values between 0.4 and 2.5‰, supportive of fully marine conditions. Wanganui oysters have the largest spread of isotopic values, $\delta^{18}O$ -3.0 to 3.0‰ and $\delta^{13}C$ -2.6 to 1.8‰, suggestive of fluctuating marginal marine to marine conditions. Patagonian samples plot tightly, with $\delta^{18}O$ values -4.4 to -3.2‰ and $\delta^{13}C$ from -2.0 to -3.2‰, supportive of a marginal marine setting.

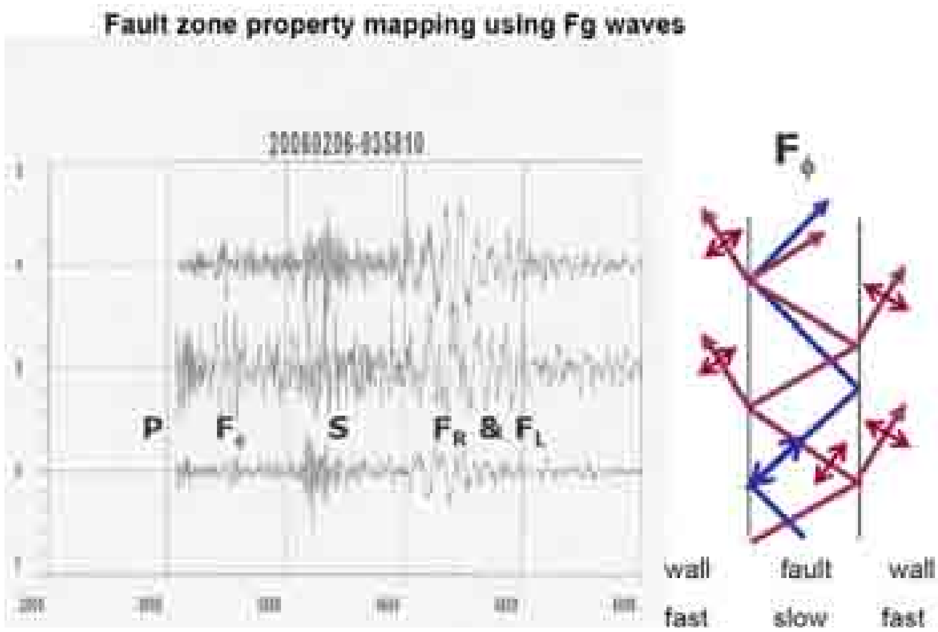
As seen in extant species, oyster reefs play an important role in the establishment of very diverse community assemblages, providing hard substrata for encrusting and boring organisms. Analyses of these communities show ichnospecies such as *Gastrochaenolithes* (bivalve), *Maeandropolydora* (polychaete), *Clionolithes* (boring algae) and *Leptichnus* (bryozoan). Chi squared tests have been performed to determine whether predefined parts of the valves were colonised preferentially. Results confirm that polychaetes, sponges, boring algae, boring bivalves, boring bryozoans, serpulids and barnacles do have preferences for specific sectors of valves.

# $F_{\Phi}$

**P.E. Malin[1] & W.L. Ellsworth[2]**
[1]Institute of Earth Science & Engineering, University of Auckland, PB 92019 AKL
[2]U.S. Geological Survey, MS977, 345 Middlefield Road, Menlo Park, CA 94025, USA
p.malin@auckland.ac.nz

Earthquake-related damage in the fault core during fault slip result in the formation of a low-velocity fault zone channel within which fault zone guided seismic waves, denoted by $\mathbf{F_g}$, can propagate (see example below). Here we show that the San Andreas Fault (SAF) crossed by a borehole near Parkfield, CA, exhibits an extensive low-velocity channel that extends more than half way through the seismogenic crust. This channel supports not only the previously recognized $\mathbf{F_g}$ waves $\mathbf{F_L}$ and $\mathbf{F_R}$, but also a new "$\mathbf{F_{\Phi}}$" type. Recorded 2.7 km underground**,** $\mathbf{F_{\Phi}}$ is normally dispersed, ends in an Airy phase, and arrives between P and S. Modeling shows that $\mathbf{F_{\Phi}}$ travels as a leaky P-mode in a 30-m-wide channel within the fault zone. The channel's extent and very low seismic velocities suggest it originates either from (1) fracturing near the slip surface of earthquakes like the 1857 Fort Tejon M~7.9, or (2) a part of the creep process.

Previously unobserved, $\mathbf{F_{\Phi}}$ was recorded in the SAFOD borehole in 2006, 2670 m below ground level and 40 m measured depth to the southwest of a creeping fault trace. The channel it propagates in has a velocity reduction of <20% of the bounding wall rocks. As P-mode, reflection from the channel walls results in the leakage of SV-waves, causing $\mathbf{F_{\Phi}}$ to rapidly attenuate, and hence be difficult to observe at ground level. The pervasive damage seen within the $\mathbf{F_{\Phi}}$-channel could be consistent with the 1857 rupture extending north to the SAFOD site. Alternatively, fault creep alone might be capable of creating and maintaining the zone of active fractures. The $\mathbf{F_{\Phi}}$ observations do, however, make it clear, that whatever its origin, the damage zone extends deep into the seismogenic crust.



## CLIMATE, CRITTERS AND CETACEANS – CENOZOIC DRIVERS OF THE EVOLUTION OF MODERN WHALES

**F.G. Marx**[1] **& M.D. Uhen**[2]
[1] Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2] AOES Geology, George Mason University, Fairfax, VA 22030, USA
f.g.marx@bristol.ac.uk

Geological biases, such as the amount of rock available for sampling, have been shown to explain much, if not all of the variation of Phanerozoic global marine diversity over geological time, calling into question the biological nature of observed paleodiversity. Here we demonstrate how the observed diversity records of smaller clades may still be determined primarily by biology, using cetaceans (whales, dolphins and porpoises) as an example.

One of the major hypotheses on the evolution of modern cetaceans (mysticetes and odontocetes) states that the evolution of these large apex predators was made possible by the rise of diatoms as the dominant marine primary producers. Because of the relatively large size of this type of phytoplankton, food webs based on diatom production tend to have relatively fewer intermediate links connecting the primary producers with the ultimate consumers. A short food web should involve less trophic fractionation of energy, allowing apex predators such as cetaceans to grow larger and more abundant as a result. Studies on extant cetaceans also have shown that global patterns of diversity in the modern oceans are influenced by ambient water temperature, which could indicate that climate change might also have played a significant role in their evolution.

We use a comprehensive global diversity downloaded from the Paleobiology Database to show that much of the Caenozoic diversity of modern cetaceans can indeed be explained by diatom diversity in conjunction with variations in climate as indicated by oxygen stable isotope records ($\delta^{18}O$). The explanatory power of such a model exceeds that of two independently sampled estimates of changes in rock availability. In addition, our findings also lend support to the validity of biologically motivated adjustments of paleodiversity estimates. Apart from providing new insights into cetacean evolution, our results may also have important implications for the study and interpretation of paleodiversity as whole, as well as the history of other taxonomically distinct groups of organisms. Because of its relatively well understood geology and highly sampled fossil record, New Zealand in particular has already featured heavily as a case study in the investigation of geological biases and drivers of paleodiversity, and may offer an excellent opportunity to test some of the ideas developed here further.

# LATE MIOCENE VOLCANICLASTIC DEPOSITS AT KAIAUA BAY AND MARAU POINT, EAST COAST BASIN.

**Ray Marx[1], James White[1] and Vern Manville[2]**
[1]Department of Geology, University of Otago, PO Box 56, Dunedin, New Zealand
[2]GNS Science, Private Bag 2000, Taupo, New Zealand
ray.marx@stonebow.otago.ac.nz

Kaiaua Bay and Marau Point, located 60 km north of Gisborne, comprise a tilted block of late Miocene age 'alternating medium to fine grained sandstone and mudstone with common tuff beds' (Mazengarb and Speden 2000). The ash for the tuff beds was sourced from the Coromandel Volcanic Zone, now located 300 km to the northwest, and deposited into the fore-arc East Coast Basin (ECB) associated with the Hikurangi subduction zone.

These beds include a mix of both suspension deposits and sediment gravity flow deposits. Trace fossils formed by burrowing soft-bodied organisms are present in most of the enclosing mudrock beds and many of the volcaniclastic beds. Mineralogical composition of the tuffaceous beds suggests they contain 1) volcaniclastic materials, 2) both allochthonous and autochthonous authigenic minerals, 3) hard bits of marine organisms.

Textural evidence, together with the presence of obvious non-volcanic fragments, suggests that some transport and reworking of the ash took place before final deposition. Typical bedding features, such as Bouma B, C and D intervals, are characteristic of density-current deposits. Microfossils in some turbidite deposits are of both shallow and deep-water origins. Volcaniclast-bearing beds inferred to have formed from suspension are well sorted, specifically depleted of very fine grains, and enclosed within hemipelagic and other suspension deposits. These are planar beds, or comprise un-abraded volcanic clasts dispersed and mingled within pelagic material in a narrow planar layer; microfossils associated with these deposits are all indicative of deep water. Absence of non-volcanic lithic fragments is taken to indicate direct pyroclastic deposition into the water column, with subsequent deposition on the seafloor from suspension.

Recent mapping shows that the tuffaceous beds are well exposed in 5 locations along Marau Point, but the sequence is disrupted into a series of landslide blocks that have been translated down slope. Three locations expose a repeated stratigraphic section no more than 10 metres thick, identifiable by bed sequence patterns, specific marker beds, and deposit composition. Rather than comprising a long temporal record of eruptions, these sections provide an opportunity for detailed interpretation of emplacement processes from the repeated exposure, which provides extended lateral outcrop of a single set of beds. Volcaniclastic deposits at Kaiaua Bay and Marau Point are interpreted to be distal from their source vents and deposited in deep water by a combination of sediment gravity flows and water settling. Few beds can be viewed as unambiguous deposits of any single eruption. The fines-poor beds may be most closely representative, but have lost part of their particle population to settling or other transport processes in the water column.

# THE ROTOMAHANA ERUPTION OF 1886: A BASALTIC FISSURE ERUPTION THROUGH AN INTENSELY ACTIVE GEOTHERMAL SYSTEM

**M. May[1], J.D.L. White[1], B.F. Houghton[2]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. Geology & Geophysics, SOEST, University of Hawaii, Manoa
maymi024@student.otago.ac.nz

On the 10th of June 1886 Tarawera and Rotomahana (Okataina Volcanic Centre, Taupo Volcanic Zone) erupted in New Zealand's largest and most destructive historic volcanic event. It opened a fissure 7 km long across Tarawera mountain and extending another 9 km across Rotomahana basin to Waimangu valley, through low-lying marshlands and an intensely active geothermal system, destroying the internationally known "Pink and White Terraces". The fissure through the Rotomahana basin excavated a series of coalescing maar-type craters which soon filled with water to become the modern Lake Rotomahana. The plume from the Rotomahana segment of the fissure produced a deposit known as the "Rotomahana Mud," a mixture of mainly finely fragmented, altered wall-rock and basalt clasts. A series of base surges swept over the surrounding landscape out to a distance of 6 km from source. Basalt pyroclasts are pervasive throughout the deposit, albeit in varying percentages, with varying textures, colors, densities and grain size. Several populations of vesicles exist in the juvenile clasts, which are extremely microlitic in texture.

A series of stratigraphic logs has been created for proximal outcrops. Variations up-section as well as an inability to correlate layers laterally along the lakeshore attest to the extreme complexity of the deposit as a whole, being erupted from several sources with varying fragmentation depths and involving varying amounts of magma and water. Coeval eruption of multiple centers along the Rotomahana segment of the fissure is inferred to have produced intense stratigraphic interleaving, preventing correlations across discontinuous outcrop. Sieve grain-size analysis supplemented with Coulter laser analysis of particles smaller than 1 phi tends to show a distinct bimodality in the southwestern deposits, representing the two main origins of the Rotomahana Mud in that region, namely fragmented country rock and hydrothermal clays. The deposits farther from the geothermal field at the northeastern section of the Rotomahana rift, while still retaining a large portion of ultra-fine-grained material, seem to lack this definitive bimodality, and result from the lack of underlying hydrothermal clays available for disruption and entrainment. Overall, grain-size analysis shows the deposits to be poorly to extremely poorly sorted and there is a tendency to be positively skewed, due to the characteristic fine grain size of phreatomagmatic eruptive products. Preliminary componentry also seems to show variation in the deposit from the northeast to the southwest, reflecting varying intensities and styles in the eruptive vents as well as in the degree of hydrothermal alteration of the wall rock material ejected.

# GAS GEOCHEMISTRY OF NEW ZEALAND VOLCANOES: PREVIOUS WORK AND FUTURE PERSPECTIVES

**A. Mazot[1], B. Christenson[2] & J. Cole Baker[1]**
[1]GNS Science, Private Bag 2000, Wairakei
[2]National Isotope Centre, GNS Science, PO Box 30368, Lower Hutt
a.mazot@gns.cri.nz

Gas studies play an important role in monitoring New Zealand volcanoes. The main purpose for monitoring gases is to help detect the intrusion of magma or see any changes in the volcanic activity. The dominant magmatic gases are $H_2O$, $CO_2$ and $SO_2$ followed by smaller concentrations of other species including $H_2$, $H_2S$, HCl, HF and CO. Increased emissions (or concentrations) of $CO_2$ and $SO_2$ are the principal gas precursors of magmatic intrusion
.
Gas monitoring of New Zealand volcanoes (including White Island and Ruapehu) has relied heavily on measuring $SO_2$ emission rates by using ultraviolet-sensing correlation spectrometer (COSPEC). White Island volcano is in a quiescent state and the $SO_2$ emission decreased from ~ 1000 -2000 t/day during the last eruptive period in 2000 to < 400 t/day since a significant crater lake appeared in 2003 and actively removed a part of $SO_2$ emissions. In June 2006, GeoNet installed two scanning mini-Differential Optical Absorption Spectrometer (DOAS) at White Island volcano offering semi-continuous $SO_2$ emission data. Short time variations have been monitored and are likely related to gas accumulation and buoyancy in the conduit and by atmospheric dispersion.

$CO_2$ is less reactive than other volcanic gases. CO is present in lesser amount in volcanic gases but the $CO/CO_2$ ratio is a good indicator of the Redox conditions at depth. A change in the ratio can be related to a new input of magma in the volcanic system. A new technique, called Open-Path laser, has been used for the monitoring of $CO_2$ degassing in volcanic area like at “Solfatara di Pozzuoli”, Vulcano and in geothermal sites in Italy. The purpose of these surveys was to have a better knowledge in the spatial and temporal dynamics of $CO_2$ degassing in the atmosphere. This presentation introduces the new laser based technique for future volcanic gas surveillance at White Island volcano.

# GOLD AND PLATINUM DEFORMATION, AEOLIAN DEFORMATION AND TOROID DEVELOPMENT IN BEACH PLACER DEPOSITS, SOUTHLAND

**R McCann & D Craw**
Dept. of Geology, University of Otago, PO Box 56, Dunedin
Mccro517@student.otago.ac.nz

The beaches of the south coast of New Zealand have historically been mined for gold with a smaller amount of platinum occurring in the concentrates. The areas are also highly affected by strong southerly winds, which increase rates of saltation and erosion. This has a direct affect on the detrital gold and platinum grains within the sediment load. Samples were recovered from the inter-tidal high water mark with separate dune samples. Detrital gold and platinum grains show a sequence of aeolian deformation, from flattened platy grains, to toroidal shaped grains, through to collapsed cylindrical toroids and grains showing reworking via renewed toroid development. Deformation is affected by beach size, vulnerability to weather, and dune size. Saltation and erosion rates with dune samples show the highest degree of deformation and toroid development. A toroid is a 'doughnut' shaped detrital grain which has a thickened rim and a thin connecting plate (fig 1). The gold in the west (Te Waewae bay) is coarse (>100μm) with minor toroid development and relict alluvial features are present. Toroidal features are increasingly developed towards the east and are best developed in the Orepuki area. Platinum shows some minor toroid development, in parallel with gold toroid development, also increasing to the east.

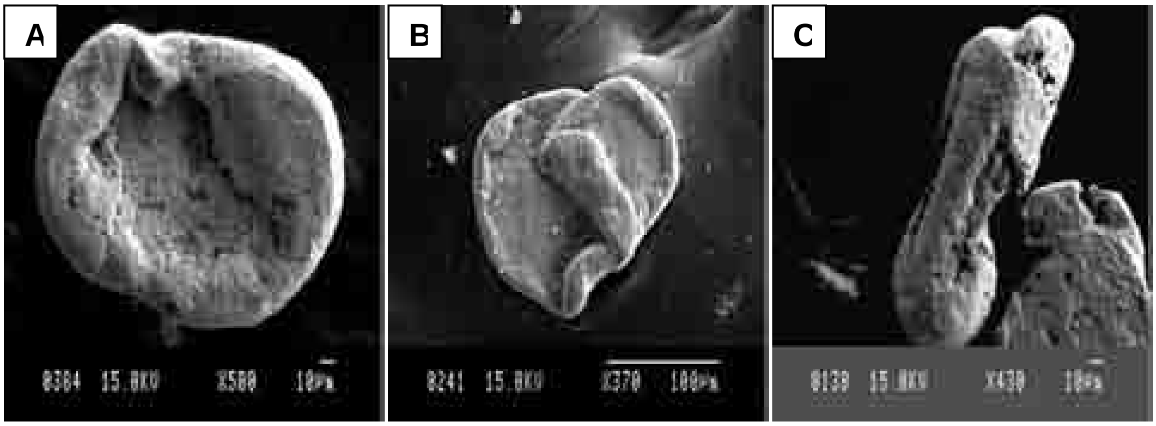



**Figure 1.** Toroids from beach placer deposits. (A) Toroid showing well rounded margins with a well thickened rim. Rim has been peened sufficiently that it is almost at the centre line of the grain. Scale bar is 10μm. (B) Over folding of toroid shows thickening of both edges in toroid development. Scale bar is 100μm. (C) Toroid profile showing thickened rim and thin connecting plate. Scale bar is 10μm.

## INTERNATIONAL SUMMER SCHOOL ON ROCKSLIDES AND RELATED PHENOMENA

**S.T. McColl**
Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch
stm45@student.canterbury.ac.nz

During August 2009 the author attended a 2-week field excursion to study large landslide phenomena and geology in the Kokomeren River Basin, Central Tien Shan mountains, Kyrgyzstan. The annual excursion is jointly run by the Kyrgyz Institute of Seismology and Russian Academy of Science with funding and support from the International Consortium on Landslides. Eight students, mostly from Europe, attended the school this year and it was the first year that a New Zealand student participated. The aims of the excursion/school are to: demonstrate various forms of large landslide and how they can be recognised by morphology, sedimentary structure and indirect evidence; provide techniques for age-dating landslide events; improve our understanding of why they occur and the influence of geology and geological-structure on their spatial distribution; and to develop our awareness of associated hazards. This presentation explains the nature of the field course, gives an introduction to the geology of region, and provides descriptions of the phenomena examined. The New Zealand Earthquake Commission and GNS Science co-funded the author's travel and attendance at the school. There is possibility of similar funding arrangements for other interested New Zealand students in following years.

# GEOCHEMICAL AND PETROGRAPHIC VARIATIONS AND THE INNER WORKINGS OF MONOGENETIC BASALTIC FIELDS

[1]**Lucy McGee**, [1]**Ian Smith**, [1]**Jan Lindsay**, [2]**Colin Wilson and** [3]**Steve Blake**
[1] School of Environment, The University of Auckland, Private Bag 92019, Auckland
[2] SGEES, Victoria University, PO Box 600, Wellington 6040
[3] Earth & Environmental Sciences, Open University, Milton Keynes MK7 6AA, UK
l.mcgee@auckland.ac.nz

The Auckland Volcanic Field (AVF) is the surface expression of an intraplate monogenetic basaltic system consisting of ~50 volcanoes of varying size overprinted by the city of Auckland. Geochemically the AVF contains a large amount of variation, with compositions ranging from nephelinite through to transitional and tholeiitic basalt; $SiO_2$ contents range from 39 to 50 wt %. A large amount of geochemical data has been collected from the rocks of the AVF, and systematic field sampling at individual centres is revealing diverse trends. In the field as a whole, discrete compositional trends can be interpreted in terms of evolution from a range of primitive parental magmas. Compositional extremes can occur over short time intervals and spatial distances, such as the example of Mt Wellington and Purchas Hill, which erupted within 1ka (or less) of each other from vents ca. 500m apart. Mt Wellington is one of the largest centres in the field and has a relatively primitive composition and shallower REE profile, whereas Purchas Hill is one of the smallest, displays some of the lowest Mg# in the field, low $SiO_2$ and a much higher proportion of LREE. However, other centres with comparable spatial relationships (e.g. Domain and Outhwaite Park) do not show the same degree of variation, and instead they have very similar geochemistry.

There appears to be a relationship between geochemistry and the size of individual centres, namely that the larger centres are more primitive (higher Mg#) and the smaller are more 'evolved' and fractionated (lower Mg#, but, intriguingly, lower $SiO_2$). As well as elucidating fractionation and melting processes throughout the field, this could have implications for future eruptions, particularly if a link could be found between source processes and resultant eruption sizes, styles and products.

Any model developed to explain the inner workings of the AVF need to address why such a large amount of variation is seen with little temporal or spatial variation. Preliminary results of modelling suggest that there is a wide range of variables within the source region as well as in the conduit environment, that together create a sliding scale of magmatic processes within the AVF. This leads to magma batches of varying sizes and compositions which in some cases may provide marked geochemical contrasts in magmas that erupt successively at single centres (e.g., Rangitoto, Pupuke) or as paired centres closely linked in space and time (e.g., Purchas Hill and Mount Wellington). Individual eruptive centres within a spatially well-defined field such as the AVF provide the opportunity to investigate small scale mantle processes, and the environment in which they operate.

# DID ANTARCTIC COOLING ~3.3 MILLION YEARS AGO HELP FACILITATE NORTHERN HEMISPHERE GLACIATIONS?

**Rob McKay[1], Tim Naish[1], Richard Levy[2], Lionel Carter[1]**
[1]Antarctic Research Centre, Victoria Uni. of Wellington, PO Box 600, Wellington.
[2]GNS Science, PO Box 30-368, Lower Hutt
robert.mckay@vuw.ac.nz

The Pliocene is a critical period in earth's climate history, as it represents a major transition from prolonged global warmth during the Early Pliocene (4.5 to 3.3 Myr ago) to the development of large-scale northern hemisphere ice sheets by 2.6 Myr B.P. This cooling and the onset of northern hemisphere glaciation is poorly understood, and has previously been attributed to changes in oceanic and atmospheric circulation that have been driven either directly or indirectly through tectonic events, or changes in radiative forcing associated with declining $CO_2$ concentrations. Somewhat conspicuous by its absence in these mechanisms is the role that the Antarctic Ice Sheet played in the onset of Northern Hemisphere Glaciation. In large part, this is due to a lack of direct geologic records of ice sheet variability during the Late Neogene.

Previous interpretations of this cooling have been derived from deep-sea proxy records of ice sheet volume, oceanic ventilation/stratification, ice rafting, and biological productivity. However, these have largely all been made in the absence of a direct and relatively continuous record of the extent of Antarctic Ice Sheet variability through this time interval. This is perhaps not surprising due to the lack of quantitative estimates of past WAIS ice sheet volume, with the most reliable estimates being derived from global proxies of ice volume, such as the benthic $\delta^{18}O$ record, and shallow continental shelf stratigraphic sequences. Other methods that have proven useful in determining the onset of major Northern Hemisphere glaciation, such as ice rafted debris from deep sea cores in the North Atlantic are more subjective in the Southern Ocean due to the continual presence of large ice sheets in terrestrial East Antarctica since the Eocene, and likely persistent alpine glaciation in West Antarctica.

Due to these complexities most estimates of past Antarctic ice volume have been made from interpretations of the benthic oxygen isotope record have therefore relied largely on speculation the extent of Antarctic ice volume change through the mid to Late Pliocene. In this talk, we discuss the potential of the ANDRILL AND-1B drillcore to calibrate and re-interpret these pre-existing proxy records for the Late Neogene. AND-1B provides the first direct, semi-quantitative record of marine Antarctic Ice Sheet extent throughout the Neogene and is examined here in the context of the role that a "more-permanent" West Antarctic Ice Sheet since 3.3 Myr B.P. (and hence preceding N.H. glaciation) may have played in altering global atmospheric and oceanic circulation patterns. We also discuss the potential for such an event to drive the Northern Hemisphere into orbitally-modulated ice age cycles.

**SPATIAL AND NUMERICAL ANALYSIS OF ANCIENT AND MODERN EPITHERMAL SYSTEMS**

**J.G. McLellan[1], L. Feltrin,[1], N.H.S Oliver[1], G.S. Nortje[1], M. Scott,[2], J.V. Rowland[3], S.F. Simmons[4]**

[1]James Cook University, Townsville, 4817, Australia
[2] Dept. of Employment, Economic Devt. & Innovation, Indooroopilly, 4068, Australia
[3] Geology Department, University of Auckland, Private Bag 92019, Auckland, NZ
[4] Hot Solutions, PO Box 32-125 Devonport 0744 Auckland, NZ
John.McLellan@jcu.edu.au

The Drummond and Bowen basins in central Queensland lie adjacent to and above older basement blocks, and are host to both high and low-sulphidation ancient (340 Ma) epithermal Au-Ag systems. Comparison with recent epithermal environments such as the Taupo Volcanic Zone provides clues as to the range of processes causing localization of flow and mineralization. Both the Drummond and TVZ show several transform faults, widespread rift faults, basement contacts, calderas and definable intrusive bodies. In the Drummond, we combined weights of evidence prospectivity models with numerical models of deformation and fluid flow (continuum and discrete element methods) to demonstrate that the primary controls on mineralization were calderas and related intrusions, with many deposits and prospects occurring in arcuate belts around curved magnetic ridges (Figure). Less important but significant controls were basement contacts, transform faults and geophysically inferred depth to intrusions. Basin bounding faults or transforms that penetrate basement may have facilitated magma redistribution and focusing. These methods have potentially high applicability to the Coromandel region in the north island of New Zealand, where strong structural controls are apparent but current kinematic and tectonic models are diverse. In the TVZ, we and others have previously tried several approaches to determine the reasons for the localisation of the geothermal upflows. Our previous interpretations favoured the influence of bulk rift geometry, or thermal and related spikes (point heat sources at base, point heat loss at top) on localisation. Comparison with the Drummond results suggests that transverse or basin-bounding faults may localise calderas and associated magmatism, which in turn provide the thermal spikes that localised convective fluid flow leading to mineralization.

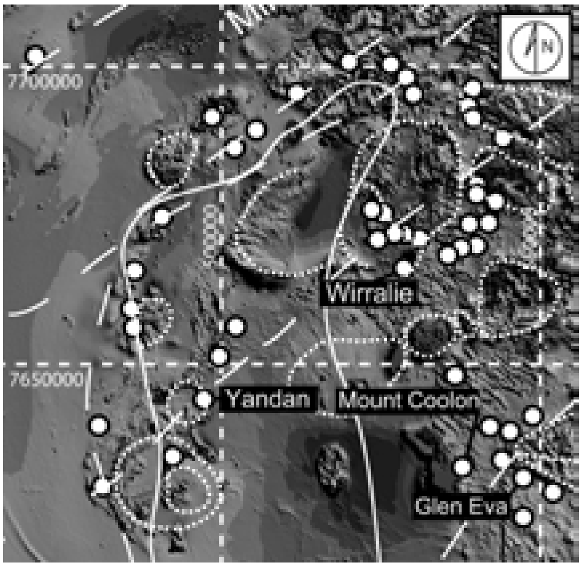



Figure: Part of the Drummond Basin (NE Queensland) aeromagnetic image (grid spacing 5 km) showing the edge of the Anakie Inlier (solid white line), inferred calderas and transform fauls (dotted and dashed lines) and the localization of precious metal deposits and prospects.

# THE ANSWER IS "ELASTIC-STRAIN ENERGY", BUT WHAT ARE THE QUESTIONS?

**Mauri McSaveney**[1] **& Tim Davies**[2]
[1]New Zealand Geological Survey, PO Box 30368, Lower Hutt
[2]Dept. of Geological Sciences, University of Canterbury, Christchurch
m.mcsaveney@gns.cri.nz

What causes earthquakes and triggers fault rupture? What causes so-called mature faults to rupture at apparently reduced strength? What causes faults to slip rapidly? What causes fault rupture to propagate long distances? What causes fault rupture to turn corners and leap from fault to fault? What causes some landslides to exhibit extraordinarily long runout at high speed? You have already been told the answer, but how does elastic-strain energy achieve these phenomena?

Stored elastic strain energy is set free when brittle grains in the granular material of an already stressed fault zone, or potential landslide, break after being stressed (and strained) to beyond their elastic limit. The suddenly released elastic-strain energy propagates beyond the breaking grain as transient elastic-strain energy (a.k.a. seismic waves and rock noise) and it achieves the above phenomena by acoustic transmission through granular media. As transient stress (and strain) passes from grain to grain at grain contacts, forces at already-stressed contacts fluctuate, and for each, the ratio of shear to normal component varies. At contacts that are already close to Mohr-Coulomb failure, the ratio can ephemerally exceed the failure criterion, and slip between the grains will occur at externally applied stresses that could not otherwise induce slip. Such slip preferentially attenuates amplitudes of the shortest seismic wavelengths.

Grain-contact forces and within-grain stresses are highly variable from grain to grain, even in a static grain mass. When some grains are already close to their elastic limit, they can break during transmission of transient elastic strain (when the Griffith brittle-failure criterion is met), suddenly releasing elastic-strain energy to the wider grain mass. Such energy is rich in large amplitudes and short wavelengths to induce large rates of force change at grain contacts, and the likelihood of large, rapid slip. Since large shear rates induce high grain stresses, this process is self-reinforcing and self-propagating.

The average amplitude of independently varying p- and s-waves, and hence overall reduction in shear strength and apparent frictional resistance, is directly proportional to the brittle failure strength of the grains (Q) and the proportion of grain mass (P(Q)) simultaneously reaching Q; the average wave amplitude is QP(Q)/3, since Q/3 is the octahedral stress stored in a grain at its breaking strength.

This grain-fracture mechanism is a dense-grain-flow application of acoustic fluidisation with much lower energy requirements than the usually considered collisional grain flow. It operates independently of any pore-fluid pressure when brittle grain breakages are occurring. Save for the additional production of fractured grains, the effect of a low proportion (<<10%) of simultaneously fragmenting grains of high Q is indistinguishable from the effect of a high pore pressure; thus, in the presence of evidence of grain breakage, fluid pressure is undeterminable by back analysis.

