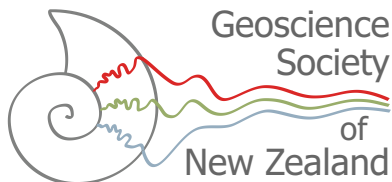
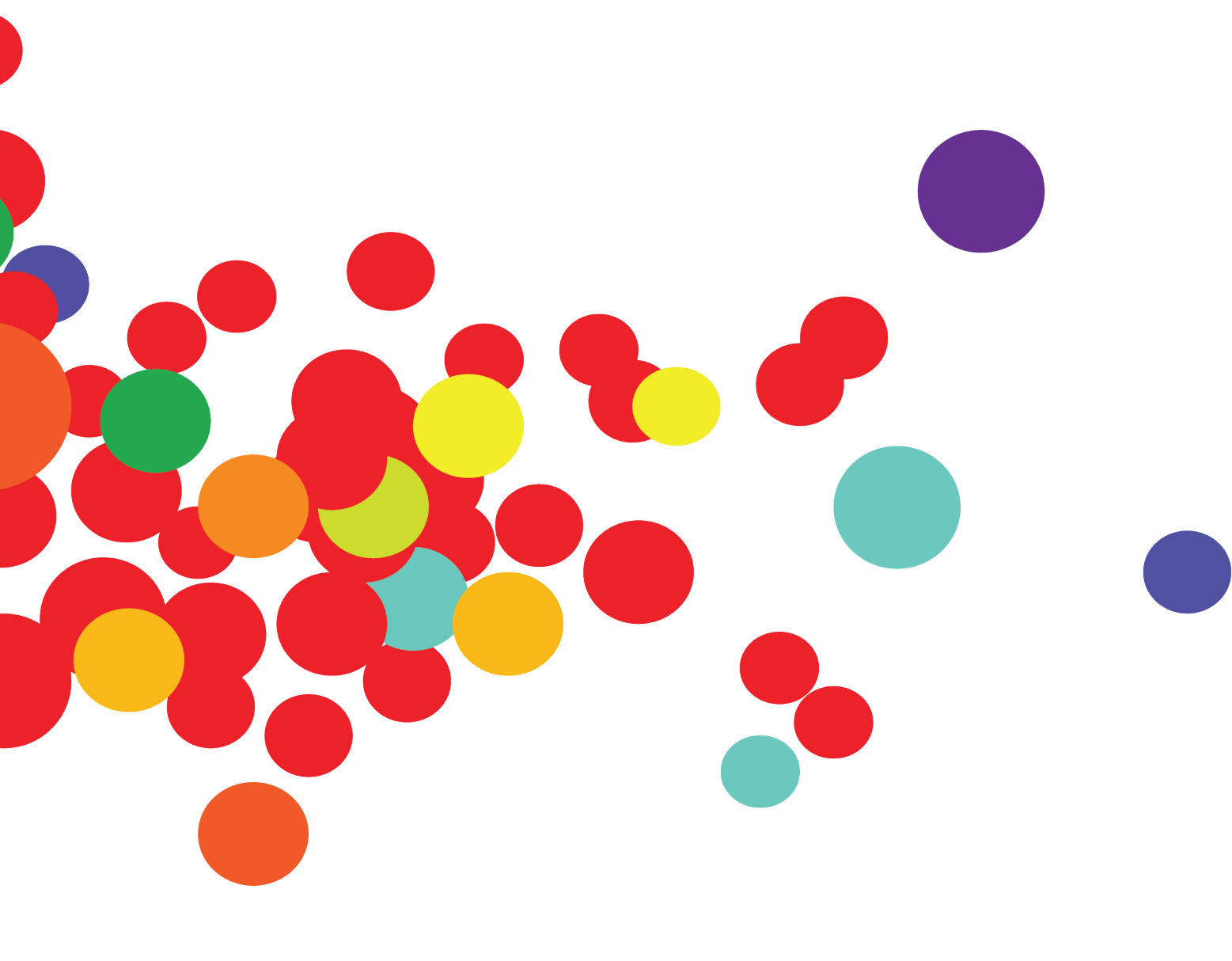


Geosciences 2013

Annual Conference of the Geoscience Society of New Zealand



Abstracts



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CHANGES IN ELASTIC WAVE VELOCITY AND ROCK MICROSTRUCTURE DUE TO BASALT-CO₂-WATER REACTIONS

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The chemical interaction between carbon dioxide, water and basalt is a common process in the earth, which results in the dissolution of primary minerals that later precipitate as alteration minerals. This occurs naturally in volcanic settings, but more recently basalts have been suggested as reservoirs for sequestration of anthropogenic CO₂. In both the natural and man-made case, rock-fluid reactions lead to the precipitation of carbonates. Here, we quantify changes in ultrasonic wave speeds, associated with changes in the frame of whole-rock basalts, as CO₂ and basalt react. After 30 weeks of reactions and carbonate precipitation, the ultrasonic wave speed in dry basalt samples increases between 4% and 20% and permeability is reduced by up to an order of magnitude. However, porosity decreases only by 2% to 3%. The correlation between significant changes in wave speed and permeability indicates that precipitate is developing in fractures and compliant pores. Thin sections, XRF-Loss On Ignition and water chemistry confirm this. This means time-lapse seismic monitoring of a CO₂-water-basalt system cannot assume invariance of the rock frame, as typically done in fluid substitution models. We conclude that secondary mineral precipitation causes a measurable change in the velocities of elastic waves in basalt-water-CO₂ systems, suggesting that seismic waves could be used to remotely monitor future CO₂ injection sites. Although monitoring these reactions in the field with seismic waves might be complicated due to the heterogeneous nature of basalt, quantifying the elastic velocity changes associated with rock alteration in a controlled laboratory experiment forms an important step toward field-scale seismic monitoring. This study is being expanded as we develop new experiments on a variety of basalt samples from the Auckland Volcanic Field.

ORAL

DIKE ORIENTATION AND STRUCTURE IN DUN MOUNTAIN OPHIOLITE, BRYNEIRA RANGE, OTAGO

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The Bryneira Range exposes a sub-vertical cross section of the Permian Dun Mountain Ophiolite that forms the basement to Permian and Triassic sediments of the Maitai Terrane. To the east it abuts the poly-deformed Caples Terrane along the Livingstone Fault. The lower (eastern) mantle section is made up of ultra-mafic rocks and is separated from the crustal section by the sub-vertical Peanut Fault. The crustal section comprises gabbros, dike rocks, pillow lavas, and sedimentary breccias. The basic "dikes" are of diverse orientation and can be subdivided into older grey intrusive sheets (GIS) that are consistently cut by younger orange intrusive sheets (OIS). In well exposed areas, the latter can be subdivided into up to four successive phases on the basis of cross-cutting relationships.

Poles to dikes, that should reveal the predominant extension direction, were found to be very diverse and rotation about the paleo-horizontal, represented by bedding in Permian Wooded Peak Limestone, provides no resolution. Older paleo-horizontals represented by bedding in the Upukerora Breccia and orientation of pillow lavas produce better results when applied to the younger sets of "dikes". The results support a moderately variable extensional stress affecting a rock mass that was rotating in the stress field. The rotation is thought to relate to extensional faulting within a system of listric faults. The extension direction is very oblique to the present strike of the ophiolite.

A potential analogue is seen in the Bransfield Strait incipient back-arc basin. Here extension is marked by numerous normal faults, listric detachment surfaces, a neo-volcanic zone and a number of 'off axis' central volcanoes; a combination of features that could explain the observed diversity in intrusive sheet pattern. An important difference, however, is that the Bransfield Strait extension is acting on pre-existing volcanic crustal rocks. In the Bryneira example we see the extension of pre-existing back-arc basin crust, possibly in an 'off axis' setting. The Peanut Fault may have originated as a detachment surface between the mantle and crustal sections of the ophiolite. The major

changes in thickness of the Wooded Peak Limestone indicate that sedimentation was influenced by further normal faulting after the magmatic phase ceased.

ORAL

AMINO ACID, OSL AND RADIOCARBON DATING OF LOESS IN NORTH CANTERBURY, NEW ZEALAND

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Late Pleistocene loess in Canterbury has been difficult to date because their oxidised condition has led to the loss of datable organic carbon. In the rare instances where radiocarbon dating of organics has been applied the ages suffer from contamination. Thermal (TL) and infra-red stimulated luminescence (IRSL) techniques have been applied but age reversals in stratigraphic sequences and conflicts with the age of a well dated tephra and with radiocarbon ages on pedogenic carbonate have raised questions about the techniques' efficacy. In this paper, new ages are presented from Mt Cass loess section in North Canterbury, where the calcareous, high pH character of the loess has preserved moa egg shell and terrestrial gastropods. The loess section also includes cryptotephra of Kawakawa/Oruanui tephra (KOT) in high concentration throughout a restricted depth zone. The section has allowed ages from (1) radiocarbon dating of the egg shell, gastropods and pedogenic carbonate, (2) amino acid racemisation (AAR) dating of the gastropods, (3) IRSL dating of the loess, and (3) the tephra, to be compared. Moa egg shell and gastropod radiocarbon ages and AAR ages are consistent with each other and with the age of KOT. An IRSL age from within the concentrated KOT cryptotephra zone is closer to the accepted age of 25.4 k cal. yr B.P. than any previous luminescence ages in New Zealand. The site also allows for local calibration of amino acid racemisation rates. We also report AAR ages from coverbeds on nearby marine terraces, which have provided the first age constraints on those landforms.

ORAL

A 16,000-YEAR LACUSTRINE SEDIMENT RECORD OF PALEOCLIMATE CHANGE FROM LAKE VON, NEW ZEALAND

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Lake Von is a small, hydrologically-closed lake in the northern Southland region of New Zealand, south of Lake Wakatipu. The lake is situated upon tills and gravels deposited by the South Von arm of the Upper Clutha Glacial system during the last glacial maximum. Two 3.5-metre sediment cores were obtained from Lake Von during the summer of 2013. Lake sediments consist of dark brown organic-rich silts comprised of algal organic matter, diatoms, and lithic fragments. Our research objective is to reconstruct changes in moisture balance related to the strength and latitudinal position of the Southern Hemisphere westerly winds, which control year-to-year precipitation variability in our study area. Here, we present first results from our multi-proxy investigation, which include 1) bulk $d^{13}C$ and $d^{15}N$ of sediments, terrestrial plants, and macrophytes; 2) dD and $d^{18}O$ of modern surface waters in the watershed; 3) dD measured on C_{31} n-alkanes extracted from bulk lake sediment; and 4) grain size analysis.

A radiocarbon chronology for Lake Von sediment cores identifies a basal age of 17,600 cal yr BP. From 17,600 to 14,500, we observe declining $d^{13}C$ and a transition from inorganic glacial silts to lacustrine sediments that reflects the retreat of ice in the basin and conditions that favoured increased influx of terrestrial carbon and/or reduced productivity. From 14,500 to 9,000 cal yr BP, we observe relatively low $d^{13}C$ values and constant C_{31} n-alkane dD values that may reflect higher lake levels. From 8,000 cal yr BP to present, we observe a distinct shift towards more positive $d^{13}C$ values and more variable n-alkane dD values that we attribute to a combination of enhanced productivity and more variable hydrologic conditions. We will integrate these results with existing Southern Hemisphere paleoclimate records to evaluate how the latitudinal position of the westerlies might have influenced Lake Von hydrology.

POSTER

**NEW INSIGHT INTO POSSIBLE GEOMETRICAL
RELATIONSHIPS IN PROGRADING CLINOFORM
SUCCESIONS: FROM ONE SIDE OF THE GLOBE TO
OTHER**

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The study details an Early Triassic northwesterly prograding sedimentary succession studied on three parallel seismic lines on the northern Barents shelf. Seven distinct clinofolds can be resolved which outline a full cycle of relative sea-level change.

Various clinofold attributes (such as preserved top-sets, shelf-edge angle, shelf-edge and bottom-set toe advance and depositional rates) have been calculated and comparisons between them made. An inverse relationship between thickness of preserved top-sets and the advance of the bottom-set toe is assumed, however, the study finds an almost perfectly inversely proportional relationship, indicating a fundamental link. We also find a near-perfect correlation between rate of deposition and advance of the toe, with only a relatively close relationship to the advance of the shelf-edge. In the studied system it therefore appears that the advance of the toe is governed solely by rate of sediment influx, whereas shelf-edge advance is also governed by relative sea-level change.

The Early Triassic shelf-edge stacks up against the Gardarbanken High suggesting it was an obstacle to sediment influx further northwest. We detail this influence across the three lines as both shelf-edge advance and sediment influx increases away from the High. The influence is also noticeable in the onlap as opposed to base-lap of the clinofolds onto the basin-floor deposits, which suggests that the Gardarbanken High limited lateral accommodation space.

It is aimed to further the understanding of geometrical relationships, lateral and vertical accommodation space and structural influence on sedimentary clinofold successions by expanding to include new data from the southern Basins of New Zealand.

ORAL

**BUBBLE COLLAPSE AND ERUPTION DYNAMICS AT
RUAWAHIA DOME, TARAWERA**

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Effusion of lava domes follows magma stagnation, connection of bubbles and degassing, allowing bubble collapse instead of fragmentation. The style of lava dome eruptions will then be affected by volatile, bubble and crystal contents, palaeotopography, effusion rate and vent morphology. Here, we present an eruption model based upon mapping of flow bands and internal structures of Ruawahia Dome, crystal content and vesicularity variation combined with results of high temperature, compression experiments from Ruawahia Dome lavas. These are used to interpret the complex internal structure, morphology and dome failure at Ruawahia Dome.

Ruawahia Dome is a crystal rich (40-60%), high silica (~76%) rhyolitic lava dome erupted during the 1314AD Kaharoa eruption at Tarawera volcano, Okataina Caldera Complex. Dome extrusion began shortly after the end of an explosive eruption phase (forming a large pyroclastic cone) with a lava flow to the northwest and a dome confined within a pyroclastic cone crater that produced near vertical flow bands above the vent. Subsequent dome extrusions next to this initial eruption formed breccia zones. Later domes erupted outside of the pyroclastic crater and formed large thick flows to the northwest and southeast of the vent areas. The morphology of these flows can be explained by stalling flow fronts, that produced a bulldozer-like effect that culminated in compression and thickening of the flow lobe, producing ramp structures and disruption of flow bands at the flow margins.

The crystal-rich Ruawahia lava will produce numerous small cracks within crystals under compaction at low strain. As bubbles collapse, viscosity increases until a crystal framework is produced that preserves ~18% porosity. As bubbles in the flow front are squashed, and the lava cools, viscosity increases. Weakening and oversteepening of the flow front from cracking and viscosity increase promotes dome collapse and the formation of block and ash flows.

ORAL

POSSIBLE CAUSES OF WEAK BSRS ON THE HIKURANGI MARGIN

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Gas hydrates are gas (usually methane) caged by water molecules under low temperature and high pressure, physically resembling ice. Gas hydrates are usually buried in the first few hundred meters under the outer continental ocean floor. They may constitute a source of energy in the future. The presence of bottom simulating reflections (BSRs, reflections from the interface between hydrate- and gas-filled rocks) and anomalous seismic responses are commonly used to indicate the existence of gas hydrates. Furthermore, the strength of BSRS and amplitude versus offset (AVO) anomalies may identify the quality of gas hydrate reservoir rocks.

The Hikurangi Margin, a promising gas hydrate province offshore of New Zealand, often has weak BSRS compared to other areas globally. Previous studies have attributed this pattern to patchy gas saturation, i.e., the presence of patches of sediments that are fully water saturated mixed with patches that are gas filled. We here show that alternatively, weak BSRS could be caused by gas saturating fractures rather than primary sediment pore space.

We calculate BSR reflection coefficients of sediments containing gas and hydrate-filled fractures by employing a combination of Kuster-Toksöz and Biot-Gassmann rock physics models. Our results show that in addition to patchy gas saturation there are several other possible reasons that could lead to weak BSRS, in particular, relatively high average velocity and density of background sediments, very low concentrations or absence of gas and a high aspect ratio of the pore space. We predict AVO responses for these models and show first comparisons with the AVO character of seismic data from the Hikurangi Margin.

ORAL

COMMUNICATING VOLCANIC ASH FALL HAZARD INFORMATION TO STAKEHOLDERS

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Volcanic ash fall is one of the most frequent and widely distributed volcanic hazards. It can cause impacts to human health, primary production and critical infrastructure (lifelines). The spatiotemporal distribution of volcanic ash fall is controlled by eruption processes and prevailing wind conditions, making distribution highly variable. This creates challenges for preparing and responding to ash fall hazards. Therefore, ash fall forecast maps are important tools for stakeholders who benefit from a warning of ash fall, i.e. so they can take preventive measures to protect their assets. This research investigates 'what is an optimal short-term natural hazards forecast map, with a special focus on volcanic ash fall?' Using literature review and interviews with pertinent scientists and stakeholders to identify key themes and requirements, critical elements of an effective short-term natural hazard forecast map have been identified. These include: style of base map, amount of geographic information, clutter, colour, clarification of uncertainty, hazard identification, and hazard extent. A matrix 'score-card' has then been developed to evaluate the effectiveness of such maps, with each element given a score between one and five based on a set of criteria. Pertinent stakeholders throughout New Zealand will be surveyed to determine their needs and explore if their priorities differ from those of the scientists and the broader suggestions of literature. These results will be presented.

POSTER

**CRETACEOUS TO MIOCENE RECORDS OF
ARAUCARIAN FOSSILS FROM SOUTH ISLAND,
NEW ZEALAND: FOLIAGE, LEAVES, WOOD, BARK,
POLLEN, CONES AND RESIN**

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Araucarian fossils comprising foliage, isolated leaves, wood, bark, cones, cone scales, resin and pollen are widespread throughout New Zealand from the Cretaceous to the present day, although they can only be assigned confidently to *Agathis* or *Araucaria* where leaf cuticle is preserved. *Araucaria* no longer forms part of the New Zealand flora, but *Agathis* is an important canopy tree in northern North Island. Recently, a large block containing well-preserved foliage of *Araucaria haastii* Ettingsh. was collected from a Late Cretaceous site at Shag Point, together with a block with foliage from the Late Cretaceous Roa Mine near Paparoa. Individual fossil araucarian leaves from several species are known from other Late Cretaceous sites, including Horse Range, Otago; near Pakawau, NW Nelson; Greymouth Coalfield; Cameron's Pit, South Canterbury; and near Lake Moeraki, South Westland. Well-preserved bark with lenticels from the Late Eocene Pikipiko fossil forest resembles bark of the modern Australian species *A. cunninghamii*. Teredinid-bored araucarian logs are also known from a Paleocene site near Wangaloa, and well-preserved silicified wood is present in the Late Oligocene Pomahaka Formation. *Agathis* leaves with cuticle are present in the Gore Coal Measures at Newvale Mine, Waimumu, and in the silcrete at Landslip Hill. Cone scales are common at several localities; a complete cone *Wairarapaia mildenhallii* (perhaps related to *Wollema*) was described from mid-Cretaceous strata at Coverham. Resin sourced from araucarians is present from the Late Cretaceous through to the Miocene at numerous South Island localities. Araucarian pollen is also widespread: *Araucariacites australis* (Cookson) is similar in morphology to modern *Araucaria* and some *Agathis*, and *Dilwynites granulatus* Harris to other *Agathis* and *Wollema*.

POSTER

**POST-SUPERERUPTION MAGMATIC
RECONSTRUCTION OF TAUPO VOLCANO, NEW
ZEALAND**

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Large explosive silicic supereruptions (>~450 km³, magma) have received much attention because of the challenges in explaining how such large volumes of magma are accumulated and stored, and over what time intervals. The processes that follow supereruptions are less fully documented and, in particular, on how and over what time scales the overall magma system moves into a 'post-caldera' mode of activity. The 530 km³ Oruanui eruption from Taupo volcano, New Zealand, is the world's youngest (25.4 ka) supereruption. Following this event and after only 5 kyr of quiescence, Taupo volcano erupted three dacitic pyroclastic units of modest volume (≤ ca. 0.1 km³), followed by another 5 kyr year time break, and then eruption of the modern sequence of rhyolitic units starting at ca. 12 ka. Here we present U/Th model age dating of zircons extracted from the post Oruanui eruption products to investigate how Taupo's magmatic system was reactivated following a supereruption. Zircon model ages in first erupted rhyolites indicate that there is minimal or no inheritance of crystals from either of the two dominant age modes (35 and 90 ka) in the Oruanui magma source. Post Oruanui age spectra are typically centered close to eruption ages with subordinate pre 300 ka plutonic and pre 100 Ma greywacke grains. In addition, there is consistent inheritance of grains between the temporally spaced but geographically overlapping post Oruanui eruption groups, allowing the identification of systematic dominant age peaks since the Oruanui supereruption. We interpret this consistent and repeated pattern to result from recycling of crystals from post supereruption episodic heating and cooling cycles, reflecting periods of magmatic rejuvenation and eruption, versus cooling and crystallization, acting within a crustal protolith independent of that which was dominant in the Oruanui system.

POSTER

STRUCTURE, LATE QUATERNARY SLIP RATE, AND EARTHQUAKE POTENTIAL OF MARINE REVERSE FAULTS ALONG THE NORTH WESTLAND DEFORMATION FRONT, WEST OF THE ALPINE FAULT

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To underpin improved assessment of earthquake and tsunami hazards along the West Coast of the South Island, we reinterpreted archived marine seismic reflection data and bathymetry, to identify and map Late Quaternary faults between Cape Farewell and northern Fiordland. Earthquake sources are characterised following empirical methods used in the current New Zealand seismic hazard model (*Stirling et al., 2012; BSSA*).

Active, east-dipping, reverse faults, lying approximately parallel to the coast, within 30 km from shore, underlie the seafloor along extensive regions of northern and southern Westland, but no active faulting is recognised for 170 km off the central Westland coast, between Hokitika and Paringa.

Off northern Westland, over the 320 km distance between Hokitika and Cape Farewell, 10 earthquake sources are interpreted along the regional deformation front. These include five segments of the Cape Foulwind Fault, the Kahurangi and Kongahu faults, and the newly named Farewell, Elizabeth, and Razorback faults. These structures are predominantly Cretaceous rift faults, reactivated under compression. The faults range in length from 10-120 km, and are interpreted to be capable of generating earthquakes with large magnitudes ranging from M_w 6.4 to 7.8. Best estimates of fault slip rates were derived where possible from interpretation of Late Quaternary (<20 ka) sedimentary sequences and specific sea-level change surfaces, and range between 0.1-0.3 mm/yr. Best estimates of recurrence intervals for individual fault sources range from about 7500 years to 30,000 years. Large uncertainties in slip rates are reflected by a large range of potential earthquake recurrence intervals.

Off southern Westland and northern Fiordland, three major coast-parallel faults within 15-30 km from shore include the Milford Basin (Madagascar) and Barn thrust faults, and the newly-named Jackson Fault. They are inferred to be capable of

generating earthquakes of magnitude M_w 7.2 to 7.6, with recurrence intervals ranging from about 6000 years to 27,000 years.

ORAL

THE STATUS AND FUTURE OF QUATERNARY STRATIGRAPHY IN NEW ZEALAND

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The 1st edition 1:250,000-scale geological map of New Zealand ('4-Mile map') required a nationwide framework for mapping Quaternary deposits (Suggate 1965; NZGS Bulletin 77). The philosophy adopted was that in any particular area, older deposits can be differentiated from younger deposits using qualitative age indicators, such as superposition, relative heights/positions and weathering contrasts. Deposits of approximately the same age in a particular area comprised a formation, whose type locality was implied through the geographic place chosen for the formation name. Under Suggate's scheme, depositional facies, such as glacial till versus outwash gravels, were assigned member status, although most '4-Mile' sheets subdivided members tacitly using different overprints rather than by name. Where good basis existed to infer connections between adjacent areas, such as downstream merging of fluvial plains, a named formation could be extended as far as seemed reasonable. Thus, the stratigraphy of New Zealand's Quaternary deposits comprises a framework of local to regional formations, regional to inter-regional correlations and tentative assignment to glacial/interglacial climatic events. Lateral changes in formation name highlighted correlation uncertainties, but a downside was a plethora of formation names.

QMAP used similar methods, but units are identified by correlation to Marine Isotope Stages (MIS). Much variation exists between QMAP sheets as to whether existing names were identified. Some map texts list formations, some tabulate QMAP units versus formation names, some include formation names in the digital data, while others offer no audit trail to earlier nomenclature.

QMAP units were not intended to replace existing formation names. It remains valid and proper to use the established names, albeit requiring some detective work through Stratigraphic Lexicon or NZ Geology webmap to track names down. I advocate the continued use and development of the existing

formational nomenclature alongside QMAP terminology, especially in the context of localised or intraregional studies.

ORAL

ORAL

**THE PALAEOSEISMIC HISTORY OF KAIAPOI,
NORTH CANTERBURY FROM
PALAEOLIQUEFACTION INVESTIGATION**

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Liquefaction features formed in the subsurface may be preserved within the geologic record, such as the dikes that fed the surface vents. Analysis of the stratigraphic relationships and likely ages of these features combined with geotechnical testing (i.e. Cone Penetration Tests) provides site specific information on the recurrence intervals and associated PGAs of strong ground motions. The identification and interpretation of these paleoliquefaction features relies on detailed observation and documentation of modern liquefaction features as well as records of historic earthquakes. Prior to the Canterbury Earthquake Sequence (CES) the only recorded liquefaction in the wider Christchurch area was in Kaiapoi, ~15km north of Christchurch, during the 1901 Cheviot earthquake. Two sites within 250m of the Kaiapoi River, that are thought to have liquefied during this event were selected for subsurface trenching to identify and analyse the preservation potential, geometry, and stratigraphic relationships of these features. At one site, the stratigraphy from 0.4m to the trench floor exhibited soft sediment deformation containing a fragmented palaeosol surrounded by oxidised, well sorted, fine sand. This morphology is consistent with the structures observed in trenches through CES aged surface blisters. The upper 0.4m of the trench exhibited no deformation, with the trench stratigraphy cross-cut by a CES aged sub-vertical planar feeder dikes that fed the surface vents. The other site revealed palaeoliquefaction features including a sill of oxidised, well sorted, fine grained sand with bioturbated contacts and a likely buried sand blow that aligned with and was cross-cut by the CES features in the subsurface. The presence of palaeoliquefaction at both sites confirms that this area liquefied in an event prior to the CES. As these features are located at similar depths it indicates they may have formed in the same event, samples were obtained from both for radiocarbon dating to further constrain the likely timing of this event.

**URBAN GEOLOGICAL MAPS: OUTPUTS AND
DELIVERY**

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Following the 2010 Darfield Earthquake, GNS Science has directed most of its Urban Geological Mapping project's resources into mapping materials beneath Christchurch, through understanding their properties, geological relationships and depositional environments. This project has resulted in a re-evaluation of what defines the geological map product and decisions are being made about the format of publication for maps, models and geological information. The subsurface 3D focus of the Christchurch geological map is the new element being incorporated into the urban geological map product.

Each urban centre has area-specific geological issues for which outputs will be tailored. The first priority for each area is production of a geological map at appropriate relatively detailed scale (1:10,000 to 1:25,000 depending on the area covered). Geomorphic maps will be compiled using lidar where available, to record current and unmodified surface features. Reconciliation of geomorphic maps with soil maps provides a representation of materials in the metre below the ground surface. Some urban areas will be complemented with 3D geological representation, probably mostly at a basic level (cross sections, structure contours, isopachs, etc.). Appropriate data sources for this work include digital drillhole log databases and CPT geotechnical soundings, tunnel logs and any available geophysics. Where such information is available, it will be possible to make generalised derivative dataset of subsurface engineering and geotechnical properties. Each urban geological map product will have a cartographic map in a digital image format, a fully attributed GIS dataset and will be accompanied by a text explaining and characterising map units. A 3D geological model will be provided where subsurface data are sufficient. Maps and text will be internally and externally peer reviewed. These data will be made available via digital image and GIS vector data using DVD media and internet

delivery. For some cities printed map production may be justifiable.

ORAL

PACIFIC PLATE TILTING IN THE HANGINGWALL OF THE ALPINE FAULT: CONSTRAINTS FROM RSCM GEOTHERMOMETRY OF ALPINE SCHIST

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Models of the Southern Alps generally show Pacific plate delamination, with lower crustal accretion into a thickened crustal root, and mid-upper crustal rocks experiencing variable amounts of tilting and rotation as they are exhumed across the Alpine Fault. Carbonaceous material in 140 Alpine schist samples, from 13 low- to high-grade transects, has been analysed by Raman spectroscopy (RSCM) to inform tectonic models. During diagenesis and metamorphism, carbonaceous material (CM) in sedimentary rocks is progressively transformed into graphite (graphitisation), with an evolution of carbon organisation that can be used as a geothermometer. Alpine schist RSCM temperatures increase systematically with metamorphic and textural grade, with reversals occurring only across folds (Otoko and Waitaha areas) and any apparent steps where there are faults, providing confidence the method's precision is near the $\pm 10^\circ\text{C}$ analytical standard errors. The RSCM temperatures are generally higher than existing temperature estimates from petrology, and the origin of this slight difference is still under investigation. Biotite-in, garnet-in and K-feldspar-in isograds occur at different temperatures along the schist belt, most likely reflecting variable ages of peak metamorphism. RSCM temperatures are plotted with respect to structural thickness (D) perpendicular to the Alpine Fault, assuming a 45° dip. Paleothermal gradients vary considerably both along and across different parts of the Alpine schist belt. Gradients are consistently low, $< 20^\circ\text{C}/\text{km}$, within the garnet-oligoclase and K-feldspar zone, suggesting these rocks were neither fully rotated, nor structurally thinned, during exhumation. Gradients within chlorite- and biotite-zone rocks are variable, being $10\text{--}20^\circ\text{C}/\text{km}$ in the south (Haast, Moeraki, Karangarua transects), but elsewhere reaching $30\text{--}60^\circ\text{C}/\text{km}$ (Waikukupa,

Franz, Whataroa, Toaroha transects). The new RSCM temperatures constrain thermal conditions experienced within the orogen, with temperature gradients reflecting varying amounts of tilting and structural re-organisation of the Pacific plate in the hangingwall of the Alpine Fault.

POSTER

QUATERNARY SEDIMENTARY SYSTEM OFF THE SOUTH COAST OF DUNEDIN IMAGED BY HIGH-RESOLUTION SEISMIC DATA

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The coastal Otago sedimentary sequence consists of a broad westward marine transgression and regression over Cretaceous fluvial sediments deposited on a basement of Otago Schist. The youngest / shallowest of these sediments is investigated in this study using a series of high-frequency boomer seismic lines collected off the coast of Dunedin's ocean beaches between Blackhead and Smalls Beach in water depths extending approximately from the surf break to 40 m. The late Cretaceous to Tertiary sequence of sedimentary units in this region have experienced faulting and erosion that has imparted a gentle ($3\text{--}7^\circ$) southeast dip to the strata through the Dunedin area; which is clearly observed in many of the seismic lines available here. Volcanic units associated with the Miocene Dunedin Volcanic Complex are also found in the offshore region (including White Island, roughly 2 km off St. Clair Head). Quaternary sedimentation thickens rapidly offshore onto the modern continental shelf. In the shallow region near the Dunedin beaches, seismic data show evidence of repeated channeling in (presumably) Pleistocene units deposited and eroded during Milankovich-scale transgressions and regressions. These channels are linked to streams flowing toward the coast from a paleovalley that has subsequently been filled by the South Dunedin tombolo. The most recent Holocene sediments consist predominantly of quartzo-feldspathic Clutha-derived sand that is preferentially pushed from the shelf onto the ocean beaches between headlands.

POSTER

CHANGES IN NITRATE UTILISATION AND PRODUCTIVITY ACROSS THE SUBTROPICAL FRONT SINCE THE LAST GLACIAL

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The Subtropical Front (STF) is the boundary between the low nutrient, warm subtropical waters of the Subtropical gyre and the high nutrient, cool subantarctic waters of the Southern Ocean. The mixing of these two water masses at the Subtropical Frontal Zone results in significant primary productivity today.

Nitrogen (N) is an essential building block of all life. It is a nutrient that underpins biological productivity and is linked to the global climate cycle. Phytoplankton in the ocean preferentially incorporate the lighter isotope of N, thus higher ¹⁵N/¹⁴N ratio (denoted d¹⁵N) measured on organic matter in bulk sediments provides information on the nutrient utilisation, thus if the d¹⁵N increases it suggests that either there is an increase in surface productivity or reduction in nitrate supply. Therefore changes in d¹⁵N in sediment cores can be exploited to reconstruct N-budgets over time. Analyses of surface sediments around the world including the SW Pacific has found that the d¹⁵N reflects the large variations in surface nitrate concentrations. We will present some new data from several cores around the New Zealand region to look at changes in the nutrient utilisation either side of the STF since the last glacial. The down core d¹⁵N data suggest changes in the nutrient utilisation since the last glacial. The increase in d¹⁵N during the deglacial may be related to increased productivity or a decline in nitrate supply. The latter could be the result of shifts in the local STF over the core sites. The d¹⁵N changes are not coincident with the sea surface temperature changes in the same cores, indicating a decoupling of the temperature and nutrient gradient that is currently present across the STF. This suggests that nitrate supply may not be controlled locally, but may be influenced by global changes in the nitrate budget and supply.

ORAL

RHEOLOGICAL IMPLICATIONS OF FLUID-ROCK INTERACTION REVEALED IN FAULT ROCK RECOVERED DURING THE ALPINE FAULT-DEEP FAULT DRILLING PROJECT (DFDP-1)

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Oblique dextral motion on the central Alpine Fault, New Zealand, in the last c. 5 Ma has exhumed garnet-oligoclase facies mylonitic fault rocks from depths of <35 km. During the shallowest increment of exhumation, co-operative fluid infiltration, reaction, and brittle deformation of these mylonites has resulted in complex mineralogical and lithological variations that we have characterized from core retrieved during DFDP-1 drilling at Gaunt Creek. Preliminary petrophysical, geochemical, and lithological results reveal that a narrow (metre-thick) fault core of highly comminuted cataclasites and fault gouges is bounded by a much thicker (decametre-scale) damage zone comprising cataclasites, protocataclasites, and fractured mylonites. The sequence is comparable to that previously described from composite outcrop logs of this section of the fault zone. The damage zone is overprinted by an alteration zone extending up to c. 20 m from the principal slip zone (PSZ) of the fault (Sutherland et al., 2012). At least two stages of chemical alteration have occurred. At temperatures at or near the brittle-to-ductile transition, metasomatic alteration reactions resulted in albite or K feldspar replacement by muscovite, and biotite (phlogopite) replacement by chlorite (clinochlore). Abundant chlorite within alteration zone cataclasites indicates that hydrous chloritization of epidote and hornblende (actinolite) also occurred. At lower temperatures, depending on local redox conditions, primary minerals were altered to kaolinite, smectite and/or pyrite or smectite, kaolinite, Fe-hydroxide (goethite) and/or carbonate. The interplay between fluid-induced changes in fault zone chemistry, mineralogy, (micro)structure and seismogenesis is explored in this study, which presents new results from hydrothermal friction

experiments, high velocity friction experiments, field studies, and stress analyses.