# COMPLEXITY OF U-Pb-Hf ISOTOPE PATTERNS IN ZIRCON DURING ARC MAGMA GENESIS: EVIDENCE FROM A HIGH-*P*, CRETACEOUS GRANULITE / ECLOGITE FACIES ARC ROOT, FIORDLAND, NEW ZEALAND

**<u>L.A. Milan[1]</u>, N.R. Daczko[1], G.L. Clarke[2], A.H. Allibone[3], *I.M. Turnbull[4] & R. Sutherland[4]**

[1]GEMOC ARC National Key Centre, Department of Earth and Planetary Sciences, Macquarie University, NSW 2109, Australia
[2]School of Geosciences, The University of Sydney, Sydney, NSW 2006 Australia
[3]Rodinian Pty Ltd, P.O. Box 1970, Queanbeyan, NSW 2620, Australia
[4]Institute of Geological and Nuclear Sciences, Private Bag 1930, Dunedin
lmilan@els.mq.edu.au

Zircons from seventeen samples of Western Fiordland Orthogneiss (WFO) Suite diorite and three samples of country rock (two schists and one Darran Suite) from the lowermost exposed sections of the Median Batholith, Fiordland, New Zealand, were analysed for in-situ U-Pb and Hf-isotopes. The WFO suite represents a Late Cretaceous flare up of arc magmatism on the East Gondwana Margin, marking the final stage of a long-lived arc spanning back to the Devonian. WFO Suite plutons were emplaced at high-*P* (*c.* 8-12 kbar) during three broad magmatic pulses between 124-122 Ma (Worsley Pluton), 120-116 Ma (McKerr Intrusives) and 116-114 Ma (Misty and Malaspina plutons). Minor very high-*P* (*c.* 18 kbar) WFO Suite eclogite and omphacite granulite facies orthogneiss (Breaksea Orthogneiss) are inferred to have crystallised at *c.* 124 Ma. The zircons in these two plutons were variably affected by Pb-loss at *c*. 115 Ma, defined by decoupling of U-Pb and Lu-Hf isotopes. By comparing these isotopic systems magmatic ages were able to be determined in respect to apparent Pb-loss ages. Hf isotope data for the WFO Suite define an excursion to less radiogenic Hf isotope ratios with time, reflecting increased recycling of an old source component. Peaks at *c*. 555, 770 and 2480 Ma, determine the age spectra of inherited populations of zircons within the WFO Suite. This contrasts with detrital zircon patterns in country rocks of the Takaka terrane, which include peaks at *c.* 465 Ma, and 1250-900 Ma that are nearly absent in the WFO Suite inheritance pattern. These results indicate a previously unrecognised Precambrian lower crustal component of New Zealand. Recycling of this lower crust became increasingly important as a source for the final stage or Mesozoic arc magmatism along this segment of the palaeo-Pacific margin of Gondwana.

# NEWVALE MINE, SEAM W6 – PALYNOMORPHS FROM A TREE-FALL DEPRESSION IN A LATE OLIGOCENE-EARLY MIOCENE AUTOCHTHONOUS SWAMP FOREST, SOUTHERN NEW ZEALAND

**D.C. Mildenhall**
GNS Science, PO Box 30368, Lower Hutt
d.mildenhall@gns.cri.nz

Three pollen samples from well preserved leaf beds within the 17 m thick lignite Seam W6, Newvale Mine, eastern Southland, New Zealand provide clues to the age, climate and depositional environment of a seam otherwise composed of degraded humic material. The leaf beds developed in hollows formed by wind throw of shallow rooting trees with leaves representing *in situ* vegetation (autochthonous) and pollen representing both regional lowland forest and *in situ* swamp forest vegetation. The hollows containing the leaf beds are only a few layers thick but were deep enough to hold fresh water in which the Chlorophycean alga *Botryococcus* bloomed.

The overlapping occurrence of the first appearance of *Assamiapollenites incognitus* and the last appearance of *Proteacidites stratosus* and *Beaupreaidites verrucosus* suggests an age of late Otaian to early Altonian. The underlying marine sediments are of Waitakian age but difficulties comparing the Oligocene-Miocene pollen zonation with well dated marine zonations means that the lignites are given a conservative age range of latest Waitakian to earliest Altonian (22-18 Ma).

The pollen flora from the leaf beds is dominated by *Haloragacidites harrisii*, probably from *Gymnostoma*, and southern beech pollen (*Nothofagidites* spp.) from all three subgenera. The dominant beech pollen type is *N. cranwelliae* (*Brassospora*) whose closest living relative occurs in humid, montane sub-tropical environments. Proteaceae pollen is present but not as varied as suggested by the diverse proteaceous leaves. Wetland vegetation is represented by pollen of *Myriophyllum*, *Phormium*, Restionaceae/Joinvilleaceae and Sparganiaceae but only forms about 10% of the total pollen count.

Generally, pollen and spores are not as diverse in the leaf beds as in the surrounding coal and above Seam W6. Myrtaceae pollen is rare in the leaf beds but common to very abundant in the surrounding coal and above Seam W6. Fern spores are very rare (?Blechnaceae and Gleicheniaceae only) and conifer pollen is sparse, but diverse, encompassing seven different modern genera or families – Araucariaceae, *Dacrydium*, *Ephedra*, *Lagarostrobos*, *Microcachrys*, *Phyllocladus* and *Podocarpus*/*Prumnopitys*.

Some of the taxa present suggest a humid, sub-tropical climate (e.g. *Brassospora*, *Beauprea*, *Strasburgeria*) and the thickness and extent of the coal seam indicates environmental conditions conducive to the production of considerable biomass. The depositional environment was probably nutrient poor, wet and acidic since many of the taxa present are typical of such environments, viz. Proteaceae, *Gymnostoma*, Ericaceae, and Podocarpaceae.

**FLUID-DRIVEN AFTERSHOCKS AND CONTROLS ON OMORI DECAY RATES**

**S. Miller**
Geodynamics, University of Bonn, Nussallee 8, 53115 Bonn, Germany
miller@geo.uni-bonn.de

The role of $CO_2$ in generating earthquakes and aftershocks has been documented in the 1997 Colfiorito earthquake sequence in Italy, and the recent L'aquila sequence in 2009 adds further evidence for the important coupling between earthquakes, aftershocks, and earth degassing. In this talk, I explore the hypothesis that many extended aftershock sequences are driven by the post-seismic release of trapped high pressure fluids ($CO_2$ and $H_2O$) at depth. Aftershock sequences are studied for the range of tectonic environments. Observations are compared with non-linear diffusion models, and show that the general aftershock patterns are consistent with a post-seismic degassing model. In addition, the rate of aftershock decay (Omori Law) is shown to be controlled by the ability of fluids to escape. Fast decay rates occur where the main-shock rupture plane is not optimally oriented for fluid flow relative to the prevailing regional stress field, and slower decay rates where the main-shock rupture plane is well-oriented for fluid flow. These findings are all consistent with many of the original ideas of Rick Sibson.

# CHARACTERISATION OF HIGHLY FRAGMENTED ASH DERIVED FROM RUAPEHU AND NGAURUHOE, NEW ZEALAND

**Anja Möbis[1], Shane J. Cronin[1], Ian E. Smith[2]**
[1]Volcanic Risk Solutions, Institute of Natural Resources, Massey University, Private Bag 11 222, Palmerston North
[2]School of Geography, Geology & Environmental Science, University of Auckland, Private Bag 92019, Auckland
a.moebis@massey.ac.nz

Ruapehu and Ngauruhoe have generated numerous VEI 1-3 eruptions over the last 150 years, producing thin, fine-grained fall deposits in narrow and restricted lobes. Observed eruptions have been vulcanian and strombolian in style. Some vents such as Red Crater and the Te Maari craters have also produced hawaiian and strombolian eruptions, along with effusion of lava flows. We aimed to identify the processes leading to the high levels of fragmentation exhibited in these volcanic ash deposits and we here present volume and particle characteristics for ash produced during the most vigorous activity phase of Ngauruhoe, ~3500 to ~2750 years B.P., along with that of the 1995/96 eruptions at Ruapehu.

To unravel the complex series of tephra deposits, major element composition of volcanic glass was used to establish a unique geochemical fingerprint for each of the volcanic sources. Developing source-specific frequency distributions, we have identified the main variations in eruption frequency and magnitude since activity began at Ngauruhoe ~ 4,300 years ago and for the last ~10,000 years of activity at Ruapehu.

Ruapehu and Ngauruhoe tephras are characterised by repeating changes in depositional features such as colour, grain size and composition. These cycles are interpreted to represent similar eruption sequences, beginning with phreatomagmatic explosions that transit into dry magmatic strombolian eruptions. Initial explosions appear to reflect magma contact with groundwater, meteoric water, hydrothermal systems or lake water. Resulting deposits are pale-brownish-grey fine ash with blocky glass shards containing small spherical vesicles, along with surface conchoidal and step-like fractures. Vesicle fillings and adhering dust are also common, along with high lithic contents, likely due to vent-widening or deepening mechanisms. In most cases, with time water contact ceases to strongly influence eruptions and the explosions grade into “dry” magmatic, mostly strombolian or small sub-plinian eruptions. This results in microlite-rich dark glass shards containing elongate vesicles with thin bubble walls and irregular and fragile surfaces. The coarser ash deposits of dry magmatic eruptions are volcanic glass rich, with lower crystal contents, accompanied by few accidental lithics.

**DETAILED ENVIRONMENTAL AND GEOPHYSICAL STUDY OF WADI HANIFAH IN CENTRAL SAUDI ARABIA**

**S. Mogren[1]& A.O. Al-Jasser[2]**
[1]King Saud University, College of Sciences, Geology & Geophysics Department, PO Box 2455,Riyadh 11451, Saudi Arabia.
[2]King Saud University, College of Engineering, Civil Engineering Department, PO Box 800, Riyadh 11421, Saudi Arabia.
ajasser@ksu.edu.sa

Wadi Hanifah is running through Riyadh city from northwest to southeast with a total length of approximately 150 km. It is considered the main valley of Riyadh area, with its distinguished length and unique natural features in the arid central Saudi Arabia. Ground water management programs as well as tertiary treated wastewater disposed from Riyadh city are the main sources for the permanent flow in certain part of Wadi Hanifah.

In this study gravity, magnetic and vertical electrical sounding (VES) data were used efficiently to map the subsurface structures and create detailed 3D models of depth to basement and faults controlling the Wadi, beside composite samples were collected along it. Such samples were selected on the basis of distance from the main source of pollution and population distribution in the Wadi's surrounding area. Each composite sample is consisted of at least 10 grab samples collected from the same area. Sample preservation was carried out when needed to avoid an effect from the delay between sample collection and testing. Parameters studied include pH, turbidity, conductivity, total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and fecal coliforms. Determination of some parameters required testing the samples on site (e.g., turbidity and pH). The physicochemical and biological analysis of greywater was performed according to the standard methods for the examination of water and wastewater. Fecal coliform most probable numbers (MPN) per 100 mL were determined using the multiple tube fermentation technique. Results showed high Bacteria and Phosphate and TDS, however, a perceptible improvement in the quality of Wadi Hanifah, such improvement is positively proportional to the distance from pollution sources. These results were assisted and integrated with the geophysical data interpretation to delineate the subsurface extension of contamination and locations of connection between ground and surface water in the study area.

# NATIONAL PALEONTOLOGICAL DATABASES PROGRAMME ACHIEVEMENTS

**B. Morrison[1], J.I. Raine[2], J.E. Simes[2] & M.G. Terezow[2]**
[1]GNS Science, Private Bag 1930, Dunedin 9054
[2]GNS Science, PO Box 30368, Lower Hutt 5040
j.simes@gns.cri.nz

The National Paleontological Databases programme has been a four year FRST-funded programme at GNS to significantly enhance two Nationally Significant Databases - the New Zealand Fossil Record File (FRF) and the National Paleontological Collection (NPC) – and some smaller associated databases. This programme has now ended and this poster highlights the achievements of the project.

The FRF was a paper database stored in filing cabinets around New Zealand at the start of the project. Over the course of the project the paper records (numbering close to 100,000 pieces of paper – many very old and hard to read) have been digitised by manual data entry and the FRED database now contains the complete FRF. In addition, a digital submission system has been developed so all new data are entered straight into FRED by the collector.

The FRED website (http://www.fred.org.nz) has been enhanced and registered users can use this website to search, view and download data as well as enter new data. The FRED database has a system for marking records as confidential for a set period of time. Initially a large number of archive paleontological records generated by GNS research and commercial work were marked confidential. Significant progress has been made to identify any records which can be made open-file, and recently all such data for outcrop localities was released (this was approximately 40,000 localities).

The NPC is a physical fossil collection and it includes a large number of type and figured specimens from New Zealand and surrounding areas (including Antarctica). The collection has been moved from Gracefield to Avalon and storage upgraded (better climate control, new cabinets, etc). Visitor facilities are also much improved allowing researchers better access to the collection.

A digital curation system for the NPC has been developed which will enable GNS staff to better manage the collection. An off-shoot of this system is a public website (http://data.gns.cri.nz/npc) listing type specimens held in the collection with images and 3D scans (where available).

Several other important databases have been worked on during this project. The Stratigraphic Lexicon (http://data.gns.cri.nz/stratlex) has had a lot of new (historic) names added, the NZ Fossil Spores and Pollen database (http://www.gns.cri.nz/what/earthhist/fossils/spore_pollen/catalog/index.htm) has been updated and a new Mollusc database is about to be launched containing data from Beu and Maxwell's 1990 Cenozoic Mollusca of New Zealand and other GNS sources.

# RELATIONSHIP BETWEEN OUT-OF-SEQUENCE UPPER PLATE THRUST FAULTING AND INTERPLATE COUPLING ON THE CENTRAL HIKURANGI MARGIN

**Joshu J. Mountjoy, Philip M. Barnes**
NIWA Private Bag 14901, Wellington. New Zealand.
j.mountjoy@niwa.co.nz

Limited areas of the offshore Hikurangi Margin have comprehensive mapping of active fault distribution, geometry and activity. We present a continuous, detailed fault map of a 220 km length of the continental shelf, from southern Hawke's Bay to southern Raukumara Peninsula. This includes new mapping of the active structures off both southern Hawke's Bay and Poverty Bay, integrated with existing mapping in central and northern Hawke's Bay. A comprehensive dataset of high quality multichannel seismic reflection data, dated seafloor samples and shelf multibeam has been used to map the distribution of the active faults, and identify their geometry and interaction at depth. High resolution 3.5 kHz and Boomer seismic data confirm Holocene activity of fault traces, and constrain post-glacial displacement rates.

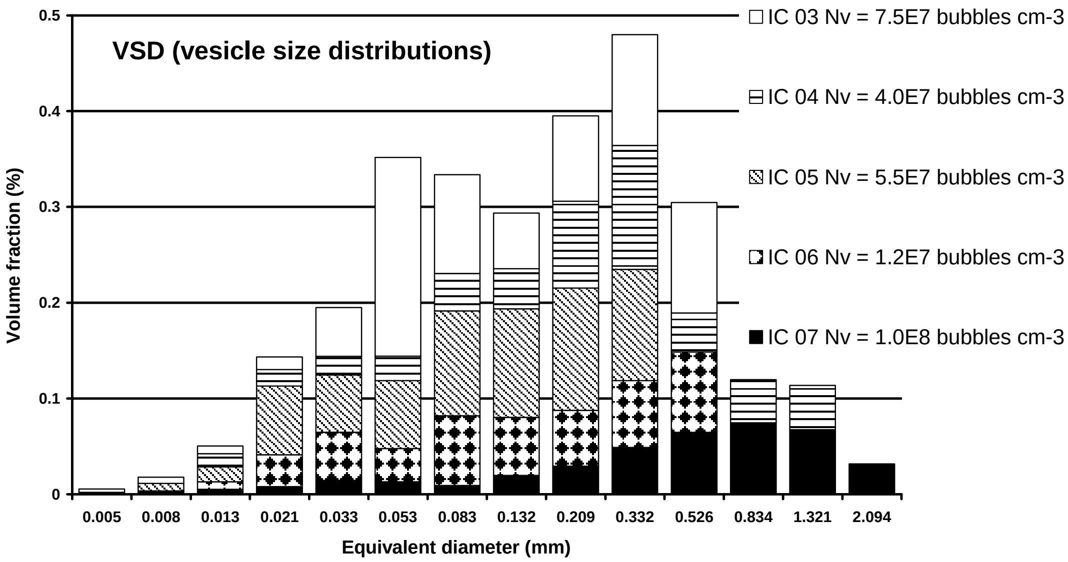
Large, active thrust faults with post-glacial vertical-separation rates of the order of 3 mm/yr occur beneath the continental shelf. In the context of the entire imbricated frontal wedge of the Hikurangi subduction zone, in which forward thrusting occurs commonly at the deformation front, these active structures beneath the shelf are out-of-sequence. Inner-shelf thrust faults in close proximity to the coast drive localised coastal uplift and influence the form of the coastline through exposure of older rock sequences. These faults project to depth inboard (i.e. landward) of the area of the interplate thrust that has been modelled from GPS data as being presently locked or strongly interseismically coupled (Wallace et al., in press), and lie landward of areas of the interface experiencing repeated slow slip. We consider implications for the nature of seismogenesis and interplate coupling on this part of the Hikurangi Margin.

**THE ILCHULBONG TUFF CONE, JEJU ISLAND, SOUTH KOREA: RECENT OBSERVATIONS AND DEVELOPMENT**

**R. Murtagh[1], J.D.L. White[1] and Y.K. Sohn[2]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. of Geology, Gyeonsang National University, Chinju 660-701, Korea
murra257@student.otago.ac.nz

Jeju Island, a Quaternary shield volcano is located approx. 95 km south of the Korean Peninsula in the Yellow Sea. The shield-forming basaltic to trachylitic lavas sit on top of ~100 m thick hydrovolcanic deposits. Ilchulbong tuff cone is one product of the most recent hydrovolcanism found on the island and, as with many of the tuff cones and rings of similar age, it formed along the shoreline of the island. The crater rim is bowl-shaped with a ~ 600m diameter and an elevation of ~ 180m above sea level. Ilchulbong has been described as an emergent Surtseyan-type tuff cone, a direct result of a spectacular and explosive eruption involving the intense interaction of magma and external water. Vertical growth of the cone is attributed to plastering of wet tephra finger jets while lateral growth resulted from failure of the over-steepened slopes.

Here we focus on the Ilchulbong tuff cone's evolution during growth, and on the nature of the magma fragmented during the eruption. Re-examination of exposures previously described, together with the new proximal observations, suggests local slumping of sizeable segments of the edifice during growth. New analyses show that the cone products are geochemically basaltic-trachybasaltic, ranging 45-52% $SiO_2$, with the main minerals present are plagioclase (73-83%An), pyroxene and olivine. We have also taken the opportunity of new sampling to quantify the vesicularity, number density, size and shape of the vesicles in juvenile lapilli. Clasts show a variety of vesicularities, from poor (20-40%) to high (60-80%) vesicularities, but they display consistent bubble number densities between $1.17 \times 10^7$ - $1 \times 10^8$ bubbles per $cm^3$ of 100% melt. Such bubble number densities are comparable to those of plinian "dry" eruptions, and we infer that had the Ilchulbong eruption no access to seawater along the coast, it would have produced a basaltic plinian plume, pyroclastic falls and flows and associated deposits instead of the existing tuff cone.



## THE STABILITY OF THE ANTARCTIC ICE SHEETS DURING THE EARLY PLIOCENE CLIMATIC OPTIMUM

**Tim Naish and the ANDRILL McMurdo Ice Shelf Science Team**
Antarctic Research Centre, Victoria University of Wellington, PO Box 600, Wellington
tim.naish@vuw.ac.nz

An understanding of the behaviour of the marine-based Antarctic ice sheets (WAIS) during the 'warmer-than- present' early-Pliocene epoch (5–3Myr ago) can provide insights into the possible range of ice-sheet behaviour and sea-level rise due to future global warming. In this talk I will present the marine glacial record from the upper 600mof the AND-1B sediment core recovered from beneath the northwest part of the Ross Ice Shelf by the ANDRILL Program (Naish et al., 2009). Analysis of the core demonstrates 40,000 year cyclic variations in ice-sheet extent linked to cycles in solar radiation influenced by changes in the Earth's orbit (obliquity) during the Pliocene. The data provide direct evidence for orbitally-induced oscillations in the WAIS and the marine margins of the East Antarctic ice Sheet, which periodically collapsed, resulting in a switch from grounded ice, or ice shelves, to open waters in the Ross embayment when planetary temperatures were up to 3°C warmer than today, and atmospheric $CO_2$ concentration was as high as 400 p.p.m.v.

Historically, the lack of precession in the geological record has been attributed to the importance of annual insolation that is controlled by obliquity, with more influence on polar temperatures than seasonal insolation modulated by precession. Given the sensitivity of WAIS mass balance to ocean temperature (as implied by a new ice sheet model, Pollard and DeConto, 2009), we suggest that 40 kyr orbital cycles may regulate southward export and upwelling of Circumpolar Deep Water (CDW) with consequences for melt rates at grounding lines of Antarctic ice sheets. The low abundance of sea-ice-associated diatoms (<5%) in the Early Pliocene diatomite intervals of the AND-1B cycles suggests, that sea surface and air temperatures may have been above freezing for a significant part the austral summer. On long time-scales, insolation integrated over the length of summer (summer energy) has been shown in models to control the surface melting of ice sheets at the obliquity period, providing the ablating margin is at high latitude, and that the surface temperature remains above 0˚C for a significant part of the season (Huybers & Tziperman, 2008). Although, the latter condition is not "presently" met by the Antarctic ice sheet, its surface melt threshold may have been exceeded during the Early Pliocene and may be exceeded again in the next century. Furthermore, documented in-phase insolation-linked warming during a Pleistocene interglacial (Scherer et al., 2008) suggests that significant melt may also occur under conditions of extreme southern high-latitude summer insolation. The geological evidence for Pliocene Antarctic Ice Sheet variability is consistent with a new ice-sheet/ice-shelf model that simulates fluctuations in Antarctic ice volume of up to +7m (above today) equivalent sea level associated with the loss of the WAIS and up to +3m in equivalent sea level from the East Antarctic ice sheet, in response to oceanic melting. During interglacial times, diatomaceous sediments indicate high marine productivity, minimal summer sea ice and air temperatures above freezing in Ross Embayment, suggesting an additional influence of surface melting under conditions of elevated $CO_2$.

# MAGNETITE GRAIN-SIZE TRENDS, CHALLENGER PLATEAU, NEW ZEALAND

**F.E. Nelson[1], G.S. Wilson[2, 1] & H.L. Neil[3]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. of Marine Science, University of Otago, PO Box 56, Dunedin
[3]NIWA, Private Bag 14901, Greta Point, Wellington
nelfa020@student.otago.ac.nz

Hysteresis parameters, magnetic susceptibility and anhysteretic susceptibility were measured on 22 sediment samples from three archived shore-normal transects (1-198m water depth) on the continental shelf off south-western New Zealand (Challenger Plateau, Tasman Sea).

The coercive remanence of samples suggests that grain-size (within the range of single-domain (SD) state (≤1μm) magnetite) decreased with water depth. Grain-size decrease with depth is also inferred from anhysteretic susceptibility, which increases linearly with water depth (R=0.87).

Wave-graded continental shelves tend to demonstrate landward coarsening of sediment and we hypothesise that the same processes are acting on the magnetic mineral component of the sediment distribution above mean wave base. Traditional hydrodynamic sorting acts on magnetic minerals with two important differences: 1) clumping via flocculation makes effective grain size larger than magnetically defined grain size, and 2) the size distribution of magnetite is smaller because the density of magnetite is ~2 times the density of silicate minerals. Below wave-base, magnetite may sorted by currents or be undergoing textural diagenesis due to depth-related anoxic water geochemistry.

A simple phenomenological model was derived from the positive linear relationship of anhysteretic susceptibility and water depth. This relative paleobathymetry corresponds to prior interpretation based on downcore magnetic susceptibility on TAN0712-14 (884m water depth).

**MORPHOLOGY OF GLASSY PYROCLASTS FROM SOFT SUBSTRATE CONTROLLED VERSUS OPEN VENT PHREATOMAGMATIC ERUPTIONS**

**K. Németh**
Volcanic Risk Solutions, Massey University, Palmerston North, New Zealand
k.nemeth@massey.ac.nz

Thermohydraulic explosions are extremely effective in fragmenting magma, through a process of brittle melt deformation, to produce fine ash. The generated fine ash particles show diagnostic shapes that are directly linked to the processes generating them. Fragmentation vaporizes the adjacent water and the sudden vapour expansion deforms the melt surrounding the explosion locus, causing ductile deformation and spalling of particles into the expanding pyroclast mixture. Textural features of pyroclasts are therefore potentially able to distinguish between the brittle deformation and the ductile deformation of the melt at the time of particle generation. Current research on understanding phreatomagmatism distinguishes two end-member eruption styles: 1) when magma encounters soft-substrate, water-saturated sediment, or 2) when magma interacts with free water in open vent conditions. While these two magma-water interaction styles involve different coolants, such eruptions commonly occur in similar environments and therefore the resulting deposits and landforms share common features. Here we test the ability of morphological analysis of pyroclasts to differentiate between the brittle and ductile processes, and hence eruption style, involved in fine ash generation in two relatively young phreatomagmatic eruptions: 1) AD 1913 eruption in Ambrym (Vanuatu) and 2) 100ka+ Orakei basin (Auckland). In Ambrym it appears that the eruption was initiated off-shore and magma erupted through a shallow marine, fringe-reef environment rich in fine lime mud. In the Orakei basin, the eruption took place near-sea level, in a water-rich plain where the immediate subsurface rocks were water-saturated porous aquifer. Light microscopy and SEM were used to identify morphology of ash of base surge beds. Morphological parameters were measured to calculate circularity (C), rectangularity (R), compactness (Co) and elongation (E). From these parameters a CXE versus RXCo discrimination diagram was prepared and used to define the deformation mode as either ductile or brittle for each particle. In the coarse ash (-1 – 2 Phi) the CXE values fell systematically below 1 suggesting that the main deformation mode of these particles was ductile in both cases. In fine grain fractions (3-4+ Phi) shape parameters in both cases gradually became more indicative for brittle fragmentation. In coarse ash fractions particles were, in both cases, diverse, exhibiting various stages of vesicularity, elongation, and common presence of spheroid shape particles. Fine ash adhering were especially common in both cases. In the Ambrym samples coarse ash commonly demonstrated fragments from peperitic domains. Similar particles were less common in Orakei basin samples. The glass morphologies in both cases conform to thermohydraulic explosion driven brittle fragmentation; however fine angular juvenile particles from Ambrym are inferred to originate both from the thermohydraulic fragmentation and the particle spallation during magma transportation. Comparison of the glassy particles from these two sites suggest a morphology and textural continuity; both show a gradual transition of morphological parameters from ductile to brittle fragmentation in the spectrum of certain particle size fractions. This potentially reflects the differences from free-water access open vent conditions of Ambrym to a muddy slurry occupied vent such as Orakei.

## HISTORY OF THE MARLBOROUGH SOUNDS DURING THE LAST 5 MILLION YEARS

**A.Nicol**
GNS Science, PO Box 30368, Lower Hutt, New Zealand
a.nicol@gns.cri.nz

The Marlborough Sounds are a drowned valley system comprising an intricate coastline of inlets and islands. The formation of the Sounds requires stream incision and dissection of uplifting bedrock followed by subsidence and marine incursion (Cotton 1913). This talk will examine when these vertical movements occurred together with the relative roles of vertical movements and eustatic sea-level changes in the generation of the Sounds. The spatial and temporal evolution of the Marlborough Sounds is constrained by a combination of seismic reflection lines in the south Wanganui Basin and by topographic information. The Sounds topography is at least ~4 Myr old and started subsiding about 1.5 Myr ago. Subsidence rates were low (<0.5 mm/yr) and the resulting accommodation space filled by sediments. As a consequence of the sedimentation the absolute elevation of valley floors (relative to a fixed datum rather than fluctuating sea level) remained approximately constant and ephemeral submergence was limited to high stand sea-levels during interglacial periods.

Cotton, C.A. 1913. The Tuamarina Valley: a note on the Quaternary history of the Marlborough Sounds district. Transactions and Proceedings of the New Zealand Institute 45, 316–322.

# THE WELLINGTON FAULT – HOLOCENE DISPLACEMENT AND SLIP RATE AT EMERALD HILL, WELLINGTON

**D. Ninis[1], T. Little[1], R. Van Dissen[2] & E. Smith[1]**
[1]SGEES, Victoria University of Wellington, PO Box 600, Wellington 6140
[2]GNS Science, PO Box 30368, Lower Hutt 5040
dee.ninis@vuw.ac.nz

The Wellington Fault is one of the major active dextral faults of the southern North Island of New Zealand. We have investigated fault-offset abandoned fluvial terraces at Emerald Hill in Upper Hutt, to determine fault activity for the southern-most segment of the Wellington Fault, the Wellington-Hutt Valley segment, during the Holocene.

Although now highly modified or destroyed due to suburban development in the region, we have re-evaluated displacement measurements of the fault-offset terraces at Emerald Hill using new digital topographic data derived from photogrammetric analysis of historical air photos. Terrace offsets analysed from these data provide the most accurate fault displacement measurements from Emerald Hill to date.

The three youngest fault-offset terraces at Emerald Hill have been displaced by $\leq 10$ m, $25 \pm {}^{3}_{2}$ m and $53 \pm {}^{16}_{12}$ m ($\geq 2\sigma$) from youngest to oldest, respectively. Using new and previously published Optically Stimulated Luminescence (OSL) ages from terraces at Emerald Hill and the adjacent Te Marua area, as well as the known relative age of each terrace in the sequence and other geological constraints, we have modelled the probable age of the terraces associated with the $25 \pm {}^{3}_{2}$ m and $53 \pm {}^{16}_{12}$ m displacements. These are $9.01 \pm 0.63$ ka, and $9.37 \pm 0.61$ ka ($1\sigma$) respectively.

From our displacement measurements and modelled terrace ages, we estimate an average Holocene slip rate for the Wellington-Hutt Valley segment of the Wellington Fault of between 4.9 mm/yr and 6.6 mm/yr ($1\sigma$), with a preferred value of 5.7 mm/yr. Moreover, our investigation shows that the slip rate has not been steady during this time. Our evidence from Emerald Hill, together with results from a similar study at nearby Te Marua, indicates that there was a phase of heightened ground rupture activity between approximately 10 ka to 8 ka, during which time about 5 surface rupture events took place. The data imply that this was followed by a period of relative quiescence between 8 ka to 4.5 ka - with evidence for only 1 event during this time - but that this was followed by another period of heightened activity - 4 events in the last 4.5 ka. This inference compares well with independent evidence for the timing of past ground rupture events during the Holocene from palaeoseismological studies at other sites along the Wellington-Hutt Valley section of the Wellington Fault.

**DO ENGLACIAL CHANNELS HAVE A CHARACTERISTIC RADAR RESPONSE AND ARE THEY CORRELATED WITH SURFACE TOPOGRAPHY? SOME PRELIMINARY OBSERVATIONS**

**David C. Nobes[1], Natalya Reznichenko[1] & Martin Brook[2]**
[1]Dept. of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch
[2]School of People, Environment and Planning, Massey University, Palmerston North
david.nobes@canterbury.ac.nz

Ground penetrating radar (GPR) images have been obtained from two locations, the Fox Glacier and the Tasman Glacier. A sample profile is shown for the latter below. The preliminary results suggest that (1) englacial channels have a characteristic response that is diagnostic, and (2) that they occur in areas with noticeable surface topographic expression, particularly areas with topographic lows. The profile below was acquired just upstream from an area of lower relative topography, and the inferred englacial channels appear to approximately align with the topographically low region.

Modelling of the response provides an initial starting point for formulating hypotheses on the structure and form of englacial channels, and their correlation with surface topography. The channels are hypothesised to be relatively rough-sided vertical cracks that vary in width and form with depth, and when filled with water yield stacked GPR diffractions with strong signal returns that serve as indicators of such features.

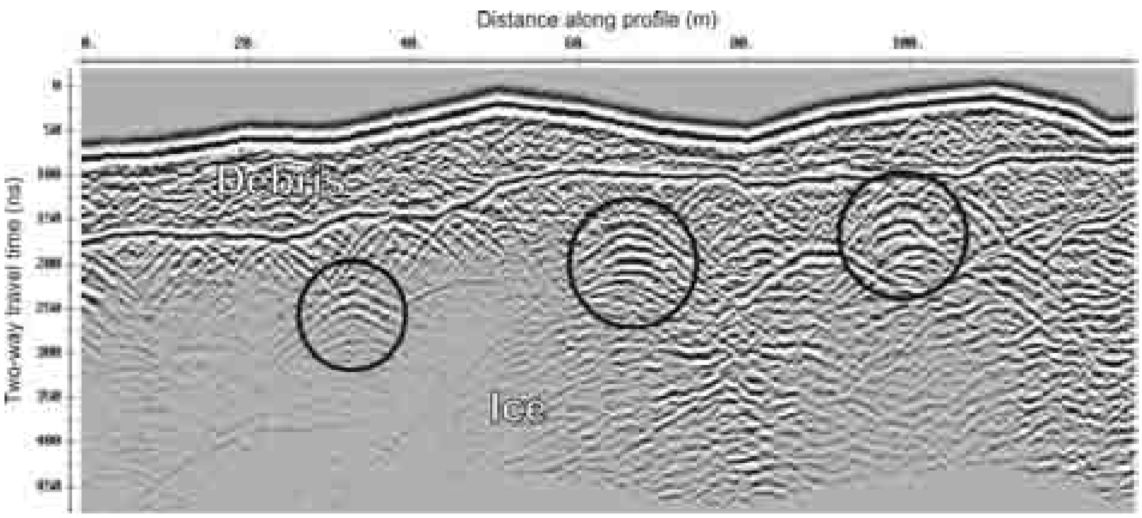



Figure 1. A portion of a GPR profile from the Tasman Glacier, showing the debris overlying the ice (labelled), and stacked radar diffractions (circled) that may be diagnostic of the presence of englacial channels, which in turn appear to align with a downstream area of lower relative topography.

**TEMPORAL VARIABILITY IN ORGANIC AND INORGANIC CARBON VERTICAL FLUX TO THE DEEP OCEAN, AND IMPLICATIONS FOR PALEOCEANOGRAPHIC RECONSTRUCTIONS**

**S. Nodder, L. Northcote, H. Neil, S. Chiswell, J. Schwarz & M. Pinkerton**
NIWA, Private Bag 14-901, Kilbirnie, Wellington
s.nodder@niwa.co.nz

Since 2000, deep ocean moorings have been deployed in subtropical and subantarctic waters to the east of New Zealand, collecting information on the physical, biological and chemical processes in the water column (e.g., stratification, vertical mixing, pelagic biological community changes, downward particle flux). In tandem, remotely sensed data from the same time have provided insights into surface biological (e.g., ocean colour) and physical processes (e.g., sea-surface temperature and height). After almost ten years of data collection, we are now linking these important data-sets to evaluate the temporal and spatial variations in marine ecosystem functioning, and to determine the relationships between surface productivity and the export flux of particulate organic and inorganic carbon to the deep ocean.

There are marked seasonal and inter-annual differences in the timing and magnitude of surface productivity and deep-ocean fluxes between subtropical and subantarctic waters. Higher organic fluxes are observed in subtropical waters and are usually coupled to seasonal surface productivity trends, while surface production and export flux seem to be more decoupled in subantarctic waters. This is perhaps related to the processes by which organic material is “repackaged” and exported to depth, with carbonate and siliceous zooplankton potentially playing significant roles.

Since foraminiferal and radiolarian fluxes have also been measured from the moored traps, we can now begin to interpret the observed variations over the last ten years. These data reveal interesting trends in total foraminiferal flux and in the composition of the sinking fauna that can be compared with faunal assemblages preserved in sediment cores collected from the same locations as the moorings. While sediment trap samples represent a snap-shot in time as opposed to the time-averaged data observed in sediment cores, trap samples allow the actual variability of foraminiferal fluxes in terms of magnitude, timing and speciation, to be elucidated in a time-series sense, over time-scales of weeks to years. Any changes in the spatial distribution of specific species may reflect significant oceanographic changes, and needs to be considered when making paleoceanographic interpretations. Paleoceanographic reconstructions are only as good as the understanding of foraminiferal ecology, hence this modern-day information is paramount to our interpretation of climate and oceanographic history derived from proxies preserved in sediment records.

**FLUID EVOLUTION DURING UPLIFT OF SCHIST IN THE HANGINGWALL OF THE ALPINE FAULT: EVIDENCE FROM OXYGEN ISOTOPES**

**Richard J. Norris**[1] **and Stephen Wickham**[2]
[1]Department of Geology, University of Otago, PO Box 56, Dunedin, New Zealand
[2]Galson Sciences Ltd, Oakham, Rutland LE15 6AX, UK
Richard.norris@otago.ac.nz

In the Alpine Schists 2-5 km east of the Alpine Fault, a sequence of structural features represent deformation during uplift and exhumation in the hanging wall of the fault [1]. Quartz-carbonate veins with biotite-rich selvedges cross-cut the Alpine foliation, but are themselves deformed. Holm et al. (1989)[1] calculated that a 50% flattening strain had affected the rock since the formation of the veins. Fluid inclusions in quartz indicate a depth of formation of 15-20 km assuming a temperature of c. 450°C. Foliation boudinage and localised ductile shear zones represent strain localisation and brittle-ductile behaviour and overprint the earlier veins. Fluid inclusions in quartz precipitated in the boudin necks indicate a temperature of c. 300-350°C and a depth of 6-8 km. Later sub-horizontal extension fractures contain euhedral quartz, calcite and chlorite. Fluid inclusions indicate temperatures of c. 250°C at depths of 2-3 km (Holm, D. K., Norris, R. J., Craw, D., 1989. *Tectonics* v. 8, 153-168).

Oxygen isotope measurements (n=39) on quartz from the country rock schist, from the early deformed veins, the boudin necks and the sub-horizontal extension fractures all lie within a range of $\delta^{18}O$ = 10-14.3‰. The country rock quartz has a mean = 12.5‰, s.d.= 1.35‰, the early vein quartz mean = 12.8‰, s.d.= 1.6‰, the quartz in the boudin necks mean = 13.5‰, s.d. = 1.0‰, and quartz in the late sub-horizontal fractures mean = 12.8‰, s.d.= 0.4‰. The mean values are all compatible with buffering of the coexisting fluid by the country rock isotopic composition. The standard deviation of the early veins is comparable to that of the country rock, suggesting local equilibrium compatible with derivation of the silica by solution in the wall rock. This is also supported by measurements of two samples of veins and their adjacent wall rocks. The boudin neck quartz has a smaller standard deviation, representing a smaller spread of values possibly due to fluid equilibration with country rock over a larger volume than the immediate wall-rocks. The late sub-horizontal veins have the lowest standard deviation indicating the fluid equilibrated with average country rock. Calculated fluid compositions in equilibrium with quartz from the various sites indicate a progressive reduction in $\delta^{18}O$ from the early veins through to the late extension fractures. This is likely to be due to equilibration of the fluid at progressively lower temperatures with the host schist. Jenkin et al. (Jenkin, G. R. T., Craw, D., Fallick, A. E., 1994. *J. Metamorphic Geology* v. 12, 429-444) report similar $\delta^{18}O$ values from the late quartz veins but light values of $\delta D$ indicating a substantial component of meteoric fluid. The lack of a shift to lighter values of $\delta^{18}O$ in the vein quartz indicates a fluid largely equilibrated with country rock oxygen but retaining the hydrogen isotopic signature of a parent meteoric fluid. The reduction in standard deviation of $\delta^{18}O$ values may reflect increasing quantities of circulating meteoric fluid through fracture porosity at and above the brittle-ductile transition. The total fluid-rock ratio must however have remained small for the oxygen isotopes to have equilibrated.

# VARIABLE FAULT COHESION AND REACTIVATION ON A PROTEROZOIC FAULT ARRAY

**G.S. Nortje, N.H.S. Oliver, T.G. Blenkinsop, J.G. McLellan**
Economic Geology Research Unit, School of Earth and Environmental Sciences,
James Cook University, Queensland, Australia
Nick.oliver@jcu.edu.au

Fluid flow leading to mineralization can occur on both newly formed faults, and on faults that are reactivated subsequent to their initial formation. Popular models of fault reactivation propose that, under high pore pressures, misoriented faults may move again due to low fault cohesion. Here, we present timing and orientation data for a mineralized Paleo- to Mesoproterozoic terrain in which multiple successive new orientations of predominantly strike slip faults developed (between 1590 and ~ 1500 Ma), requiring that faults either had high cohesion and/or that pore pressures were not high enough to induce reshear.

The Mount Gordon Fault Zone (MGFZ) is a ~ 150 km long strike-slip-dominant zone in the Mt Isa copper province of northern Queensland, hosted in quartzites, metabasalts, and some phyllites, with a steep master fault aligned NNE. Subvertical faults of many different strike orientations are cut by, or cut this fault. We applied a younging analysis to four domains of approximately 250 $km^2$ each. Simple orientation, overprinting and offset rules were used to define 5 to 7 sets of faults with different orientations and consistent overprinting, within each domain. Several of these fault sets correlate across domains and time steps. We used the youngest well-correlated fault set (trending roughly SE), inferred to correlate with the timing of copper mineralization, to determine a stress field within which the potential for older fault reactivation could be assessed. Stress inversion techniques were used to determine the stress field ($\sigma_1$ trending ~100 to 120°), and numerical models were used to cross-check. Many (but not all) older faults oriented in optimal or near-optimal orientations show no field evidence for reactivation. This includes a lack of new kinematic indicators on older faults for which reactivation would have resulted in a reversed movement sense relative to the original movement, and the development of new faults in orientations consistent with the new stress field, cutting older faults that should have reactivated.

Evidence for local high pore fluid pressures may be found on some examples of the young fault set, as well as on some apparently reactivated older faults, but only those in optimal orientations. This includes jigsaw-fit dilatant breccias, copper mineralization in veins and breccia infill, and subvertical tensile quartz veins aligned sub-parallel to $\sigma_1$. By implication, the generation of new faults in faulted rock masses indicates that older misoriented faults developed enough cohesion that the younger deformation did not 'see' many older faults. Furthermore, faults with high cohesion may have acted as barriers and compartments, so that intersections between them and newly formed faults provide exploration targets. The biggest deposits, however, are found on the rare examples where well-oriented older faults were reactivated at high fluid pressures, but this analysis suggests that those faults also had substantial cohesion prior to reactivation.

**DYNAMIC AND COMPLEX STATES OF STRESS RELATED TO THE SEISMIC CYCLE**

**J.-A. Nüchter & S. Ellis**
GNS Science, PO Box 30368, Lower Hutt
jens.nuechter@rub.de

We use numerical modelling to analyse the geometry of coseismic stress redistribution and postseismic recovery in the crust surrounding a straight normal fault. The model has a 300 km wide and 30 km thick crust underlain by a 70 km thick mantle. The strength of the crust is limited by frictional-plastic yield described by the Mohr-Coulomb criterion for optimally oriented slip. Where temperatures are sufficiently high, thermally activated creep described by a flow law for quartz relieves stresses to below frictional yield. During the experiment, the crust is subjected to continuous extension. After an initial loading step, 6 seismic cycles with constant recurrence intervals of 1000 years are simulated. The model fault is represented by a straight contact surface dipping at 60° and reaching down to 20 km depth. Along this model fault, 'earthquakes' are triggered by a short-term reduction in fault friction to values below the internal friction of the crust. The postseismic periods are simulated by setting the fault friction to high values to lock the fault. The resulting slip along the fault induces simple shear deformation along steep dipping planes in the upper crust surrounding the fault. The tapering off in fault slip at depth causes an increase in the importance of fault parallel compression and extension and pure shear in the hanging wall and the footwall, respectively. During this stage, shear stress results on horizontal and vertical planes throughout the crust, so that these planes no longer represent directions of principal stress after the earthquake. Therefore, we show that coseismic stress redistribution is inherently coupled to a characteristic deflection of the principal stresses, and that a complex stress field geometry prevails in the crust. In the upper crust, the geometry of deformation causes a drop in differential stress. In contrast, the middle and lower crust are loaded to high differential stress, controlled by the tapering off in fault slip. The magnitudes of coseismic stress drop in the upper crust and loading in the middle crust are in agreement to data obtained from seismological and geological sources. During the postseismic period, this differential stress peak relaxes by postseismic creep in the middle and lower crust, while the upper crust is reloaded by this creep and by the continuous extension of the model. The principal stresses rotate gradually towards the vertical and horizontal, but significant deflection of the principal stresses endures long into the postseismic period. A stress field geometry in accordance to Andersons theory of faulting cannot be re-established in any model. This result suggests that the crustal stress field enters into a new, 'dynamic steady state' regarding both the magnitude and orientation of the principal stresses when subjected to cycles of coseismic stress redistribution and postseismic recovery. The residual complex stress field geometry at the end of the postseismic intervals would support normal faults with a somewhat lower dip angle, consistent with observations of lower normal fault dips in nature than those predicted by the Andersonian theory of faulting as shown by histograms of active normal fault dips with a significant peak at 45°±5 (Collettini, C., & Sibson, R. H. (2001).

# TIMING AND MECHANISM OF CALCITE-FILLED VEIN FORMATION IN A CONTRACTIONAL STRIKE-SLIP SETTING, THE DEAD SEA FAULT

**P. Nuriel[1], R. Weinberger[2], G. Rosenbaum[1], S.D. Golding[1], J.X. Zhao[3], M. Bar-Matthews[2], I.T. Uysal[4], M.R. Gross[5]**

[1]School of Earth Sciences, The University of Queensland, QLD 4072, Australia
[2]Geological Survey of Israel, Jerusalem 95501, Israel
[3]Radiogenic Isotope Laboratory, CMM, The University of Queensland, QLD 4072
[4]Queensland Geothermal Energy Centre, The University of Queensland, QLD 4072
[5]Dept. of Earth Sciences, Florida International University, Florida 33199, USA
p.nuriel@uq.edu.au

The Kefar Giladi vein system is located in a contractional strike-slip setting within the Dead Sea Fault Zone in northern Israel (DSFZ). These west-east striking calcite-filled fractures are closely associated with major N-S trending folds and sinistral strike-slip faults, which comprise this segment of the DSFZ. Field-relations indicate that the vein system represents the most recent and presently active phase of deformation, which is related to the transition from an early phase of pure strike-slip motion (Miocene to Pliocene) to convergent strike-slip motion (Pleistocene to Recent). Calcite vein-filling can precipitate actively during the seismic cycle, or passively from meteoric water or groundwater in open-mode fractures. By studying mineralized fractures, one may differentiate between these two mechanisms, which in turn may contribute to the understanding of paleoclimate and paleoseismic activity along this major plate-boundary fault system. We use structural, stable isotopes and U-Th geochronology approach in order to constrain the mechanism, conditions and timing of vein formations.

The veins are up to 30 cm in width and 20 m in height with band morphology that is parallel to vein walls. Elongated-blocky calcite crystal texture is perpendicular to vein walls and karst-type morphology is observed on vein-filling surface. The absence of any indication for shearing along the walls of the east-west striking veins suggests a pure Mode I opening mechanism. In addition, the presence of dilation breccia adjacent to vein walls may attest the presence of a fluid phase during initial fracturing. Oxygen and carbon isotope compositions indicate that the calcite vein-filling material precipitated by karst processes and $\delta^{18}O$ and $\delta^{13}C$ values are similar in composition to speleothems from a nearby karst cave. The U-Th dating results indicate that calcite vein-filling has been accumulating between 360 ka and 10 ka ago with an average growing rates of 0.07 cm/ka. During this time an order of magnitude higher growth rates (up to 0.8 cm/ka) occur in a number of discrete events.

The results indicate that while veins were opened actively during the seismic cycle, calcite vein-filling precipitated passively by meteoric water in opening-mode fractures over much a longer time. Calcite mineralisation stores an important chronology of vein opening rates of fault-controlled fissures. Once opened by extension, these fractures can act as rainwater flow paths functionally similar to those develop by karst processes. Thus, such tectonic environments can provide conditions favourable for accumulation of deposits preserving long and continuous records of paleoclimate and paleoseismic events.

# MAGNETOSTRATIGRAPHIC RECORDS FROM EOCENE-MIOCENE SEDIMENTS CORED IN THE EQUATORIAL PACIFIC: INITIAL RESULTS FROM THE PACIFIC EQUATORIAL AGE TRANSECT (PEAT) IODP EXP 320/321

**C. Ohneiser[1], G. Acton[2], J.E.T. Channell[3], H. Evans[4], C. Richter[5], Y. Yamamoto[6], T. Yamazaki[7], and the Expedition 320/321 Scientists**
[1]Department of Geology, University of Otago, PO Box 56, Dunedin
[2]Department of Geology, University of California-Davis, Davis, CA 95616, USA
[3]University of Florida, 1 University of Florida, Gainesville, FL 326112002, USA
[4]Columbia University, 2960 Broadway New York, NY 100276902, USA
[5]University of Louisiana at Lafayette, 104 University Circle, Lafayette, LA 705032701
[6]Kochi University, B200 Monobe, Nankoku, Kochi, 783-8502, Japan
[7]Geological Survey of Japan, AIST Tsukuba Central 7, Tsukuba, 305-8567, Japan
christian.ohneiser@otago.ac.nz

Integrated Ocean Drilling Project (IODP) expeditions 320 and 321 were part of a single drilling program known as the Pacific Equatorial Age Transect (PEAT). PEAT was designed to recover a composite Pleistocene – Eocene sedimentary succession from beneath the Equatorial Pacific high productivity zone in order to construct a continuous paleoclimatic, paleoceanographic, and paleoenvironmental record for this period and to validate and improve the astronomical calibration of key climate events and the geological timescale.

During PEAT, 6141 meters of sediment were recovered from 23 holes at 8 coring sites (initial results at http://iodp.tamu.edu/publications/PR.html). Age models and sedimentation rates were determined from bio-magnetostratigraphic datums. Initial paleomagnetic results from Expedition 320 comprise measurements at 56,222 intervals along c. 2000 split-core sections. Progressive alternating field (AF) and thermal demagnetisation of discrete samples revealed shallow magnetic inclinations, consistent with the paleoequatorial coring locations. Magnetic polarity zonations were recognised by the downhole mapping of 180° alternations in declination on split core data. The resulting magnetostratigraphies were used to develop initial age models at each drill site and yield 803 absolute ages ranging from 51.743 Ma (the base of Chron 23n.2n at Site 1331) to the present (Chron C1n; 0 to 0.783 Ma at Site U1335). Numerous short polarity intervals were also identified which may correspond to short term fluctuations of the geomagnetic field.

We present an overview of the PEAT program and will discuss the initial efforts in constructing magnetostratigraphies and how, together with bio-, chemo-, and cyclo-stratigraphies, the data will be used to fine-tune the astronomical calibration of the geologic timescale.

# DO EARTHQUAKES GENERATE ELECTROMAGNETIC SIGNALS?

**S. Onacha, P. Malin, E. Shalev, C. Walter & A. Lucas**
Institute of Earth Science and Engineering, Private Bag 92019 Auckland
s.onacha@auckland.ac.nz

In recent years there has been significant interest in the seismoelectric effect which is the conversion of acoustic energy into electromagnetic energy. At the onset of the earthquake, it is postulated that the seismoelectric signal propagates at the speed of light and thus travels much faster than the acoustic wave. The focus has mainly been to use this method as a tool of predicting earthquakes. In this paper, our main objective is to study the possibility of using the seismoelectric effect to determine the origin time of an earthquake, establish an accurate velocity model and accurately locate microearthquakes. Another aspect of this research is to evaluate the possibility of detecting porous zones where seismic activity is postulated to generate fluid movement through porous medium. The displacement of pore fluid relative to the porous medium solid grains generates electromagnetic signals.

The Institute of Earth Science and Engineering (IESE) has installed electromagnetic coils in 3 different areas to investigate the seismoelectric effect. Two of the research areas (Krafla in Iceland and Wairakei in New Zealand) are in active geothermal fields where high microearthquake activity has been recorded. The other area of research is at the site of the San Andreas Fault Observatory at Depth (SAFOD) at Parkfield area on the active San Andreas Fault which is associated with repeating earthquakes. In the Wairakei and Parkfield cases a single borehole electromagnetic coil close to borehole seismometers has been used whereas in the Krafla study area, 3 borehole electromagnetic coils coupled to borehole seismometers have been used.

The technical difficulties of working in the borehole environment mean that some of these deployments had a short life span. Nevertheless in all cases data was gathered and is being analysed. At the SAFOD site, the electromagnetic coil recorded seismoelectric signals very close to a magnitude 2 earthquake. In the Wairakei and Krafla study areas, large swarms of earthquakes were located very close to the electromagnetic coils. Preliminary data analysis has been carried out by band pass filtering and removing of the harmonics of the 50 Hz power line frequency. The initial results clearly show that electromagnetic signals accompany the seismic P and S waves. The origin time may be associated with the change of the seismoelectric signal from high frequency to low frequency. The seismoelectric signal contains higher frequencies than the seismic signal. This may be due to multiple conversions of seismic signals to seismoelectric signals.

# RESOURCE EVALUATION, EXPLORATION AND CURRENT PROSPECTING INTERESTS OF WEST COAST IRONSANDS, NORTH ISLAND, NEW ZEALAND

**A. Orpin, H. Bostock, S. Nodder, P. Barnes & G. Lamarche**
NIWA, Private Bag 14-901, Kilbirnie, Wellington
a.orpin@niwa.co.nz

Ironsands are iron-rich oxides and are the largest known reserve of metalliferous ore in New Zealand. They occur extensively in coastal dunes and on the continental shelf of the western North Island. Figures published by Crown Minerals and New Zealand Steel Ltd indicate that around 1.8 million tonnes of sand are extracted annually from the Taharoa and Waikato North Head mines, from deposits reportedly containing 322 million tonnes of Proved and Probable Ore Reserves (as of 2004).

Offshore deposits of ironsand have been known since the early 60's, but estimates of their reserves are poorly constrained and to date remain largely unexploited. With the growing demand for raw materials on international markets, there has been increasing interest in the feasibility of exploiting beach, shoreface and submarine ironsand deposits. Since 2005 the Ministry of Economic Development has released mineral exploration licenses that geographically cover almost the entire west coast of the North Island, north of the Wanganui Bight. The reinvigoration of offshore prospecting brings new challenges for the coastal zone, both in terms of the exploration and quantification of ironsand resources and adaptable and sustainable management strategies for their exploitation.

The highest reported surficial ironsand concentrations are typically associated with the shore-connected, Holocene muddy-sand wedge that tapers seaward, offlaping onto an older gravelly-sand unit. The gravelly-sand unit is interpreted as a coarse-grained transgressive lag deposit that ranges in thickness from ca 2–5 m. These coarse-grained sediments were deposited as the shoreface-connected wave abrasion zone swept landwards during rising sea level. This unit has not been covered everywhere by Holocene sediment, but is subject to sediment reworking under the present wave climate. The shoreface-connected sand wedge has accumulated largely since the stabilisation of post-glacial sea level ca 7 ka. This unit is strongly influenced by waves and currents in the present littoral zone.

This paper outlines the key scientific hurdles that currently limit a full assessment of the nature and exploitability of these reserves, including: (1) the location, quantity and quality of ironsand deposits at the surface and economically-extractable depths below the seabed; (2) ironsand concentrating mechanisms and zones of likely enrichment, in the past and today; (3) creation of accommodation space and ironsand-rich deposits on tectonically-active areas of the shelf; (4) impact of extraction techniques to benthic and demersal habitats; (5) role of beach renourishment in ironsand enrichment, and the impact of extraction to local beaches; and (6) geotechnical solutions to mitigate against seabed disturbance and elevated turbidity associated with resource extraction.

# EARLY MIOCENE DOLPHINS FROM AWAMOA BEACH, NORTH OTAGO

**M.E. Ortega & R. Ewan Fordyce**
Dept. of Geology, University of Otago, PO Box 56, Dunedin
orteganmegan@gmail.com

The Miocene was a time of peak diversity for Cetacea—whales and dolphins. Yet, the global record of cetaceans for the Early Miocene is patchy, with only a modest range of specimens from few localities in, e.g., the United States (California and Oregon), Italy (Belluno), and Argentina (Patagonia). In New Zealand, Early Miocene cetacean fossils from Awamoa Beach greatly expand the understanding of cetacean history, particularly in the southwest Pacific. The Awamoa Beach dolphins (Odontoceti) and baleen whales (Mysticeti) are from two Early Miocene units: the Gee Greensand (basal, Otaian) and the Mt Harris Formation (Otaian-Altonian). The Mt Harris Formation gradationally overlies the Gee Greensand. The sequence was variably exposed from about 2000 to 2007 but is currently deeply buried under beach sand, prohibiting detailed fieldwork.

The Gee Greensand and Mt Harris Formation have produced the only previously-named Early Miocene cetaceans described from New Zealand. Walter Mantell sent T.H. Huxley a fossil cetacean from Awamoa Creek, later named *Phocaenopsis mantelli* Huxley 1859 (Family Eurhinodelphinidae?; Mount Harris Formation). A cetacean from Kakanui, first reported by J.A. Thomson, was later named *Tangaroasaurus kakanuiensis* Benham 1935 (Family Squalodontidae?; Gee Greensand).

Additional specimens from Awamoa Beach include specimens from concretions (float) and those recovered from outcrop; all study specimens are curated in the Geology Museum, University of Otago. Fossils from the Gee Greensand include a fragmentary skull and many associated postcranial bones apparently from a species of Squalodelphinidae (genus not yet identified), as well as another partial skull and associated remains which represent the short-jawed shark-toothed dolphin, *Prosqualodon* (species not yet identified) — this is the first firm report of a *Prosqualodon* skull from New Zealand. Elsewhere in the Southern Hemisphere, *Prosqualodon* and Squalodelphinidae also occur together in the Patagonian Early Miocene.

The Mt Harris Formation has yielded at least two species of probable kentriodontid dolphins, including small cf *Kentriodon* (Delphinida: Kentriodontidae) and some baleen whale material, the latter not yet studied. One float specimen, a partial skull of a dolphin, appears closer to the *Lophocetus* group of kentriodontids than to other New Zealand taxa. Elsewhere, small and large kentriodontids (*Kentriodon*, *Lophocetus*) are significant members of latest Early Miocene and early Middle Miocene assemblages from the US Atlantic Coastal Plain, California, and Japan.

## GEONET: MONITORING NEW ZEALAND'S NATURAL HAZARDS

**S. Page**
GNS Science, 1 Fairway Drive, Avalon, Lower Hutt
s.page@gns.cri.nz

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 eight 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.

# PLINIAN TO SUBPLINIAN ERUPTIONS OF ANDESITIC VOLCANOES: FROM LITHOFACIES TO ERUPTION DYNAMICS

**N. Pardo S. Cronin, A. Palmer, K. Németh**
Institute of Natural Resources, Massey University, POBox 11222, Palmerston North
n.pardo@massey.ac.nz

Understanding the physical aspects of the largest explosive eruptions at subduction-related, andesitic volcanoes is critical for estimating their hazard implications. The tephras within 23,500 to ~10,000 yr BP geological record of Mt. Ruapehu contain evidence for multiple and complex controls on magma degassing, fragmentation and variations in explosive eruption style and magnitude.

The thickest and coarsest fallout deposits, apparently representing the largest eruptions at Mt. Ruapehu, are pale-brown, phenocryst-bearing pumice lapilli 20 to 50 cm thick beds with subordinated grey, fresh, porphyritic, volcanic lithics concentrated at the base. They usually overlie matrix-supported, poorly sorted, heterolithologic units, representing long, non-eruptive periods during which lahar and fluvial deposit accumulation or soil formation take place. Their features suggest initial vent-clearing phases, during which the conduit wall is abraded and/or a dome or plug occupying the conduit/vent zone is removed, followed by a major phase feeding open-conduit, sustained eruption columns. Juvenile clasts include: a) Subrounded, isotropic, fine vesicular, foamy pumice, with spherical bubbles of restricted size, representing supersaturated magma portions undergoing late bubble nucleation; b) Angular to subrounded, anisotropic, coarse to fine vesicular pumice clasts with fibrous texture, showing ovoid to tube-like, highly interconnected and orientated bubbles, reflecting regions of bubble coalescence and high shear stress along the conduit; c) Highly irregular and angular, coarse vesicular pumiceous or scoreaceous clasts with spherical to irregular bubbles of different sizes and thick bubble walls, evidencing less viscous portions of the magma allowing high bubble interaction and growth, and reflecting early nucleation and more complex degassing histories. d) Pyroxene glomerocrystals are common, either free or as part of the pumices, probably representing cool, crystalline portions of the magma chamber. The wide textural variation of juvenile clasts in the same fallout deposit suggests that the rising magma is not a simple homogeneous body but comprises portions of different volatile saturation, degassing histories, viscosity, and ascent rates that reach the fragmentation level at the same time. Moreover, these eruptions suggest magmatic fragmentation linked to dominant heterogeneous bubble nucleation. Although there are no clear cyclical patterns, the thickest lapilli beds, are commonly followed by thinner, lithic-rich beds of dark brown, fine vesicular, phenocrysts-lacking pumice coarse lapilli and bombs, and abundant hydrothermally altered volcanic lithic coarse lapilli and fine blocks. They suggest short-lived, discrete events, associated to conduit instability and/or vent migration. Contrasting eruptive styles and magnitudes are evidenced by small-scale eruptions with different degrees of magma-water interaction, similar to the known historical activity for Mt. Ruapehu. They include lithic-rich, fine-grained thin beds or platy ash laminae, and accretionary lapilli rich thin beds that bound the major phases, suggesting opening and closing phreatomagmatic eruptions that probably precede and followed major changes in conduit geometry.