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ORAL

HETEROGENEITY OF THE HIKURANGI PLATE INTERFACE, FROM SEISMIC S-TO-P CONVERTED PHASES

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Along the Hikurangi subduction margin, regions of the plate interface recognised to be weakly coupled are associated with high values of Vp/Vs (the ratio of P-wave to S-wave speed) across and above the interface, suggesting that fluids are present across and above the plate interface. The region of strong coupling inferred from geodetic inversions is characterised by moderate Vp/Vs values in the overriding plate and a sharp gradient of Vp/Vs across the plate interface, suggesting that fluids remain in the subducted crust. Based on those observations, it has been proposed that plate coupling along the subduction margin may be controlled by the ability of fluids to cross the plate interface. A sharp gradient in seismic velocities can promote the conversion of one seismic phase into another, depending on a range of factors such as the angle of incidence. We performed a systematic search for Sp conversions (S-waves from earthquakes occurring in the subducted plate which are converted into P-waves at the plate interface) in order to map regions of the plate interface that might have a high fluid content. We find that the distribution of strong Sp conversions along the Hikurangi margin shows no obvious spatial correlation with previously inferred plate coupling. Our observations suggest that the plate interface is relatively heterogeneous at the scale of a seismic wavelength, and that plate coupling may be dominated by larger-scale factors, such as stress regime in the upper plate or the rheology on either side of the plate interface.

POSTER

MURIHIKU OLISTOLITHS OR RE-DEPOSITED CONGLOMERATES IN THE EARLY MIOCENE, TARANAKI FAULT ZONE; ONE-DIMENSIONAL VIEW-POINT FROM MAUKU-1 FMI LOG

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Mauku-1 was drilled by Kea Petroleum in early 2013 on the west coast Taranaki/Waikato, spudding into Early Miocene mudstones that are exposed at Tirua Point, a few Km to the north. Target for the well was the Eocene Kapuni Formation at around 2700m below Triassic Murihiku that had been overthrust westwards along the Taranaki Fault. The focus for this presentation is the Miocene section above the basal unconformity with the Murihiku.

From the mix of fine grained silty mudstones with Miocene ages (Altonian) and coarse grained volcanoclastic sandstones/conglomerates with Triassic ages (Etalian), coupled with a fast or slow ROP, it wasn't apparent while drilling where this unconformity was to be placed. Having run the electric logs in 12 ¼" hole which comprised Schlumberger PEX and FMI it still remained an interpretive conundrum.

Certainly the background sedimentation was within moderately deep water (800m) with planar bedded mudstones largely unaffected by bottom currents or bioturbation. Introduction of conglomerates in beds up to 17m thick was sudden with little obvious gradational contacts or incorporation of mudstones into a basal lag. There appears however to be little/no attendant deformation within the underlying muds. Within an interval of 435m (513 to 948mAH) the conglomerates comprise some 36% of the total. No sequential arrangement to their input is apparent.

Our interpretation has tended towards two end members: one of contemporaneously reworked and proximally deposited beds derived from a nearby Triassic conglomerate, or otherwise olistoliths of Triassic conglomerates emplaced intact. The triggering mechanism was most likely similar for both i.e. movement on one of the spurs to the Taranaki Fault. We present some excellent images from the FMI and other logs to enable the audience to help in elucidating a solution to the conundrum.

POSTER

**PYROCLASTIC FLOW DYNAMICS ASSOCIATED
WITH RECENTLY-EXPOSED UPRIGHT TREE STUMPS
WITHIN THE 232 AD TAUPO IGNIMBRITE, WAIPA
VALLEY, SOUTHEAST OF TE KUITI**

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Visible impacts on vegetation by pyroclastic density currents can provide information on dynamic emplacement processes. Within the last 10-15 years rapid erosion by the Waipa River southeast of Te Kuiti has removed an approximately 250 m-long by 100 m-wide section of the 232 AD Taupo ignimbrite, and exposed 28 tree trunks preserved in their original upright position. The Taupo ignimbrite at this site, which is 75 km northwest of its source caldera, is confined to bottom of the 250 m-deep Waipa Valley, and forms a terrace on the eastern river bank. Buried vegetation beneath or within the Taupo ignimbrite has been previously documented elsewhere, including the famous Pureora buried forest about 50 km from the source caldera. However, the preservation of trunks in their growth position is unique. The distribution, dimensions and damage characteristics of the tree trunks, as well as the physical characteristics of the Taupo ignimbrite have been documented. The ignimbrite is a 20 m-thick massive, lithic-poor valley-ponded deposit, with around 10-15% pumice lapilli; although it is stratified with a higher abundance of pumice in the top 2 – 3 m. Individual tree trunks are typically 40 to 150 cm in diameter and are up to 6 m high, however, the height decreases systematically in the downstream direction. Tree trunks have jagged, fractured or tapered tips indicating that the tree canopies were torn off violently and the remaining tips continued to be abraded. The degree of charring varies between trunks, although most are uncharred and bark layers are either intact or variably stripped off. The preservation of tree trunks at systematic heights alludes to vertical variations in dynamic pressure within the Taupo pyroclastic flow or temporal changes in dynamic pressure during progressive aggradation of the deposit. The effect of 'sheltering' on the lee-side of a topographic high, which occurs immediately up-flow, may also have impacted on the height distribution.

ORAL

**NEW PALEONTOLOGICAL AND
SEDIMENTOLOGICAL RESULTS FROM
CANTERBURY BASIN IODP EXPEDITION 317, SITE
U1352**

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Integrated Ocean Drilling Program (IODP) Expedition 317 investigated the record of global sea-level change in sedimentary sequences of Canterbury Basin, where high rates of Neogene and Quaternary sediment supply have preserved a record of depositional cyclicity, tempered by eustasy and strong submarine currents. The principal scientific objective of the expedition was to date 19 seismically-defined Miocene to Recent sequence-bounding unconformities of regional extent, and to sample associated facies both landward and seaward of paleo-shelf edges to quantify eustatic amplitudes.

The expedition cored a transect of three shelf sites located landward of seismically-defined paleo-shelf edges (Sites U1353, U1354, and U1351), and an upper slope site located basinward of paleo-shelf edge (Site U1352). This presentation focuses on new paleontological and sedimentological results from the fully cored Recent to late Eocene succession of Site U1352.

The cored succession at Site U1352 is biostratigraphically subdivided into four major units. 1) Recent to Pleistocene: a progradational upper slope succession with subtle biostratigraphically-defined hiatuses, and abundant downslope shelfal microfossils. 2) Pliocene to latest Miocene: a progradational, upper to lower slope succession with no biostratigraphically-resolved hiatuses, and decreasing abundances of downslope-transported shelfal microfossils. 3) Late Miocene to early Miocene: a lower slope, sediment drift succession with six biostratigraphically resolved unconformities, and common reworked microfossils. 4) Early Oligocene and late Eocene: deep basin floor successions of pelagic ooze with no faunal reworking.

Sediments recovered from this site also provide a unique record of depth-related diagenetic changes and lithification, in a succession that transitions from unconsolidated sandy-mud at the seabed, to well cemented fine-grained limestone at 1927 m TD. Early products of lithification involve incipient

carbonate nodule development from ~10 m depth. Thin sections show the first signs of compaction at ~347 m and pressure solution at 380 m. Styolites are common below 1660 m, and soft sediment injection features occur below 1680 m.

ORAL

MID-CRETACEOUS FLUVIAL TO SHALLOW MARINE SEDIMENTS, PITT ISLAND: IMPLICATIONS TO RESERVOIR STUDIES OF THE GREAT SOUTH BASIN

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The Tupurangi Formation exposed on Pitt Island, represents a mid-Cretaceous rift succession which serves as a useful analogue for equivalents of the Great South Basin. Excellent exposures of the Tupurangi Formation on Pitt Island, part of the Chatham Islands group, are Motuan to Teratan (late Albian-Santonian) in age.

During mid-Cretaceous time, this area was part of a contemporaneously active rift-basin and bounded by west-east trending normal faults. Four seismically resolvable units can be identified at this time and indicate an overall sediment fill up to 0.5 sec TWT (Two Way Time). The lowest unit is characterised by highly dipping reflectors, variable amplitude and discontinuous reflections and represents initial rift fill sediments in alluvial fan and fluvial environments. Overlying units show moderate to high amplitude, fairly continuous reflectors interpreted as prograding delta and marginal to shallow marine systems.

In outcrop, conglomerate, sandstone, alternating sandstone and mudstone and mudstone are exposed. They represent deposition in a variety of fluvial, deltaic and shallow marine settings including sandy distributary channels, fine-grained overbank peat swamps, paleosols, bioturbated estuarine mudstones, and shallow marine cross-bedded sandstones. Compositionally the sands are feldsarenite and subfeldsarenite, similar to compositions of sands of the Hoiho Group in Rakiura-1. Lithics are most typically igneous, and include rhyolite, rhyodacite, ignimbrite, granodiorite, and granite together with dioritic gneiss, quartzite, siliciclastic and calcareous siltstone. These lithologies are not presently represented in the basement geology of the Chatham Islands, which is overwhelmingly schistose. Paleocurrents indicate the sediment was derived from the north or east (Campbell et al. 1993). We suggest the sediment that forms the Tupurangi Formation was derived from a terrane

dominated by igneous rock types which is no longer exposed, and that if the schist that now forms the northern parts of Chatham Island were exposed in Cretaceous time, they did not contribute sediment to this particular part of the rift basin.

POSTER

DEPOSITIONAL AND TECTONIC HISTORY OF THE KUPE REGION IN THE SOUTHERN TARANAKI BASIN

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The Southern Taranaki Basin is currently being mapped on seismic reflection profiles as part of the GNS Science "4D Taranaki Project", which aims to produce a digital atlas of the seismic stratigraphy and structure within the basin, including derivative products such as 4D petroleum generation and migration models. High resolution mapping of up to 16 seismic horizons using both 2D and 3D seismic reflection lines tied to 8 wells constrains the structural evolution and depositional history of the Kupe area, Southern Taranaki Basin. Basin strata up to 9 km thick provide a near complete record of sedimentation and deformation since the Late Cretaceous (~85 Ma) that reflect changing plate boundary configurations.

Late Cretaceous to Paleocene strata record extension from ~85 Ma to ~55 Ma on the Manaia fault during Gondwana breakup. A 15-20 Ma period of tectonic quiescence and passive margin sedimentation followed and ended with the onset of mild shortening between c. 40 and 35 Ma. Contraction is manifest as reverse faulting and folding with sediments locally sourced from uplifted anticlines, transported westwards across the Taranaki and Manaia faults and deposited to form thick Oligocene to Miocene successions (> ~1.5 km) on the downthrown sides of the faults. Seismic facies mapping suggests that these faults (and their associated folds) locally influenced sediment dispersal and deposition throughout the Miocene with paleocurrent directions variously to the north (parallel to the structures) and northwest. Cessation of reverse faulting was followed by the start of normal faulting at ~3.6 Ma which does not appear to have strongly influenced the patterns of sedimentation in the Kupe area. These late stage normal faults may however locally

promote the vertical flow of hydrocarbons through the regional seal.

ORAL

PALEOMAGNETIC CONSTRAINTS ON VERTICAL-AXIS ROTATIONS IN THE ACTIVE WOODLARK RIFT, SE PAPUA NEW GUINEA

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The Woodlark Rift in SE Papua New Guinea is a continental rift ahead of active oceanic spreading in the Woodlark Basin. The rift separates Australian Plate to the south from anticlockwise rotating Woodlark Plate to the north. While the Woodlark Basin contains a seafloor spreading record since ~6 Ma, and GPS data describe present-day plate motions, the Neogene evolution of continental rifting is poorly constrained. We compare characteristic magnetizations with expected field directions for the Australian Plate to constrain long term crustal motions across the Woodlark Rift. We obtained >250 oriented cores from Miocene to late-Pliocene rocks from across the rift. From a total >300 step-wise demagnetization profiles, ~180 characteristic remanence components contribute to 6 inferred primary directions across 4 key localities.

These localities, from north to south, record: 1) The Amphlett Islands (~3 Ma), ~10° anticlockwise rotation, near the northern extent of rifting; 2) NW Normanby Island (~3 Ma), ~20° clockwise rotation, within the rift; 3) Cape Vogel, on the mainland Papuan Peninsula, 3 mean directions from a sedimentary sequence with ~25°, ~10, and ~-7° declination anomalies for early-Miocene, mid-Miocene and early-Pliocene respectively; 4) Fife Bay, a ~22° declination anomaly for Miocene dikes on the south coast.

At locality 1 paleomagnetic data are consistent with GPS plate motions. From these results we infer that the current kinematics in this area were established by at least ~3 Ma, and that locality 1 is fully on the Woodlark Plate. The results for locality 2 indicate a clockwise rotation, also seen in

anomalous GPS vectors there, and may record development of an incipient dextral transfer fault.

Time-varying declination anomalies from localities 3 and 4, suggest that rifting began by ~15 Ma, 7 Ma earlier than previously inferred. Furthermore, the locus of extension may have shifted north of the mainland by ~6 Ma.

ORAL

OROGENIC CLUES ALONG THE CHATHAM RISE MARGIN OF ZEALANDIA

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We draw attention to a mystery unit of regional extent within Zealandia that relates to local orogenesis and erosion of the Gondwanan margin prior to rifting of Zealandia from Gondwanaland and prior to formation of the Tasman Sea floor. This unit is worthy of targeted investigation. It is Seismic Unit IIA, first recognised from seismic interpretation of data from the Chatham Rise and offshore Canterbury in the mid-1970s. As yet, it has not been intercepted in any exploration drill-hole. This paper will describe what is known of this seismic unit and why it is so significant. Our interest arises from recent investigations of the Tupurangi Formation on Pitt Island, Chatham Islands, and consideration of the provenance of these fluvial-estuarine sediments (up to 400 metres thick) of mid-Cretaceous age (Motuan-Teratan; late Albian-Coniacian; 100.3 - 86.5 Ma). Most notably, these sediments preserve a significant reworked palynomorph flora of Permian, Triassic and Jurassic age. These fossils demand explanation. They are well-preserved, more so than the mid-Cretaceous flora within the Tupurangi, and yet reflect relatively low thermal maturity. They must relate to sedimentary rocks (sandstones and siltstones) of only moderate induration. About 40% of the clasts in the Tupurangi are sedimentary. On the basis of our knowledge of mainland New Zealand, they are most likely derived from Murihiku Terrane or age correlatives such as Topfer Formation (Western Province). Most interestingly, they must be derived from sources that are relatively proximal to the Chatham Islands, within a few hundred kilometres at most. They may well be telling us something about Seismic Unit IIA.

ORAL

FAN-DELTA PROGRADATION FOLLOWING THE 2008 ERUPTION OF CHAITEN VOLCANO, CHILE

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Most deltaic deposits accumulate in the fluvial-to-marine transition zone recording the sensitive interactions of terrestrial and marine sedimentary processes. Timescales of physical, chemical and biological processes means that observations of delta evolution require at least multi-decadal monitoring. Following the 2008 Chaiten Volcanic eruption in the Southern Volcanic Zone of Chile, the resultant hyperconcentrated flood flows initiated rapid unprecedented growth of the deltaic system. This study aims to quantify Chaiten deltaic evolution from 2000-2013 by integrating modern sediment cores, laser grain size analysis, X-ray-diffraction, bathymetric surveys and DEMs. This provides an opportunity to obtain information about a syn-eruptive marine-depositional system following the first rhyolitic volcanic eruption in modern history.

Within days of the heaviest tephra fall, the coastal town of Chaiten, located 10 km from the volcano, was inundated by 1 to 5 m of volcanic sediment flushed from ash-mantled slopes of the drainage basin. A new sequence of deltaic progradation and aggradation took place as a result, raising the river bed by ~7 m and extending the delta offshore by ~1.7 km. Contrasting previous-post-eruption subaerial and seafloor changes via spatial-temporal remote sensed data and bathymetric surveys permitted calculating delta-front slope gradient ~10° and identification of post-depositional activity responsible for compositional deviation (~74.18 SiO₂, ~0.15 TiO₂, and ~13.66 Al₂O₃). Total volume deposited on beachface is approximately 3-8x10⁶ m³- roughly 15-30% of the volume that mantled Chaiten's River basin. Comparison of contemporary features to that of former deposits suggests that modern short-lived inputs may leave distinct sedimentary traces throughout the fluvial-marine transition. Therefore it is likely that the magnitude and frequency of disruptive events control the morphological recovery period of a coastal system. Depositional distribution of sediments across the inner and offshore deltaic system generates trends in textural and compositional characteristics, and shows a tendency for the net seaward development of sediments.

ORAL

CAUSES AND MECHANISMS OF MASS MOVEMENT IN LOESS SLOPES: A CASE STUDY FROM THE CHRISTCHURCH PORT HILLS, CANTERBURY

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Slope stability assessment and management of steep terrain in urbanised areas requires an understanding of the underlying processes of failure development. This study addresses this through a series of controlled laboratory tests which replicate failure mechanisms in loess landslides.

Fine-grained loessial soil deposits cover 10% of the land surface of South Island and are also present within the Southern part of the North Island. Their unique fine grained nature and wind-blown depositional characteristics results in deposits which can form relatively steep slopes and vertical faces.

Evidence from both New Zealand and internationally indicates that these materials are highly susceptible to failure in earthquakes and after prolonged or intense rainfall. In such instances, loessial materials can develop into earth flows and large-scale debris avalanches which can pose a risk to both life and property. Understanding the mechanisms by which such failures develop and the relative susceptibility of different loessial soils to failure is essential to assess potential future landslide risk.

This study combines field mapping of recent loess mass movements in the Canterbury Port Hills with a series of specialist shear-box tests on intact field samples collected in-situ from marginally stable loess slopes.

The study provides new knowledge regarding the mechanisms of shear-surface development in fine grained soils and provides improved understanding of these mechanisms through high-quality data sets on loessial soils in Canterbury. The study aims to provide new data to inform risk assessments from slope failures in fine-grained soils.