## FORECASTING THE CONSEQUENCES OF THE FAILURE OF THE EASTERN RIM OF CRATER LAKE, MT RUAPEHU – A RESEARCH OUTLINE

**E. Phillips, G. Lube, S. Cronin & J. Procter**
Volcanic Risk Solutions, INR, Massey University, Private Bag 11222, Palmerston Nth
redemu10@hotmail.com

The eastern rim of Mt Ruapehu (including Pyramid Peak) containing crater-lake consists of a stratigraphic sequence comprising highly hydrothermally altered deposits of intercalating pyroclastic fall, surge and lava units. This rim is under outward pressure from Crater Lake and constitutes one of the steepest parts of the active volcano. The proposed hypothesis is that a sudden failure of this 40 million $m^3$ rim would generate a debris avalanche, almost certainly followed immediately by a break-out lahar that could be 8-9 times the size of the March 2007 event. Geological evidence shows that similar failures of hydrothermally altered flank materials on this side of the volcano have happened at least twice (at c. 4000 yrs and c. 26 000 yrs B.P.). A quantitative hazard and risk analysis of this scenario has never been undertaken, despite an apparent increasing likelihood of its occurrence due to ongoing hydrothermal alteration and erosion of the inside and outside of the rim caused by explosive eruptions and wet surges from Crater Lake during 1995/1996 and 2007 eruptions and lahars. The increasingly precarious rim could fail with a range of triggers, including: new magmatic intrusion, explosive eruption; increased seismicity; or even elevated pore-water pressure, especially along weak strata.

Our proposed research will include: (a) quantifying the 3D geometry, porosity, permeability, saturation, state of alteration and failure conditions of all geologic units composing the eastern rim; (b) measuring any current surface motion to detect active failure plans; (c) modelling pore water flow through the rim and (d) computing flow runout, diversion, inundation, velocity and mass transport into Whangaehu, Mangatoetoenui, and Tongariro Rivers and Lake Taupo, using statistically validated numerical models for the range of likely collapse scenarios.

This study will answer one of the largest outstanding and urgent hazard problems on Ruapehu mass flows and produce the first detailed geological mapping of Pyramid Peak. It will constitute New Zealand's first hazard forecast for a cascading-event scenario, utilising a range of geological, geotechnical, geomorphological and numerical techniques and will provide a team of New Zealand researchers with the opportunity to use their skills in numerical / computational hazard modelling and develop them further to create multi-hazard forecasts that take into account the complexities of multiple cascading event scenarios that combine a range of uncertainties at each step. It will provide the base for realistically estimating impacts on public safety, infrastructure and power supply as well fresh-water resources for the "Maximum Likely Event" flank-collapse scenario from Ruapehu.

## THE GRAVESTONE PROJECT – WEATHERING RATES FROM THE DEAD

**Brad Pillans**
Research School of Earth Sciences, ANU, Canberra, ACT, 0200, Australia
brad.pillans@anu.edu.au

In July 2009, the Geological Society of Australia launched the Australian arm of the Gravestone Project, which is being conducted by EarthTrek, a "global citizen science program" of the Geological Society of America. The Gravestone Project is an international project to measure weathering rates on marble headstones in cemeteries around the world. Results from the project, which will run from 2009 to 2011, will be used to track local, regional and global patterns in pollution levels and climate change.

In the Gravestone Project, participants will go to their local cemetery, determine its location using a GPS and add the location to the global cemetery (graveyard) map on the EarthTrek website (www.goearthtrek.com). They will also note whether the cemetery has, or does not have, marble headstones. The next step for participants is to choose several headstones of different age, record the dates of death on the headstones, and measure the amount of weathering on each headstone using a Vernier calliper.

So how is the amount of weathering measured? The best way, is to use marble headstones with lead lettering. When the headstone was made, normally the stonemason polished the face so that the lead lettering was flush with the surrounding marble. However, over time, the marble is slowly dissolved by rainwater trickling down the face of the headstone, whereas the relatively inert lead lettering is unaffected except for surface oxidation. This results in the lead lettering standing out from the surrounding marble, the amount of which can be measured with a Vernier calliper. The rate of weathering can then be calculated by dividing the calliper measurement by the number of years since the date of death.

Weathering rate is influenced by the amount and acidity of the rainfall – the higher the amount and the greater the acidity, the faster the marble will be dissolved. Thus, it is expected that the data collected by the Gravestone Project will reveal interesting patterns in long-term changes to pollution and climate. Another, less obvious outcome is that the very slow rates of rock weathering, measured by the project, will highlight the fragility of our soil resources. Soils, after all, are ultimately derived from rocks by weathering and with accelerated soil erosion affecting agriculture all over the world it is a timely reminder that natural rates of rock weathering are so slow that eroded soils will not be replaced by rock weathering on human timescales.

The Gravestone Project is all about people power. The more people that participate the larger the dataset and the more we will learn. The project is particularly suitable for school science projects and we hope that school children around the world will take the opportunity to get out of the classroom and contribute to a global science project. Members of the Geological Society of New Zealand are also encouraged to participate.

# TEXTURAL ALTERATION STYLES AND PROCESSES IN VOLCANICLASTIC KIMBERLITE DEPOSITS AT THE FORT À LA CORNE FIELD, SASKATCHEWAN

**A. Pittari[1,2], R.A.F. Cas[1], S. Kurszlaukis[3], N. Lefebvre[3] & K. Webb[3,4]**
[1]School of Geosciences, Monash University, Victoria, Australia
[2]Dept. Earth & Ocean Sciences, University of Waikato, P/Bag 3105, Hamilton
[3]De Beers Canada Inc, Ste 300-65 Overlea Blvd, Toronto, Ontario, Canada
[4]Mineral Services Canada, 205-930 Harbourside Dv, North Vancouver, BC, Canada
apittari@waikato.ac.nz

Ultramafic volcanic rocks (e.g. kimberlites, komatiites) are highly susceptible to modification by secondary alteration processes. Distinguishing primary depositional textures 'beneath' overprinting alteration textures can be particularly difficult in kimberlites, but it is essential to do so if an understanding of emplacement processes is to be achieved. Primary components of volcaniclastic kimberlite deposits in the Fort à la Corne kimberlite field, Saskatchewan, have been partially replaced by serpentine and carbonate group minerals, and to a lesser extent magnetite and rare Fe and Ni sulphides. This study synthesises results from field drill core logging, microscopic petrography, XRD analyses, SEM and backscattered SEM imaging, and semi-quantitative EDS analyses and element maps of the Orion Central kimberlite volcanic centre, to characterize and assess the distribution of different alteration textural styles.

Six different alteration styles overprinting depositional facies of the main kimberlite volcaniclastic packages have been identified: (i) pervasive vermiform serpentine-rich and (ii) buff carbonate-rich alteration, enhanced along the edges of the packages; serpentine-carbonate alteration zoned upwards through packages from (iii) dark green-grey with speckled calcite domains, to (iv) dark green-grey, to (v) pale bluish-green tones; and (vi) patchy magnetite alteration. Each of these alteration styles consist of characteristic textures and textural variations associated with: (a) partial to complete replacement of olivine crystals; (b) irregularly-bound fine-crystal-rich domains, representing either juvenile pyroclasts, secondary pseudoclasts of an original texturally continuous deposit, or a mixture of both; (c) serpentine-carbonate alteration matrix between clasts/pseudoclasts; and (d) the occurrence of networks of serpentine/carbonate veins, opaque blebs and stringers and large serpentine nodules. Unique textures are also associated with more advanced degrees of alteration also occur within less voluminous kimberlite facies.

Secondary alteration within the main kimberlite packages would have been influenced by early interaction with warm deuteric fluids, trapped seawater and meteoric/connate groundwater from the surrounding country rock sedimentary succession. Bulk rock textural modification progressed from primary matrix replacement; to further alteration 'matrix' replacement and pseudoclast development; through to complex secondary porosity development and infilling, and veining. Individual olivine crystals also show multiple phases of secondary textural development. The complex textural paragenesis reflects the temporal interplay between changing fluid compositions, fluid and deposit temperatures and phases of porosity development and reduction.

# STRUCTURE, FAULTING AND GAS ACCUMULATION, SOUTHEAST WANGANUI BASIN, NEW ZEALAND

**L. Pledger** & **T. Stern**
SGEES, Victoria University of Wellington, PO Box 600 Wellington
ljpledger@gmail.com

There has been low interest in petroleum exploration in the Wanganui Basin due to a lack of known hydrocarbon source rock of sufficient age or burial depth. In the Southeast Wanganui Basin however there are multiple instances of methane-rich gas found in shallow water wells. This biogenic gas is likely generated in Pleistocene peat and lignite lenses, but isotope analysis has found the presence of higher hydrocarbons (C3-C5), suggesting a thermogenic source might also be present.

In this project we examine the faulting style in the Southeast Wanganui Basin where it abuts the Tararua range-front, and how faulting relates to the accumulation of gas deposits in the shallow sedimentary section. We use shallow seismic refraction methods in conjunction with gravity data to map two possible shallow gas reservoirs, and to examine the basement depth along the boundary between the Tararua range-front and the Southeast Wanganui Basin.

Southeast of Levin the basement dipping off the Tararua range-front under the Southeast Wanganui basin was originally modelled (Aharoni, MSc thesis, 1991) using gravity data and a seismic reflection line. This seismic line was later reprocessed (Ewig, PhD thesis, 2008), and shows a deeper event which is possibly side-swipe from basement to the South. Approximately 1km south of this line, the strike-slip fault at the base of the ranges steps west 4km creating a pull-apart basin. We are modelling the basement depth near this step in the fault by collecting more gravity data and shooting a new seismic line perpendicular to the first one.

One of the two potential shallow gas reservoirs lies northeast of Levin, abutting the Tararua range-front, and was discovered when a water well was drilled. The other potential reservoir lies southwest of Sanson and was located during an aerial resistivity survey as a domed structure with high resistivity. In both areas gas is thought to be trapped in buried sand dunes at a depth of around 20m. We are using shallow seismic refraction methods in conjunction with gravity data to map these reservoir bodies.

This study of the faulting style at the edge of the Tararua range front and the mapping of these reservoirs will lead to a better understanding of the formation of these structures and aid future studies of similar structures.

# GOLD "BREAKS": SOUTHERN ABITIBI GREENSTONE BELT, CANADA

**K.H. Poulsen**[1] **& F. Robert**[2]
[1]Consultant, 34 Wallford Way, Ottawa, Canada, K2E 6B6
[2]Barrick Gold Corporation, 161 Bay Street, Toronto, Canada, M5J 2S1
howardpoulsen@gmail.com

Gold "breaks" are well-established metallotects for gold in the Archean Southern Abitibi Belt of the Canadian Shield. They are steeply dipping features with curvilinear traces, up to 250 kilometers long and the loci of major gold camps such as Timmins, Kirkland Lake and Val D'Or. Although important sites for deformation and fluid flow, the euphemism "break" acknowledges they are more than simply late-orogenic faults. Despite their great length, the breaks are commonly marked by persistent bands of metavolcanic rocks only 10-100 metres thick, in many cases with sharp compositional or age contrasts to neighbouring lithologies. The breaks are also loci for coarse clastic rocks which are arguably of alluvial-fluvial origin and deposited above angular unconformities prior to dynamothermal metamorphism and deformation. The conglomeratic rocks are now preserved as narrow synclines or half-synclines adjacent to and truncated by the breaks. Shoshonitic igneous rocks are common along the full length of both breaks. The rocks within and adjacent to the breaks are commonly strongly carbonatized, in places to the point where ultramafic rocks now contain more than 50% carbonate minerals. Intensity of brittle-ductile deformation varies such that well-preserved primary volcanic and sedimentary textures give way over short distances to zones of intense phylonite and discrete fault surfaces. The preserved kinematic record is dominated by reverse-slip and dextral strike-slip displacements.

Nearly all of the gold production and resources (~ 6000 t or 200 Moz) of the Southern Abitibi belt are concentrated along the Larder Lake-Cadillac and Destor-Porcupine Breaks, with deposits clustering in specific camps spaced 40-50 km apart. Some of the larger deposits are well removed from the breaks but never more than 10 km distant. Different styles and ages of mineralization are present along the breaks, reflecting multiple gold-depositing events at different crustal depths of emplacement.

The belt developed over approximately 100 million years and the breaks have been in existence for at least the second half of that interval. The breaks likely evolved from syn-volcanic basin-bounding faults, to a growth faults along which conglomerate and intrusions concentrated, to the syn-orogenic shear zones which dominate their configuration today. Some gold was deposited during each of these main stages of fault evolution, including syn-volcanic gold-rich massive sulfide accumulations in the Noranda and Bousquet camps. Reactivation of the mis-oriented, inherited structures is an implicit, if not critical, part of their metallogenic history. A possible modern analogue, although not as deeply exhumed or advanced in terms of orogenic deformation, metamorphism or gold endowment, is the massive sulfide-rich Honshu Region of Japan where the switch from constructional extensional faulting to compressional inversion took place as little as three million years ago.

**METAMORPHISM AND DEFORMATION IN SOUTHERN FIORDLAND: CORRELATION WITH NORTHERN AND EASTERN FIORDLAND**

**N.G. Powell**
Forensic & Industrial Science Ltd, PO Box 67-087, Mt Eden, Auckland, New Zealand
homicide@forensicscience.co.nz

Six deformational episodes are identified in southern Fiordland. $D_1$ and $D_2$ are both probably mid-Paleozoic or older. $D_1$ is largely obliterated by later deformation and recrystallisation. $D_2$ was accompanied by a high temperature, low-pressure metamorphic episode ($M_2$) which outlasted $D_2$ deformation. $M_2$-$D_2$ fabrics of annealed aspect dominate the Southwest Fiordland Block. $D_3$, an episode without associated penetrative deformation, is identified only within southwest Fiordland. $D_4$ took place within a brief interval of $M_3$ time. $D_4$ fabrics are subtly developed in southwest Fiordland but are evident throughout northern Fiordland as strong linear fabrics locally with a coeval foliation; these correspond to the earliest recognisable phase of deformation in Eastern Fiordland. The Grebe Fault is a $D_4$ structure; reverse movement at this previously eastward-dipping structure was accompanied by subsidiary left-lateral strike-slip displacement; associated mylonites are annealed. Low-angle normal faults with associated mylonite- and brittle-series rocks are identified as $D_5$. No penetrative deformation accompanied $D_6$, which is expressed as open folding associated with the Hauroko Fault, a post-Tongaporutuan structure. The Kilcoy Fault and the Vincent Fault are post-$D_6$ faults marked by post-glacial scarps.

Metamorphic conditions attending $M_1$ are unknown. $M_2$ was a low pressure amphibolite facies episode during which southwest Fiordland sillimanite-zone pelites were metamorphosed at 665 ˚C, *c.* 3 kbar with $P_{H_2O} < P_{total}$. Emplacement of the Thundercleft Quartz Diorite and other dioritic bodies to shallow crustal levels significantly augmented $M_2$ heat flow. Grade and intensity of $M_3$ is variable: early $M_3$ is essentially of contact metamorphic aspect; late $M_3$ is distinctively polybaric: garnet- and kyanite-bearing amphibolite facies assemblages in central Fiordland recrystallised at *c.* 8.5 kbar after earlier metamorphism in the sillimanite field at *c*. 3.5 kbar. Development of high pressure granulite facies assemblages in the Western Fiordland Orthogneiss, northern Fiordland, is also an expression of the late $M_3$ pressure increment. Spatial variation of $M_3$ grade is partly fault-controlled and is most evident across the Dusky Fault, a reactivated $D_5$ transfer structure. The subtlety of $M_3$ in the Southwest Fiordland Block is attributable to suppression of recrystallisation in a previously metamorphosed hence coarse-grained, anhydrous and unresponsive substrate, which had cooled substantially from high $M_2$ temperatures. In southeastern Fiordland, the $M_3$ metamorphic field gradient continues, slightly disrupted by post-$M_3$ faults, across the Grebe Fault into eastern Fiordland, where chloritoid is superseded by late $M_3$ staurolite and garnet in lacustrine (meta-) sapropel-silts.

# THE FIORDLAND 2009 TSUNAMI: OBSERVATIONS AND INTERPRETATION

**W. Power, G. Prasetya, X. Wang, K. Wilson**
GNS Science, PO Box 30368, Lower Hutt
w.power@gns.cri.nz

The $M_w$7.6-7.8 Dusky Sound earthquake of July 15th 2009 was one of the largest earthquakes historically recorded in New Zealand, and the largest to be clearly identified as occurring on the subduction interface. The subsequent tsunami was observed and recorded in several ways: by the observations of the occupants of boats present in the sounds near the epicentre, by an Australian deep-ocean buoy in the Tasman Sea, and on tide gauges throughout the Pacific. In addition a post-event survey uncovered evidence of the environmental impact of the tsunami on specific locations within the sounds.

Several of the tsunami observations will be presented. They raise a number of questions which will be discussed; such as why were the observable environmental impacts confined to only a few locations when the waves reported by boat occupants were quite widespread within the sounds? And why was the largest wave to be recorded at the Jackson Bay tide gauge so much later (by about an hour and a half) than the first to arrive? These issues have implications for how post event and paleotsunami surveys are conducted in Fiordland and similar environments, and on how real-time measurements can be used for tsunami warnings.

A variety of tsunami simulations have been made of this event and some will be presented here. These models, in combination with instrumental and other observations, can help to interpret some of the properties of the source earthquake, since the tsunami properties reflect the distribution of seabed uplift. Another application of tsunami modelling is to generate a database of pre-calculated scenarios or unit-source models that can be used to improve tsunami warnings at locations too far away to self-evacuate from the earthquake shaking alone, and this will also be discussed in the context of this event.

# USE OF COSMOGENIC NUCLIDES IN TECTONIC GEOMORPHOLOGY RESEARCH

**M. Quigley**
Dept. of Geological Sciences, University of Canterbury, Christchurch, NZ
mark.quigley@canterbury.ac.nz

The measurement of *in situ* produced terrestrial cosmogenic radionuclide (CRN) concentrations (e.g., $^{10}$Be and $^{26}$Al) in bedrock and sediment by AMS can provide profound quantitative information on the interplay between tectonics, climate, and surface processes. The COsmogenic RAdionuclide Laboratory (CORAL) in the Department of Geological Sciences at the University of Canterbury is currently engaged in a number of CRN-based research projects around the globe, including New Zealand. I present a summary of recent process-based research highlights resulting from these projects, including (1) continental-scale coupling of bedrock erosion rate and rate variability with seismic strain rate, implying first-order tectonic control on erosion rate, (2) absence of any clear correlation between bedrock erosion rate and climate parameters such as mean annual temperature and precipitation, implying limited control of climate variability on erosion rate, and (3) coupling of catchment-scale CRN erosion rate to basin morphometric parameters such as hypsometric integral, longitudinal stream profiles, and intracatchment relief, implying a clear correlation between drainage basin geomorphology and erosion rate.

# THE TRANSITION FROM OTAGO SCHIST TO ALPINE SCHIST, HAAST REGION

**M.S. Rattenbury**[1], **R. Jongens**[2] **& S.C. Cox**[2]
[1]GNS Science, PO Box 30368, Lower Hutt
[2]GNS Science, Private Bag 1930, Dunedin
m.rattenbury@gns.cri.nz

New fieldwork as part of the QMAP 1:250 000 geological map of the Haast area has constrained the textural and mineral metamorphic transition from Otago Schist to Alpine Schist between the Wilkin River and the Mahitahi River. The width of metamorphic textural zone t.z. IV schist reduces from 40 km in the southwest to 10 km in the northeast. This is achieved through increasing strain of the syn-metamorphic folded schist and steepening of foliation. Post-metamorphic folds (e.g. Haast Antiform, Thomas Synform) with axial plane crenulations deforming Otago Schist structures in the south tighten to the north. The axial plane fabric intensifies with increasing transposition of earlier foliation into a new syn-metamorphic foliation that dominates Alpine Schist. In the Otoko River area, this same generation of folding is late metamorphic, although still folds peak Alpine metamorphic isograds.

The transition from lower greenschist to amphibolite facies metamorphism contracts dramatically in the Otoko and Mahitahi river sections. Otago metamorphism (Garnet1 and Biotite1) can be differentiated from Alpine metamorphism (Garnet2, Biotite2). The Aspiring lithologic association has been delineated north of the Haast River where it gets increasingly caught up in high strain associated with the Alpine Fault and Alpine Schist. The Aspiring lithologic association also reduces in width but its outcrop extent is complicated by the superposition of later folds on earlier syn-metamorphic folds.

The t.z. IIA-IV transition similarly contracts fourfold to the north to approximately 4 km width in the Otoko River through predominantly brittle fault juxtaposition of packets of semischist and schist in the south and fold tightening in the north. Some of these faults link with the Burke Fault and the Siberia Fault Zone. A northward extension of the Moonlight Fault has been discovered through the Te Naihi, Mueller and Turnbull rivers, displacing post-metamorphic fold axes. The Moonlight Fault probably terminates at the Alpine Fault and kilometre-scale movement documented farther south did not entirely shift to the northeast-trending Siberia Fault Zone in the Wilkin River headwaters as previously believed.

**FOLLOWING IN DARWIN'S FOOTSTEPS IN VAN DIEMEN'S LAND.**

**C. Reid**[1] **& C. Buttler**[2]
[1]Dept of Geological Sciences, Uni. of Canterbury, Private Bag 4800, Christchurch
[2] Dept of Geology, National Museum of Wales, Cathays Park, Cardiff, CF10 3NP
catherine.reid@canterbury.ac.nz

During the voyage of the Beagle, Charles Darwin made geological descriptions and fossil collections of the countryside around Hobart during a visit to Tasmania (then Van Diemen's Land). His geological descriptions were included in the 1844 publication "Geological Observations on the Volcanic Islands, visited during the voyage of H.M.S. Beagle", along with fossil descriptions of the material collected in Van Diemen's Land. The bryozoans, or Palaeozoic "Fossil Corals", were described by William Lonsdale as an appendix, and although full descriptions, for the time, were given, the material was not figured. Subsequently, in 1845, Strzelecki published his "Physical description of New South Wales and Van Diemen's Land", and he also had passed his fossil bryozoan material to William Lonsdale. The species originally described from Darwin's material were then figured in Strzelecki (1845), which in itself contributed to general confusion.

The species described by Lonsdale in Darwin (1844) were *Stenopora tasmaniensis, S. ovata, Fenestella ampla, F. internata, F. fossula* and *Hemitrypa sexangula*. These species names are still in use and *Fenestella ampla* was subsequently designated the type species for *Protoretepora*, a designation now being debated and clarified in a separate study, and *Stenopora tasmaniensis* was designated the type species for that genus, although not formalised until 1890 by Ulrich. A major complication in bryozoan taxonomy has been the loss of type material of the above species and the present authors are now redescribing the latter species based on material collected from Darwin's original localities. Systematic descriptions have changed dramatically in the last 150 years, as have our understanding of bryozoan growth and biology, and the lack of type material has meant several new, and unnecessary, species designations, that have subsequently been reduced.

**DOWNSTREAM VARIATION IN MINERALOGY OF BEDLOAD SEDIMENT, TAIERI RIVER: AN APPLICATION OF QUANTITATIVE XRD**

**N.J. Reid** & **C.E. Martin**
Dept. of Geology, University of Otago, PO Box 56, Dunedin
nataliejanereid@gmail.com

The downstream differences in mineralogical composition of streams reveal the chemical and physical processes affecting their source rocks. The effect of quartz dilution can obscure these processes, making quantification of mineralogy crucial for unravelling patterns of weathering and provenance. Quantitative X-Ray Diffraction (QXRD) is a useful tool which can help with this problem. Previously QXRD has been hampered by the significant effort involved, issues of laboratory calibration and instrumentation, the availability of standard materials and difficulties with diffraction theory. In recent years major advances have taken place leading to increased interest and publication of QXRD results, and the development of modern QXRD software is resulting in more accurate and user friendly programmes. The Rock Jock computer program (Eberl, 2003), utilising the Solver function of Microsoft Excel, compares the integrated XRD intensities of individual minerals in powdered samples to the intensities of an internal standard, in order to calculate abundances of phases in the sample. Rock Jock has successfully been applied to suspended and bedload sediment, drill core samples, soil profiles and clay mixtures. Despite recent QXRD success, poor results can still be obtained due to inadequate sample preparation or incorrect phase identification (Kleeburg 2009). Testing at the University of Otago facilities and calibrations with synthetic mixtures demonstrate that a micronising mill is a vital piece of equipment necessary for this method to work. QXRD using Rock Jock was then undertaken on bedload sediment from the Taieri River, East Otago. This 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 Paleozoic schist, with other less extensive units including mafic volcanics and sediments of Cretaceous to Quaternary age. Bedload sediment was collected from eight locations, and up to six grainsize fractions were separated from each sample. Quartz ranges widely in abundance, between 18.7 - 75.3 normalised wt%, and is concentrated in the sand fractions. The phyllosilicates (e.g. chlorite – up to 16.2 norm wt%) and heavy minerals (e.g. titanite - up to 2.7 norm wt%) are concentrated in the finer grainsize fractions. There is a lack of calcite, with all sediments containing <1 norm wt %; this observation supports studies suggesting that chemical weathering has removed calcite from the solid into the dissolved load (Jacobson et al, 2003). Schist-derived minerals dominate the sediment assemblage, and the ratio of feldspar to clay minerals correlates well with chemical weathering indices.

**PUTTING EARTHQUAKES IN THEIR (RIGHT) PLACE: NEW INSIGHTS INTO SEISMOTECTONICS OF THE SOUTH ISLAND**

**Martin Reyners[1], Donna Eberhart-Phillips[2,1] & Stephen Bannister[1]**
[1]GNS Science, PO Box 30368, Lower Hutt
[2]Geology Department, University of California Davis, USA
m.reyners@gns.cri.nz

Traditionally New Zealand earthquakes have been located with one-dimensional seismic velocity models (velocity changing only with depth). Such models oversimplify the 3-D heterogeneity of the plate boundary, and often provide a poor fit to the arrival times of seismic waves. This can result in some earthquake arrival times being excluded during the location process, and can lead to the need to restrict the depth of some shallow earthquakes (usually at 5, 12 or 33 km). In the last 15 years, numerous dense networks of portable seismographs have been deployed throughout New Zealand, enabling tomographic inversions for local 3-D seismic velocity structure. These local models have now been stitched together into a nationwide 3-D seismic velocity model, which in future will be used for routine location of New Zealand earthquakes.

Here we relocate New Zealand seismicity for the period January 2006 to June 2009 using this new 3-D model. Because this model captures structural heterogeneity, we can use all recorded arrival times and rarely have to restrict depths of crustal events. The net result is a significant reduction in the misfit of the arrival time residuals for individual earthquakes, and a "sharpening up" of the seismicity associated with specific structures (such as the crust of the subducted Pacific plate). We also find that the 3-D model gives much more robust locations of historical events, such as the 1942 Wairarapa earthquake sequence. This indicates that neglect of structural heterogeneity, rather than sparse station spacing alone, was a major impediment in past studies.

In the South Island, some earthquakes beneath the Southern Alps previously restricted to the crust now relocate at mantle depths. Together with dipping lineations of crustal earthquakes, these events define a northwest-dipping subducted slab, similar to that previously seen with the Pukaki microearthquake network, which operated from 1975 until 1983. In the northern Fiordland subduction zone, the relocated seismicity associated with the subducted Australian plate becomes vertical with depth and then overturns to dip northwest in the 70-110 km depth range. A viable explanation for this seismicity distribution is that it reflects impact of the subducted Australian slab with the southernmost end of the subducted Pacific plate mantle.

# IT'S OUR FAULT: RE-EVALUATION OF WELLINGTON FAULT CONDITIONAL PROBABILITY OF RUPTURE

**D. Rhoades[1], R. Van Dissen[1], R. Langridge[1], T. Little[2], D. Ninis[2], E. Smith[2], R. Robinson[1]**
[1]GNS Science, PO Box 30-368, Lower Hutt, New Zealand
[2]Victoria University of Wellington, PO Box 600, Wellington, New Zealand
r.vandissen@gns.cri.nz

A primary goal of the Likelihood Phase of It's Our Fault (IOF) is a re-evaluation of the conditional probability of rupture of the Wellington-Hutt Valley segment of the Wellington Fault accounting for new IOF-catalysed Wellington Fault data. Specifically, new estimates of: 1) timing of most recent rupture, and the next four older ruptures; 2) size of single-event displacements; 3) Holocene dextral slip-rate; and 4) rupture statistics of the Wellington-Wairarapa fault-pair, as deduced from synthetic seismicity modelling. The methodology used is that of Rhoades et al. (1994; JGR 99: 13,701-13,712), along with Rhoades & Van Dissen (2003; NZJGG 46: 479-488) and Rhoades et al. (2004; GNS Client Report 2004/141 prepared for EQC), that allows probability of rupture to be expressed as a single value that accounts for both data and parameter uncertainties. Four recurrence-time models were explored (Exponential, Lognormal, Weibull, Brownian Passage Time), and sensitivity runs were conducted entertaining different bounds and shapes of the probability distributions of important fault rupture data and parameters. For example, sensitivity runs were undertaken that favour the older end of the age range of the most recent event; that approximate a "retarding" effect of the 1855 Wairarapa Fault rupture on the Wellington Fault by shifting the datum from which probability is estimated from 2010 to 1945; that exclude the occurrence of a more speculative Event 5; and that adopt a higher coefficient of variation of single-event displacement (0.57 c.f. 0.30).

Important findings and conclusions include:
1) The estimated probability of rupture in the next 100 years is ~10% (with sensitivity results ranging from ~5% to 14%), and the probability of rupture in the next 50 years is about half that (~5%; with results ranging from ~2% to 7%).
2) Favouring the older end of the age range of the most recent event increases the estimated probability of rupture, not surprisingly, and inclusion of an approximation of an "1855 effect" decreases the probability - both by about the same, but opposite, amount over the time frames considered (i.e. over the next 100 years).
3) Inclusion of Event 5 reduces the importance of the choice of recurrence-time distribution. That is, with Event 5, results derived from the four recurrence-time distributions are fairly close to each other; whereas, without Event 5 there is greater variability in the results derived from the different recurrence-time distributions.
4) In all cases, the inclusion of the new IOF data has reduced the estimated probability of rupture of the Wellington Fault by 50%, or more, compared to pre-IOF estimates.

## U-Pb AGES OF DETRITAL ZIRCON FROM EOCENE-OLIGOCENE SEDIMENTS IN TE ANAU BASIN AND PROVENANCE IMPLICATIONS

**R.E Richards and P.J.J. Kamp**
Department of Earth and Ocean Sciences, University of Waikato, Hamilton
rer7@waikato.ac.nz

U-Pb ages have been derived by LA-ICPMS for detrital zircon from the Eocene – Oligocene section in Te Anau Basin, to help establish the provenance of these sediments and implications for the timing of exhumation of basement in Fiordland. The ages of some of the basement units in Fiordland have also been determined to establish the degree of variability in grain ages within these plutonic and metamorphic units to help explain the variability in the detrital ages. The grains selected for analysis were done so on the basis of zircon colour and morphology, chiefly as a means of ensuring that the data were reasonably representative of the host rocks, which is a particular issue in working with sedimentary units. The quartzo-feldspathic composition of the sediments and their accessory minerals suggest that they were chiefly derived from crystalline basement within Fiordland.

U-Pb ages have been derived from samples for the following formations: Earl Mountains Sandstone, Boyd Creek Formation, Stuart Formation, Turret Peaks Formation and Point Burn Formation.

In general, the Eocene formations show broad age peaks including Early Permian to Middle Devonian, and Early Cretaceous to Late Triassic. There is one grain with a Neo-Proterozoic age. The Oligocene formations show broad age peaks from Early Permian to Early Carboniferous, and from Late Triassic to Early Cretaceous. There are also a few grains with Devonian, Middle Ordovician, Neo-Proterozoic and Meso-Proterozoic ages.