ORAL

**TRANSPORT AND DEPOSITIONAL SETTINGS OF
THE HUKA GROUP, WAIRAKEI-TAUHARA
GEOTHERMAL FIELD, TAUPO**

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Lake and volcanic processes are long known to have interacted in the central Taupo Volcanic Zone (cTVZ) producing abundant basin-filling hydrovolcanic and reworked volcanogenic sedimentary deposits. Lithological and textural examinations of Huka Group (Wairakei and Huka Falls Formations, c.330 – 28 kyr) drill-core samples from Wairakei-Tauhara Geothermal Fields (WK-TH) support the presence of a dynamic lake, Lake Huka, which existed from at least the final deposition of the Wairakei Ignimbrite. Determining the transport and depositional natures of lake-deposited basin-fill deposits is less straightforward due to the lithologically variable, extensive and hydrothermally altered natures of the Huka Group rocks. Differentiating similar resulting subaerial flow, subaqueous flow and volcanogenic sedimentary deposits within a lake setting to infer transport processes is often also challenging. Here sedimentological-based criteria have been compiled to qualitatively assess and infer the dynamic source, transport and depositional conditions associated with 5 principal Huka Group lithofacies in space and time. In northern Tauhara Geothermal Field, the middle unit of the Huka Falls Formation consists of a 10 m-thick breccia and 100 m of vitric tuff pumice breccias interpreted to be the product of an unsteady, sublacustrine phreatomagmatic eruption and water-supported turbidity currents. In contrast, the underlying 500 m-thick Waiora Formation comprises multiple pyroclastic and epiclastic deposits divided by thinly bedded lacustrine mudstone or volcanogenic suspension horizons (well WKM15). Such horizons indicate that the formation consists of at least 10 distinct depositional events in Wairakei accumulating over c.100 kyr.

Insight into the transport processes and depositional environments of the Huka Group provides an initial framework to determine the sequence of and details concerning volcanic processes locally in Wairakei-Tauhara. This, in turn, has implications for furthering the current understanding of regional evolution of the cTVZ and begins to explain stratigraphic variations in geological models.

ORAL

**LOW-FREQUENCY EARTHQUAKES ON THE ALPINE
FAULT**

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Seismic tremor has a key role to play in understanding deep tectonic stresses and transferral of these stresses to the shallow seismogenic crust. Documentation of tremor on the San Andreas Fault and the Alpine Fault provides new insight into the vertical extent of brittle behaviour and ambient stress conditions at continental transform faults. Here we extend previous analysis of tremor on the Alpine Fault by detecting and locating low-frequency earthquakes (LFEs) using data from the Southern Alps Microearthquake Borehole Array (SAMBA) and the national seismic network, GeoNet. We first identify LFE template events visually within previously reported tremor and compute hypocenters using standard methods. We next assume a LFE source region surrounding the hypocentre of a template event and compute station delay factors. To identify further LFEs, we apply a matched-filter detection algorithm to data from all stations at which tremor has been detected, with a minimum of five stations showing LFE phases required for a reliable LFE detection. In this way we generate families of events for each template before applying a finer cross-correlation routine to individual LFE detections to generate S-phase lag times for each detection. These S-phase lag times are finally used to compute refined hypocenters for each detected event relative to the hypocentre of the corresponding template event. Using these methods, we have to date detected and located 210 new LFEs between 2009/03/36 and 2012/04/28 matching 4 template events, a 52.5-fold increase in the size of the catalogue. Our ability to identify LFEs on multiple, distant stations (>50 km epicentral distances) is promising for future investigations incorporating data from additional stations installed south of the tremor in early 2013. We conclude that tremor on the Alpine Fault is composed, as elsewhere, of sequences of LFEs.

POSTER

**DIFFUSION PROFILES IN SANDINE,
ORTHOPIROXENE AND QUARTZ: TIMESCALES
FOR PRIMING OF THE BISHOP TUFF ERUPTION,
CALIFORNIA**

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The ~0.76 Ma Bishop Tuff (Long Valley, eastern California) is an archetypal product of a compositionally and thermally stratified silicic magma chamber. The presence of a late-stage compositionally distinct melt in Bishop deposits is recognised in, for example, CL-bright rims on quartz and Sr- and Ba-rich rims on sanidine in material erupted from vents along the northern caldera rim [1,2,3]. Two key questions in understanding the evolution and evacuation of the Bishop magma chamber are: to what extent did mixing with the compositionally distinct magma contribute to the compositional and thermal zoning, and what effect did the mixing have on magma chamber stability? Here we present two-feldspar thermometry from samples throughout the Bishop Tuff to test against previous Fe-Ti oxide and oxygen-isotopic thermometry [4,5]. We use our new thermometry estimates to conduct 1D diffusion modelling of Ba and Sr in sanidine, Ti in quartz and Fe-Mg interdiffusion in orthopyroxene from all samples where zoning resulting from the mixing event was preserved. Timescales from diffusion modelling of Ti in quartz, Fe-Mg in orthopyroxene and Sr in sanidine all yield results of <150 years between magma mixing and eruption, contrasting markedly with the longer-lived history delineated from U-Pb dating of zircons [5,6]. Notably, however, timescales from Ba diffusion in sanidine are 1-2 orders of magnitude longer than the other element/mineral combinations. These anomalously long timescales raise questions about applicability of this geospeedometer in low T (<900 °C) silicic systems.

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ORAL

**THE BISHOP TUFF: PRODUCT OF ONE OR TWO
MAGMA CHAMBERS?**

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The 0.767 Ma Bishop Tuff (Long Valley, California) is an archetypal supereruption, and has been extensively studied as a case study of the products of a single compositionally and thermally zoned magma chamber. However, recent work using Rhyolite-MELTS modelling and silica-in-melt-inclusion barometry has proposed that the Bishop Tuff compositions do not show a systematic range in pressures [1]. This work is combined with the notion that Bishop phenocryst chemistry is bimodal and used to suggest that there were two Bishop magma chambers, erupted consecutively [1] as with the Kidnappers fall deposit, (Mangakino, TVZ) [2].

Here we present major and trace element analyses from all major crystal phases and associated glass in the Bishop Tuff, inferred to be the inverted products of the magma chamber [3]. These samples reflect our systematic collections throughout the Bishop Tuff deposits, from the earliest fall unit (F1) to the latest ignimbrite units (lg2NWb, lg2Nc) and including the less widely studied units (e.g. Sherwin Grade & lg2Na). We show that glass chemistries represent a continuum, and highlight the transitional role of ignimbrite unit lg2Na in chemical and textural changes from earlier-erupted ("eastern-type") deposits to later erupted ("northern-type") deposits. The apparently bimodal nature of phenocryst chemistry reflects core-rim relationships in single crystals, and represents late stage introduction of a less-evolved rhyolite, which causes overgrowth of compositionally distinct rims. With careful sampling of the full eruption sequence, it is apparent that the Bishop Tuff does indeed represent a continuum in compositions, derived from a single magma chamber, zoned in composition, temperature and pressure, as previously suggested [3,4,5].

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POSTER

**PHOSPHORUS PARTITIONING IN MELT WATER
PONDS IN VICTORIA LAND, ANTARCTICA:
INSIGHTS INTO THE P CYCLE**

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Meltwater ponds are an important habitat for terrestrial biota on continental Antarctica. The productivity of benthic cyanobacteria, the dominant biomass, appears to be limited by phosphorus (P) availability in inland areas. Sources of P and factors limiting its bioavailability are poorly understood. Consequently it is difficult to predict how productivity might be affected by potential climate change-induced increases in meltwater volume and pond size. This study has explored P concentration and speciation in key reservoirs of ponds to identify important processes involving P, to allow insight into how these systems may respond to change.

Over three years (2011 – 2013) soils, sediments, waters, biological material and snow were collected from 15 ponds in the Dry Valleys, and from 7 ponds in the McMurdo Iceshelf /Ross Is. region in Victoria Land, representing inland and coastal meltwater environments respectively. Total dissolved P concentrations were much lower in inland ponds, with Upper Wright Valley, the most inland site, having <3 mg/m³ dissolved P, while at coastal Bratina Island concentrations ranged from 54 – 776 mg/m³. In coastal areas, P concentrations were up to an order of magnitude higher in the soils adjacent to ponds (mean 2.2 g/kg), compared to inland pond soils (mean 0.32 g/kg). Sequential extraction data indicates that <3% of the P in the soils is in a form easily released during flooding or during the seasonal anoxia that may develop in ponds. However, up to 44% is in a form that could be released under alkaline conditions (pH>10), as can occur during periods of intense photosynthesis. The remaining P (55 to 99%) is refractory, requiring weathering of P containing minerals and/or oxide phases to release P. Sediments in ponds typically have <25% of the readily exchangeable P concentration found in adjacent soils, and generally contain less total P, indicating both immediate and long term release of soil and sediment P into pond water.

ORAL

**COMPARISON OF PREHISTORIC AND
CONTEMPORARY COASTAL DEFORMATION
ALONG THE HIKURANGI MARGIN AND
IMPLICATIONS FOR SUBDUCTION EARTHQUAKE
STUDIES**

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Subduction paleoearthquake data of the Hikurangi margin will be compared with models of interseismic coupling and slow slip derived from geodetic data collected by John Beavan and colleagues to see where agreement and discrepancies lie with regards to the signal of coastal deformation and its bearing on understanding the seismic hazard of the Hikurangi margin. In the National Seismic Hazard model we currently use the degree of geodetically-derived interseismic plate coupling as a guide to the location and size of a future plate interface rupture zone; the rationale being that parts of the subduction interface currently accumulating the greatest stress are likely to rupture in future earthquakes. However, there is evidence from earthquakes such as the 2011 M_w 9.0 Tohoku earthquake, that subduction earthquakes may transcend geodetic coupling boundaries. This prompts us to ask: Can geological data tell us whether past ruptures match or transcend the contemporary coupling boundaries? Furthermore, slow slip events (SSEs) have been documented on the plate interface at the Hikurangi margin from GeoNet continuous GPS data. Despite the widespread observation of SSE behaviour worldwide, the relationship between SSE's and subduction interface earthquakes is poorly understood. We will compare the locations of interseismic coupling and SSE's with current estimates of the extent of subduction interface paleoearthquakes based on correlating coastal sites that experienced synchronous (within radiocarbon uncertainties) deformation. We will also compare coastal deformation rates over timescales of thousands of years (from geologic data) and tens of years (from GPS data) and see that along the Hikurangi margin the present-day deformation rates are up to an order of magnitude faster than the long-term rates and typically of opposite sign. This is due to the effects of elastic strain accumulation caused by the current interseismic locking of the plate interface.

POSTER

HOLOCENE EVOLUTION OF THE MANAWATU COASTAL PLAIN INCISED-VALLEY SYSTEM

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Vibracores and water well logs were used to reconstruct the sedimentary infill of the lower Manawatu River valley, North Island, New Zealand, in response to Holocene relative sea-level (RSL) change and the influx of sediment from the bordering axial ranges. Features identified within the Holocene fill of the valley include: LGM fluvial terraces buried at depth; the extent of the estuary which occupied the lower valley at the culmination of the Holocene marine transgression; the Holocene sedimentary succession which filled the valley associated with the Holocene sea-level highstand; and late-Holocene coastal progradation of 4-5 km.

Detailed analysis of vibracores recovered from the lower valley enabled the facies architecture to be reconstructed. The valley was infilled quickly in response to rapid sediment delivery by the Manawatu River. The palaeo estuary achieved a maximum extent of 245 km² at c. 7,500 cal yr BP, and was almost completely infilled by 4,900 cal yr BP. This rapid infilling resulted in an almost instantaneous transition from estuarine to alluvial conditions as the coastal plain prograded down the valley. Evidence of a transitional bay-head delta facies is limited, possibly as the rapid infilling eliminated the necessary accommodation space.

The RSL history of the valley was reconstructed using estuarine bivalves recovered from the vibracores. The RSL record shows that in the valley the Holocene marine transgression culminated c. 7,500 cal yr BP. Thereafter the RSL indicators record a brief highstand, followed by a fall in RSL. This fall is interpreted as a record of subsidence of the valley, due to a combination of sediment compaction, post-glacial water and sediment loading, the evolution of the Wanganui Basin, and neotectonics. Glacial-isostatic adjustment (GIA) modelling suggests that the valley may also be subject to uplift due to meltwater loading on the continental shelf in the vicinity of Cook Strait.

POSTER

HOLOCENE RELATIVE SEA-LEVEL RECONSTRUCTIONS FOR REGIONS WITHIN THE NEW ZEALAND ARCHIPELAGO

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Holocene relative sea-level (RSL) changes were reconstructed for four regions within the New Zealand archipelago: the northern North Island (including Northland, Auckland, and the Coromandel Peninsula); the southwest coast of the North Island; the Canterbury coast; and the Otago coast. All four sea-level reconstructions follow the broad pattern of RSL change predicted for the southern latitudes, with an early-Holocene culmination of the marine transgression, followed by an extended mid-Holocene sea-level highstand. However, there are demonstrable differences between the regions in the timing and magnitude of the mid-Holocene sea-level highstand. In the North Island, the marine transgression culminated c. 7,700-7,500 cal yr BP. This is c. 1000 years earlier than has been previously indicated for the New Zealand region as a whole, and is consistent with recent Holocene RSL reconstructions from Australia. In the South Island the marine transgression culminated later, between 7,300-6,400 cal yr BP. North Island locations feature a pronounced mid-Holocene sea-level highstand with RSL up to 2.5 m higher than present, while South Island sites experienced a mid-Holocene sea-level highstand much lower in magnitude. The spatial variation in RSL around New Zealand is the product of a number of potential drivers: (1) At the regional-scale, glacial-isostatic adjustment (GIA) modelling shows that post-glacial meltwater loading on the continental shelf may have a significant effect on observed RSL changes around New Zealand, through the phenomena known as 'continental levering'. (2) The rise in RSL in the intermediate field around Antarctica in response to reduced gravitational attraction of the Antarctic Ice Sheet (AIS) as the AIS has lost mass during the Holocene. (3) Related to this is subsidence of the lithosphere in the intermediate field around Antarctica as a result of hydro-isostatic loading and mass loss of the AIS, which may result in southern latitude downwarping during the Holocene.

ORAL

**REFINING THE TIMING OF THE LAST SIX SURFACE-
RUPTURING EARTHQUAKES ON THE SOUTH-
WESTLAND SECTION OF THE ALPINE FAULT**

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The timing of past large earthquakes on any active fault close to civilisation is important not only for the scientific insights to be gained regarding fault behaviour, but more immediately for improving forecasts and hazard estimates. Advances in understanding the Alpine Fault in the South Island of New Zealand have been made recently with publication of age estimates for the last 24 surface-rupturing earthquakes on the south-westland section of the fault at Hokuri Creek. This showed that large earthquakes occur relatively regularly at intervals averaging 330 years. However, in the Hokuri Creek record evidence for the most recent earthquakes is missing and the highest variability among recurrence intervals occurs in the last few thousand years. We aim to strengthen the long earthquake record derived from Hokuri Creek by refining the timing of the last six surface-rupturing earthquakes at John O'Groats River located 20 km south along the fault.

Derivation of the long earthquake record from Hokuri Creek relied on a mechanism involving scarp-controlled hydrological changes that enabled sedimentary evidence of multiple earthquakes to be preserved in a basin next to the fault without over-printing. We have found a modern analogue situation at John O'Groats River where the most recent earthquakes are likely to be preserved. Here, the upstream-facing, 15 m high scarp of the Alpine Fault impedes drainage and a swamp exists on the south-eastern side of the fault. Cores taken from the swamp in March 2013 reveal alternations of peat and silt similar to those observed in outcrops at Hokuri Creek. Initial stratigraphic and radiocarbon results indicate we have evidence for six earthquakes that ruptured the ground surface in the last 2000 years. We will determine ages for these earthquakes and test the variable recurrence interval of the last few thousand years.

ORAL

**CONSTRUCTING A PALEOSEISMIC RECORD FOR
THE CASCADE RIVER VALLEY, WESTLAND**

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The Alpine Fault delineates the boundary between the Australian and Pacific plates and seismic activity along this boundary poses a major hazard to New Zealand's South Island. Paleoseismic studies indicate that earthquakes of magnitude 7 or greater have recurred at intervals between 300 – 400 years, most recently in 1717 AD. Understanding the magnitude, timing, and frequency of high magnitude Alpine Fault earthquakes provides a very important base for hazard analysis. However, uncertainties exist further in the past with very few records extending beyond the Holocene. Additionally, few paleoseismic studies have been carried out in the tectonically complex Cascade River Valley, which lies in close proximity to the Alpine Fault.

Here, we present data from deformed silt rhythmites, bounded by planar laminated rhythmites that were likely deposited in a proglacial lake setting after the last glacial maximum, (ca. 20 ka). The deformed sediment exhibits a variety of fold geometries including, cylindrical, box, and monoformal folds. All show some degree of asymmetry.

Based on field observations and analysis, we interpret these deformed sedimentary packages to be seismites. The fold geometries and general morphology of these horizons suggest two possible mechanisms of formation. The first by slumping, as during an earthquake event pore fluid pressure within the sediment increases, which reduces effective stress, destabilizing the slope and triggering failure. Silt is then deformed in distinct layers, accommodating shear during downslope displacement of overlying material. The second mechanism is formation of tsunami and seiche waves due to earthquake shaking. Water movement in these waves applied shear stress to the lake floor sediments, parallel to wave propagation, resulting in deformation of silt on the lake floor. Further laboratory analyses, fieldwork, and radiocarbon dating of the deformed structures will be undertaken to discriminate earthquake and glaciotectonic processes, and ultimately to evaluate whether a post-glacial earthquake record for the region can be established.

POSTER

**PLENARY: 170 YEARS OF TAUPO VOLCANIC ZONE
VOLCANOLOGY**

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The Taupo Volcanic Zone (TVZ) is an internationally recognised zone of active volcanism, which in the past 170 years has contributed significantly to our understanding of many aspects of volcanism.