These data show that Paleozoic basement units contributed a small proportion of grains to the sediments, with the majority of the zircons having been derived from Late Jurassic and Early Cretaceous plutons and metamorphic complexes. Modelling of the age data shows that the Early Cretaceous basement units currently at the surface in Fiordland must have been there in the Eocene and Oligocene, thus pointing to substantial Late Cretaceous tectonic exhumation. The substantial Neogene exhumation across Fiordland known from our fission track data appears not to have fundamentally changed the outcrop distribution of the main basement units, which appears to have been established during the Late Cretaceous.

## THREE YEARS OF REGIONAL MOMENT TENSOR ANALYSIS IN NEW ZEALAND

**John Ristau**
GNS Science, Lower Hutt, New Zealand
j.ristau@gns.cri.nz

In November 2006 GNS Science began to implement the routine calculation of moment tensor solutions using regional broadband seismic data (source-receiver distances < 1000 km) as part of the GeoNet Project. The purpose is to provide routine and rapid calculations of moment magnitude ($M_w$), focal mechanism and depth for New Zealand earthquakes with M >~ 3.5 – 4.5. Regional moment tensor (RMT) solutions differ from moment tensor solutions calculated using teleseismic data by using higher frequencies and velocity models specific to the source region in order to model the observed waveforms from smaller magnitude earthquakes (i.e. $M_w < 5$). Since the RMT project began more than 600 RMT solutions have been calculated for New Zealand and the immediate offshore regions. The catalogue dates from the August 2003 $M_w$ 7.1 Secretary Island earthquake in Fiordland through to the present. Solutions range from $M_w$ 3.3 – 7.3 and depths 2 – 400 km. By comparison the Global CMT Project calculated 50 moment tensor solutions for earthquakes with $M_w > 5$ for the same region over the same time period. The RMT solutions are being used to provide improved magnitude estimates by comparing $M_w$ with local magnitude ($M_L$) which is the magnitude routinely calculated by GeoNet, and the focal mechanisms and depths are used to provide constraints on the active tectonics in New Zealand. An overview of the RMT project to date is given here and how it contributes to the understanding of seismic hazard analysis and tectonic studies in New Zealand.

## THE COROMANDEL TO TAUPO VOLCANIC ZONE TRANSITION: QUASI-PREDICTABLE STRUCTURAL CONTROL ON ASCENDING HOT WATER

**J.V. Rowland**[1, 2] **& C.J.N. Wilson**[3]
[1]School of Environment, University of Auckland, Private Bag 92019, Auckland
[2]Institute of Earth Science and Engineering, 58 Symonds Street, Auckland
[3]School of Geography, Environment and Earth Sciences, PO Box 600, Wellington
j.rowland@auckland.ac.nz

The Coromandel Volcanic Zone (CVZ) and the TVZ are contiguous through space and time and represent paleo and active versions, respectively, of the same evolving magmatic system. The onset of Colville Arc volcanism is not well established, but the arc was most likely reasonably stable with respect to its position by about 17 Ma. There ensued 5 to 10 million years of volcanic activity before the onset of rapid slab rollback and concomitant back-arc rifting in the Havre Trough. The driving heat source, as expressed by the distribution of andesitic volcanism and epithermal mineral deposits, migrated southwards both in Coromandel and offshore Taranaki areas, but volcanism was conspicuously absent from the intervening region until ca. 3 Ma. This anomalous situation may be explained by the concurrent activity on the back-thrust Taranaki Fault, which implies a compressive stress regime was present throughout central North Island up to ca. 4 Ma. There appears to be linkage over a period around 4 ± 2 Ma in: a) significant opening of the Havre Trough, b) rapid migration and onset of major silicic volcanism into the early TVZ, c) cessation of thrusting on the Taranaki Fault, and d) diminution of offshore Taranaki volcanism. Prior to 4 Ma, north to south migration of ages in Coromandel is matched by migration of centres in offshore Taranaki, implying that from 17 Ma onwards expression of the arc across the North Island was parallel to its modern orientation. Subsequent to 4 Ma, arc volcanism and magmatism has been focused in the TVZ (from 2 Ma onwards), and intraplate volcanism of gradually diminishing volume and intensity moved northwards from the former alignment of the arc to where it now lies underneath Auckland.

The modern fabric of volcanic and structural lineaments and crustal anisotropy in and below the central North Island is dominated by Mesozoic large scale terrane boundaries, block faults associated with the Cretaceous rifting of New Zealand from Australia, and NW-trending structures parallel to the Vening Meinesz Fracture Zone. Progressive southward cessation of activity on the Taranaki Fault coeval with rapid opening of the Havre Trough permitted the loci of rifting to jump in en echelon fashion to the SE across the continental crust of the North Island in part exploiting these pre-existing structures. The wedge-shaped Central Volcanic Region thus developed by differential opening of arc parallel rift segments, rather than rotation of the arc as a whole. This architecture is recognisable as a localising influence on the mineral deposits of the Coromandel Volcanic Zone and the geothermal systems of the Taupo Volcanic Zone. Similar distributions of relic geothermal systems presumably reside within the intervening region.

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

**M. Ryan**[1, 2], **G. Dunbar**[1, 2], **M. Hannah**[1, 2], **M. Vandergoes**[3], **H. Neil**[4], **H.Bostock**[4]
[1]School of Geography, Environment and Earth Sciences, Victoria University
[2]Antarctic Research Centre, Victoria University of Wellington
[3]GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand
[4] National Institute of Water & Atmosphere, PB 14901, Wellington, New Zealand
matt.thomas.ryan@gmail.com

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 proximal to Okarito swamp, which yielded a detailed record of vegetation change over the last glacial cycle (Vandergoes *et al*., 2005).

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 60ka.

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.

In particular, a recently published Antarctic ice volume model suggests that marine isotope stage 5c and 7a were characterised by greatly enhanced ice sheet melting. The model is driven by high latitude Southern Hemisphere insolation and global ice volume. The significance of this proposed melting event on the New Zealand climate is presently unknown, as it is poorly represented in terrestrial pollen records.

**CAUSES OF EVOLUTION AND EXTINCTION OF DEEP-SEA BENTHIC FORAMINIFERA IN THE INDIAN OCEAN**

**Ashwaq Sabaa[1], Bruce Hayward[1], Ellen Thomas[2], Shungo Kawagata[3], Ritsuo Nomura[4], Claudia Schröder-Adams[5], Anil Gupta[6], and Katie Johnson[1]**
[1]Geomarine Research, 49 Swainston Rd, St Johns, Auckland
[2]Department of Geology and Geophysics, Yale University, New Haven, CT, USA
[3]Faculty of Education and Human Sciences, Yokohama National University, Japan
[4]Faculty of Education, Shimane University, Nishikawatsu, Matsue 690-8504, Japan
[5]Department of Earth Sciences, Carleton University, Ottawa, Ontario, Canada
[6]Department of Geology and Geophysics, Indian Institute of Technology, India
a.sabaa@geomarine.org.nz

A group of ~100 species of elongate, cylindrical deep-sea benthic foraminifera (Families Stilostomellidae, Pleurostomellidae, Nodosariidae) with complex, often constricted apertural structures, became extinct during increasingly cold glacial periods in the late Pliocene to mid-Pleistocene Climate Transition (MPT, ~2.6-0.6 Ma). We document the evolutionary history and architecture of this Extinction Group (Ext. Gp) through the Cenozoic at four lower bathyal-upper abyssal Indian Ocean sites (ODP 722, 744/738, 758, 763), seeking clues to the cause of this morphologically-targeted extinction episode late in the Cenozoic.

Eighty percent of the extinction group species present in the Cenozoic of the Indian Ocean originated globally in the Eocene or earlier, compared with 23-37% of other Quaternary deep-sea foraminifera. The Ext. Gp had its peak species richness, relative and absolute abundance in the late Eocene. The rapid warming of the Paleocene-Eocene Thermal Maximum, that resulted in a loss of 30-50% of deep-sea foraminiferal species, had no impact on the Ext. Gp in the one Indian Ocean section (ODP 744/738) studied. Major Cenozoic changes in the Ext. Gp, including increased species turnover, changes in dominant species, a decline in abundance, loss in diversity, and finally extinction, mostly occurred during the middle Eocene-early Oligocene, middle-late Miocene, and late Pliocene-middle Pleistocene. These were times of stepped increase in the volume of polar ice, global oceanic cooling, surface-water eutrophication, seasonality of phytoplankton production, deep-water ventilation and southern deep-water carbonate-corrosiveness. The final decline and disappearance of the Ext. Gp began in the late Miocene at high latitudes (744/738), but not till the late Pliocene (758, 763) or MPT (722) at lower latitudes.

We hypothesise that the loss of the Ext. Gp of deep-sea foraminifera may have been caused by the decline or demise of their specific food source (detrital phytoplankton or bottom-dwelling chemosynthetic microbes) that was abundant in the Greenhouse World and was decimated by the step-wise cooling, ventilation and/or eutrophication of the oceans that began in the middle and late Eocene.

# CHARACTERISATION OF THE WAIPAWA FORMATION, EAST COAST BASIN, NEW ZEALAND

**Sadaf, Julie Palmer and Christopher Anderson**
Soil and Earth Sciences, INR, Massey University, Palmerston North
sadafphysics@yahoo.com

Oil and gas seeps in the East Coast Basin have attracted the attention of geologists and oil explorers for over 100 years. More than 300 oil and gas seeps are recorded in the East Coast Basin and some 45 wells have been drilled in the area with no commercial discoveries. There are three main oil seeps at Waitangi, Totangi and Rotokautuku, however, the source rocks for these are unproven. Potential source rocks are present in the Cretaceous to Paleocene sequence and Davies (2000) proposed that the Waipawa, Whangai and older Cretaceous Formations could be the possible source rocks for the oil and gas.

This study focuses on the Waipawa Formation which is widely distributed throughout the East Coast Basin between East Cape and Wairarapa. It has not been encountered in the central Hawkes Bay. The Waipawa Formation is poorly bedded, hard to moderately soft, dark brown-grey to brownish black, bioturbated, non-calcareous, micaceous siltstone of Teurian (Paleocene) (65.5-55.8) in age. The total organic carbon content varies between 1.81-12 % (Moore, 1987). It is up to 50 m thick in the East Coast and is thin in the coastal Southern Hawkes Bay. Faunal evidence shows that it was deposited in a shallow marine environment which was largely anoxic. Stratigraphically, it lies between the Whangai and Wanstead Formations.

Characterization of the Waipawa Formation using initially thermogravimetric analysis (TGA) shows that as the decomposition temperature increases, weight loss increases. The TGA curve shows three regions of weight loss. The heat flow versus temperature curve shows regions where exo- and endothermic reactions are occurring. Characterisation using XRD and SEM with EDS is providing useful data to compare this potential source rock with similar shales both in New Zealand and other parts of the world. The average connected porosity using a gas Pycnometer is 0.8. The aim of this project is to characterise the Waipawa Formation and to assess its source rock potential using analytical techniques.

References:

Davies, E. J., Frederick, J. B., Leask, W. L., & Williams, T. J. (2000). East Coast drilling results 2000. New Zealand Petroleum Conference Proceedings (pp. 84–93): New Zealand. Ministry of Economic Development.

Moore, P. R. (1987). Maturation and petroleum source rock potential of the Whangai and Waipawa Formations (Late Cretaceous-Paleocene), eastern North Island. New Zealand Geological Survey record 20: 17-23.

## HIGH-GRADE GNEISSES & GRANITOIDS OF THE GLENROY & GRANITE HILL COMPLEXES, WEST COAST REGION

**M.W. Sagar[1], J.M. Palin[1], V.G. Toy[1] & A.J. Tulloch[2]**
[1]Deptartment of Geology, University of Otago, PO Box 56, Dunedin 9054
[2]GNS Science, Private Bag 1930, Dunedin 9054
sagma887@student.otago.ac.nz

High-grade gneisses and plutonic rocks are common components of the Western Province and Median Batholith – they comprise much of Fiordland, and outcrop at numerous localities in the West Coast, Tasman and Nelson regions. The Granite Hill and Glenroy Complexes are two areas with distinctive lithologies that occur adjacent to the Alpine Fault, near Lake Brunner and north of the Lewis Pass area, respectively. Amphibolite facies paragneiss, metabasite and granodiorite orthogneiss, cross-cut by pyroxene+hornblende norite constitute the Granite Hill Complex. Hornblende+biotite granite, amphibolite facies metasedimentary gneiss, and Early Cretaceous granulite facies dioritic orthogneiss in part retrogressed to amphibolite facies, form the Glenroy Complex. The Granite Hill Complex is inferred to correlate with the Fraser Complex, and the Glenroy Complex gneisses with the Western Fiordland Orthogneiss (WFO) plus related metasediments, and granite with the Separation Point Suite. However, their affinities are far from certain. The timing and conditions of deposition, intrusion and metamorphism of these complex associations of rocks are also mostly unknown. Furthermore, the mode, timing and rate of exhumation of the Glenroy and Granite Hill Complexes remain largely unresolved.

Recently commenced studies will address the above issues. Specifically, resolving the following questions through integration of structural and geochemical methods will form the basis of a new project:

- What are the field relations of the constituent lithologies of the Granite Hill and Glenroy Complexes, and what relations do they exhibit with adjacent rocks (e.g., faulted, depositional or intrusive)?
- Were the Granite Hill and Glenroy Complexes exhumed by normal detachment faulting during mid-Cretaceous continental extension, post-Miocene movement along the Alpine Fault or other major fault(s), or a combination of these?
- What was the tempo and absolute timing of uplift?
- What is the relationship of these gneissic rocks to others in Zealandia? For example, the WFO (Median Batholith), or Fraser Complex and Charleston Metamorphic Group in the West Coast region (Western Province)?
- In what tectonic environment (e.g., passive margin) were the metasediments deposited?
- When did deposition, emplacement and subsequent metamorphism of the gneisses occur?
- What are the ages and affinities of post-metamorphic intrusive rocks?
- What pressure-temperature conditions did the gneisses and intrusive rocks experience during metamorphism-deformation and emplacement, respectively?
- What implications do the geological histories and affinities of the Glenroy and Granite Hill Complexes have for processes in similar tectonic settings elsewhere, and the geological evolution of Zealandia?

# DEPOSITIONAL HISTORY OF PALEOGENE STRATA IN THE CANTERBURY BASIN

**S.P. Samuel[1], C. Atkins[1] & M. Arnot[2]**
[1]SGEES, Victoria University of Wellington, PO Box 600, Wellington.
[2] 1 Fairway Drive, Avalon, Lower Hutt.
sanjaysamuel@gmail.com

The depositional history of the Canterbury Basin is known broadly. However, the Paleogene succession has been relatively less well studied and mapped in contrast to the Cretaceous and Neogene successions.

The aim of this project is to map in greater detail the Paleogene succession in the Canterbury Basin: to map specific horizons, and to undertake a detailed sequence stratigraphic analysis and interpretation of the depositional history and evolution of the Canterbury Basin during the Paleogene.

The Paleogene interval represents a relatively thin package of sediments deposited over a long interval of time. These sediments are mostly fine grained mudstones and siltstones. However, locally coarser-grained material is also present as at the Cutter-1 well where there were gas indications in tight Eocene sandstones. These local depositional regimes have yet to be documented within the public domain.

Overall, the Paleogene interval represents a transgression with smaller cycles of transgression/regression. These smaller cycles have yet to be studied and elucidated.

So far, key horizons and faults have been interpreted on seismic lines across Canterbury Basin. Observations include amplitude variations of reflectors, channel like features and also subtle onlap/offlap/truncation relationships within sedimentary packages.

Future work includes identifying and mapping subtle seismic reflector relationships and variations in seismic reflector properties over the seismic grid, picking up subtle cases of smaller regressions within the overall transgressive regime, performing well correlations across the four wells in the area and picking out sequence stratigraphic surfaces. This will produce more detailed paleogeographic maps at the Paleogene level.

## AUTOMATIC SHEAR WAVE SPLITTING, WITH APPLICATION TO TIME-VARYING STRESS

**M.K. Savage[1], A. Wessel[1] , N. Teanby[2] & A. Hurst[3]**
[1]Institute of Geophysics, Victoria University, PO Box 600, Wellington
[2]Atmospheric, Oceanic and Planetary Physics, Oxford, OX1 3PU, U.K.
[3]GNS Science, 1 Fairway Drive, Avalon, Lower Hutt 5010, PO Box 30368
Martha.Savage@vuw.ac.nz

In the upper crust, seismic anisotropy is often caused by fluid-filled cracks aligned by the Earth's stress field. Objective methods that leave no room for human bias are needed to determine changing stress from time variations in anisotropy. We present an automatic shear wave splitting measurement tool tuned to local earthquakes, which runs with the sole requirement that an S arrival time has been chosen. We apply the technique to three data sets recorded on Mt. Ruapehu volcano, which were determined by manual analysis to have fast polarisations that vary in time and with earthquake depth. When the same filters are used for events determined to be high quality from manual studies, the two techniques returns virtually identical results. Scatter increases when the automatic technique chooses the best filter, but the average automatic results remain consistent with the manual results. However, when the automatic technique is used on data previously judged as poor quality, scatter increases again, and some stations yield distributions of fast orientation (ϕ) that include peaks that were not present in previously published results (Fig.). Detailed examination reveals that there might have been some unconscious bias in the manual selection process which downgraded measurements that did not fit expectations, but also that manual selection can detect subtle waveform changes that are not apparent in the automatically determined measures. Nonetheless, results from the new objective analysis confirm changes in the average fast orientation of anisotropy between 1994 and 2002, and between shallow (<30 km) and deep (>55 km) earthquakes. Such changes may be evidence of a near-isotropic regional stress field.

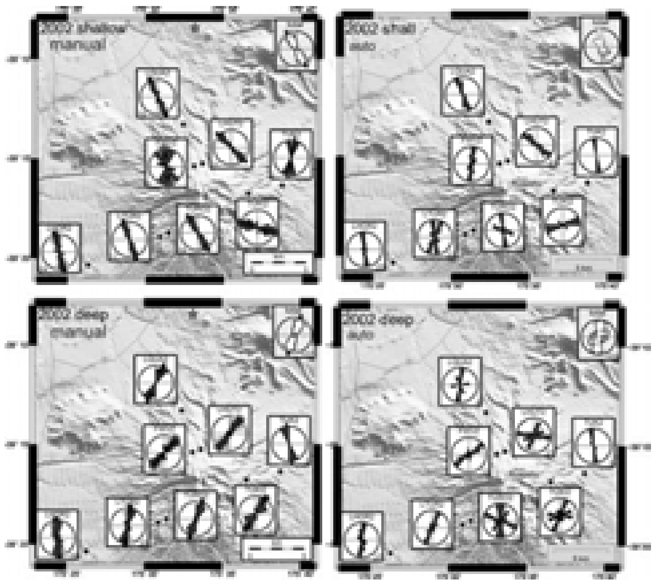


Fig. Circular histograms of ϕ for manual (left) and auto (right) measurements of shallow (top) and deep (bottom) earthquakes.

## INTRA-VESICULAR EXTRUSIONS: SENSITIVE INDICATORS OF SUBMARINE EXPLOSIVE CONDUIT DYNAMICS

**C.I Schipper & J.D.L. White**
Dept. of Geology, University of Otago, PO Box 56, Dunedin.
schipper.ian@gmail.com

We report on a unique textural feature, here termed "intra-vesicular extrusions" (IVE), that are found in submarine basaltic pyroclasts collected from a ~22 m thick submarine pyroclastic deposit at ~1100 mbsl on Loihi Seamount Hawaii. IVE are small (50-200 μm) droplet-shaped domains of sideromelane found in vesicles of low- and modal-density basaltic scoria. They occur exclusively in vesicles that are set in >50 % microcrystalline, tachylitic groundmass; in clasts with a mixture of sideromelane and tachylite groundmass, the first appearance of IVE coincides with areas of patchy, vuggy, pseudo-spherulitic textures at the sideromelane-tachylite transition. An examination of IVE morphology suggests that they formed by viscous flow of hypocrystalline melt through a rigid but permeable network of microlites- penetrating host vesicle walls where heterogeneous microlite nucleation had "locked-in" host vesicle shapes. The inferred mechanism of IVE formation is nearly identical to that of "filter pressing," regularly invoked to explain melt segregation and in-situ magmatic differentiation, with effects ranging in scale from the concentration of evolved melt in individual vesicles, to the evolution of entire magma chambers. Geochemical relationships, however, demonstrate that the melt mobilized to form IVE is not differentiated with respect to the bulk melt in their host lapilli, demonstrating that classical "filter pressing" could not have formed these unique textures at any reasonable timescale. We present textural and geochemical evidence to explain IVE formation by an alternative mechanism, involving a 5-step process of: (1) initial vesiculation; (2) shallow magma stagnation and partial crystallization; (3) syn-eruptive magma remobilization and secondary vesiculation; and (4) quenching. IVE formed by this mechanism, unlike classical segregation structures, have no bearing on in-situ magmatic differentiation. Instead, they are sensitive indicators of magmatic pressure-temperature-time relationships in the shallow conduits that feed submarine explosive eruptions.

# RAPID SOMATIC EXPANSION CAUSES THE BRAIN TO LAG BEHIND: THE CASE OF THE BRAIN AND BEHAVIOUR OF NEW ZEALAND'S HAAST'S EAGLE (*HARPAGORNIS MOOREI*)

**R. Paul Scofield[1]** & **Ken W. S. Ashwell[2]**
[1]Canterbury Museum, Christchurch, New Zealand
[2]School of Medical Sciences, University of New South Wales, 2052, NSW, Australia
pscofield@canterburymuseum.com

New Zealand's late Pleistocene and Holocene Haast's eagle (*Harpagornis moorei*) was the sole predator of the Dinornithiform moa and the largest eagle so far described. Recent molecular evidence has hypothesised that it evolved from a much smaller Asian/Australian eagle within the past 1.8 my. We have used osteometry and high resolution spiral CT of skeletal remains of Haast's eagle to determine morphological and functionally significant characteristics of the central and peripheral nervous system and sensory apparatuses and to test these against hypotheses about behaviour and evolution based on molecular and external morphology. We find that compared to other accipitrids, Haast's eagle had a proportionally low endocranial volume for its body weight. Similarly, the size of the osseus bony labyrinth was found to be not greatly different from that of much smaller extant Accipitridae and indicators of visual system anatomy (e.g. scleral ossicle ring size, optic foramen area and optic fossa volume) were smaller than in many modern Accipitridae of much lower body weight. There was no anatomical evidence to support the significant use of olfaction by Haast's eagle, since the olfactory bulb size and cross-sectional area of the olfactory nerve foramen were no larger than would be expected for Accipitridae of this body weight. Our data are consistent with the hypothesis that *Harpagornis* had evolved rapidly to large size from a smaller ancestor following recent dispersal to New Zealand and that the ancestors of Haast's eagle appear to have undergone rapid expansion of body size and elements of the hindlimb somatic nervous system at the expense of enlargement of the brain and visual, olfactory and vestibular apparatuses.

# DIKE INTRUSION AND DISPLACEMENT ACCUMULATION AT THE INTERSECTION OF THE OKATAINA VOLCANIC CENTRE AND PAEROA FAULT ZONE, TAUPO RIFT, NEW ZEALAND

**H.Seebeck[1,2] & A. Nicol[1]**
[1]GNS Science, PO Box 30368, Lower Hutt, New Zealand
[2]SGEES, Victoria University of Wellington, PO Box 600, Wellington, New Zealand
h.seebeck@gns.cri.nz

We examine the relationship between dike emplacement and normal fault displacement along the south-western margin of Okataina Volcanic Centre, New Zealand. At this location dikes (including a basaltic dike up to 5 m wide at the ground surface intruded during the 1886 AD Tarawera eruption) formed over the last 22 kyr in the Tarawera linear vent zone within a few kilometres of the Paeroa Fault zone. Displacement analysis and mapping of fault scarps indicate that fault and dike extension are complementary over time periods of 10's of thousands of years. Extension that is primarily accommodated by faulting outside the volcanic complex is achieved by dike intrusion and faulting within it. Historical observations following the 1886 AD eruption and previously published active fault trenching collectively indicate, however, that dike intrusion generally does not induce slip within the Paeroa Fault zone close to the lateral dike tip. We suggest that displacement in the Paeroa Fault zone outside the Okataina Volcanic Centre is generally not triggered by eruptions and that this fault is principally tectonic in origin.

# IT'S OUR FAULT: GEOLOGICAL AND GEOTECHNICAL CHARACTERISATION OF THE WELLINGTON CENTRAL COMMERCIAL AREA

**S. Semmens[1], N. Perrin[2] & P Barker[2]**
[1]MSc Student, Dept. of Geology, University of Canterbury, PB 4800, Christchurch
[2]GNS Science, PO Box 30368, Lower Hutt
sbs25@student.canterbury.ac.nz

The city of Wellington has a high population density and lies within a geologically active landscape at the southern end of the North Island, New Zealand. Wellington has a high seismic risk due to its close proximity of several major fault systems, including the Hikurangi Subduction Zone, Wairarapa and Ohariu Faults with the Wellington Fault crossing the north-western central city. Varying soil depths in combination with the close proximity of active faults mean that in a rupture event strong earthquake shaking is expected with the potential for liquefaction to occur particularly in areas reclaimed with hydraulic fill.

The study focuses on the area from Thorndon overbridge in the north, through to Wellington Hospital in the south, from Kelburn in the west, to Oriental Bay in the east, and includes many of the major buildings and infrastructural elements located within the central Wellington commercial area.

Borelogs from 1025 holes with accompanying geological and geotechnical data obtained from GNS, Tonkin & Taylor and Wellington City Council were compiled for this study along with the results from "SPAC" microtremor testing at 12 sites undertaken specifically for this study.

The aims of this project were: to create an electronic database which allows for convenient access to all available data within the study area, to create a 3D geological model based upon this data, and to define areas of different seismic subsoil class and depth to rock within the study area at a scale that is useful for site-specific analysis (1:5,000).

This presentation will give a brief introduction to NZS1170.5 site classification. Key geotechnical terms including standard penetration testing (SPT), shear wave velocity and site period will be defined as necessary and their significance to this study outlined. Database construction, access and applications will be discussed. A 3D geological model of the central Wellington commercial area based on the compiled geological and geotechnical data created using Earth Research will be presented along with accompanying surficial, depth to bedrock and site class (NZS1170.5) maps.

# P-WAVE TRAVEL TIME RESIDUALS ACROSS THE WESTERN NORTH ISLAND: IMPLICATIONS FOR VARIATIONS IN THICKNESS OF THE MANTLE LITHOSPHERE

**Anya Seward, Sonja Greve, Tim Stern & Martha Savage**
Institute of Geophysics, SGEES, Victoria University of Wellington (VUW)
anya.seward@gmail.com

This study uses P-wave residuals from temporary and permanent seismic stations to infer variations in the lithospheric structure beneath the western North Island, New Zealand. We have retrieved datasets from previous temporary deployments and looked at the P-wave arrival times of teleseismic events with origins located in the western Pacific.

We use a total of 20 seismic stations from temporary (VUW) arrays and 6 National Network Seismometers, extending from D'Urville Island (DUWZ), Marlborough Sounds in the south to just north of Hamilton (TOZ) in the north. Teleseismic events from westerly back azimuth relative to the strike of the subducting Pacific slab (210° - 30°) were used. 30 s seismic records were cut, starting 10 s before the expected P-arrival (calculated from AK135). The waveforms were then cross-correlated and relative delay times calculated. Delay times were corrected for local known crustal features, such as the sediment infill of the Wanganui Basin, and the observed step in the crustal thickness over the Taranaki-Ruapehu Line (TRL). Residuals are as high as 2 s relative to the arrival of P-waves at station TOZ. A distinct increase in early arrivals at the southern stations is seen across the TRL. A ~200km difference in the thickness of the mantle lid is one way to account for the P-wave delay of 2s. We cannot however, rule-out some contamination of the data by slab-guided P-wave phases.

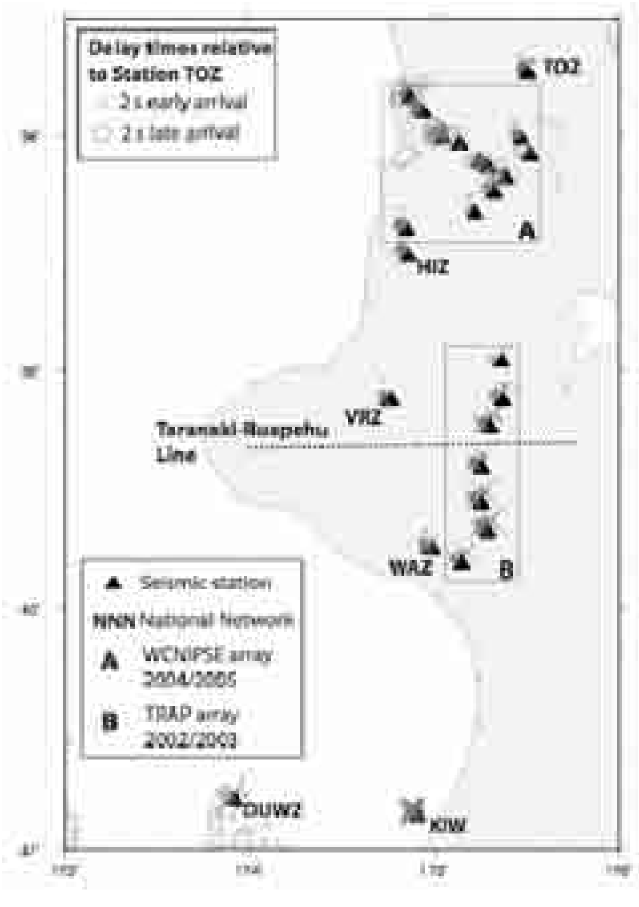



Figure: Travel-time residuals for the western North Island. All residuals are calculated relative to station TOZ. Crosses indicate early arrival, while circles indicate late arrivals. Size is proportional to the measured delay time. Symbols are plotted in the direction of the back-azimuth of the event relative to the station. Temporary arrays are indicated by Boxes A (WCNIPSE) and B (TRAP), while stations belonging to the national networks are names

# IMPACTS OF RICK SIBSON ON FAULT MECHANICS

**Toshihiko Shimamoto**
Department of Earth and Planetary Systems Science, Graduate School of Science
Hiroshima University, Higashi-Hiroshima, 739-8526 Japan
shima007@hiroshima-u.ac.jp

Rick Sibson's series of innovative papers have had tremendous impacts on wide variety of studies on faults, earthquakes and fluid flow. Reviewing all of his work is beyond my ability and I will focus on his three early contributions on (1) pseudotachylites (Sibson, 1975, *J. R. Astron. Soc.*), (2) thermal pressurization (Sibson, 1973, *Nature*) and (3) fault model and fault rocks (Sibson, 1977, *J. geol. Soc. London*). I have worked on all of them through experimental approaches. I feel as if I have spent my career trying to quantify the concepts proposed by Rick after his deep thoughts and imaginations in fields. I never intended to follow Rick's track. But Rick's contribution is so fundamental and that is my frank impression after looking back my career. I will try to follow how Rick's ideas have evolved through experimental and theoretical studies from my own perspectives.