The earliest European explorers to New Zealand recognised the volcanic rocks of TVZ. Ernst Dieffenbach, for example, noted in 1843 that “there is much obsidian and pumice near Taupo”. It was however Ferdinand von Hochstetter’s remarkable ‘Geologie von Neu Seeland’ published in 1864, that described many features of the TVZ. Shortly afterwards, on 10 June 1886, came the Tarawera eruption, and many excellent descriptions of the event. Since that time there has been almost continuous activity from TVZ volcanoes, with notable events at White Island in 1914, 1966-69, 1976-82, 2000; Te Māri (Tongariro) in 1869, 1892, 1896-7, 2012; Ngauruhoe in 1949, 1954, 1975, and Ruapehu in 1945-6, 1995-6 (lahars in 1953 and 2007). In 1917, the spectacular Waimangu geyser erupted.

Many scientists have contributed to our knowledge of TVZ. Only a few can be named here. These include: S.P. Smith, F.W. Hutton and A.P.W. Thomas (accounts of the Tarawera eruption), Patrick Marshall (naming ‘ignimbrite’), Les Grange (initial TVZ mapping), Jim Healy (post-war TVZ volcanism-geothermal), George Grindley and Alfred Steiner (Wairakei), Colin Vucetich and Alan Pullar (ash stratigraphy), Tony Ewart (TVZ petrology and geochemistry), Bob Clark (Tongariro/White Island), George Walker and Colin Wilson (physical volcanology/ Taupo volcano). Mapping has continued throughout, but with 3 map series produced; Bulletin 37 (1937); the 1:250,000 series (Taupo-1960, Rotorua-1964), and the QMAP map and publication (2010). Notable events include the establishment of the NZ Geological Survey, Rotorua Office (1945); beginning of the White Island research programme (1967); development of the Wairakei geothermal field (1949-1958); expansion of geothermal drilling and rock and mineral dating (1990s-present), and setting up of GEONET (2001).

ORAL

**FOSSIL FRUITS AND SEEDS FROM THE EARLY
MIOCENE FOULDEN MAAR, NEW ZEALAND**

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Fruits, cones, and seeds representing a wide range of subtropical rainforest plants are present in the laminated diatomite deposit at the 23 Ma Foulden Maar site, southern South Island, New Zealand. Families recognised to date include Araliaceae, Atherospermataceae, Bignoniaceae, Casuarinaceae, Cunoniaceae, Euphorbiaceae, Lauraceae, Fabaceae, Meliaceae, Menispermaceae, Myrtaceae, Picrodendraceae, Podocarpaceae, Proteaceae, and possible Moraceae, Pittosporaceae, Rubiaceae, and Rutaceae, amongst others. They range in size from 3–50 mm in diameter, and the majority so-far recovered appear to have been animal (bird) dispersed. Many of these diaspores (seed dispersal units) are also present at the site as leaves, pollen, and/or flowers and fell from, or were blown in from forest trees, vines, and shrubs growing around the perimeter of the 1500 m diameter volcanic lake. The majority of the diaspores are from genera no longer present in New Zealand, but which still occur in Australia or New Caledonia. Others, including Araliaceae and Myrtaceae are still important components of the modern New Zealand flora, but the fruits and seeds at Foulden are from extinct species, as might be expected after 23 million years.

ORAL

**PYROCLASTIC DENSITY CURRENT DEPOSITS AT A
GLACIATED VOLCANO; MOUNT RUAPEHU, NEW
ZEALAND**

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Pyroclastic Density Currents (PDCs) are a largely unrecognised hazard at Mount Ruapehu. Here we provide new insights into the <13.6 ka BP cal. proximal PDC deposit record from Eastern Ruapehu. The oldest deposits, Units 1 & 2, are massive whitish-yellow PDC deposits that correlate with Ruapehu's largest known eruptions (Oruamatua and Akurangi). These contain dense to expanded pumices reflecting collapsing plinian eruption columns from Ruapehu's Northern Crater. Overlying these, Unit 3 is a whitish-yellow PDC deposit containing fibrous and colour-banded pumices produced by the last known plinian eruption (Pourahu) at Ruapehu that opened the presently active South Crater. Directly overlying this, a sequence of orange-yellow PDC deposits (Unit 4) containing dense juvenile clasts represents PDCs produced during smaller early Holocene eruptions at South Crater. This sequence is capped by a <1m thick black PDC deposit (Unit 5) containing large cauliflower bombs indicative of a partly phreatomagmatic eruption. Unit 6 is a distinctive grey-black PDC deposit up to ~30m thick that is variably welded and has metre-scale bedding. It contains rounded monolithologic scoriaceous clasts with chilled margins in a vesicular ash matrix of the same composition. This represents multiple collapses from a near-vent breccia/agglutinate pile deposited on Ruapehu's steep upper flanks. Unit 6 reflects transport over ice with its unusual clast rounding, chilled margins, vesicular matrix, and extremely pure, monolithologic character. These newly described PDC deposits span a large range of eruption magnitudes and styles, suggesting that PDCs represent an important hazard at Ruapehu even during small eruptions. These deposits, together with textural evidence for PDC-ice interaction, are important for understanding small-to-medium volume PDCs at composite cones, and the until-

now overlooked PDC hazard at Ruapehu and other glaciated volcanoes worldwide.

ORAL

**INTER-ANNUAL, SEASONAL AND EARTHQUAKE-
INDUCED FLUCTUATIONS IN WATER TABLE
ELEVATION, WITH IMPLICATIONS FOR STUDIES OF
LIQUEFACTION IN CHRISTCHURCH**

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Three main factors control liquefaction: (i) nature, strength and stratigraphy of the ground; (ii) earthquake shaking and intensity; (iii) groundwater level. For a given return period of interest in hazard assessment, ground remains constant at any one location, but shaking and groundwater are variable. The significance of groundwater level on potential for damaging liquefaction is highlighted in sensitivity calculations of Liquefaction Severity Numbers (LSN) and other liquefaction indices from Cone Penetration Tests (CPT). Liquefaction assessments currently use probabilistic shaking models to account for temporal variations in hazard, but groundwater fluctuations can also influence the time-varying probability that liquefaction will occur/not occur. Assessments can be improved by considering natural fluctuations in groundwater level and the potential for earthquake-induced pressure change.

The shallow water table beneath Christchurch slopes coastward, from >10 m elevation (asl) west of the city to <1 m in the east, reflecting changes in ground elevation. Groundwater is generally >5 m below ground in the west, but <2 m deep beneath much of the city. Between 1990 and 2010, inter-annual variations (~2 m in west, ~1.2 m in east) were approximately twice those of seasonal variations (west ~1 m, east ~0.5 m). In most places the water table appears unaffected by Canterbury earthquakes, as indicated by assessment of 55 monitoring wells with extended (decadal) records. Transient, earthquake-induced, shallow groundwater level increases (up to 1.5 m) occurred in 9 wells, mimicking pressure changes in deeper aquifers, lasting for up to 1 week throughout aftershock sequences. The median water table elevation was lowered by 0.5–1.0 m to new base

levels in 4 wells, independent of local uplift or subsidence. In Christchurch, liquefaction studies need to consider the influence of sea level changes on water table elevation, and whether paleo-liquefaction records have any relationship to present or future conditions.

ORAL

THE DEVELOPMENT OF A DATABASE OF AGRICULTURAL LOSSES DUE TO TEPHRA FALL

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Agricultural development commonly occurs near volcanoes to take advantage of fertile soils, resulting from the weathering of tephra deposits. However, direct exposure to tephra fall can cause a range of immediate and near-immediate impacts to agricultural systems before tephra deposits are integrated into the soil or eroded. Collecting and analysing the potential impacts in a systematic approach aids identifying areas of vulnerability and ultimately assessing risk. This study aims to create a catalogue of the effects that tephra fall events from historic eruptions have had on agricultural systems.

A review of available literature identified that agricultural impacts due to tephra deposition are complex and reliant on the interdependent characteristics of the exposed agricultural systems. These complexities informed the design of the database and demonstrated the need to include information about the farming system and depositional environment in order to provide a holistic view of losses and the mechanisms that caused them. Tephra hazard intensity information includes tephra load deposited, physical characteristics (such as grain-size) and chemical characteristics of the tephra (e.g., soluble leachate chemistry). Both direct and indirect impacts from tephra deposition are recorded, including crop, livestock and agriculture infrastructure information. Thirdly, existing animal and crop conditions, exposed farm assets, and required essential service inputs (e.g., electricity, water supplies, etc.) are also detailed to define the features of the exposed agriculture system. Finally, environmental and meteorological conditions are

incorporated, as this influences the rate at which tephra is integrated into the soil structure or eroded.

Ultimately, the database will aid in the quantification of agricultural losses through the development of fragility functions; and identifying any relationship that may exist between deposit, environmental and agricultural properties, and losses sustained. An additional aim of the catalogue is the creation of guidelines for loss assessment when evaluating agricultural damage in the field.

POSTER

IS EXTINCTION RATE BIMODAL? VERY HIGH RESOLUTION SURVIVORSHIP ANALYSIS OF THE GRAPTOLOID CLADE

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Several key debates in paleontology reduce to a question about the shape of the frequency distribution of extinction rates: do extinction rates occupy a continuum between the most extreme mass extinctions and times of low background extinction, or are there distinct modes of extinction rate? Derivative questions include the qualitative difference (or not) between processes of mass and background extinction, the occurrence (or not) of times when background extinction is essentially zero, and the prevalence of pulsed extinction.

Here we use segmented slopes of cohort survivorship curves to examine this question at high resolution. For any cohort of an ecologically homogenous group, survivorship analysis plots the log of proportion surviving on the ordinate against time on the abscissa, and extinction rate is measured as the slope of the fitted line. Our data comprise a continuous (unbinned) time series of origination and extinction for 1802 of the most common graptoloid species spanning the entire 74 m.y. Ordovician-Silurian history of the clade and several "mass" extinction events. The time series derives from quantitative biostratigraphic analysis

of 518, globally distributed stratigraphic sections using the CONOP method. The average time resolution between origination or extinction events in our dataset is 37 k.y.

At the time of writing, we are using automated line segmentation routines to examine the slopes of distinct log-linear segments of the graptoloid survivorship curves. In this way we will be able to determine, at unprecedented resolution, whether there are characteristic modes of extinction rate, whether these modes vary through the history of the clade and, ultimately, how extinction rates relate to environmental and biotic drivers.

ORAL

TECTONO-METAMORPHIC EVOLUTION OF THE ANITA SHEAR ZONE, NW FIORDLAND

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The Anita Shear Zone is a sub-vertical, c. 3-4 km wide ductile shear zone in Fiordland that encompasses kyanite-bearing pelites (St Anne Formation) and an extensive unit of largely unserpentinised peridotite (Anita Ultramafites). The metapelitic rocks record peak metamorphic conditions, prior to shearing, of c. 9 kbar, 650°C. Zircon grains within the St Anne Formation exhibit a high degree of recrystallisation, with low Th/U and HREE-depleted overgrowths comprising more than half the volume of many grains. The overgrowths are most likely metamorphic in origin, suggesting they remained at high temperature for a protracted period of time (consistent with the lack of growth zoning in garnet). The overgrowths yield a U-Pb concordia age of 104 ± 2 Ma, interpreted as the timing of peak metamorphism. This age is younger than the adjacent granulite-facies rocks (Western Fiordland Orthogneiss, Pembroke Granulite), suggesting significant displacement along the shear zone. Recrystallised matrix biotite grains yields temperatures of c. 575°C (Ti-in-biotite) and are interpreted as the temperature of mylonitisation.

The Anita Ultramafites consist primarily of dunite with subordinate bands of harzburgite. This unit represents a fragment of sub-continental lithospheric mantle. High olivine Mg# suggests that the ultramafites represent a residue of extensive mantle melting that exceeded the point of predicted clinopyroxene and orthopyroxene consumption. Olivine-spinel and olivine-

orthopyroxene pairs yield equilibration temperatures of c. 600-650°C at 1.5 GPa. The occurrence of clinopyroxene and orthopyroxene, as well as tremolite and phlogopite, is evidence for metasomatic addition of Si, Ca, K, OH. Preliminary LA-ICP-MS analysis of diopside grains indicates LREE enrichment (likely via metasomatism), as well as pronounced Eu and Sr anomalies, suggesting exchange with plagioclase at some stage. Mylonitisation has produced spectacular porphyroclastic textures in the ultramafites.

ORAL

THE 2013 COOK STRAIT EARTHQUAKES (NEW ZEALAND): A GPS PERSPECTIVE

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The magnitude 6.5 and 6.6 strike-slip earthquakes that struck the Cook Strait area on July 21st and August 16th 2013 were recorded by continuously operating GPS stations of the GeoNet network. GeoNet cGPS stations acquire at 30s and 1s sampling rates; a subset of the sites acquires at 0.1s. 30s raw data are downloaded every hour. This configuration enables a first estimate of the coseismic offsets within less than a few hours after the earthquakes, allowing a quick estimate of the slip distribution at depth (see Hamling et al., "Geodetic observations of the 2013 Cook Strait and Lake Grassmere earthquakes, New Zealand", this session).

Processing of the GPS data at different sampling intervals provides different insights into ground displacements due to these earthquakes. The 30s daily positions show that the July 21st Cook Strait earthquake, located offshore, caused static coseismic ground surface offsets of up to 5 cm towards east at a cGPS site WITH, near Blenheim. The largest displacements in the August 16th Lake Grassmere earthquake, located onshore, were observed at Cape Campbell (site CMBL), where there was 18 cm westward and 8 cm downward motion. Epoch-by-epoch kinematic processing at 30s interval allowed us to retrieve true coseismic offsets by removing small coseismic offsets due to $M > 5$ aftershocks and early postseismic afterslip

displacements. Kinematic processing at higher sampling rates (0.1 and 1s) enables to track the dynamic displacement in the near field. Transient, dynamic displacements reached 10 cm of eastward motion on July 21st and up to 30 cm of westward motion on August 16th. Finally, a few centimetres of postseismic displacement have been observed on WITH and CMBL, the two cGPS stations closest to the earthquakes' epicentres. Our results confirm that geodetic data have a great potential for improving rapid-response to large earthquakes in New Zealand.

ORAL

RADON ACTIVITY AROUND ACTIVE FAULTS IN A GEOTHERMAL ENVIRONMENT

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Variation in radon gas concentration has been associated with faults and faulting processes at several locations globally. The Central Taupo Volcanic Zone (TVZ) is an active volcanic rift which hosts more than 20 geothermal fields. The geothermal activity is only occasionally associated with fault traces visible at surface, however it is possible that many active faults have been buried by recent volcanic deposits (blind faults). In order to detect these faults and their prospectivity for geothermal energy, soil gas Radon surveys have been proposed over areas potentially hosting blind faults. We surveyed soil gas around the Rehi fault and the Paeroa fault, both substantial faults (i.e. slip rates 0.5-1.5 mm/yr) in the TVZ, with the purpose of showing the relationship between soil gas Radon activity and active faults. We used an electrostatic precipitation Radon detector (Durrige RAD7) to measure Radon activity of two Radon Isotopes (220Rn and 222Rn) in soil gas sampled at 1m depth. We also collected several soil samples at the location and depth of the gas measurements, for further testing of Radon emanation potential in a laboratory setting.

Our data show a clear relationship between faults and Radon activity at several locations. However, the isotope activity ratios and the laboratory testing show that this activity variation is in most cases due to shallow and local soil processes, not faulting processes. This leads us to conclude that in the TVZ measuring Radon activity in soil gas may not be a reliable technique for detecting faults in

the sub-surface. Exceptionally high Radon activity for 220Rn and 222Rn isotopes was however recorded in steam vents around the Waikite geothermal spring, a boiling bicarbonate spring which flows at ~60 l/s at the base of the Paeroa fault scarp. Preliminary data support the idea that the Radon isotopic ratio can be used to determine the travel time and flow path of steam from the source to the detector. These Radon isotopes constrain the flow model for the Waikite geothermal spring and could be used in environmental and hydrological studies of other bicarbonate geothermal springs.

ORAL

CONVERGENT MARGINS OF THE NEW ZEALAND EASTERN PROVINCE

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The Triassic-Cretaceous Chatham Rise is the most widely recognised convergent margin structure associated with long-lived, Triassic-Cretaceous, subduction at the Gondwana margin in the New Zealand region. Detailed examination of gravity, magnetic and seismic reflection data, tied to known geology suggests however, at least three paleo-convergent margin complexes exist and can be traced across much of the Eastern Province.

The nature and distribution of these paleo-convergent margins, and whether they had an associated volcanic arc will be discussed. Recognition of the geophysical signature of these convergent margins/arcs(?) has been complicated by deformation associated with the Cretaceous subduction of the 10 My-old Hikurangi Plateau Large Igneous Province at the New Zealand Gondwana margin and this will also be discussed.

ORAL

CHRISTCHURCH LIQUEFACTION SUSCEPTIBILITY REVEALED BY CONE PENETRATION TESTS (CPT) AND SEISMIC CPT INVESTIGATIONS

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The cone penetration test (CPT) is a method used to determine the geotechnical properties of sediments and to determine stratigraphy. CPTs are very useful for the identification of soils susceptible to liquefaction. The method consists of pushing an instrumented cone, into the ground at a controlled rate, in this case using a 20 t CPT truck. As part of the Christchurch rebuild we have collected over 500 CPT locations around Christchurch down to depths up to 35 m for the collection of engineering geology parameters. Additionally we have collected Seismic CPT tests, which allow the development of 2-D shear wave velocity profiles which can also assist with the identification of liquefaction susceptibility. Through the collection and analysis of over 400 regional CPT test locations, we are able to develop subsurface contour maps of the Christchurch area showing the distribution and depth to units with <50 MPa and >50 MPa sediments in addition to determining the distribution and depth to the uppermost confined aquifer in the Christchurch area (the Riccarton Gravel). The maximum MPa recorded regionally was 105 MPa with our system. The considerably variable distribution (both vertically and laterally) of deposits and liquefiable sediments are observed in these CPT data and are particularly apparent in the seismic CPT data with low velocity layers coincident with observed liquefaction during the 2010-2012 Canterbury Earthquake Sequence (CES). Shear wave profiles coincident with conventional CPT tests provided the most reliable 2-D identification of liquefaction susceptibility. CPT tests are an important tool for the identification of liquefaction soils in areas with seismic hazards, and the spatial distribution of low resistance sediments we present here illustrates the variability in stratigraphy and within the Christchurch region and associated challenges for both land zonation and for mitigation of liquefaction zones through avoidance and foundation design.

POSTER

LIDAR REVEALS PALEOSEISMIC SITES AND RECENT STRIKE-SLIP AND THRUST FAULTING ALONG THE CENTRAL ALPINE FAULT, NEW ZEALAND

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In the South Island of New Zealand, the dextral-reverse Alpine fault forms the major plate

boundary structure between the Pacific and Australian plates and is thought to fail in large to great earthquakes approximately every 100 to 400 years, with the most recent major surface rupture event occurring in 1717 AD. We used a recently collected lidar dataset to evaluate the central section of the fault to both measure recent slip along the fault, recent co-seismic uplift, and to find new paleoseismic sites. The new high-resolution topography in the dense temperate coastal rainforest allowed insight into the fault that was previously unavailable. Lidar mapping, combined with field mapping facilitated the discovery of a multi-event thrust fault scarp of the Alpine Fault that was later trenched at Gaunt Creek. C14 dating of units in the trench and mapping there, show that the last earthquake was probably the 1717 event. Along the length of the lidar survey, small (< 25 m) dextral offsets were also mapped along the fault, which were rated for quality, and then visited in the field. The lidar itself was a guide to locate these offsets, and the offset measurements in the field have lower uncertainties than the lidar resolution; dextral slip in the 1717 earthquake here was c. 7 m +/- 1 m. Additional sites with evidence for cumulative slip were also mapped in the field which showing repetitive slip of ~ 7 to 8 m per event for the past three surface ruptures on the fault. Sag ponds discovered during field mapping are important new targets for investigation and will likely yield slip-rate information here for the correlation of slip with timing. Additional field mapping near the Whataroa River and Mint Creek demonstrates that between debris flow fans that cross the Alpine Fault at the range front of the Southern Alps, preservation of strike-slip scarps is rare due to post-earthquake deposition and erosion. However, one likely scarp was found in a post-earthquake aggradation surface, along strike from a clear-strike slip trace, between two post-1717 fans. Based on field and lidar mapping, this scarp likely formed in the 1717 earthquake in the c. 1620 Whataroa River outwash deposits.

ORAL

MAGMATIC UNDERPINNINGS OF THE OKATAINA VOLCANIC CENTRE

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In the Taupo Volcanic Zone (TVZ), the relationship between the volcanic and plutonic realms is not well understood. In an attempt to better understand the magmatic underpinnings of one of the most active silicic volcanic complexes on Earth, we have compared the textural, petrological and geochemical variations of rhyolite deposits and a variety of co-eruptive plutonic and mafic to intermediate cognate or coeval rocks from the active Okataina Volcanic Centre (OVC), to several well-studied mid- to upper-crustal plutonic sections.

Our petrologic and geochemical comparison indicates that mid- to upper-crustal plutons provide a good plutonic analogue for the deeper unexposed OVC magmatic system, and hold important clues to the petrogenetic processes operating within the active TVZ silicic system and continental arc settings globally. Similarities between the plutonic and volcanic systems include;

- depth range (rhyolitic and intermediate magmas stored between 4-15 km),
- longevity of active magmatism (> 750 ka – 1 Ma)
- incremental construction of magma reservoirs by multiple intrusions of magma
- compositional range (excellent correlation with Zr/Hf ratio and depth, indicative of crystal-liquid separation)
- magmatic textures (i.e. cumulates, quenched mafic rocks)
- magmatic processes (mafic recharge, magma mixing, magma remobilization, fractional crystallization, crystal accumulation and melt extraction)

A petrogenetic model is presented for the generation of silicic magmas in the OVC via crystal fractionation (\pm assimilation) by extraction of evolved silicic magma from an intermediate cumulate mush. Mafic magma recharge into silicic-intermediate magma is shown to be an important

process in keeping the OVC magma reservoir active, remobilizing highly crystalline magma, triggering eruptions (1314 AD Kaharoa), and in at least one instance, erupting basalt directly at the surface (1886 AD Tarawera).

ORAL

SEISMIC REFLECTION FABRIC OF THE LOWER CRUST IN THE VICINITY OF KAPITI SLOW SLIP EVENTS BENEATH THE WANGANUI BASIN

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Crustal seismic reflection data was recently acquired during the SAHKE project, including a 140 km long and roughly NW-SE line which crosses the southern end of the Taranaki and Wanganui Basins (SAHKE02 line). A key feature imaged within the Wanganui Basin is a buried irregular erosion surface representing what would have been a subareal landscape with similar relief to parts of the Southern Alps, which has also experienced a broad basin-wide downward in the order of 2 km vertically. Directly beneath the downward surface maxima, the intersection of the subducting Pacific Plate with the Moho of the Australian Plate is imaged at a depth of about 35 km, in the vicinity of a region of slow slip modelled from GPS displacements in 2003, 2008 and 2013 (Kapiti SSEs). We present migrated reflection seismic images of the crustal structure of the Kapiti slow slip zone. Unlike shallow (<15 km deep, short duration) slow slip imaged beneath the North Island offshore Poverty Bay (Bell et al. 2010), the Kapiti SSEs (>30 km deep, long duration) are not associated with a broad zone of crustal reflectivity, but rather an apparent buckle in the Moho. Given the contrasting images of slow slip beneath the North Island at different depths, we question whether seismic reflection data are imaging diverse phenomena, or perhaps relate to differences in shallow and deep slow slip mechanisms, or some combination of both.

References

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ORAL

**CHARACTERIZING ACTIVE DEFORMATION IN
CENTRAL SOUTH ISLAND, NEW ZEALAND, USING A
NOVEL METHOD OF ANALYZING GPS DATA**

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A significant component of the Australia-Pacific plate motion must occur on faults other than the Alpine Fault, but this is not fully accounted for in catalogues of known active faults. In the central part of the South Island, low slip rate active faults are not well-expressed due to the rapid erosion of the Southern Alps and deposition of these sediments onto the Canterbury plains. We apply a novel inversion technique to dense campaign GPS velocities in the region to solve for the vertical derivatives of horizontal stress (VDoHS) rates which are a substantially higher resolution expression of subsurface sources of on-going deformation (including faults slipping at depth) than the GPS velocities or GPS derived strain rates. Integrating the VDoHS rates gives us strain rates. Relationships between the VDoHS and strain rates allow us to calculate the variation in fault slip rate and locking depth for the identified faults; e.g., we estimate along fault variations for locking depth and slip rate for the Alpine Fault, and provide first estimates on the smaller, previously-uncharacterized faults which account for as much as 50% of the plate motion depending on location. For the first time, we note that the area between the Alpine Fault and the Main Divide is undergoing extensional areal strain, potentially indicative of gravitational collapse of the Southern Alps. The Arthur's Pass region exhibits no shear component in the spatial derivatives of the VDoHS rates, in marked contrast to the Alpine Fault segments just northeast and southwest, suggesting that post-seismic deformation related to the 1994 Arthur's Pass earthquake is masking the signal from the Alpine Fault beneath. We characterize in detail the transfer of slip further north into the Marlborough Fault System, where much of the slip on the Alpine Fault passes onto the Kelly and Hope Faults.

POSTER

**STRATIGRAPHY, FACIES ARCHITECTURE AND
EMPLACEMENT HISTORY OF THE C. 3.6 KA B.P
NGATORO FORMATION ON EGMONT/TARANAKI
VOLCANO, NEW ZEALAND**

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Lahars are typically catastrophic water-supported mixtures of dominantly volcanic detritus and encompass debris, hyperconcentrated, and flood flow events, which have been well documented both within New Zealand (i.e. 1995/96 eruption of Ruapehu) and around the world. The Ngatoro Formation is a lahar deposit (Neall 1979; Alloway et al. 1995) located on the eastern lower slopes of Egmont Volcano/Mount Taranaki and is closely associated with the c. 3.6 Ka B.P. Inglewood Tephra which represents one of the largest eruptive events experienced in Taranaki over the last 10 Ka B.P. Previous work suggested that this event was generated from a dome collapse shortly after the paroxysmal eruption of the Inglewood Tephra with this event undergoing lateral transformation from a block-and-ash flow to debris flow at sites proximal to source through to hyperconcentrated flow to flood-flow at distal and/or flow margin localities.

In this study, detailed stratigraphy and chronology combined with palaeomagnetic emplacement temperature estimates, grain size/shape analysis and electron microprobe analysis of enveloping Egmont-sourced tephra suggest a more complicated sequence of events which appear unrelated to the immediately preceding Inglewood eruptive episode.

Preliminary results indicate that the Ngatoro Formation was emplaced in multiple pulses and at ambient temperatures, presumably by the progressive collapse of a remnant (cold) lava dome originally formed during the Inglewood eruptive episode. Certainly, the evidence indicates triggering and emplacement unrelated to any contemporaneous volcanic activity. How the Ngatoro event was initiated is highly speculative but the remnant dome may have been rendered unstable either by volcano/tectonic seismic events and/or by adverse meteorological events. This understanding provides new insights when considering the range of hazards already posed by Egmont Volcano. Debris/hyperconcentrated flow lateral transformations are typically associated with volcanic activity however, catastrophic

failures of remnant dome unrelated to volcanism could also be expected and would be more difficult to predict.

POSTER

RECONSTRUCTING POST-GLACIAL THROUGH HOLOCENE SEA LEVEL RISE IN FIORDLAND

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Fiordland's modern landscape was carved by multiple glaciations through the Last Glacial Maximum and flooded by rising sea level during the ensuing de-glaciation. During the de-glacial period, stranded lakes formed in some fiords where entrance (or secondary) sills acted as dams. When sills were inundated, the fiords transitioned from a lacustrine to a marine environment. This unique feature allows the use of marine incursion as a proxy for determining timing and magnitude of post-glacial sea level rise.

Marine incursion is identified in sediment cores using diatom assemblages to indicate past environments. Timing is determined by radiocarbon dating appropriate material from the transition to a marine environment and magnitude is defined by the shallowest sill depth. Seismic profiles (Boomer and CHIRP) are interpreted to identify marine incursion throughout the fiord. Together, these methods provide a small and large-scale reconstruction of sea-level rise and a preliminary sea level curve for Fiordland will be presented.

Findings will be compared with regional and global records of sea level rise with a focus on meltwater pulses. This will allow analysis of the relationship between sea level rise and millennial-scale climate events, as well as the source of ice-sheet melt at a mid-latitude Southern Hemisphere location.

POSTER

TEACHING GEOSCIENCE WITH SIMULATION: SCENARIO-BASED ROLE-PLAYS

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Interactive, scenario-based role-plays have been designed with the purpose of teaching tertiary geoscience students (at the University of Canterbury and the University of Auckland) to forecast and mitigate a volcanic crisis. One part of the activity is focused on recording, processing, and interpreting real volcano monitoring data (e.g., seismographs, etc.; i.e., the "GeoNet" Team), while the other is to forecast and manage likely impacts, and communicate emergency response decisions and advice with local communities (i.e., the "Emergency Management" Team). These authentic learning experiences were aimed at enhancing upper-year undergraduate students' transferable- (specifically communication and teamwork) and geologic reasoning-skills. It also exposes students to relevant future career opportunities within the New Zealand geoscience and emergency management sectors.

Teaching with scenario-based role-play is unlike traditional (i.e., stand-and-deliver) style instruction. It requires students to accomplish higher-level learning goals (e.g., respond, judge, synthesize) by working together.

Our research followed a design-based approach to ascertain if the pedagogical design of the simulations were achieving the learning goals and if students enjoyed the experience. Results from observations and interview data indicate that these role-plays are a highly engaging learning experience for students. By playing roles, students experience the responsibilities of a professional within authentic organisational structures. Team dynamics (within, and between the teams) were varied depending on the students: their background, preparedness, and personalities. Students struggled to initiate and maintain effective communication pathways, especially during times of stress. They reported difficulties with communicating uncertainty, use of jargon, and the amount of and appropriateness of information content to differing stakeholders. Students reported an overall improvement of their

teamwork and communication skills through experience with the crisis scenario, which was corroborated by pre-/post-simulation assessment of students' communication efficacy.

Future research is concentrating on designing new earthquake scenario-based role-plays which aim to specifically improve science communication skills.

ORAL

**TIMING AND PROVENANCE OF SYNOROGENIC
SEDIMENTATION DURING ARC-CONTINENT
COLLISION AND EXTRUSION IN THE TIMOR
SECTOR OF THE BANDA ARC**

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The island of Timor is the product of collision between the Australian continent and the Banda Arc but the timing and nature of that collision are controversial. New provenance data, including geochemistry and Nd model ages improve constraints on the timing and effects of arc-continent collision in the Timor sector of the Banda Arc. We studied two widely-separated, well-dated sections of the Synorogenic Megasequence of Timor Leste. The basal carbonate sediments accumulated in grabens that formed due to simultaneous crustal shortening and extensional exhumation. The increasing muddy sediment flux recorded by carbonate geochemistry indicates that the island of Timor was emergent and shedding terrigenous sediment into carbonate basins prior to 4.5 Ma. Rapid uplift followed, and created an extreme relief that fed an abundant supply of coarse detritus to synorogenic basins. This clastic sedimentation began at 3.5 Ma in the Marobo Basin of central Timor, and propagated east and west, reaching the Viqueque Basin in eastern Timor ~0.5 Myr later, and the Central Basin of West Timor ~1Myr later. This is consistent with models that suggest early collision of an outlying plateau in the central part of Timor. The Nd model ages of the synorogenic mudstones reflect recycling of the Australian passive margin mudstones through melange and diapirs.

ORAL

**INVESTIGATING THE COLLAPSE AND INFLATION
OF ERUPTING LAVA DOMES**

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Actively growing lava domes can produce devastating block and ash flows from partial dome collapses. Decompression associated with these collapse events induces vesiculation in clasts of rhyolitic lava within these flows and the remaining lava in the collapse scar when the viscosity, volatile content and permeability is suitable. This process is observed in many block and ash flow deposits by breadcrust bombs.

The AD1315 Kaharoa eruption of Tarawera Volcano, New Zealand produced three large, rhyolitic lava domes and significant block and ash flow deposits. On the outer edge of one of these domes -Ruawahia Dome, we have found highly vesicular zones and large slabs of breadcrusting that correspond to the breadcrust textures observed in the block and ash flows. We theorise that the large (up to 5mm) spherical vesicles observed in these zones formed by in situ vesiculation associated with decompression following a partial dome collapse.

In a series of experiments, samples of dense lava dome material were heated (700°C and 725°C) in an autoclave at steam pressure (5 and 10 MPa) and subjected to different decompression rates. Porosity and textural analysis of samples post-inflation were performed using synchrotron tomography, along with measurements of micron-scale variations in water content around bubbles by synchrotron FTIR spectromicroscopy. Our textures and water gradients around bubbles from 6 hour and 5 MPa decompression experiments are similar to those found in the inflated parts of the dome that sourced block and ash flows. Hence, our experiments reveal a new methodology to assess the timescales and magmatic conditions for block and ash flow formation.

POSTER

**FLUID BUDGETS ALONG THE NORTHERN
HIKURANGI SUBDUCTION MARGIN, NEW
ZEALAND: THE EFFECT OF A SUBDUCTING
SEAMOUNT ON FLUID PRESSURE**

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The northern Hikurangi subduction margin, offshore North Island, New Zealand, has a shallow transition from locked to aseismically creeping behaviour (<5-15 km) that is accompanied by well-characterized slow-slip events. This region has recently been the focus of international efforts to understand transient slip events at subduction margins. Subduction of a seamount, and excess pore fluid pressures along and above the subduction interface, have been implicated in the particularly shallow region over which SSEs have been observed there. We estimate fluid sources and sinks for the northern Hikurangi subduction margin using thermo-mechanical numerical modeling constrained by wedge structure and porosities from multichannel seismic data. Sediment transport through and beneath the accretionary wedge is calculated assuming a pressure-sensitive frictional rheology. The change in porosity, pressure and temperature with rock advection is then used to compute fluid compaction and dehydration sources as sediment flows through and under the accretionary wedge.

Computed fluid source terms yield more precise information about source locations in time and space than previous averaged estimates for the Hikurangi margin. The magnitude of fluid release in the accretionary wedge is an order of magnitude smaller than previously predicted for the entire margin, and is smaller than calculated fluid release from pore water in subducting sediments. Clay dehydration, while producing only small quantities of fluid, occurs over a large enough area to be a significant source landward of a subducted seamount imaged on the seismic profile. Fluid source terms are used to estimate fluid pressures around a subducting seamount. Models in which the decollement acts as a fluid conduit overlying low-permeability subducting sediment generate significant fluid overpressure landward of the seamount, supporting the idea that short duration,

shallow, slow slip events (SSEs) events in this region may be related to anomalous fluid pressures.

POSTER

**VARIATIONS IN MID-CRUSTAL DENSITY BENEATH
NORTHERN CANTERBURY: THE EFFECT ON
STRESSES AND POSTSEISMIC STRAIN-RATES**

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Tomography shows that the Greendale fault lies above a steep boundary marking a northward increase in the depth to the 2750 kg m⁻³ density contour, interpreted as the approximate transition from quartz-rich rocks to stronger mineralogy. Similarly, part of the Ashley fault lies above a change in 2750 kg m⁻³ density-depth, and the faults that ruptured during the Christchurch earthquake sequence are located on a strong depth/density boundary associated with the volcanic rocks of Banks Peninsula. We investigate the effects of such variations in crustal density for stresses and strains in the northern Canterbury region using a 3D numerical model, with the interseismic GPS velocity model applied as a boundary condition. The model includes temperature-dependent non-linear creep and pressure-sensitive frictional Coulomb yield. Creep parameters depend on density derived from detailed tomography.