Pseudotachylite was known long before Rick's paper, but I think that Rick for the first time tried to use this rock to infer intrafault processes during earthquakes and that his work tied fault and earthquake studies. J. Spray reproduced frictional melting processes in laboratory in late 1980's and my first high-velocity friction apparatus made it possible to conduct frictional melting experiments while measuring mechanical properties of faults in early 1990's. It had taken us about 10 years before Hirose & I (2005, *JGR*) proposed that frictional melting can be solved as a Stefan problem (a moving boundary-value problem). Several groups indeed solved frictional melting problem and Nielsen *et al.* (2008, *JGR*) report most complete theory with nearly perfect agreement with experimental results. About 30 years have passed since Rick's paper. Those recent studies demonstrated marked slip-weakening of faults consistent with seismically-determined source parameters and with the stress change during frictional melting that Rick inferred from natural pseudotachylite in his 1975 paper (amazing!).

Thermal pressurization, I think, was proposed on a philosophical basis trying to explain why pseudotachylite is not so common along major faults. Lachenbruch (1980, *JGR*) and others worked out theories for this process. I decided to work on this problem by measuring transport properties of natural fault zones and to apply theories to evaluate the process. Wibberley & I (2005, *Nature*), Rice (2006, *JGR*) and others have shown that thermal pressurization process based on measured properties could yield source parameters such as slip-weakening distance and fracture energy on the same order as those determined seismically. In the last few years we have been struggling with complex interactions between thermal pressurization and high-velocity gouge behaviour. Rick's fault model combined with MIT brittle-plastic strength profile has provided a simple basis for plate structures and seismicity. Shearing experiments on dry halite (my group) and on wet halite-phyllosilicate mixtures (C. Spiers' group) lead to some modifications to the original model. Slow slip and low-frequency earthquakes in subduction zones will be active topics to be examined with renewed fault models.

# COUPLED VMS/LODE-GOLD MINERALIZING SCENARIOS ASSOCIATED WITH INTRA-ARC COMPRESSIONAL INVERSION IN NE HONSHU, JAPAN

**R.H. Sibson**
Department of Geology, University of Otago, PO Box 56, Dunedin 9054, New Zealand
rick.sibson@otago.ac.nz

NE Honshu, Japan, is a magmatic arc under arc-normal compression with near-orthogonal convergence (c. 90 mm/yr) occurring across the PAC-NAM plate boundary. The volcanic front together with the flanking forearc and backarc regions are currently undergoing shortening and compressional inversion following Early- to Mid-Miocene extensional rifting associated with the opening of the Japan Sea. At present, reverse fault rupturing occurs predominantly on steep (dip > 45°), arc-parallel faults inherited from the former extensional phase, with the volcanic front hosted within the Ou Backbone Range, itself a 'pop-up' structure bounded by active reverse faults. Actively growing regional antiforms also parallel the volcanic arc. Depending on heat flow, which reaches a maximum around the volcanic front, the depth of the crustal seismogenic zone is generally between 10 and 20 km. This compressional setting with steep inherited faults provides optimal conditions for the containment of fluid overpressure. In fact, geophysical indicators suggest that the lower seismogenic zone and mid-crust are heterogeneously overpressured to near-lithostatic values by hydrothermal fluids, derived in varying proportions from ongoing magmatism, metamorphism associated with crustal thickening, and dewatering of the underlying subducting slab.

Kuroko VMS mineralisation developed near the seafloor in association with minor felsic intrusives within thick pyroclastic sequences infilling extensional basins towards the end of the back-arc rifting phase in the Mid-Miocene (c. 13-15 Ma). The deposits are now exposed through uplift and erosion of the basins as a consequence of the ongoing compressional inversion. Active reverse faulting in the present overpressured arc is likely associated with episodic fault-valve discharges in the lower seismogenic zone, creating a mineralising environment analogous to that inferred for ancient mesozonal (orogenic) lode-gold systems. Continuation of shortening by reverse faulting across the arc, leading to crustal thickening, uplift and erosion, will eventually expose fault rock assemblages and associated hydrothermal mineralisation from the lower part of the crustal seismogenic zone in close proximity to the Kuroko deposits. The juxtaposition of the arc-parallel reverse faults hypothesized to be undergoing fault-valve activity (perhaps yielding lode gold mineralisation) with the belt of high-level Kuroko VMS deposits matches paleoassemblages in the Archean Abitibi belt, and the Cretaceous Mother Lode belt of California.

The evolving magmatic arc in Honshu emphasizes the role of compressional inversion tectonics as a mineralising environment favouring the formation of hydrothermal deposits of varied kinds, with significant implications for exploration.

## THE NATIONAL PALEONTOLOGICAL COLLECTION – A VIRTUAL TOUR

**J.E. Simes, M.G. Terezow & J. Thomson**
GNS Science Ltd., 1 Fairway Drive, Avalon, Lower Hutt 5010,
M.Terezow@gns.cri.nz

The National Paleontological Collection (NPC) is New Zealand's most extensive collection of type and reference fossil material. The Fleming Centre at GNS Avalon houses the macrofossil collections of the NPC, alongside the two paleontology laboratories, the sedimentology laboratory and the Micropaleontology Research Centre.

With the use of Easypoano's Panoweaver 6.0 and Tourweaver 4.0 software we created a walk-through virtual tour of the Fleming Centre and opened the doors of the GNS macropaleontology collection and laboratories to the public. Using Panoweaver 6.0 we stitched an array of consecutive normal still photographs and created a number of 360-degree panoramas of the Reference Collection room. We then imported the panoramas, along with still photographs of close-up areas and discrete specimens into Tourweaver 4.0. With this software, we were able to link the various panoramas and still images in a specific order to create a virtual tour of the area. Tourweaver 4.0 allows multi-directional linking of images, text, sound and pop-ups to each other. There really appears to be no limit to how many scenes and add-ons one can add to the tour. After linking the scenes and add-ons, we linked each component to a specific location on the Fleming Centre floor map. Hence, one can have full control of the tour and go directly to a set location.

This, and other virtual tours we plan to create, will be published through the web and used as outreach tools. We aim to give the public a front-seat view of the work we do at GNS, and also to introduce them to places that may otherwise be restricted, such as glaciers, Antarctica and other remote localities. The possibilities of Tourweaver 4.0 as an education tool are endless. We also hope to incorporate our 3D scanning capabilities into some of our tours, in order to enhance the visual experience.

# A STRANGE OCCURRENCE OF PYRITE-COATED GRANITIC COBBLES AT LEE BAY ON STEWART ISLAND

**D.N.B. Skinner[1], R.L. Brathwaite[1] & E. Edwards[2]**
[1]GNS Science, PO Box 30-368, Lower Hutt 5040
[2]10A Hartland Avenue, Glendowie, Auckland
d.skinner@gns.cri.nz

On the 8th November 2007, a ventifact-shaped cobble of granite with a brassy sulfide coating was found by Ernest Edwards just below high tide mark at Lee Bay, NE Stewart Island. In November 2008, six more similar cobbles were found. A cobble collected at Lee Bay by R.J. Beck in 1959 was identified as pyrite coating fine-grained aplitic granite (Watters 1967). A pyrite-coated boulder of amphibolite from Bungaree Beach, 9 km NW of Lee Bay, was recorded by Watters (1967). The pyrite-coated cobbles collected by Edwards consist of quartzo-feldspathic grey granite and finer grained quartz-feldspar granite. The feldspar is predominantly perthitic K-feldspar, with subordinate microcline and lesser oligoclase (c.$An_{27)}$. Minor interstitial biotite is locally altered to pyrite, and there is accessory magnetite. A possible source of the granite cobbles is the minor granitic rocks of the Bungaree Intrusives such as the dike between Lee Bay and Little River described by Watters (1978).

The pyrite skin (c. 1 (±) mm thick) completely covers the granite cobble and has locally penetrated up to 2 mm into the outer edge of the granite. It is zoned, with an inner zone (0.1-0.3 mm thick) of fine grained, colloform pyrite consisting of alternating subparallel darker and lighter bands that mantle the surface of the granite, and an outer framboidal zone that contains aggregates of micron-sized crystals forming the typical raspberry-like texture of framboids. Sub-rounded grains (0.1-0.4 mm) of hematite, ilmenite with hematite blebs, magnetite, feldspar, biotite (with rutile needles), quartz, feldspar and zircon are present in the outer framboidal zone, some ilmenite and hematite grains being partially replaced by pyrite.

The assemblage of ilmenite-hematite-magnetite-biotite-zircon within the framboidal zone is similar both in mineralogy and size range, to that found in heavy mineral beach sands. Framboidal pyrite is typically formed in anoxic sedimentary environments. Thus the presence of granitic ventifacts coated with pyrite and heavy mineral beach sand, suggests a dune or beach environment, with peat swamps in which sedimentary framboidal pyrite formed.

Turnbull IM, Allibone AH (compilers) 2001. Geology of the Murihiku Area. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 20. 1 sheet and 74 p. Lower Hutt, New Zealand. Institute of Geological & Nuclear Sciences Ltd.
Watters WA, 1967.GNS Science TECHFILE, Record No. E48/572 (Stewart Island).
Watters WA, 1978. Diorite and associated intrusive and metamorphic rocks between Port William and Paterson Inlet, Stewart Island, and on Ruapuke Island. New Zealand Journal of Geology and Geophysics 21: 423-442.

## DEVORA: YEAR 1 OF DETERMINING VOLCANIC RISK IN AUCKLAND

**E. Smid**[1], **J.M. Lindsay**[1,2] **& G. Jolly**[3]
[1]IESE, University of Auckland, Private Bag 92019, Auckland
[2]School of Environment, University of Auckland, Private Bag 92019, Auckland
[3]GNS Science, Wairakei Research Centre, Private Bag 2200, Taupo
e.smid@auckland.ac.nz

As a growing major metropolis, Auckland is a vital link in New Zealand's economy. However, it is built on the potentially active Auckland Volcanic Field (AVF) and is also at risk from ash fall from other North Island volcanoes. An integrated, multi-disciplinary, multi-agency research programme co-funded by the EQC, ARC, UoA and FRST aims to complete a much-improved assessment of volcanic hazard in the Auckland metropolitan area with the ultimate goal of **DE**termining **VO**lcanic **R**isk in **A**uckland (DEVORA). After successfully launching the project, the key objective of the first full year (2008-2009) of this 7 year research programme was to complete 4 synthesis reports, combining the available literature on the petrological, structural, geochronological, and risk and social aspects of the AVF. Using these reports, researchers started to systematically address information gaps in the three main research themes: geological, probabilistic hazard, and risk.

The Geological theme aims to integrate structural, petrological, and geophysical data into a geological model of the AVF to explain source-to-surface magma migration and dynamics. During DEVORA's first year, new samples from centres with little or no geochemical or isotopic data were collected and analyzed, allowing the creation of the first ever baseline geochemical database for the AVF. Maps of the AVF and analogue fields were constructed using data collected from the field and the literature in order to identify any volcanic patterns controlled by structural features and to create a template of basaltic monogenetic volcanism.

The Probabilistic Volcanic Hazard theme focuses on creating a realistic volcanic hazard outlook for Auckland, using dating and tephrochronology techniques to assess magnitude-frequency patterns in both AVF eruptions and distal ash fall impacting Auckland. A major accomplishment of the first year of DEVORA was collating and assessing the robustness of all existing age determinations from the AVF, including 19 new ages collected by DEVORA researchers. Macrotephrochronology analysis of over 200 samples collected from the newly-drilled twin cores from Pukaki maar was completed with the hopes of matching source volcanoes to tephra, and cryptotephra analysis began during this year with the goal of identifying previously undocumented eruptions.

In the Risk and Social theme, information presented in themes 1 and 2 will be used to describe how an AVF eruption would affect Auckland and the rest of New Zealand economically and socially, and to develop a quantitative risk assessment and emergency management risk reduction framework for Auckland's vulnerable groups and structures. Work commencing in this theme in the next year will be based upon the suggestions outlined in the risk and social synthesis report produced in Year 1.

**PROVENANCE OF QUARTZ-RICH SANDSTONES IN THE CENOZOIC BASINS OF WESTERN SOUTHLAND**

**Matthew Smillie and J. Michael Palin**
Department of Geology, University of Otago, PO Box 56, Dunedin
smima003@student.otago.ac.nz

Western Southland comprises a mosaic of basement tectonostratigraphic terranes overlain by a number of Cenozoic basins (Te Anau, Waiau, Solander, Waitutu. and Balleny). These basins are filled with fluvial to deep marine sediments of Eocene through Pliocene age that provide records of the exhumation of Fiordland and adjacent crustal blocks, paleo-oceanographic changes accompanying opening of the Tasman Gateway, as well as attractive targets for ongoing hydrocarbon exploration. The basins are structurally complex, reflecting both syn- and post-depositional deformation.

A provenance study of sandstones in the onshore Te Anau and Waiau basins is being undertaken with a particular emphasis on titanium-in-quartz thermometry. Titanium (Ti) substitution for silicon in quartz is directly proportional to temperature (Wark & Watson, 2006, CMP) so the temperature of crystallisation of quartz in igneous and metamorphic rocks can be estimated. Although the amounts of Ti dissolved in quartz are minute (parts per million), accurate measurements can be made by laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS). Equilibrium between quartz and rutile is a requirement for application of the Ti-in-quartz geothermometer, but corrections to the temperature can be made provided quartz crystallised with titanite or ilmenite, criteria that are met by most igneous and metamorphic rocks.

Twelve samples of the Point Burn Formation from the western margin of the southern Te Anau (Borland) Basin have been examined. Fine- to medium-grained quartz was separated, mounted in epoxy, polished and analysed by SEM-cathodoluminescence (SEM-CL) and LA-ICP-MS. SEM-CL images reveal the grains are internally uniform with no resolvable zonation. LA-ICP-MS results (n=73) show a narrow range of Ti concentrations that do not vary within individual grains or with stratigraphic position, indicating a single homogeneous source. Ti-in-quartz temperatures calculated for *a* (TiO2) = 0.6 ± 0.2 average 580°C (range 530-640°C). These are lower than anticipated for the immediately underlying Borland granite, but consistent with temperatures of retrograde equilibration in gneissic basement in the adjacent Hunter Mountains (Scott et al., 2009, Tectonics).

Future work using this approach will examine samples of correlative units from across the Te Anau and Waiau basins as well as stratigraphically older and younger sandstone units with the aim of better constraining the exhumation history of Fiordland.

**BIOMINERALISATION IN AN URBAN ENVIRONMENT: A CARBONATE BUDGET FOR OTAGO HARBOUR**

**A.M. Smith[1], A.C.L. Wood[1], M.F.A. Liddy[1], A. Shears[1] & C.I. Fraser[2]**
[1]Department of Marine Science, University of Otago, PO Box 56, Dunedin
[2]Department of Zoology, University of Otago, PO Box 56, Dunedin
abby.smith@otago.ac.nz

Otago Harbour is a long (23 km) narrow (<5 km) shallow (mean water depth = 4.5 m) tidal inlet covering 4600 ha on the southeast coast of South Island, New Zealand (45°50'S, 170°35' E). Development of the City of Dunedin (pop. 125,000) and its associated port at Port Chalmers has been associated with extensive dredging, land reclamation, and shoreline construction. Here we develop a carbonate sediment budget for Otago Harbour, with limits defined at Mean High Water Spring and the harbour entrance; from the water-air interface to a few cm below the sediment-water interface.

Carbonate is added to this system primarily by *in-situ* precipitation (about 10,000 tonnes $CaCO_3$/y) and by transport though the harbour entrance from the longshore system (13,000 tonnes $CaCO_3$/y). Shellfishing (2 tonnes $CaCO_3$/y), dredging (18,000 tonnes $CaCO_3$/y), and early sea-floor processes such as abrasion and dissolution (3450 tonnes $CaCO_3$/y) remove carbonate from the system. The present-day carbonate budget results in 1548 tonnes $CaCO_3$/y sediment storage, equivalent to 0.02 mm/y accumulation. 2000 years ago, the budget would have had nearly the same inputs but many fewer outputs, resulting in storage ten times what it is today; increasing human impacts into the future suggest that storage may end in the next century (Table 1).

Carbonate storage in sediments has a role in preserving environmental information and sequestering carbon, but the major value of a budget model is in clarifying important impacts. Otago Harbour is not in a 'natural' state, and increasing human activity, both locally and globally, is affecting its overall health.

Table 1: Carbonate budget for Otago Harbour (tonnes $CaCO_3$/y)

| | **Present (2010 AD)** | **Past (10 AD)** | **Future (2110 AD)** |
|---|---:|---:|---:|
| **INPUT** | | | |
| *In situ* production | 10,000 | 11,000 | 9,000 |
| Net sediment transport | 13,000 | 10,400 | 13,000 |
| **Total Input** | **23,000** | **21,400** | **22,000** |
| **OUTPUT** | | | |
| Dredging | 18,000 | 0 | 19,800 |
| Shellfishing | 2 | 0 | 4 |
| Abrasion/Bioerosion | 2300 | 2140 | 2200 |
| Dissolution | 1150 | 214 | 3300 |
| **Total Output** | **21,452** | **2354** | **25,304** |
| **Balance Storage** | **1,548** | **19,046** | **0** |
| Accumulation rate (mm/y) | **0.02** | **0.25** | **0** |

# QUANTIFYING VESICULARITY ON SEMI-CONSOLIDATED AND ALTERED PALEOGENE SURTEYAN DEPOSITS CHATHAM ISLANDS. NEW ZEALAND

**Leonor Sorrentino, Raymond Cas and Jeffrey Stilwell.**
School of Geosciences, Monash University, Melbourne, Australia.
Leonor.sorrentino@sci.monash.edu.au

The Chatham Islands are located approximately 860 km east of the South Island, New Zealand, and are situated on the eastern boundary of the partially submerged continental plateau, the Chatham Rise. The group of islands comprises two main islands, Chatham (approximately 57km wide and 49km long) and Pitt (approximately 10km wide and 22km long), surrounded by a cluster of islets.

The Red Bluff Tuff Formation preserves the remains of small, monogenetic Surtseyan continental shelf volcanoes of Late Palaeocene- Early Eocene age, distributed on both Chatham and Pitt islands. The primary volcanic successions consist of poorly to moderate-sorted, well-bedded to cross-bedded, angular and vesicular coarse ash to lapilli size units, interpreted as resulting from the eruptive aggradational-cone-building phase.

Each individual primary volcanic facies exhibits a variable degree of vesicularity. Several methods can be used to estimate vesicularity in a pyroclastic deposit, such as field based observation or more accurate point counting or comparison of solid and bulk clast density (via Archimedes principle). However, as these ancient Surtseyan deposits are semi-consolidated, highly altered and some of the vesicles are filled with carbonatic cement; none of the above mentioned methodologies can be applied. Consequently, in order to quantify the minimum vesicularities, as well as vesicle sizes and shapes, thin sections were created of individual juvenile clasts for image analysis. Thin section microphotographs were processed using Adobe Illustrator and the shareware software package, Image J. Clasts selected from primary volcanic facies range from a minimum of 4% to a maximum of 44% vesicularity, with an average of 20.6%. This corresponds to very poor to moderate degrees of vesiculation. Additionally, the vesicles are predominantly the same size within any one sample and reveal an equant, spherical shape (circularity ~0.89) with diameters between 28μm and 95μm, reflecting complex variations in the relative timing of vesiculation and water-induced fragmentation.

# A SUBTROPICAL BIOTA FROM A LATE OLIGOCENE ROCKY SHORE, WAIMUMU, SOUTHLAND

**Jenny Stein, Daphne Lee, Andrew Grebneff, Jon Lindqvist**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
steje245@student.otago.ac.nz

A new fossil locality near Waimumu has yielded an array of exceptionally well preserved fossils from the Chatton Formation. Specimens are remarkable for large size, abundance, diversity (including several new species) and preservation of nacreous shell and colour patterns.

Approximately 20 different species of bivalve have been identified including *Glycymeris*, *Megacardita ponderosa, Divalucina huttoniana, Goniomyrtea*, very large *Maoricardium* and a number of pectinids. Over 50 gastropods are represented including species of *Sigapatella, Magnatica, Polinicies, Taniella, Amalda, Austrofusus,* and two genera of pelagic pteropods, *Limacina* and *Clio.* Specimens of ?*Maoricolpus* reach 15cm in length. Two gastropods, *Melanopsis* and possible *Potamopyrgus* are fresh water to estuarine taxa. Numerous other taxa are indicative of shallow water and rocky shore environments including various trochids, the intertidal rock dweller *Bembicium*, several genera of algal grazers (including large *Sarmaturbo*), the spongivore *Calliostoma*,and the holothurian parasite *Melanella*. Two types of opercula are present. Other significant discoveries are representatives of two families of chiton including a new species of the under-boulder dweller *Ischnochiton*, an eelgrass inhabiting lottiid, and at least three other genera of true limpets including a species of *Asteracmea* with refractive blue lines still visible.

Other taxa include the brachiopod *Notosaria antipoda*, a barnacle, at least three genera of scaphopods, large benthic foraminifera, bryozoans (including *Selenaria*), echinoderms (including *Fibularia*), three genera of solitary corals and the first hermatypic coral to be recovered from the Chatton Formation. *Teredo*-bored wood is abundant, as well as locally derived lithic boulders forming a poorly sorted, semi-concretionary boulder lag of angular to rounded clasts derived from Murihiku basement. One boulder has an oyster in life position.

The fauna recovered from the new locality is consistent with a Duntroonian age. The abundance of large, warm, shallow water species provides further evidence of subtropical climate in southern New Zealand at this time. Shallow water marine and estuarine species, boulder lags and the abundance of fossilised wood indicate proximity to a shoreline at the time of deposition. This rocky shore biota is further evidence for the existence of land in southern New Zealand in Late Oligocene times.

# EVIDENCE OF MULTIPLE SCORIA CONES AND CONE COLLAPSE AT POUERUA VOLCANO, NORTHLAND VOLCANIC FIELD, NEW ZEALAND

**R.B. Stewart** & **K. Nemeth**
Volcanic Risk Solutions, INR, Massey University, Palmerston North, New Zealand.
r.b.stewart@massey.ac.nz

Pouerua volcano, in the Plio-Quaternary Northland monogenetic intraplate volcanic field, has an outwardly simple classic cone shape but is complex in detail. A semicircular array of intact older cone flank remnants, grading out to a region of hummocky topography, defines the SE side of the volcano. This remnant field forms a well-defined plateau-like feature that lies 120-140 m asl and comprises a 1000 m wide central zone hosting a younger scoria cone on its northern edge that reaches 260 m asl. The circular central area comprises a smooth-surfaced lava field initiated from 120-140 m asl on the edifice and traceable NE to 90 m asl over a distance of 1300 m. The young scoria cone has a breached southern margin which was partially healed during the final stages of eruptive activity.

The SE edge of the older cone is broad, U-shaped and scalloped. A south-easterly collapse created a 250 m wide gap and the deposit expanded to over 1000 m wide at about 1000 m from its initiation point. The topography is subdued by fine ash and lapilli cover beds and littered with scoria and bombs. A flank remnant of the older cone consists of red, oxidized scoria lapilli interbedded with occasional agglomeratic units containing thin, clastigenic lava, typical of Stombolian eruption. A lava field flanks the SE edge of the hummocky surfaced region. Hummocks are tens of metres across, and 5-15 m high, occurring from 160 m down to about 105 m asl over a 1300 m distance. Although the topography is similar to that of sector-rafted scoria cones, the architecture of the hummock field is more consistent with formation as a debris-avalanche, generated by collapse of the older Pouerua cone due to gravitational instability of its growing southern side. Rafting of the cone is also unlikely to be the major cause of collapse as lava flowed to the S and NE rather than to the SE.

The youngest cone has a 150 m wide breach to the south from which aa lava with clastogenic flow remnants and rafted scoria cone walls emanated. These deposits are younger than the smoothed cone remnants in the south, and also the debris-avalanche deposit, as their surface is irregular with little cover material.

On the basis of the 3D architecture of the cone complex, a potentially long-lasting eruption history can be interpreted for Pouerua. An early scoria cone formed by purely volatile-driven Strombolian eruption with a high eruption cloud, creating an approximately 1000 m wide and 90 m high edifice that was slightly asymmetric toward the south. Gravitational instability caused the cone to collapse to the SE, forming a debris-avalanche deposit and the current breached cone was formed by later eruptive activity.

**EXHUMATION HISTORY OF FIORDLAND, SOUTHWEST NEW ZEALAND, DURING SUBDUCTION INITIATION, WITH IMPLICATIONS FOR THERMOCHRONOLOGIC ANALYSIS STRATEGIES**

**Rupert Sutherland[1], M. Gurnis[2], P.J.J. Kamp[3], & M.A. House[4]**
[1]GNS Science, PO Box 30368, Lower Hutt, NZ
[2]California Institute of Technology, Pasadena, California 91125, USA
[3]Department of Earth Sciences, University of Waikato, Hamilton, NZ
[4]Pasadena City College, Pasadena, California 91106, USA
r.sutherland@gns.cri.nz

We analyse spatial trends and statistical properties of 410 apatite and zircon fission-track and (U-Th)/He ages, and implement a weighted-least-squares regression scheme to obtain the regional rock-uplift history associated with subduction initiation beneath Fiordland, New Zealand. We observe the onset of rapid exhumation at 25-15 Ma in southwest Fiordland, immediately following a time of significant change in regional plate motions. During the period 15-5 Ma, the locus of rapid exhumation broadened and migrated towards the northeast at approximately 30% of the plate motion rate, but exhumation remained localised along the northwest margin. Since 5 Ma, the zone of rapid exhumation has become broader, and the present high-amplitude gravity and topographic anomalies are spatially associated with the most tightly folded part of the subducted slab. We suggest that the pattern of exhumation tracks the along-strike and down-dip development of the subducted slab, which requires tectonic erosion of mantle lithosphere of the over-riding plate. Based upon local patterns of age variability, we hypothesize that brittle faults have displaced and rotated equal-cooling-age surfaces, and that there is short-wavelength (<10 km) spatial correlation between faults and topographic features. Our regression method allows us to simultaneously consider implications of all age data, evaluate 'geological noise' introduced by brittle faults, and make cooling age predictions at any point in the region. The residuals from our regression indicate that, on average, mountain tops in Fiordland have experienced slightly greater rock uplift than adjacent valleys, even though our data are too sparse to identify specific faults. We suggest that sampling programmes in active tectonic settings such as Fiordland must be sufficiently dense to determine both mean exhumation history and regional geological variability associated with faults.

## SEISMIC ATTENUATION ANISOTROPY IN THE SOUTHERN PART OF TAUPO VOLCANIC ZONE

**Syuhada, M.K. Savage & J. Townend**
Institute of Geophysics, SGEES, Victoria Univ. of Wellington, Wellington
syuhad@myvuw.ac.nz

We investigate the mechanisms of seismic anisotropy and attenuation beneath the southern part of the Taupo Volcanic Zone (TVZ) by computing variations in the S-wave attenuation factor with the direction of wave propagation (north, east, radial and transverse components). The quality factor Q of $S_{NS}$, $S_{EW}$, *SV* and *SH* waves are estimated by means of the non-parametric generalized inversion technique (GIT) of Castro et al., (1990) using earthquakes recorded by GeoNet within 100 km of Mt. Ruapehu. To analyze the effects of attenuation properties with source locations, we divide our dataset into two groups: one containing earthquakes within the TVZ and the other containing earthquakes outside the TVZ. For events outside the TVZ, we use shallow (> 30 km) earthquakes for the analysis. However, inside the TVZ the signal-to-noise ratio is poor for shallow events, and we use deeper earthquakes occurring within 150 km of the southern end of the TVZ to retrieve enough events for the inversion.

To measure Q, we first compute the spectral amplitude decay with distance in terms of empirical functions for 30 frequencies in the frequency bands 2—15 Hz and 2—20 Hz for the “TVZ” and “non-TVZ” datasets respectively. The frequency dependence of Q is calculated as $Q_{NS}=71.1f^{(1.0)}$, $Q_{EW}=26.2f^{(1.2)}$, $Q_{SV}=96.6f^{(0.8)}$ and $Q_{SH}=25.9f^{(1.3)}$ for the TVZ data and $Q_{NS}=68.9f^{(0.3)}$, $Q_{EW}=41.3f^{(0.5)}$, $Q_{SV}=138.4f^{(0.1)}$ and $Q_{SH}=39.5f^{(0.6)}$ for the non-TVZ.

$Q_{NS}$ and $Q_{SV}$ are significantly higher than $Q_{EW}$ and $Q_{SH}$ respectively, indicating that the shear wave attenuation is highly anisotropic in this region. Our results also suggest the presence of vertical fluid-filled cracks, striking north-south. In general, the inferred attenuation anisotropy beneath Mt. Ruapehu is consistent with the results of an ongoing shear wave splitting study (Johnson et al., this volume). Furthermore, the low values of Q obtained for the TVZ data suggest the presence of hot or partially molten material beneath the southern part of TVZ, as inferred from other attenuation studies of this region (e.g. Styles, 2009).

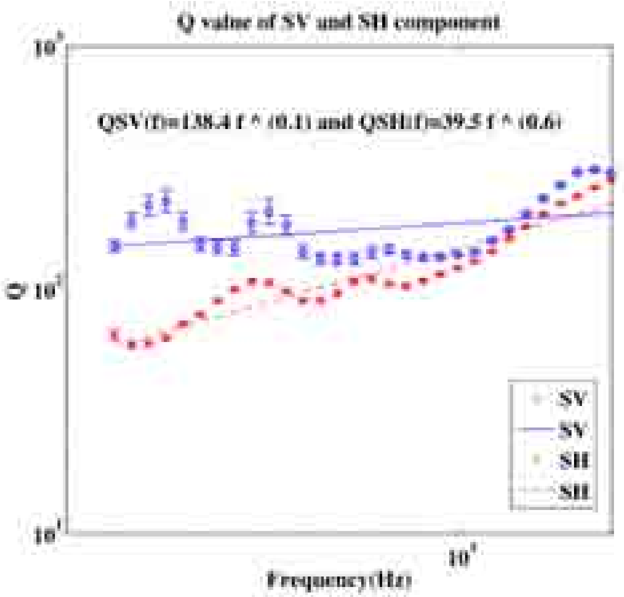



Figure 1. The Q model of the non-TVZ dataset

# THE MIOCENE ST BATHANS FAUNA: AN UPDATE

**A.J.D. Tennyson[1], T.H. Worthy[2], R.P. Scofield[3] & S.J. Hand[2]**
[1]Museum of New Zealand Te Papa Tongarewa, P.O. Box 467, Wellington
[2]University of New South Wales, Sydney, Australia
[3]Canterbury Museum, Rolleston Ave, Christchurch 8001
alant@tepapa.govt.nz

Several thousand bones have been recovered from Early Miocene (19-16 Ma) lacustrine sites near St Bathans, Otago. This has provided the only insight into the terrestrial vertebrate fauna of Zealandia for the whole Tertiary.

At least 32 bird taxa are now known, with the waterfowl fauna including six ducks and two geese. Other birds include moa, a diving petrel, a flamingo-relative (*Palaelodus* species), two accipitrids (including an eagle), a heron, a large gruid, two rails, a gull, two wading birds, three pigeons, three parrots, an owlet-nightjar, a swiftlet and four passerines (including a NZ wren and a cracticid).

Amphibians and reptiles found include three frogs (including two leiopelmatids), a crocodylian, a sphenodontine, two geckos and two skinks. Mammals include four species of bat (including a mystacinid) and an enigmatic terrestrial mammal dubbed the "waddling mouse".

In addition to these vertebrates and several species of fish, a diverse range of molluscs and a freshwater crayfish are present.

The St Bathans Fauna reveals that in the Early Miocene, Zealandia had a vertebrate fauna that in many ways was similar to the present one. The iconic endemic NZ families - moa, NZ wrens, leiopelmatid frogs, sphenodontines and mystacinid bats - were all present. The major faunal change since then has been the extinction of several major groups – two bird families, a frog, a crocodylian and at least one bat family.

## A COMPILATION OF THE DETAILED MAP OF ATMOSPHERIC CORRECTION TO OBSERVED GRAVITY (CASE STUDY FOR NEW ZEALAND)

**R. Tenzer[1], J. Mikuška[2], I. Marušiak[2], R. Pašteka[3], R. Karcol[3], P. Vajda[4]**
[1] School of Surveying, University of Otago, Dunedin, New Zealand
[2] G-trend. s.r.o., Bratislava, Slovakia
[3] Department of Applied and Environmental Geophysics, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia
[4] Geophysical Institute, Slovak Academy of Sciences, Bratislava, Slovak Republic
Robert.Tenzer@surveying.otago.ac.nz

Although the gravitational effect of Earth's atmosphere is relatively small, it is generally recommended to account for it in precision gravimetry. Since the effect is height-dependent, it is especially worth considering when the survey covers a broad range of gravity station heights and where the survey is performed close to coastal regions.

In this study we compile a detailed map of the atmospheric correction to observed gravity for New Zealand using a newly derived formula for the gravitational effect of a spherical shell with variable density. A simple atmospheric radial density distribution is assumed based on the United State Standard Atmosphere 1976 model. Disregarding temporal and lateral atmospheric density variations, the atmospheric density is defined as a function of the nominal atmospheric density at the sea level and the elevation. The 5×5 arc-min global elevation data from the ETOPO5 are used to model the geometry of the lower bound of atmospheric masses in computing the atmospheric correction within the distant zone, while the 30×30 arc-sec detail elevation data from the GLOBE30 are used within the near zone. The global digital elevation models ETOPO5 and GLOBE30 are provided by the NOAA's National Geophysical Data Centre. The computation area is bounded by the parallels of 60 and 25 arc-deg Southern latitude and the meridians of 160 arc-deg Eastern longitude and of 170 arc-deg Western longitude. All data are evaluated on a detailed grid at the Earth's surface.

# EVOLUTION OF THE HUMERAL PLEXUS IN PENGUINS

**D.B. Thomas[1], R.D. Frew[2] & R.E. Fordyce[1]**
[1]Dept. of Geology, University of Otago, PO Box 56, Dunedin
[2]Dept. of Chemistry, University of Otago, PO Box 56, Dunedin
thoda073@student.otago.ac.nz

Hot-blooded penguins (Sphenisciformes) forage in cold oceans, and face the constant risk of hypothermia. The energetic costs incurred through foraging are partially mitigated by a complex set of heat-conserving upper-wing arteries and veins known as the humeral plexus. The humeral plexus provides a counter-current heat exchange system that redirects heat back towards the body core. Such a system is hypothesised to be a major contributor towards the evolutionary fitness of marine homeotherms, and efforts have been made to understand the antiquity of the humeral plexus within the relatively ancient penguin lineage.

Dissections of *Eudyptes sclateri*, *Eudyptula minor* and *Megadyptes antipodes* wings confirmed that the humeral plexus occurs in all living penguins, whereas the absence of a humeral plexus in *Puffinus griseus* and other outgroup taxa suggested that the soft tissue structure evolved after the split between Sphenisciformes and Procellariiformes. The humeral arterial sulcus, an osteological correlate to the humeral plexus, was identified in 15 species from all six modern penguin genera. Two fossil penguin species, *Palaeeudyptes klekowskii* and *Tonniornis mesetaensis* from Seymour Island, Antarctica, are the oldest penguins studied with humeral arterial sulci and indicate that humeral plexi have been part of the penguin lineage since at least the Late Eocene.

Additional evidence for humeral plexi in fossil penguins was sought from the paleophysiological proxy of oxygen isotopes incorporated into bone while the animal lived. Wing temperature profiles calculated from phosphate oxygen isotopes were calibrated using modern species. *Megadyptes antipodes* exhibited a strong cooling profile along the length of the wing, whereas *Puffinus griseus* exhibited thermal constancy between the middle humerus and proximal phalanx of the second digit. Isotopes from *Palaeeudyptes gunnari* demonstrated a cooling pattern similar to *M. antipodes*, providing further evidence that the humeral plexus had evolved by the Late Eocene. The humeral plexus must, therefore, have evolved within the penguin lineage during the warmest times of the Cenozoic, or Late Cretaceous, indicating that heat retention conferred a significant energetic advantage to stem-penguins foraging in waters that were cooler than the core body temperature of ~38.5°C.

# THE MARSHALL PARACONFORMITY IN THE TENGAWAI-1 DRILLCORE, SOUTH CANTERBURY: EROSION AND DEPOSITION ASSOCIATED WITH EARLY DEVELOPMENT OF THE ANTARCTIC CIRCUMPOLAR CURRENT

**K. Tinto[1], G. S. Wilson[1&2], H.E.G. Morgans[3] & R. Dagg[1]**
[1]Geology Department, University of Otago, PO Box 56, Dunedin, NZ
[2] Marine Science Department, University of Otago, PO Box 56, Dunedin, NZ
[3]Institute of Geological and Nuclear Sciences Ltd., PO Box 31312, Lower Hutt, NZ
dagro862@student.otago.ac.nz

The Marshall Paraconformity is a widely recognised hiatus in the Oligocene sequence of New Zealand, commonly overlain by a thin greensand horizon and with a type-section defined in South Canterbury. Its formation has variously been attributed to the ocean currents and sea level fall coincident with mid-Oligocene intensification of the cryosphere.

The Tengawai-1 drillcore was recovered from near Cave in South Canterbury, approximately 30 km from the type section of the unconformity. The core contains a 273 m sedimentary record spanning the *Bortonian* to the *Otaian* and includes a record of the Marshall Paraconformity, which appears as a sharp change in lithology across a burrowed horizon. The underlying unit is a calcareous fine sand which includes a mid-inner shelf, late Eocene fauna. The unconformity is overlain by an 11 m thick greensand containing a shelfal *Duntroonian* fauna, which gives way to a Waitakian glauconitic limestone. Magnetostratigraphy from the core indicates that deposition of the greensand was rapid, as the entire greensand unit is correlated with the 313 kyr Chron C7r (25.496-25.183).

Elsewhere in the basin, the Marshall Paraconformity is commonly underlain by the early Oligocene Amuri Limestone. A small outcrop of this unit is exposed in the Tengawai River, 2.5 km upstream of the TNW-1 drillsite but the unit is not observed in the core. The absence in the core of the Amuri Limestone, combined with the character of the surface observed in a 3.5 km seismic line across the drill site, suggest significant, localised erosion associated with the Marshall Paraconformity. We infer that this resulted from intense inshore currents existing before 25 Ma. Post 25.2 Ma, several metres of reworked glaucony were deposited under a waning current. Resumption of deposition at the TNW-1 site corresponds with a time of low Oligocene $\delta^{18}O$ (around 1.6 Myr after Oi-2b but still 1.8 Myr before Mi-1) and closely precedes the suggested initiation of the full Antarctic Circumpolar Current.

**A GEOMORPHIC HISTORY OF THE LOWER WAITAKI PLAIN, INTERPRETED FROM LOESS AND SOIL STRATIGRAPHY**

**P.J. Tonkin[1], D.J.A. Barrell[2] & T.H. Webb[3]**
[1]16 Rydal Street, Christchurch 8025
[2] GNS Science, Private Bag 1930, Dunedin 9054
[3] Landcare Research, PO Box 40, Lincoln 7640
d.barrell@gns.cri.nz

The Lower Waitaki Plain merges downstream onto a coastal plain that extends both north and south seaward of a Pleistocene interglacial marine cliff. The Waitaki River lies in a terraced valley down the axis of the Lower Waitaki Plain, graded to an actively eroding Holocene coastal cliff. The Lower Waitaki and coastal plain are constructed of alluvial gravel with a brownish, slightly weathered matrix, mapped as Morven Formation and assigned an early Otiran (Marine Oxygen Isotope Stage (OIS) 4) age on regional geologic maps. Within the incised river valley, the highest terraces have been mapped as Waikaura Formation of assumed late Otiran age (OIS 2), with lower terraces mapped as Holocene (OIS 1). We examine this conceptual framework by considering the distributions and characteristics of surficial coverbeds (loess and alluvium) and soil development on the main plains surfaces (‘Morven Surface’).

A distinctive soil with a reddish brown subsurface pan (Steward soil - Cemented Firm Brown) occurs in localized patches on stony central parts of the Morven Surface. Towards the hillslope margins of the plain, extensive fans and sheets of alluvium, as well as loess, mantle the Morven Formation gravels. At Oamaru, a reddish brown pan developed in the top of Morven gravels is similar to the Steward soil pan, and is overlain by coverbeds comprising up to 6m of silty loess and ‘loess’ alluvium, with surface Pukeuri and Landon soils (Laminar and Mottled Pallic). Luminescence dating indicates a mid-Otiran age for the base of the coverbeds. Extending from the margins towards the axis of the plain, fine-textured coverbeds, with shallow Pukeuri and Wakanui (Mottled Immature Pallic) soils, thin progressively and pass outward to areas of grey unconsolidated sandy gravels and some finer alluvium on which Darnley (Argillic Pallic), Lismore (Pallic Firm Brown) and Templeton (Immature Pallic) soils occur. The reddish brown pan commonly underlies these less consolidated deposits, at depths of up to several metres. Darnley, Lismore, Templeton and Wakanui soil profiles are characteristic of late OIS 2 to early OIS 1 alluvial surfaces in the Canterbury region.

Soil patterns and coverbed distributions indicate a geomorphic history comprising (i) deposition of Morven Formation and widespread development of proto-Steward soils; (ii) accumulation of loessial and alluvial coverbeds, encompassing at least one buried soil, on stabilized parts of the Morven Surface; (iii) resumed or continued river activity on parts of the plain well into late Otiran time, with localized burial of the Steward subsoil pan interspersed with extant ‘islands’ of Steward soils that represent exhumed remnants of the older geomorphic surface. Soil and coverbed evidence highlights that the Morven Surface is of composite age, and that development of the incised valley and terraces of the lower Waitaki may be more recent than is implied by simple terrace/age concepts.

# STATES OF STRESS IN THE CRUST AND AT PLATE BOUNDARIES: WHAT DO SMALL AND LARGE FAULTS FEEL?

**J. Townend**
School of Geography, Environment & Earth Sciences, Victoria Univ. of Wellington
john.townend@vuw.ac.nz

The interplay of fluid pressure and tectonic stress, each modulated by repeated cycles of fracturing, fluid flow, and mineralization, has been a constant and influential refrain of Prof. Rick Sibson's research since the mid-1970s. In repeatedly emphasising the significance of geological field observations to understanding seismic rupture, Prof. Sibson has provoked seismologists and structural geologists alike to consider the seismic cycle and faulting processes in common, mechanistic terms rather than as isolated, purely elastic or kinematic phenomena. This presentation reviews evidence pertaining to the stresses acting on active faults of different scales and the related question of how widely applicable the precepts of Andersonian faulting are — at least, given our ability to remotely infer the relevant parameters at depth.

Numerous independent observations imply both that the crust lies in a state of frictional failure equilibrium and that the corresponding stress magnitudes are governed by hydrostatic fluid pressures (pore fluid factors of $\lambda$~0.4) and friction coefficients similar to those observed in laboratory experiments ("Byerlee friction" coefficients of $\mu$~0.6–1.0). These observations include in situ measurements of stress magnitudes and fluid pressures in deep boreholes as well as less direct lines of evidence such as fault plane dips, seismicity induced by reservoir impoundment, and earthquakes triggered by other earthquakes. The different data sets enable a seemingly broadly applicable reference model of crustal stress to be established in which stress magnitudes increase with depth at rates governed by the failure of optimally oriented, cohesionless, Andersonian faults with Byerlee friction coefficients and hydrostatic ambient fluid pressures.

Other observations imply that some large faults — most infamously, the San Andreas, but also the Denali fault, the Marlborough faults, and most if not all shallow subduction thrusts — have distinctly non-Andersonian geometries. Here, the pertinent observations include stress orientations inferred from focal mechanism inversion, direct borehole measurement, and geodynamical calculations; fault geometry (e.g. shallowly-dipping subduction thrusts and low-angle normal detachments); and more contentious factors such as heat flow data and maximum earthquake stress drops. Such findings do not contradict the observations made above for in situ stress magnitudes being controlled by high-friction fractures and generally hydrostatic fluid pressures, since they address the orientations of the principal stresses relative to the fault planes and hence the resolved stresses (tractions). They nevertheless point to some faults operating at levels of shear stress much lower than anticipated on the basis of the Andersonian faulting model.

These observations suggest a difference in the gross mechanical behaviour of small faults pervading the crust and large faults forming plate boundaries. What governs the transition between these end-members (or at what scales such a transition might take place) remains an outstanding question, as is that of how stress and fault *strength* vary temporally in response to earthquakes and other perturbations.

# THE QMAP 1:250 000 GEOLOGICAL MAP OF THE HAWKE'S BAY AREA: NEW FEATURES AND UPDATES

**D.B. Townsend, K.J. Bland, J.M. Lee, G.H. Browne, J.G. Begg, and P.J.J. Kamp**
GNS Science, P.O. Box 30-368, Lower Hutt
d.townsend@gns.cri.nz

The 1:250 000 Hawke's Bay map is the final sheet to be published in the 21 map QMAP series, and provides the link between the surrounding Raukumara, Rotorua, Waikato, Taranaki, and Wellington QMAPs. The map sheet represents a compilation of student theses, published and unpublished maps and reports, aerial photo interpretation, and new fieldwork.

QMAP Hawke's Bay covers a large part of eastern North Island, from Hawke Bay in the east to the central volcanic plateau in the northwest. The main geological features in the Hawke's Bay map area include the Ruapehu and Tongariro volcanic massifs and their associated deposits, the Ruahine-Kaimanawa greywacke axial ranges, the eastern parts of Wanganui Basin, inverted Miocene sedimentary basins in eastern Hawke's Bay, prominent ranges and dip-slopes formed by thick Plio-Pleistocene limestones, active faults in the North Island dextral fault belt, and the Quaternary deposits of the Heretaunga, Ruataniwha, and Takapau plains.

Some new features shown on the map include: a greater extent of the Whakamaru ignimbrite in the Kaimanawa and Ahimanawa range front and within the ranges themselves; detailed mapping of the Plio-Pleistocene Te Aute limestones in northern and western Hawke's Bay; delineation of the Kaweka terrane with the Torlesse composite terrane; revised mapping of the eastern part of the Ruapehu volcanic area; several new faults and revised fault traces.

QMAP Hawke's Bay will be published in late 2010.

**DIVERSE HABITATS OF PSEUDOTACHYLYTE IN THE ALPINE FAULT ZONE AND IMPLICATIONS FOR SEISMICITY DISTRIBUTIONS**

**V.G. Toy, S. Ritchie & R.H. Sibson**
Dept. of Geology, University of Otago, PO Box 56, Dunedin
virginia.toy@otago.ac.nz

Pseudotachylytes, or friction melts produced during coseismic fault slip, are ubiquitous within New Zealand's Alpine Fault Zone. However, they are not volumetrically dominant enough to have formed during all increments of earthquake faulting over the lifetime of the structure. Most pseudotachylyte fault veins are only a few mm thick; a few are up to 1cm thick. Simple energy conversion arguments suggest 1mm thick pseudotachylytes formed during $M_w$ 4-5 events and 1cm thick pseudotachylytes during $M_w$ 6 events. These are smaller than typical large Alpine Fault earthquakes but compatible with smaller events that occur on an annual basis. We infer most pseudotachylytes formed during small events between major fault ruptures, during fore- and aftershock sequences, or on splay faults at the downwards termination of larger fault ruptures.

The pseudotachylytes are found in four main settings; (i) as thin fault veins, mixed with cataclasite, parallel to existing foliation in hangingwall mylonites; (ii) as thicker fault and injection veins around and within metabasite lenses in hangingwall fault rocks; (iii) as chaotic injected masses and rare fault veins within granitoid –protolith, footwall-derived mylonites; (iv) as chaotic injection structures into protocataclasites within the fault core.

It is particularly difficult to prove a melt origin for type (iv) pseudotachylytes due to alteration, but we will present new analyses of clast size and shape distributions that may resolve this difficulty both here, and in other similar situations worldwide. Types (iii) and (iv) pseudotachylytes rarely contain vesicles, suggesting they were generated in the presence of free fluids, requiring high permeabilities of the surrounding rock mass to prevent thermal pressurisation from prohibiting frictional heating.

The largest volumes of pseudotachylyte are found within the granitoid-derived mylonites (type (iii)), perhaps suggesting that high-stress, anhydrous seismic slip is most common in the immediate footwall of the fault. Alternatively, it is possible the starting footwall material is structurally and chemically more likely to form friction melts. Mineral assemblages, structural setting, and microstructures of overprinting veins indicate the pseudotachylytes mostly formed at or near the base of the seismogenic zone. Hangingwall, type (i) pseudotachylytes may even represent propagation of ruptures down-dip into a zone that would usually fail by aseismic creep in the period between larger fault ruptures.

# SEDIMENTOLOGY AND PETROLOGY OF MIOCENE COLD-SEEP CARBONATES IN SOUTHERN HAWKE'S BAY: GEOLOGICAL EVIDENCE FOR PAST SEA-BED HYDROCARBON SEEPAGE

**Melissa J. Troup[1], Cam S. Nelson[1], Steve D. Hood[1] & Kathy A. Campbell[2]**
[1]Department of Earth & Ocean Sciences, Univ. of Waikato, Private Bag 3105, Hamilton
[2]Department of Geology, University Of Auckland, Private Bag 92019, Auckland
mjt38@waikato.ac.nz

Along many modern continental margins there is evidence for the escape of methane rich fluids from the lithosphere to the hydrosphere. This evidence comes in the form of mud volcanoes, seafloor pock marks, and carbonate build-ups. The carbonate build-ups have a variety of morphologies, including irregular mounds of different sizes, slabs or pavements, and chimney structures. The carbonates are collectively referred to as 'methane derived authigenic carbonates' or MDACs. They are a by-product of the anaerobic oxidation of methane, carried out by a consortium of microbes that thrive on or near the sea floor around areas of focused fluid escape. These microbes also support a distinctive chemosynthesis-based community, many of which are fossilised as their remains become enveloped in the precipitating MDAC.

Ancient analogues of these seep systems are being increasingly recognised around the world, dating back to the Devonian. At least 16 paleo-seep carbonate outcrops have been identified in the onshore East Coast Basin. They are hosted within slope mudstone sequences of Early to Late Miocene age. The carbonate deposits contain a variety of fossilised biota, including several bivalve species, corals, worm tubes, gastropods, and burrow structures. The MDAC deposits vary in appearance across the region, as characterised by their fossil assemblages, extensive brecciation, vein networks, and/or multiple phases of carbonate precipitation and neomorphism.

This study focuses for the first time on the five southern Hawke's Bay seep carbonate outcrops of Early Miocene age, located near the town of Porangahau. These ancient MDAC outcrops have been documented, their distribution mapped, and the structure and sedimentology of the local geologic setting investigated. Detailed petrography has been undertaken in order to unravel the complex evolution/paragenesis of the carbonates – a fundamental aim of the study - along with UV microscopy (to identify hydrocarbon inclusions), and X-ray diffraction (to determine mineralogy), stable carbon and oxygen isotopic analysis (to determine source fluids and temperatures), and carbonate percentage analysis. Trace element and lipid analysis remain to be carried out.

The outputs of this study will include a conceptual model of sea bed hydrocarbon seepage in the East Coast Basin, which can then be applied to modern fluid escape along the Hikurangi Margin to add to the current understanding of the East Coast Basin petroleum system.

## AUTOCHTHONOUS INHERITANCE OF ZIRCON IN THE ARTHUR RIVER COMPLEX, FIORDLAND, NEW ZEALAND

**Andy Tulloch[1], Trevor Ireland[2], J. Ramezani[3], Dave Kimbrough[4] & Bill Griffin[5]**
[1]GNS Science, Dunedin Research Centre, Private Bag 1930, Dunedin
[2]Research School of Earth Sciences, ANU, Canberra, Australia
[3]Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, USA
[4]Geological Sciences, San Diego State University, San Diego, USA
[5]GEMOC, Macquarie University, Sydney, Australia
a.tulloch@gns.cri.nz

Interpretation of complex U-Pb zircon age data in high grade metaigneous rocks usually invokes the common suspects of Pb loss and/or inheritance to explain relatively young or old analyses, respectively. However, both models have proven inadequate to explain the zircon U-Pb systematics observed in many rocks of the Arthur River Complex of Fiordland.

ID-TIMS and SHRIMP U-Pb analyses of zircons from a sample of Milford Orthogneiss metadiorite reveal two predominant populations with Th/U ~ 0.6; prismatic zircons with oscillatory zoning (~356 Ma), and ovoid grains with sector or patchy zoning (~134 Ma). This younger age component is not observed overgrowing older grains.

We interpret these data as indicating initial igneous emplacement and crystallisation of a dioritic protolith pluton at ~356 Ma, followed by Early Cretaceous granulite-facies metamorphism at ~134 Ma, during which a significant fraction (~59%) of the zircon grains dissolved, and subsequently recrystallised, effectively in situ, in partial melt pockets. Major loss of radiogenic Pb during solid state replacement is ruled out because sector zoning indicates a growth mechanism. The remaining ~41% of original Paleozoic grains were apparently not in contact with the partial melt, remained intact, and show only slight degrees of Pb loss. This interpretation is supported by the absence of 134 Ma overgrowths on Paleozoic zircon cores, equivalent time-integrated $^{177}Hf/^{176}Hf$ compositions of both age groups, similar average zircon Th/U ratios, and the presence of chemically and isotopically similar Paleozoic plutons in the upper crust to the south.

The alternative explanation, that the Paleozoic component represents a 41% inherited component in an Early Cretaceous transgressive dioritic magma, is considered less likely given the relatively high solubility of zircon in magma of this composition, the absence of 134 Ma overgrowths, the single discrete age of the older component, and the absence of Cambrian-Proterozoic detrital zircon from metasedimentary rocks.

Similar bimodal Carboniferous-Early Cretaceous age distributions are also characteristic of the wider Arthur River Complex; 8 of 12 previously dated dioritic samples have a Paleozoic component (ranging from ~300-365 Ma), averaging 51%. In addition, the specific Paleozoic ages and their chemical suite affinities can be matched with the "plutography" of the relatively unmetamorphosed Carboniferous plutonic terrane in southern Fiordland. This also supports an autochthonous inheritance model, and thus a Paleozoic protolith "age" for much of the Arthur River Complex.

# QMAP FIORDLAND

**I.M. Turnbull[1], A.H. Allibone[2] & R. Jongens[1]**
[1] GNS Science, Private Bag 1930, Dunedin
[2] Rodinian, PO Box 1970, Queanbeyan, NSW2620, Australia
i.turnbull@gns.cri.nz

Following six seasons of field work, the revised 1:250 000 QMAP geological map of Fiordland has been completed and is being readied for printing. The map incorporates data from both University theses and ongoing research. The revised map includes and updates part of the adjacent Wakatipu QMAP sheet in northern Fiordland. Some 950 person-days were spent in the field, 50 of which were written off due to bad weather. The QMAP Fiordland database includes 15000structural measurements. Around 3500 rock samples were collected during field work, of which 350 were analysed by XRF; PETLAB now records more than 6500 samples from the map area.

The new Fiordland map differs from previous versions in showing much more detail in the basement rocks. Paleozoic sedimentary rocks of the Buller and Takaka terranes are recognised in southwest Fiordland. Metasediments with higher metamorphic grade else where Fiordland are inferred, but not confirmed, to be Takaka terrane. These terranes are intruded by the Median Batholith, which is subdivided into at least 10 petrogenetic suites, and more than 100 plutons (Allibone *et al*., Jongens *et al*., this conference). Some suites are correlatives of those on Stewart Island and in Westland and northwest Nelson, but others appear unique to Fiordland. Some 25% of the batholith was emplaced during the Paleozoic, and the remainder during the Triassic and Early Cretaceous. Paleozoic and Mesozoic plutons occur throughout the batholith, although Paleozoic rocks are most common in central Fiordland. Mesozoic extrusive and volcaniclastic equivalents of some Median Batholith plutons occur in eastern Fiordland, locally unconformable on Carboniferous granite.

The Cretaceous metadiorites of the Western Fiordland Orthogneiss Suite (WFO) are subdivided into several plutons, including the eclogite facies Breaksea Orthogneiss which is the highest pressure metamorphic unit yet found in New Zealand. Most WFO contacts are intrusive, although some have subsequently been modified by shearing. Metasedimentary country rocks locally contain granulite facies assemblages in narrow aureoles around parts of the WFO. Country rocks >500m from the WFO retain Carboniferous and Early Cretaceous amphibolite facies assemblages.

Previous mapping of Cretaceous and Cenozoic sedimentary rocks and glacial deposits on the margins of Fiordland remains largely unchanged, although there is now more control on the ages of raised marine terraces in southwestern Fiordland. Uplift rates have been refined from fossiliferous Quaternary fiord deposits near Puysegur Point. Newly mapped steeply to gently dipping ductile faults are inferred to be of Cretaceous age, and numerous previously unrecognised sub-vertical Cenozoic brittle fault systems are also mapped. Few active fault traces have been recorded, in spite of large recent earthquakes.

# CONSTRUCTION AND EVOLUTION OF A MAFIC-FELSIC MAGMA CHAMBER: AN EXAMPLE FROM STEWART ISLAND

**R.E. Turnbull[1], S.D. Weaver[1], A.J. Tulloch[2]**
[1]Department of Geological Sciences, University of Canterbury, Christchurch
[2]GNS Science, Private Bag 1930, Dunedin
rose.turnbull@pg.canterbury.ac.nz

Field evidence from exposed plutonic rocks indicates that felsic magma chambers often trap basaltic magmas as they rise through the crust. This process commonly results in the formation of spectacular mingling structures and textures in which quenched mafic material is enclosed within a more felsic host. Mingling structures and textures have previously been ascribed to processes occurring during pluton emplacement, but detailed field observations from several authors indicate that these textures represent processes operating within an active magma chamber during the process of pluton construction. The composite Bungaree Intrusives on the northern coast of Stewart Island preserve evidence for the interaction between coeval mafic and felsic magmas. Interpretation of the mingling structures and textures and the identification of way-up structures have allowed us to reconstruct the magma chamber stratigraphy and determine the processes involved in pluton construction.

The Bungaree Intrusives of Stewart Island were emplaced at ~140 Ma along the convergent New Zealand margin of Gondwana. Textural, mineralogical and geochemical data indicate that the Bungaree Intrusives consisted of at least two adjacent magma pods that formed incrementally as the result of multiple replenishments of mafic magma into an aggrading magma chamber of evolving intermediate-felsic composition.

Field interpretations, whole-rock geochemistry and detailed mineral zoning profiles indicate that a number of physico-chemical processes operated within the active magma chamber including magma mixing and mingling, crystal accumulation, fractional crystallization, compaction, and multiple heating events due to mafic magma injection. The style of magma mingling preserved changes from the base of the chamber towards the top, which also corresponds with a change in the whole-rock geochemistry. The change in mingling style from thick mafic sheets to mafic enclave swarms is a function of several factors including composition, temperature, viscosity and the volume of the injected mafic magma.

Study of this magmatic system offers insights into the generation and evolution of magmas in subduction-related settings, and the processes that operate within such magma chambers.

# CRUSTAL CRACKS IN AREAS OF ACTIVE DEFORMATION: CORRELATION OF GPS AND SEISMIC ANISOTROPY

**K. Unglert[1], M. Savage[1], N. Fournier[2]**
[1]SGEES, Victoria University of Wellington, Wellington, New Zealand
[2]GNS Science, Wairakei Research Centre, Taupo, New Zealand
unglerkath@myvuw.ac.nz

Shear-waves traveling through anisotropic materials split into two quasi-perpendicular components with different velocities. The direction of the faster polarisation and the time delay between the two parts of the wave can be measured at the surface. Crack orientation is one of the crucial factors in the crust that causes anisotropy. The fast polarisation usually aligns parallel to the crack alignment, which represents the direction of maximum horizontal stress. Changes in this direction or stress amplitude will cause a redistribution of cracks and hence result in a change in the anisotropic parameters of shear-waves.

Consequently, shear-wave splitting measurements have been suggested as a tool to monitor volcanic environments. The parameters provide information about subsurface processes integrated along the travel paths of the seismic rays. GPS data are a common measure of surface deformation, which results from e.g. magma movement at depth in volcanic areas. As processes of magma migration are likely to change the local stress field, such changes should also be reflected in shear-wave splitting measurements. We apply shear-wave splitting to the Taupo Volcanic Centre (TVC), North Island.

The TVC is an area influenced by backarc rifting from the Hikurangi subduction zone and is undergoing extension and active volcanism since 2 Ma. Recent observations have shown three episodic uplift events for the Northeastern part of Lake Taupo in 2006, 2007 and 2008. Modeling of this deformation suggested Mogi point sources at relatively shallow depths, which could be related to magma movement. The aim of this study is to investigate shear-wave splitting for the times around the deformation episodes, compare the results to the GPS data and to test if they are correlated.

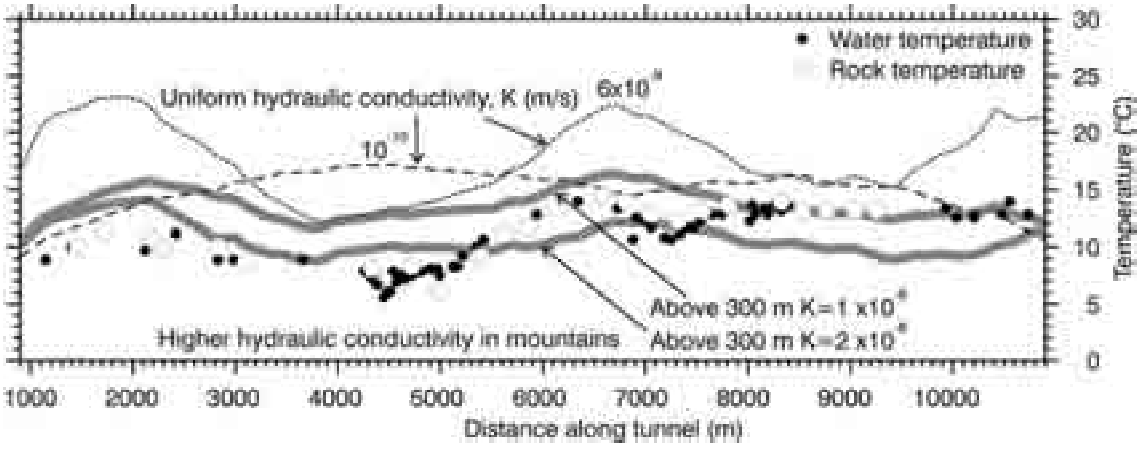
8 seismic stations from the GeoNet network in the vicinity of Lake Taupo have been chosen for shear-wave splitting analyses. Automated measurements for 2006 show fast directions of the stations with the most measurements with a similar trend to previous studies in the TVC. Further analyses will include handpicking the S-arrivals, expanding the magnitude range of the earthquakes used for shear-wave splitting, comparison with GPS and additional modeling of local stresses.