The modelled maximum compressive stress direction is in good agreement with those measured for North Canterbury and predicts that, north and west of the Canterbury region, strike-slip mechanisms dominate, whereas in the Canterbury basin near the Greendale fault, a hybrid stress regime occurs, with both reverse and strike-slip mechanisms. To the east of Christchurch in the Pegasus Bay region, reverse faulting is predicted. We also investigate the effect of basement density variations on strain accumulation. Despite the potential for increased mid-crustal detachment to the north of the Greendale Fault, the models indicate only small interseismic variations in strain-rate from north to south. However, stress magnitudes are predicted to change across the projection of the Greendale fault at depth. On shorter timescales, lateral variations in ductile strength can affect the degree to which stresses and stress orientations are

perturbed in earthquakes such as the Darfield event, and can change the magnitude and directionality of the postseismic response.

ORAL

SEA LEVEL RISE IN NEW ZEALAND WITH VERTICAL LAND MOTION ESTIMATED USING SPACE GEODETIC AND GEOLOGICAL DATA

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New Zealand's 20th century sea level, derived from long-term tide gauge records, is rising at 1.46 ± 0.10 mm/yr. This is in agreement with the regional rates of South Australia and Tasmania, and comparable to the global rate of 1.70 ± 0.20 mm/yr.

Vertical land motion (VLM) has been estimated at tide gauge sites by combining satellite altimetry and adjacent tide gauge data. This approach has proven to be a robust method with an accuracy of 0.4 mm/yr. In comparison, no clear sea level rise pattern can be inferred when the sea level trends are corrected for VLM derived from GPS.

Absolute sea level rise based on VLM derived from both altimeter-tide gauge and geological data are consistent. When applied to the sea level trends, three temporal phases of sea level rise are revealed: for the period 1900 – 1936 there is an increase from 1.46 ± 0.10 mm/yr to 1.72 ± 0.10 mm/yr; followed by a decrease to 1.48 ± 0.10 mm/yr (1936 – 1956); and a substantial increase to 2.60 ± 0.10 mm/yr (1956 – 1975). In contrast, the 20th century microfossil proxy records of absolute sea level rise are nearly twice the global sea level rise rate at 3.17 ± 0.30 mm/yr and 3.28 ± 0.45 mm/yr respectively once salt-marsh records are corrected using GPS and geological vertical rates. Differential autocompaction is a possible explanation, which needs further investigation.

POSTER

INSAR OBSERVATIONS AND INTERPRETATION OF POSTSEISMIC DEFORMATION FOLLOWING THE 22 FEBRUARY 2011 CHRISTCHURCH EARTHQUAKE

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We aim to measure and interpret the postseismic deformation that occurred following the 22 February 2011 Christchurch earthquake (MW 6.2) using interferometric synthetic aperture radar (InSAR) observations made between March 2011 and June 2013. This time period spans a number of significant aftershocks including those of 13 June 2011 (MW 6.0) and 23 December 2011 (MW 5.9). In order to determine the postseismic deformation associated with the 22 February 2011 earthquake itself, it is necessary to detect and remove the coseismic offsets caused by large aftershocks in the region (which are of comparable magnitudes to the postseismic velocities), and also the deformation signals associated with seasonal changes, atmospheric phase delays and liquefaction (which are each of the order of 1/10th of the postseismic velocities). In this presentation we describe methods of improving the accuracy of the measured deformation signal by removing non-postseismic sources from the results. By using SAR images acquired at multiple epochs throughout the aftershock sequence, we are able to account for repeated coseismic offsets using least squares inversion. We can use the same approach to mitigate the ground changes in different seasons occurring within multi temporal images. To account for phase delays arising from changing atmospheric conditions, we apply an Atmospheric Phase Screen (APS) by filtering in both space and time.

POSTER

**ASSESSING AND MODELLING THE BALLISTIC
HAZARD OF UPPER TE MAARI CRATER,
TONGARIRO**

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At 23:52 (GMT + 12) on August 6th, 2012 Upper Te Maari Crater, Tongariro erupted for the first time in over one hundred years. Observational data describe a 16 second eruption that began with a debris avalanche, followed by low angle blasts and surges which unzipped a fissure from east to west. The eruption culminated in a vertical eruption plume from the main Upper Te Maari crater. These combined eruptions ejected ballistic blocks up to 2.3km from the vents. The ballistic blocks represent a hazard to users of the Tongariro Alpine Crossing (TAC), a walking track frequented by ~ 80 000 people each year, as 2.5km of the track was within the impacted area. We mapped crater dimensions and blocks characteristics from orthophotos and from field ground truthing. Orthophoto mapping revealed 3587 impact craters with a mean diameter of 2.4m. Smaller sized craters (< 1.5m in diameter) proved difficult to map due to the limitations of the photo resolution. Ground-truthed field data found a smaller mean crater diameter of 1.2 m and on average 7 times as many craters. The number of ballistic projectiles (now thought to be around 24 500) was therefore greatly underestimated during initial hazard assessments. Data gathered from the mapping and acoustic signals allowed eruption parameters from 5 eruption pulses to be entered into a numerical ballistic trajectory model. The model considers the effects of drag, and particle collisions in 3D and reproduces the spatial and size distribution of impacts at Upper Te Maari. Varying these input parameters from this validated model allows for the assessment of future ballistic hazard from larger and smaller eruptions of Upper Te Maari Crater.

POSTER

**HIGH MAGNITUDE, LOW FREQUENCY RAINFALL
EVENTS DRIVE LANDSCAPE DEVELOPMENT IN THE
SOUTHERN ALPS**

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One of the key challenges in understanding the interactions between climate and tectonics is reconciling our knowledge of surface processes from instrumental records with reconstructions of processes over millennia and greater timescales. Two limitations of instrumental records are that they frequently do not capture extreme events or the episodic coupling and uncoupling that is a characteristic of hillslope and channel processes. Conventional thinking in geomorphology is that events with a moderate frequency, moderate magnitude, such as the mean annual flood in river systems, are the key drivers of geomorphological change. However, in situations where sediment supply is strongly limited, significant volumes of sediment can be mobilised by extreme events that may have a return period of decades to millennia.

In this paper we have used aerial photographs, analysis of a 50-year rainfall record, and the sedimentary record of sediment accumulation from 2 lake basins to examine the impact of an episodic slope instability on sediment production. The data shows that a temporal and spatial cluster of landslides was triggered by a localized rainfall event that delivered 500mm of rainfall in less than 48 hours. The event triggered numerous shallow mass movements and reactivated two deep-seated mass movements in Palaeozoic greywacke and the sediment was rapidly conveyed from the slopes to channels and into the lakes. The sediment flux which has been sustained for 50 years resulted in rapid aggradation on alluvial fans, and transformation of meandering channels into braided channels as the rivers changed from a supply-limited to transported-limited configuration. Although the instrumental record of the event has a return period of >50 years, the sedimentary records of lakes Moeraki and Paringa show that the event is unique in the last 2000 years. We conclude that surface processes in South Westland are characterised by high magnitude, low frequency events.

ORAL

SUBMARINE LANDSLIDE MORPHOLOGY OF BOX SLIDES PRESENT ON THE CONTINENTAL SLOPE OFFSHORE FRASER ISLAND, QUEENSLAND, AUSTRALIA

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The Fraser Island slide complex is located on eastern Australia's continental slope offshore Fraser Island in southern Queensland. Two potentially tsunamigenic submarine landslides identified here as the 'North Fraser Island Upper Slope Slide' (upper slope slide) and the 'Middle Fraser Island Middle Slope Slide' (middle slope slide) are described. Morphologic, sedimentologic and geomechanical properties for these two slides are compared to data reported for existing submarine landslides located to the south in northern New South Wales. The two Fraser Island slides are translational, box-shaped, slab slides. It is suspected that the slabs remained intact during downslope transport. The upper slope slide is situated at a water depth of approximately 750m at the northern end of the Fraser Canyon complex. The head of this slide has apparently detached from a structural surface comprised of a Miocene reef complex located beneath the continental shelf edge and this slide is estimated to be 25km² in area and 100m thick. The middle slope slide is situated to the south of the Fraser Canyon complex in 1500m of water. It estimated to be 12km² in area and 50m thick. Cores taken in the continental slope within both slides are long (upper slope 5.65m, middle slope 3.64m) and present hemipelagic muds. Cores taken adjacent to both slides are short (upper slope 1.33m, middle slope 0.43m) and terminate in stiff muds of suspected Miocene or Pliocene age. Additionally, the 1.33m core on the slope adjacent to the upper slope slide presents a near surface layer of upper-fining of coarse to fine shelly sand which we interpret to be a turbidite deposit. This layer was deposited above hemipelagic muds which are ubiquitously present on the upper eastern Australian continental slope in New South Wales and Southern Queensland.

POSTER

USING HIGH-DENSITY AUTOMATED VELOCITY ANALYSIS TO AID INTERPRETATIONS OF GAS AND GAS HYDRATE ACCUMULATIONS IN THE PEGASUS BASIN, EAST OF COOK STRAIT

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Gas hydrates and associated shallow gas are often characterised in seismic data by amplitude anomalies of various sorts – often associated with bottom simulating reflections (BSRs) that mark the top of free-gas charged sediments beneath an overlying hydrate stability zone. A dataset consisting of approximately 3000 km of 2D seismic lines, collected in late 2009 and early 2010 to encourage commercial petroleum exploration in the Pegasus Basin, contains abundant BSRs and other signs of an active shallow natural gas system. This dataset gives us an opportunity to develop the use of high-density velocity analysis to examine short length scale variations in seismic velocity that may correspond to gas or hydrate accumulations. The Pegasus Basin lies off the northeast coast of New Zealand's South Island at the southern end of the Hikurangi Subduction Zone. The basin contains a sedimentary succession more than 10 000 m thick and covers at least 25 000 km², with water depths ranging from 200 to more than 2000 m. The lack of well control to tie the geology of the basin to the seismic data complicates the interpretation of seismic units in this region. However, high-density velocity analysis (velocities are picked for every CDP gather in the dataset at intervals of 50 ms) provides a new method for identifying locations of anomalously low or high concentrations of hydrate or gas – where more rigorous techniques such as inversion can be applied later. Examples presented include hydrate and gas features associated with seismic blanking within the hydrate stability zone adjacent to a gas chimney and gas migration within a thrust anticline.

ORAL

**3D RESTORATIONS OF THE MIOCENE-PLIOCENE
SYNOROGENIC BASINS WEST OF THE ALPINE
FAULT: STRUCTURAL CONTROL OF BASEMENT
DEFORMATION AND COMPRESSIONAL INVERSION**

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The tectono-stratigraphic setting of the Australian crust in the West Coast region of the South Island of New Zealand is imprinted by a long deformation history, involving: (i) Paleozoic collision along the Gondwana margin; (ii) mid-Late Cretaceous rifting culminating with separation of the Zealandia continental mass from eastern Gondwana (90-60 Ma); (iii) propagation since 25 Ma of the transpressive, right-lateral Alpine Fault, and development of the collisional orogen of the Southern Alps.

Neogene deformation of the Australian crust is not consistent with simple flexural models against the collisional margin, because of the double vergence of folding and faulting, the irregular time-space propagation of shortening and uplift from the inner to the outer zones, with complex evolution of syntectonic marine-terrestrial sedimentary basins separated by basement uplifts.

We present a regional study integrating surface and subsurface data to provide a 3D reconstruction of deformed Australian crust, recorded by the geometry of the top basement surface, chrono-stratigraphic transects, and restored and decompacted regional cross sections that constrain the vertical mobility within fault-bounded basins undergoing progressive shortening. Our reconstruction shows the role of inherited Late Cretaceous conjugate normal faults that were reactivated in compression, controlling several km of relief between antiformal basement pop-ups bounded by steep reverse faults and synformal depressions hosting syntectonic sequences up to 6-8 km thick. Some faults already breached the top basement during the extensional phases, whereas others propagated from deeper levels of the basement, controlling folding of the sedimentary cover. Currently active faults comprise sets of newly-forming blind reverse faults at the base of the seismogenic crust that propagate up-section exploiting the inherited extensional fault fabric.

The resulting geometry controls short-wavelength, irregular undulation of the top basement surface,

disrupting the regional trends of uplift and progressive migration of "foreland basins" from the inner to the outer zones.

ORAL

**MICROBIALY-MEDIATED MERCURY
TRANSFORMATIONS AT HOT SPRINGS AND MINE
SITES IN THE NORTH ISLAND, NEW ZEALAND**

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Hot springs and abandoned mine sites in the North Island contain the highest mercury concentrations in New Zealand. The potential for these environments to contaminate surrounding ecosystems with mercury has not been well studied. Microbial mercury transformations deserve attention for their ability to convert mercury across redox states, and between inorganic and organic forms. These biotransformations variably affect mercury mobility and reactivity in soils and natural waters. We investigated microbial community structure and mercury speciation in the Ngawha geothermal field. Dissolved total- and methylmercury concentrations ranged from 250-16,000 ng/L and 0.5-13.9 ng/L respectively, and total solid mercury concentrations ranged from 1273-7000 µg/g. Microbial 16S rRNA and MerA genes were sequenced from waters and sediments, and the degree of mercury methylation in each hot spring was interpreted to reflect the dominance of acidophilic demethylating bacteria over proteobacteria. The presence of sulfur-cycling and iron-cycling microbes suggests that microbially-mediated sulfide oxidation may enable methylation of mercury from cinnabar. A conceptual model of processes controlling mercury speciation in mesothermic, acidic and sulfidic hot springs is proposed. We also investigated total and methylated mercury levels in soils, waters and air at the abandoned Puhupuhi Mine, to assess the probability and form of mercury release from the site to the surrounding natural environment. Total soil mercury concentrations across the mine ranged from 37.8- 1748 µg/g. Waters collected from nearby Waikiore Stream contained total and methylated mercury concentrations of 69.9- 240

ng/L and 0.637- 1.95 ng/L, respectively. Volatile mercury analyses from relict mercury vapour condensation towers yielded gaseous mercury concentrations of 60 – 500 mg/m³ air. Results showed that transport of mercury in windblown soils and dust, and with rainfall run-off from the historical tailings deposit of the mine would be the most likely mechanisms for local and regional ecosystem contamination.

ORAL

A NEW ACCRETIONARY OROGEN MODEL FOR THE TASMANIDES OF EASTERN AUSTRALIA

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The well-known southwest to northeast younging of stratigraphy over a present-day cross strike distance of >1500 km in the southern Tasmanides of eastern Australia has been used to argue for models of accretionary orogenesis behind a continually eastwards-rolling paleo-Pacific plate. However, these accretionary models need modification, since the oldest (*ca* 530 Ma) outcrops of Cambrian supra-subduction zone rocks occur in the outboard New England Orogen, ~900 km east of the next oldest (520–510 Ma) supra-subduction zone rocks. Thus, the southern Tasmanides display an early history characterised by a westwards-migrating margin between *ca* 530 and *ca* 520 Ma, followed by rapid eastwards rollback of the paleo-Pacific plate from 520–502 Ma that opened a vast backarc basin ~2000 km across (depending on possible orogen-parallel strike-slip duplication). From the Ordovician through to the end of the Carboniferous, the almost vertical stacking of continental margin arcs (within a hundred kilometres of each other) in the New England Orogen indicates a constant west-dipping plate boundary in a Gondwana reference frame. The actual position of the boundary is inferred to have undergone contraction-related advances and extension-related retreats, these movements are estimated to be ~250 km or less. Rollback in the early Permian was never completely reversed, so that late Permian–Triassic to Cretaceous arcs lie farther east, in the very eastern part of eastern Australia, with rifted fragments occurring in the Lord Howe Rise and in New Zealand. The northern Tasmanides are even more anomalous, since they missed out on the

middle Cambrian plate boundary retreat seen in the south. As a result, their Cambrian to Devonian history is concentrated in a ~300 km wide strip immediately west of Precambrian Australia and above Precambrian basement. In this interpretation, Lower–Middle Ordovician quartz-rich turbidites did not accumulate in multiple subduction complexes lying behind the plate boundary.

ORAL

SEARCH FOR TEMPORAL CHANGES IN SHEAR-WAVE SPLITTING AND V_p/V_s ASSOCIATED WITH THE 2012 TE MAARI ERUPTIONS AT MOUNT TONGARIRO, NEW ZEALAND

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Temporal variation of seismic wave velocities has recently been proposed as an eruption precursor. We investigated potential variation of the shear wave splitting (SWS) parameters (fast polarization/ Φ , delay time/ δt) and V_p/V_s ratios from local earthquakes recorded on four permanent seismographs sited around Mount Tongariro during a 16 month period beginning a year before the first Te Maari eruption on August 6, 2012. We identified four time periods during which moving averages of Φ and δt are steady, however absolute averages vary between periods. Sharp transitions between periods are coincident with observed changes in recorded seismicity. Analysis of data where epicentre location, hypocentre depth and event magnitude are restricted illustrates that observed temporal changes in SWS parameters are likely due to heterogenous anisotropy and spatial variation of raypaths, which is governed by the spatial distribution of recorded seismicity and measurement quality. Layered material causing horizontally propagating rays may be affecting NGZ as there appears to be a weak trend of Φ perpendicular to back azimuth, however this is not apparent at other stations. V_p/V_s is steady throughout the entire study period at 1.75 at all stations, although excursions occur in the Tongariro swarm events before the first eruption. Certain events of magnitude less than 2.0 that occur after a change in earthquake location method also return unreasonable values. We interpret this V_p/V_s variation as an artifact of event origin time uncertainty of low magnitude earthquakes or incorrect S-phase arrival timing for

events in the Tongariro swarm. Our results suggest that any volcanic processes able to cause changes in SWS or V_p/V_s associated with the unrest were too localised to the Te Maari area to be observed at the seismographs studied using our methods.