# UPPER CRUSTAL HYDRAULIC CONDUCTIVITY BETWEEN LAKE MANAPOURI AND DOUBTFUL SOUND, FIORDLAND

**P. Upton**[1] **& R. Sutherland**[2]
[1]GNS Science, Private Bag 1930, Dunedin, New Zealand
[2]GNS Science, PO Box 30368 Lower Hutt, New Zealand
p.upton@gns.cri.nz

The Manapouri Tunnel, linking Lake Manapouri to Doubtful Sound, Fiordland, provides us with a unique opportunity to explore the magnitude and spatial variability of upper crustal permeability. Rock and groundwater temperature measurements taken in the 10 km long tunnel range from 6°C to 14°C, despite there being greater than 1 km of rock above the tunnel in places. The coolest temperatures within the tunnel are found beneath the highest topography. The opposite of what would be predicted for a purely conductive geotherm. The temperatures measured suggest that the thermal regime in the upper 1-2 kms of this region is dominated by the flow of groundwater through the rocks and that the hydraulic conductivities are high enough to cool the rocks to greater 1 km below the ground surface.

We use three-dimensional coupled thermal/fluid flow models to simulate the thermal regime of the Manapouri Tunnel region for different values of the hydraulic conductivity. Model hydraulic conductivity controls the rate of fluid flow and hence the amount of cooling of the rock by infiltration of surface waters. Assuming a basal heat flow of 40 $mWm^{-2}$, rock advection of 0.8 mm $yr^{-1}$ and a porosity of 0.1, the thermal regime changes from being conduction-dominated to fluid advection-dominated when the hydraulic conductivity is greater than $2 \times 10^{-9}$ m $s^{-1}$. Models with a high uniform hydraulic conductivity do not fit the observations because fluid from greater depths is predicted to focus into the valleys, producing temperatures much higher than observed along the tunnel. To reproduce the observations, we require high hydraulic conductivity in the mountains above the tunnel.



# PALAEOCENE-EOCENE EVOLUTION OF DEEP-SEA BENTHIC FORAMINIFERA

**Liesbeth Van Kerckhoven[1,2] & Bruce W. Hayward[1]**
[1] Geomarine Research, Auckland, New Zealand
[2] University of Auckland, Auckland, New Zealand
l.vankerckhoven@auckland.ac.nz

To increase understanding of the drivers of global evolution and extinction in the deep sea, we study the enigmatic extinction of a distinctive group of cosmopolitan deep-sea benthic foraminifera during the late Pliocene-Middle Pleistocene "Last Global Extinction" (LGE) (3 – 0.12 Ma). 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. The so-called "Extinction Group", comprising nearly 100 species (c. 20% of deep-sea foraminiferal diversity at that time), all shared a similar morphology of elongate, cylindrical and uniserial tests with small, specialised apertures.

To elucidate the factors driving their evolution and ultimate extinction, we extend the studies back in time. During the Cenozoic, the deep-sea benthic foraminiferal community underwent three earlier intervals of increased turnover (late Palaeocene-early Eocene, late Eocene-earliest Oligocene and middle Miocene) all of which seem to have coincided with intervals of major climatic change. In a first stage of this research, we performed a low-resolution study of ODP Sites 689 and 1211 to obtain a record of the occurrence and abundance of the "Extinction Group" species throughout the Cenozoic. In a second phase, presented here, a high-resolution study of the "Extinction Group" species was undertaken in ODP Sites 689 and 690 (Southern Ocean) over the late Palaeocene-early Eocene warm interval, including the Palaeocene-Eocene Thermal Maximum during which 30-50 % of deep-sea benthic foraminiferal species went extinct. Focus on the late Palaeocene-early Eocene warm period, and investigation of whether this warm event had any impact on the "Extinction Group" species, indicates whether only the cold-related events caused the loss of "Extinction Group" taxa and helps us to understand the extent to which the LGE was stress-related or temperature-related.

# SLOW RUPTURE OF THE MARCH 1947 GISBORNE EARTHQUAKE SUGGESTED BY TSUNAMI MODELLING

**X. Wang, W.L. Power, R.E. Bell, G.L. Downes, & C. Holden**
GNS Science, PO Box 30368, Lower Hutt
x.wang@gns.cri.nz

In March 1947 an unusually large tsunami swept the Gisborne region of the east coast of the North Island. Up to 10 meter tsunami runup heights were observed along the stretch of over 100km coastline. The observations show that major tsunami energy was directed toward the coastal portion between Wainui Beach and Waihau Beach. This tsunami was triggered by an Mw7.1 earthquake, located about 50 km offshore. Considering its magnitude, the surprisingly large tsunami heights suggest that it is a typical tsunami earthquake, which is usually characterized by a slow rupture speed.

With the help of seismic reflection data in the area of the March 1947 earthquake, Bell et al. proposed a source model with stronger geodetic coupling over a subducted seamount, identified in this area, and weak coupling in the surrounding transition region. To correlate with the proposed coupling pattern, in our study, a variable slip distribution model was constructed for the March 1947 earthquake and a variety of rupture velocities and patterns were investigated to study the tsunami runup heights along the coast with a tsunami model.

We find out that the rupture velocity of the March 1947 earthquake should be comparable with the wave speed of tsunami in this area to obtain a favourable agreement between the observations and the numerical results. An exceptionally slow rupture velocity of about 150m/s provides the best agreement in our modelling so far. Numerical simulations also suggest that a significant portion of the subduction interface southwest of the epicentre needs to be involved in the rupture process in order to produce a tsunami runup height distribution along the coast similar to that of the observations.

**STRATIGRAPHY OF THE SOUTHEAST TORLESSE**

**J.B. Waterhouse**
25 Avon Street, Oamaru
perma@xnet.co.nz

Aspects of the stratigraphy of the Torlesse from below the Rangitata Gorge in the north to the west side of Waitangi Station near Benmore Dam in the south have been covered in the 1:250 000 geological maps by Forsyth (2001) and Cox & Barrell (2007). Extensive mapping shows that the rocks differ from most of the Torlesse, or Rakaia Terrane. Most are of Permian age, with rare conodonts and widespread although usually fragmented atomodesmid bivalves, recognisable as *Maitaia trechmanni* Marwick and *Aphanaia otamaensis* Waterhouse. Unlike the volcanogenic Permian of the Rakaia Basin, exemplified by the Rose Formation, Glenfalloch Member and Te Akatarawa rocks, the Permian consists of arkoses and quartzites with thick sandstone to the south, extensive grey siltstone, and turbidite, showing a westerly source for most outcrops. There are nests of basalt rare limestone, and rare red argillite. The rocks appear to overlie the Carboniferous Kakahu Carboniferous, which is largely restricted in outcrop as shown by Hitching (1979), but may include cherts in the Pareora Gorge. Towards the top of the Permian are extensive black argillites and thin turbidite. Low grade schist is widespread, and not as pervasive as suggest in the 1:250 000 maps, except for a horst southeast of Fairlie and ridges at Waitangi Station.

Triassic is of limited extent. It may commence with the black argillite, or with coal measures a little higher in the sequence: the coals occur in many bands up to 1.5m in thickness, and contain apparently Triassic plant remains. They are overlain by Te Moana conglomerate, with granitic and quartz pebbles prominent, as described by Smale (1983), and the stratigraphic succession does not appear to support the "Dorashamian" or "Kazanian" (ie Middle and Late Permian Lopingian and Wordian) age ascribed to the beds. The conglomerate near Devil's Peak forms a tight and truncated syncline, and differs little from the band further that extends from north of Burke's Pass to Waitangi Station. Thick silty shale and well-spaced intervals of sandstone follow, derived from the west. The rocks are separated from the Rakaia rocks by a major fault, and to the north, by the Late Cretaceous Mt Somers rhyolites, ignimbrites, andesites and dacites described by Oliver & Keene (1989, 1990), with Clent Hills Jurassic. They include minute Hewson Formation outcrops of Cretaceous quartzite.

The classification of the southeast Torlesse rocks as Rakaia terrane appears inappropriate, given the substantial differences in Permian lithostratigraphy , further reinforced by differences, though less striking, for Triassic rocks. Should Kakanui Terrane be revived and extended from Carboniferous to encompass the area in question, remembering that it is well demarcated from the Rakaia Basin? And what was the relationship to the Pahau Basin (sensu lato) to the north, which involves chiefly Cretaceous and Jurassic, but may be envisaged as embracing older rock to the south?

# FORMATION OF SYSTEMATIC JOINTS IN METAMORPHIC ROCKS DUE TO RELEASE OF CRETACEOUS RESIDUAL STRAIN, OTAGO SCHIST, NEW ZEALAND

**R. Weinberger[1], Y. Eyal[2] & N. Mortimer[3]**
[1]Geological Survey of Israel, 30 Malkhe Israel 95501, Jerusalem, Israel
[2]Dept. Geol. & Env. Sciences, Ben Gurion University, Beer Sheva, Israel
[3]GNS Science, Private Bag 1930, Dunedin, New Zealand
n.mortimer@gns.cri.nz

We present the first regional study of joints in the Otago Schist, New Zealand. The purpose of the study was to explore the origin and mechanism of joint formation in metamorphic rocks, especially any possible association between brittle and previous ductile deformation. The Otago Schist is cut by numerous systematic joints, up to tens of metres long, at any one exposure. We measured the orientation of joints, schist foliation planes, and quartz rods/mineral lineations at 46 sites across the Otago Schist, and calculated the spherical angles between their means.

In relatively high metamorphic grade schists (greenschist facies) typically one systematic joint set has developed subperpendicular to penetrative foliation and lineation, irrespective of foliation and lineation orientations. This relationship also holds in lower grade schists (pumpellyite-actinolite facies), but more than one joint set is occasionally present. The flanking unfoliated schist protoliths (prehnite-pumpellyite facies) contain no systematic joint sets.

A pre-85 Ma age for schist joint formation is indicated on the basis of (1) lack of joint continuation into late Late Cretaceous conglomerates that unconformably overlie jointed schists, (2) schist cooling history, (3) consistent orthogonality of joints with foliation and lineation, and (4) lack of relationship of systematic joints to late Cenozoic plate-boundary features. We propose a model for joint formation during 120-85 Ma exhumation of the schist, and suggest that the systematic joints formed due to release of residual strain stored in the schists from Early Cretaceous ductile deformation.

# EVALUATING TSUNAMI THREATS

**N. Welch & the GeoNet Team**
GNS Science, 1 Fairway Drive, Avalon, Lower Hutt
n.welch@gns.cri.nz

GNS Science is the technical advisor to the Ministry of Civil Defence and Emergency Management (MCDEM) for all potential tsunami threats to New Zealand. The Wellington-based GeoNet Duty Officer, with assistance from the Tsunami Experts Panel (TEP), will evaluate all tsunami threats to New Zealand. If possible, the GeoNet Duty Officer will advise MCDEM on travel-time estimates, wave height estimates, and threat levels for respective regions of New Zealand. Response procedures will vary with the tsunami travel-time from the source to the nearest New Zealand coastline. Local source tsunami will offer very little (if any) time to implement official warning procedures and for this reason public awareness is being promoted. Regional and distant source tsunami should provide adequate time for issuing National Advisories and Warnings.

GNS Science is developing tools to aid the GeoNet Duty Officer and TEP in decision making for tsunami threat evaluation. These include tsunami threat level models, tsunami propagation models, and potentially GPS streaming for real-time tsunami detection. The New Zealand Tsunami Monitoring Network is an additional resource that can inform decision making. The network is useful for 1) detecting first arrivals of tsunami waves on land, 2) issuing an 'all clear' after an event, and 3) collecting data on tsunami that can be used to calibrate tsunami propagation models.

All sea level data collected by GNS Science is being shared with the international tsunami monitoring community via the Global Telecommunications System (GTS) and SeedLink. Sharing sea level data amongst Pacific nations (a recommendation of the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System) is critical for tracking tsunami travelling across the ocean basin and accurately assessing potential regional and distant source tsunami threats.

# THE TAUPO VOLCANIC ZONE IN THREE DIMENSIONS

**P. White, C. Tschritter, M. Raiber & N. Jebbour**
GNS Science, Private Bag 2000, Taupo, New Zealand
c.tschritter@gns.cri.nz

With advances in technology and the need for a better understanding of the subsurface geological structure, three-dimensional geological modelling has become a useful tool for the investigation, visualisation and interpretation of geologic settings.

GNS Science has been conducting geological modelling in three dimensions (3D) for over 10 years, developing models for various areas in New Zealand. The complex geological setting of the Taupo Volcanic Zone (TVZ) is of high interest for various applications. Sub-regional geological models have been developed in the TVZ including: Western Bay of Plenty (between Waihi Beach and Te Puke), Paengaroa - Matata, Lake Rotorua catchment, Reporoa basin, Lake Taupo catchment and also for the Hauraki Plains adjoining the TVZ. These models are now in the process of being combined into one 3D geological model of the TVZ to define the distribution of chronostratigraphic units across a large part of this zone.

Each of these models was constructed from data extracted from geological maps, logs of water wells, published cross-sections and isopach maps, etc., using a combination of GIS (ESRI ArcGIS 9.3) and 2D and 3D modelling software (EarthVision, Dynamic Graphics Inc.). Additional information is sourced from neighbouring geological models.

The sub-regional models were developed for groundwater hydrology applications, where a model is the basis for understanding the geometry of key formations for groundwater flow, understanding groundwater flow directions and flow rates, and estimating groundwater storage volumes. For example the geological model of the Western Bay of Plenty identified the most important aquifers on the basis of groundwater storage volumes, groundwater use and groundwater flow as: Tauranga Group sediments, Waiteariki Ignimbrite and Aongatete Ignimbrite. Groundwater available for allocation in the Western Bay of Plenty area was estimated as 13.7 $m^3$/s based on a water budget that included: rainfall recharge to groundwater; surface water baseflow; groundwater discharge to the adjacent Lake Rotorua catchment; surface water inflows to the Western Bay of Plenty area from the Kaituna River; and groundwater inflows to the Western Bay of Plenty area. The geological model was used to assess the allocation of groundwater from particular aquifers where well depth was known. For example, allocation from Tauranga Group sediments, Waiteariki Ignimbrite and Aongatete Ignimbrite was approximately 0.7 $m^3$/s, based on about 50 % of groundwater wells for which depth information was available.

Sub-regional models are also used in studies of lake water quality (e.g. in the Rotorua Lakes Restoration Programme) as geological models assist in identifying pathways for nutrients to enter lakes. The combined geological model of the TVZ could also be used in assessing the regional geology of hydrological systems associated with geothermal fields as well as for consideration of geothermal resources in general.

# THE EFFECTS OF MATERIAL INHOMOGENEITY AND TOPOGRAPHY ON THE PREDICTED SURFACE DEFORMATION FOR HIKURANGI SLOW SLIP EVENTS

**C. Williams[1], L. Wallace[1], J. Beavan[1], D. Eberhart-Phillips[2], & M. Reyners[1]**
[1]GNS Science, 1 Fairway Drive, Avalon, PO Box 30368, Lower Hutt
[2]Geology Dept., Univ. California Davis, Davis, CA, USA
C.Williams@gns.cri.nz

Slow slip events (SSEs) at the Hikurangi subduction margin adjacent to the North Island, New Zealand display a remarkable diversity of characteristics. Long duration (1-2 years), deep (40-60 km depth), large events (equivalent to Mw ~7.0) occur at the southern Hikurangi margin, while shallow (10-15 km depth), short (1-2 weeks), smaller events (equivalent to Mw ~6.5) occur at the northern and central Hikurangi margin. Since 2000, three major slow slip events have been identified at the southern Hikurangi margin; the 2003 Kapiti SSE, the 2004/2005 Manawatu SSE, and the 2007/2008 Kapiti SSE (which ended in early 2009). In some cases, these SSEs may have triggered moderate seismicity within the subducting Pacific plate (e.g., Reyners and Bannister, 2007).

To date, all of the inferred slip distributions for the SSEs have been obtained using elastic half-space dislocation models. Numerous recent studies of coseismic displacement fields have shown that variations in elastic properties and surface topography can influence the predicted deformation. We examine the possible influence of these factors on the Hikurangi SSEs using a 3D finite element model. We investigate the effects of topography by evaluating models with both a flat upper surface and an upper surface corresponding to topography. To evaluate the effects of material inhomogeneity, we infer elastic properties from a 3D seismic velocity model. These properties are then used in the finite element model and compared against results assuming homogeneous elastic properties.

In all of the models, we use slip distributions obtained from elastic half-space inversion results, and then compare the predicted surface deformation field to that predicted by the half-space model. In addition to looking at the predicted surface deformation field, we look at changes in the Coulomb stress along the Hikurangi margin due to the various SSEs. We compare the Coulomb stress changes predicted by the different models and compare the stress changes with the locations of subsequent seismic events, as well as the direction of propagation of the SSEs.

# NUMERICAL MODELS OF TVZ WITH MIXED NEUMANN AND DIRICHLET BOUNDARY CONDITIONS

**S.J. Williams**[1], **N.H.S. Oliver**[1], **J.G. McLellan**[1], **B.E. Hobbs**[2], **H. Bibby**[3]
[1]School of Earth & Env. Sciences, James Cook University, Townsville, 4811, Australia
[2]CSIRO Exploration & Mining, P.O. Box 1130, Bentley, 6102, Australia
[3]GNS Science, PO Box 30368, Lower Hutt, New Zealand
sally.williams@jcu.edu.au

Numerical models of the broad scale thermal characteristics of the Taupo Volcanic Zone typically prescribe a fixed temperature boundary condition along the entire upper surface. Such a condition may reasonably describe inflowing meteoric water temperature, but does not allow for regions with upwelling hot fluid. We made simple two and three-dimensional thermal models with a mixed surface boundary condition, where a zero normal temperature derivative is specified where upwelling hot fluid exits the domain (Neumann surface boundary condition), and water enters the remaining porous domain at a fixed temperature of 10ºC (Dirichlet-type surface boundary). Since inflowing and outflowing locations are *a priori* unknowns, the surface boundary condition is applied as a function of the vertical velocity vector. Boundary temperatures are thus determined by the emergent flow field (itself dependent on an initial geological perturbation or convection geometry). It is noted that only at the top boundary this condition neglects horizontal diffusion of heat from the hot upwelling plume to the cold downflowing water; below that horizontal diffusion is possible. Numerical model results show that the application of a mixed boundary condition always results in an open (single pass) convection cell in contrast to the partially open and closed, or fully-closed flow patterns of previous models.

Models inspired by geological and geophysical observations of the Taupo Volcanic Zone were carried out to investigate the effects of a mixed boundary condition on convection characteristics. We are trialing both a TVZ-like rectangular geometry of 30km by 150km, and a smaller caldera-like equivalent, containing a two-layer homogenous domain representing higher permeability extrusive ignimbrites overlying less porous greywacke basement. Constant basal temperature boundary conditions are specified at a depth of 8km where it is assumed that the onset of ductile behaviour provides an effective impermeable barrier to the convecting flow regime. The full thermo-physical fluid properties are specified via a lookup function to the conventional steam tables for pure water. Two-phase flow effects are accounted for using a relative permeability variation of Darcy's Law, and the effect of this relative permeability function is explored.

For a range of initial conditions and source terms assumed typical of the TVZ and model calderas, our models show that open convection cells form with spacing typically on the order of twice the cell depth developed. Whilst the flow regime remains fundamentally non-steady, the open-top nature of these cells modified the usual unsteady cell overturning which is typical of the previous closed-top models at high Rayleigh numbers.

# FAULT CONTROL ON GOLD MINERALISATION IN THE CENTRAL VICTORIAN PORTION OF THE LACHLAN FOLD BELT, AUSTRALIA

**Christopher J.L. Wilson[1], Jamie Robinson[2] & Lawrence Leader[1]**
[1]School of Earth Sciences, The University of Melbourne, Vic. 3010, Australia
[2]CSIRO Exploration and Mining, Bentley, WA. 6102, Australia
cjlw@unimelb.edu.au

Faults that act as highly permeable channel-ways for fluid discharge control the distribution of gold mineralisation across the Victorian section of the Lachlan fold belt. It is the prevailing far-field stress field that triggers the abrupt localised fluid pressure fluctuations that accompany the deposition of the gold. Mineralisation is associated with changes in the stress field, which are likely to be the result of strain localisation and strain migration across the Lachlan fold belt, as well as upward migration of over-pressured fluids. High-grade gold mineralisation occurs after major east-west shortening and associated folding and major faulting in all cases examined. However, the younging in age of the gold deposits, from west (~440 Ma) to east (370-380 Ma), is associated with the progressive change in the stress field from east-west to a north-south orientation with time and to shallower crustal levels.

The mineralisation related to the major faults in the western Lachlan fold belt suggest that the mineralisation in the Stawell Zone was associated with a low-differential stress, transient supra-lithostatic fluid pressures and a shift from reverse-dip-slip to reverse-oblique-slip fault kinematics. This mineralisation in the western Lachlan orogen occurred synchronously (~440 Ma) with major east-west contraction and emplacement of the major quartz lodes in the Bendigo Zone. In contrast, the high-grade gold mineralisation in the eastern Bendigo Zone and in the Melbourne Zone was associated with low-strain northwest-southeast compression, following the east-west compression, resulting in reverse-sinistral slip on pre-existing, west-dipping faults. Structural analysis and numerical simulation studies of deformation associated with mineralisation at Fosterville suggest the mineralised fault systems all formed under very similar stress conditions (and potentially similar timing i.e. ~370-380 Ma).

It is the fluid pressure in combination with the applied stress field and resultant hangingwall transport direction that influence fluid flow and the potential location of mineralisation. Understanding the optimum geometric conditions producing dilation in potential host rocks adjacent to faults, and ranking fault bedding relationships based upon their potential to produce dilation may be a key tool to understand the reasons for the localisation of the gold deposits. Increased dilation as influenced by these geometric relationships would have facilitated the influx of gold-bearing fluids that in combination with geochemical factors, have led to significant amounts of localised gold mineralization.

# USE OF GRAVITY DATA TO CHARACTERISE GEOLOGICAL STRUCTURES BENEATH THE SEA FLOOR, NEW HARBOUR, ANTARCTICA


**G. Wilson[1,2], K. Tinto[2], A. Pyne[3], H. Blakemore[2], A. Clifford[2], D. Sunwall[4], S. Thornton[5], M. Speece[4] & S. Pekar[6]**

[1]Department of Marine Science, University of Otago, Dunedin, NZ
[2]Department of Geology, University of Otago, PO Box 56, Dunedin, NZ
[3]Antarctic Research Centre, Victoria University of Wellington, Wellington, NZ
[4]Department of Geophysical Engineering, Montana Tech, Butte, MT, USA
[5]GNS Science, PO Box 30368, Lower Hutt, NZ
[6]School of Earth and Environmental Sciences, Queens College, Flushing NY, USA
gary.wilson@otago.ac.nz


In the 08/09 Antarctic Season, new gravity data were collected from the sea ice in New Harbour and immediately offshore in collaboration with the USAP supported acquisition of new seismic data for the ANDRILL Offshore New Harbour (ONH) Project. New gravity data were collected along the ONH seismic lines and along lines, which extended previous survey lines collected in the 01/02 and 05/06 seasons. All surveys were tied to gravity base stations at Scott Base and McMurdo Station and old data updated to new calibrations of the base stations made in the 08/09 Antarctic Season.

Free air anomaly data were reduced to bouger anomalies with 1) bathymetry corrected as sediment to target any structure in the basement surface and 2) bathymetry corrected as basement to target sediment distribution and thickness. Long wavelength components assumed to represent Moho or Mantle derived gradients at the level of our survey were removed from each of the bouger anomaly data sets using a 50km radius filter. Finally, sediment thicknesses were ground-truthed using sediment thickness data from the CIROS-2 drillhole and minimum sediment thickness data from the DVDP-10, -11, -15, MSSTS-1 and CIROS-1 drillholes which all lie within the area of the gravity surveys.

The resulting anomaly maps identify a range front parallel NW-SE lineation between offshore Butter Point and Marble Point as well as a range perpendicular lineation co-incident with the Kukri Hills and extending offshore. Both anomaly lineations are interpreted to represent faults, which predate and control subsequent valley glacier development and late Neogene sediment accumulation. Offset valley-perpendicular basement sills are also indicated in front of the Ferrar and Taylor valleys with paleoadvances of the Ferrar Glacier diverted north through the sill offset. Northward diversion of the Ferrar Glacier along with the basement sill might have provided a dam, which resulted in the deposition of a thicker sedimentary succession in the mouth of the Taylor Valley or paleofiord than in the mouth of Ferrar Fiord. An offshore sedimentary basin is also indicated with the thickest sediment accumulation centred in the vicinity of the MSSTS-1 drill site.

# MORHPOLOGY AND STRUCTURE OF THE SOUTHERN KERMADEC ARC – HAVRE TROUGH

**R.J. Wysoczanski[1], E. Todd[2], I.C. Wright[3], M.I. Leybourne[4], J.M. Hergt[5], C. Adam[6], K. Mackay[1]**
[1]National Institute of Water and Atmospheric Research, Wellington
[2]Dept. of Earth and Planetary Sciences, University of California, Santa Cruz, USA
[3]National Oceanography Centre, Southampton, United Kingdom
[4]Ocean Exploration, GNS Science, Box 30-368, Lower Hutt
[5]School of Earth Sciences, The University of Melbourne, VIC 3010, Australia
[6]Japan Agency for Marine Earth Science and Technology, Yokosuka, 237-0061, Japan
r.wysoczanski@niwa.co.nz

Extensive multibeam mapping of a large portion of the southern Havre Trough (SHT) acquired using a DGPS navigated 12 kHz SEABEAM 2000 system (2006 RV *Yokosuka* cruise YK06-14), combined with previous mapping, provides the most complete overview of SHT seafloor structure to date. These data show the SHT to comprise sub-equal areas of basal plateaus with a mean height of 2500-3000 m, and deep rifts exceeding 4000 m. The rifts are equally distributed across the back arc, with many impinging on the arc front, occurring centrally, or adjacent to the Colville Ridge. Seamounts, knolls and ridges, aligned in lineaments, top the plateau and a number of volcanoes extend well into the backarc either as topographic swells or as a chain of distinct volcanoes. The occurrence of rifts and volcanic plateaus loosely defines areas of ‘rift regime’ and ‘arc regime’, respectively, in the southern Kermadec Arc – Havre Trough.

The cross-arc volcanic chains, isolated volcanoes and basement plateaus may represent a “cap” of extrusives. However, the spatially extensive basement fabric of elongated volcanic ridges suggest they are the surface expression of pervasive dike intrusion that has thoroughly penetrated and essentially substituted the original arc crust with newly accreted intrusives. The ‘cap’ then is a minimum estimate of the volume of young volcanism, which could be significantly greater if the observed features are built not on pre-existing arc crust but entirely from young magmatism. Mass balance modelling indicates maximum crustal thickness of ~ 11 km to < 6 km, similar to estimates of crustal thickness in the Lau Basin to the north.

The high degree of crustal attenuation combined with extensive apparently young backarc mafic magmatism within deep SHT rifts, suggests that the SHT is in an incipient phase of distributed and “disorganised” oceanic crustal accretion in multiple, ephemeral and deep (> 4000 m) spreading systems. These discontinuous spreading systems are characterised by failed rifts, rift segmentation, and propagation. Successive episodes of magmatic intrusion into thinned faulted arc basement have resulted in de-focused asymmetrical accretion. This form of spreading, rather than organised spreading along a linear ocean ridge, is also seen at the Valu Fa Ridge in the southern Lau Basin.

# HOT ZONE" DEVELOPMENT BENEATH A LONG-LIVED ANDESITE STRATOVOLCANO: MAGMATIC EVOLUTION OF MT. TARANAKI, NZ

**A.V. Zernack[1], R. Price[2], R.B. Stewart[1] & S.J. Cronin[1]**
[1]Volcanic Risk Solutions, Massey University, Private Bag 11222, Palmerston North
[2]School of Science & Engineering, University of Waikato, Private Bag 3105, Hamilton
a.v.zernack@massey.ac.nz

Due to poor stratigraphic control of the older deposits, geochemical studies at Mt. Taranaki have mainly focused on the well-known succession of the last 20 ka. However, a recently developed stratigraphic framework for the >200 ka volcanic history identified a record of 14 debris-avalanche deposits, which have provided a better age control and allowed a more systematic sampling of the older succession. Clast assemblages within these units provide insights into past edifice compositions and the base for extending mineralogical and geochemical studies into the early magmatic history of the volcano.

Throughout the volcanic history of Mt. Taranaki, similar eruptive styles produced a similar range of lithologies, indicating a long-term sustainability of the volcanic system. However, the analysed sample suites show a progressive enrichment in $K_2O$ and LILE reflecting a gradual evolution to a high-K andesite magmatic system. The significantly less potassic composition of early melts is also marked by the absence of orthoclase-rich plagioclase. Instead, the immature, early magmatic system erupted more primitive rocks with a more distinct mantle signature and phenocryst assemblages that imply crystallisation at greater depth, including a broad range of clinopyroxene compositions, high-$Al_2O_3$ hornblende, olivine and phlogopite. A higher proportion of high-silica compositions in the younger sample suites and the appearance of late-stage low-pressure mineral phases, such as high-$TiO_2$ hornblende, biotite and Fe-rich orthopyroxene, reflect a gradual shift to more evolved magmas with time.

These new data suggest the development of a lower crustal 'hot zone' beneath Mt. Taranaki as a result of repeated intrusions of primitive melts into the lower crust, which gradually raised the geothermal gradient. The geochemical and mineralogical evidence indicates that this zone was significantly thinner and colder >100 ka, allowing less interaction of the melt with underplated material and causing more primitive magmas to rise rapidly through the crust without intense modification. Early stages of hot zone development were characterised by 'normal' upper mantle/lower crustal conditions and more extensive fractionation of high-pressure mineral phases at greater depth. As the hot zone evolved, larger proportions of the underplated basaltic material were partially remelted, generating the progressively K- and LILE-enriched compositions observed within the Taranaki debris-avalanche sample suites. The increasingly complex crustal structure with a more dispersed plumbing system also resulted in magma assembly and storage at upper crustal levels where the melts were further modified through fractional crystallisation, magma mixing and mingling processes.

This study shows that debris-avalanche clast assemblages can be used as windows into the volcanic past, in some cases back to the earliest stages of the volcanic system. This new method is particularly important at long-lived stratovolcanoes where the older records are incomplete and the full range of products not exposed.