ORAL

INVESTIGATING IF SAUNDERS RIDGES IS A DROWNED SHORELINE ON THE OTAGO CONTINENTAL SHELF

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The Saunders Ridges, approximately 10 km off the Otago coast, are anomalous on the otherwise smooth, low-gradient continental shelf. It has been proposed that the ridges represent a drowned shoreline resulting from a rapid sea level rise that followed the Last Glacial Maximum. We propose that the ridges are related to meltwater pulse 1a which resulted in a rapid sea level rise of 40 mm/y between 14.7 – 13.8 ka. This meltwater pulse is touted as a global event however, a lack of data from the Southern Hemisphere, especially in the mid-latitudes, makes it difficult to determine the source, magnitude and timing of the event. Constraining this event on the Otago Continental Shelf will increase evidence for the source of the meltwater and assist with quantifying the date and magnitude of the event.

A multi-scale seismic survey that collected high-resolution single-channel boomer, CHIRP and side scan sonar data has been run over a 25 × 8 km field area covering the Saunders Ridges. A sequence stratigraphic interpretation has been undertaken on the seismic sections and an image of the surveyed area has been produced from the side scan sonar. Grab sampling and piston coring will be undertaken on a future cruise targeting the interpreted estuarine deposits shoreward of the proposed shoreline to collect sediment samples for dating the marine incursion using radiocarbon dating methods.

The sequence stratigraphic interpretation supports the proposal that the ridges are a separate package of sediment that is potentially part of an ancient barrier island complex. The interpretation has identified good potential coring sites to target the estuarine to marine interface. Comparisons of the Otago shelf profile and the Barbados and Tahiti sea level curves show a similar step around meltwater pulse 1a.

POSTER

IS THE CENTRAL TAUPO VOLCANIC ZONE A SINGLE LARGE CALDERA?

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Calderas, their associated structures, and the geometry of their pre-collapse magma reservoir(s) have been the subject of much scientific intrigue, largely because they represent the largest scale of volcanic eruptions and our knowledge has only been gleaned from ancient examples. The Central Taupo Volcanic Zone (TVZ) and Yellowstone are two of the youngest sites of large caldera-forming eruptions on Earth and have often been compared. The volume of magma erupted from these two regions is almost identical but one striking difference is that caldera-forming eruptions in the Central TVZ occur every 50 thousand years whereas at Yellowstone they occur every 600 thousand years. This frequency of eruptions has pock marked the Central TVZ with several discrete structures that have been defined as individual calderas by volcano researchers over several decades. However, recent studies have illuminated the strong connection between magmatism, volcanism and tectonics leading to the eruption and formation of calderas over remarkably short time periods and spanning much of the area encompassed by the Central TVZ (i.e. paired-eruptions and ignimbrite flare-ups). Here, we discuss multiple examples and evidence for widespread magmatism occurring over different time-scales (from 100's of thousands to hundreds of years) that have all led to multiple and geographically separate caldera-forming eruptions. The most alarming of these examples comes from new petrochemical evidence for a complex subvolcanic plumbing system including multiple juxtaposed magma bodies that were extracted simultaneously across an area of ~1000 km² to erupt and form twin calderas more than 30 kilometers apart and an area of collateral and tectonically controlled subsidence in between. From such an intimate (and regional-scale) magmatic-volcanic-tectonic interplay, one could argue a case for the Central TVZ being single large caldera complex, like Yellowstone, with extraordinary rates of eruptible magma production.

ORAL

**PALAEOMAGNETIC SECULAR VARIATION FROM
HOLOCENE LAVA FLOWS OF THE TAUPO
VOLCANIC ZONE (TVZ), NEW ZEALAND**

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In order to understand the origin, temporal behaviour and spatial characteristics of Earth's magnetic field, global data coverage and high resolution age control are required. Here we study Holocene records of the direction and intensity of the palaeomagnetic field from volcanic materials sampled within the Tongariro Volcanic Complex, New Zealand. Fieldwork was undertaken in February 2013, with the assistance of the volcanic research group at Victoria University of Wellington and GNS Science. Multiple oriented core samples were collected from five lava flows of andesitic to basaltic composition at a minimum of three localities per flow.

Progressive alternating field or thermal demagnetization has been carried out on a minimum of 10 specimens from each locality. First assessment indicates consistent results between different sites for three flows. Retrieval of the intensity of the palaeomagnetic field is often hindered by alteration of the primary magnetic minerals and/or non-ideal (eg. non single domain) magnetic behaviour. In order to minimize these problems, we will combine the results of extensive rock magnetic investigation with thermal and microwave based palaeointensity techniques. The effect of composition and grain size in individual samples on different methods will also be discussed. The project is part of a three year Marsden funded programme "Unlocking the Secrets of the Geodynamo: The Southwest Pacific key", which also includes archaeomagnetic and lake sediment studies. We aim to close an important gap in the global database and to produce regional dynamic models of magnetic field direction and strength, which should provide a new and powerful dating tool for geological and archaeological materials sampled over the Southwest Pacific region.

POSTER

**KINEMATICS OF THE GREBE SHEAR ZONE,
FIORDLAND, NEW ZEALAND**

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This study presents preliminary structural and petrological data from ductilely deformed plutonic rocks of the Jaquiere stream part of the Grebe shear zone. Jaquiere Stream comprises 4 principle lithologies: amphibolite, striped gneiss, porphyroclastic gneiss and pegmatite, the first three have developed a steeply west dipping foliation containing a moderate to shallow south plunging lineation. The mineralogy is dominated by hornblende and plagioclase in amphibolites; quartz and plagioclase in striped gneiss; hornblende, plagioclase, quartz, chlorite and cm scale K-feldspar porphyroclasts in the porphyroclastic gneiss and K-feldspar. Amphibolite and striped gneisses contain amphibolite facies metamorphic assemblages. The pegmatites cross cut the deformation structures and contain plagioclase and quartz. Shear sense was determined from sigma and delta type tailed feldspar porphyroclasts, mineral and mica fish, and rotated mineral grains. These indicate a dominant sinistral / west side down sense of shear movement of the north striking shear zone. Crystallographic preferred orientation (CPO) data for quartz, plagioclase and hornblende were obtained using electron backscatter diffraction (EBSD). In the amphibolite, hornblende (100) planes are oriented preferentially parallel to foliation plane and [001] directions are oriented parallel to lineation. These data show orthorhombic symmetry and give no information about simple shear senses. Plagioclase CPOs in both the amphibolites and striped gneisses shows (001) planes oriented preferentially parallel to the foliation and [100] directions oriented parallel to the lineation. There are complexities in the plagioclase fabrics that may indicate more complex deformation. CPO data for quartz within the striped gneisses shows [0001] directions (c-axes) lie preferentially within the foliation plane but oblique to lineation. These are interpreted as the result of high-temperature (~600 °C) deformation with different kinematics to that reflected by field scale structure and the other mineral CPOs.

ORAL

**ANALYSIS AND MODELLING OF BOREHOLE
PIEZOMETRIC RESPONSES DUE TO CANTERBURY
EARTHQUAKES**

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Groundwater level changes occurred in boreholes as a result of the Darfield 7.1 M_w earthquake in Sept 2010 and the Christchurch 6.3 M_w earthquake in Feb 2011. Borehole responses were categorised as a transient spike in the piezometric head level that decays in less than a few days, and a longer term offset in the piezometric head. Comparisons showed that boreholes responded consistently to the different earthquakes despite the difference in the location and style of earthquakes. The scale of spikes, the time that the spikes persisted for, and the offset were approximately twice as large in Christchurch city urban area for the 6.3 M_w earthquake cf. the 7.1 M_w earthquake.

Gravel- and sand-rich aquifers beneath Christchurch city are separated by clay-rich aquitards. A negative pressure gradient attempts to push water upwards. Borehole responses for both earthquakes showed that the deeper aquifers beneath Christchurch city have a negative offset in piezometric head, whereas the shallower aquifers tend to have a smaller, generally positive, offset. Observations of groundwater ponding and flooding at the surface immediately after the earthquakes concur with a hypothesis that vertical movement of water occurred as a result of the earthquakes. This can be explained by a transient increase in permeability of the aquitards during passage of seismic waves, allowing water to flow temporarily upwards. The process was modelled using the groundwater flow equation with time varying permeability and a moving water table. The model was fit to data from a borehole 70 km south west of Christchurch city that has multi-level piezometers, from which quantities of interest such as water volume and aquifer permeability, can be inferred. Changes in water level and pressure can be used to characterise aquifers and are potentially important for understanding processes of liquefaction that caused so much ground damage throughout Christchurch.

ORAL

**GEODETTIC OBSERVATIONS OF THE 2013 COOK
STRAIT AND LAKE GRASSMERE EARTHQUAKES,
NEW ZEALAND**

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On July 21st and August 16th 2013, two $M_w \sim 6.5$ earthquakes struck at shallow depths beneath central New Zealand. During the first event, which was located offshore some 50 km south of Wellington, continuously recording GPS instruments across central New Zealand recorded up to 5 cm of horizontal motion. Using simple elastic dislocation models, we invert for the best fitting slip distribution. The best fit model for the first event suggests slip of up to 1.2 m occurred on a fault with a dip of 65° and strike of 232 degrees at ~12 km depth. For the second event, which occurred ~20 km to the south of the first, beneath Lake Grassmere, we use TerraSAR-X and Radarsat-2 InSAR data and both campaign and continuous GPS displacements to jointly invert for the best fitting slip distribution. Up to 18 cm of westward motion was observed at the continuous GPS site located at Cape Campbell. Line-of-Sight (LOS) displacements of up to 30 cm are observed in the vicinity of Lake Grassmere and suggest that up to 1.7 m of slip occurred along a fault dipping northward at 83°, and striking 235 degrees. The geodetic inversions produce $M_w \sim 6.5$ for both the events, consistent with the seismological estimates of M_w . These models are used to resolve the Coulomb stress change onto nearby faults to investigate potential loading of faults around central New Zealand.

POSTER

**INDUCED SLIP ALONG THE WELLINGTON AND
RUAHINE FAULTS DURING THE 2004 MANAWATU
SLOW SLIP EVENT: INSIGHTS FROM THE JOINT
INVERSION OF INSAR AND GPS DATA**

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With durations of weeks to months, slow slip events (SSEs) have been observed along

subduction zone plate boundaries around the globe including Cascadia, Japan and New Zealand. SSEs have been observed geodetically with equivalent seismic moment magnitudes ranging from 6 up to Mw 7, displacements of a few to tens of centimetres. Typically, land based GPS measurements are used to detect SSEs and determine the slip distribution along the plate interface. However, the inherent sparsity of GPS sites, can inhibit the precise determination of the slip distribution. InSAR, unlike GPS, provides a high spatial density giving a more complete view of deformation at the Earth's surface. Although widely used for the modelling of coseismic displacements, SSEs at most well-studied locales such as Cascadia and southwest Japan produce surface deformation that is too small (< 5 mm) to detect with InSAR techniques. However, large SSEs in New Zealand, involving up to ~4 cm of vertical deformation, provide a unique opportunity to develop the use of InSAR as a new tool to contribute to investigations of this intriguing form of fault slip. Here we use Satellite Radar Interferometry and continuous GPS data to invert for the slip distribution associated with the 2004 Manawatu slow slip event in New Zealand. In order to fit the observations, we find that reverse slip is required along a portion of the Wellington and Ruahine faults in a region where the Coulomb failure stress is in excess of 0.01~MPa suggesting that slow slip along the plate interface may have induced slip along the overlying faults. This is the first-ever documented example of a subduction interface SSE triggering a transient slip event on a major upper plate fault, and it has wide-ranging implications for the role that SSEs can play in seismic hazard on shallow, crustal faults.

ORAL

BANKS PENINSULA: NEW ZEALAND'S FIRST GEOPARK? INVESTIGATIONS AND GEO- EDUCATION RESEARCH INITIATIVES

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Horomaka / Banks Peninsula on the eastern coast of New Zealand's, South Island, is a highly eroded Miocene volcanic complex with geological exposures and vistas offering unique views into volcanic processes and landscape formation. Lava domes, plugs, dykes, flows, scoria cones, and other volcanic features have not only spawned a unique

biodiversity, but have provided a rich environment for the settlement and prosperity of pre-historic Maori (i.e. significant archaeological sites) and subsequent early European occupation (i.e. heritage sites). As such, Banks Peninsula is currently being scoped as a future Geopark, a UNESCO designated area or territory encompassing one or more sites (geosites) of scientific importance. And here, we present our methodology for achieving Geopark status while linking closely with an undergraduate research geo-education initiative.

Initial recognition of geosites is through collation of historical datasets, previous geological mapping and studies, archaeological and cultural sites and studies, established parks and reserves, walking tracks, tourist operations, areas of ecological significance, and areas of natural significance. Current investigations of geosites are being completed as part of undergraduate student research projects in conjunction with Frontiers Abroad (a New Zealand based study abroad programme) and the University of Canterbury, and are part of a research goal to produce a high-resolution geological map, stratigraphy, and research on the volcanics of Banks Peninsula.

Students are deployed in field research teams, in areas of known geological significance, aiming to produce high resolution geological maps, stratigraphically controlled geochemical sampling and analysis, unraveling of geological histories of prominent features (i.e. dykes, domes, scoria cones, lava sequences), recognize areas of significance (i.e. biological, archaeological, cultural), produce geo-education materials, establish frameworks for geosites/trails, and collate Geopark application materials.

ORAL

THE ICE-THICKNESS DISTRIBUTION OF A LOW- ANGLED, DEBRIS-COVERED GLACIER: TASMAN GLACIER, NEW ZEALAND

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The ice-thickness distribution of temperate valley glaciers is an important physical constraint for modelling their flow. Ice-thickness measurements are used to calculate the geometry and ultimately the driving stress of a glacier. These parameters are all required if realistic models are to forecast

the response of glaciers to climate forcings. For New Zealand's Tasman Glacier, two factors complicate its response to climate: 1) A layer of insulative rocky debris covers the lower half of the glacier, retarding surface melt, and 2) the glacier has recently entered a period of iceberg calving into a proglacial lake, introducing complex mechanical processes. These complications, along with the uncertainty of the current bed topography of the Tasman Glacier, make future predictions of its retreat behaviour difficult. The bed of the Tasman Glacier has not been fully imaged but datasets obtained through seismic (Anderton et al. 1975) and gravity (Broadbent, 1974) surveys have provided important ice-thickness measurements for sparse regions of the Tasman Glacier. Here we employ a range of geophysical methods (gravity and active-source seismics) to measure and model the ice-thickness distribution across the lower Tasman Glacier. We surveyed orthogonal to glacier flow to obtain 12 two-dimensional profiles within the lower 5 km of the glacier. Two-dimensional and three-dimensional gravity models indicate that the ice-thickness ranges from 500-650 m approximately 5 km upstream from the present day terminus decreasing to several hundred meters near the terminus. Our results confirm an over-deepened channel with reverse-slope geometry, typical of highly erosive, low-slope glaciers. Our findings provide an important first-order constraint for glacio-dynamic models looking to estimate the retreat behaviour of the Tasman Glacier.

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POSTER

ORAL

TAPHONOMICALLY-ADJUSTED FORAMINIFERAL PALEOELEVATION ESTIMATES PROVIDE IMPROVED HOLOCENE EARTHQUAKE RECORDS FROM NEW ZEALAND SALT MARSHES

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**STATIC COULOMB STRESS MODELING IN A
COMPLEX EARTHQUAKE SEQUENCE: CAN IT
PROVIDE USEFUL INFORMATION FOR
EARTHQUAKE RISK ANALYSIS?**

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The 2010-2011 Canterbury earthquake sequence provided an opportunity to assess the effectiveness of static Coulomb stress modeling to provide predictive information for earthquake risk analysis in the event of a complex rupture sequence. Modeling was undertaken to gauge the extent to which changes in the localised stress fields from the 2010 Darfield earthquake contributed to the rupture of the three large subsequent events in the Canterbury sequence and their associated aftershocks. Coulomb stress modeling was undertaken for the four largest earthquakes in the sequence using two different published fault models. The effect of the Coulomb stress change from these ruptures was tested on the subsequent fault ruptures and also on the fault planes derived from the moment tensor solutions of all aftershocks $M_w \geq 4.0$. Results indicate a positive correlation between the location of $M_w \geq 4.0$ aftershocks and areas of positive Coulomb stress change, with a significant number of aftershocks occurring in areas where models show a reduction in normal stress resulting in the unclamping of fault planes. Calculations of positive Coulomb stress change on the fault planes of the major earthquakes prior to their rupture suggests the possibility that previous seismicity within the sequence resulted in the advancement of their failure, although rupture cannot be attributed to Coulomb stress change alone. Further, the modelled geometry of major ruptures proposes a number of misoriented reverse faults in the sequence. This suggests the additional complication that negative Coulomb stress change, combined with substantial fluid overpressure may have been involved in the rupture nucleation on these faults. Inter-model variation of modelled stress change domains suggests a high sensitivity to changes in source model parameters, especially at distances of less than one fault length from the rupture. Visual correlations between areas of increased Coulomb stress change for idealised strike-slip and thrust faults for the regional stress field is, however, relatively poor and thus highlights the importance of accurate fault geometry in modelling Coulomb stress change for complex ruptures.

ORAL

**AMBIENT NOISE TOMOGRAPHY OF THE DARFIELD
2010-2011 EARTHQUAKE SEQUENCE**

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The 2010-2011 Canterbury earthquake sequence occurred largely on previously unmapped and buried faults. The 4th September 2010 Darfield earthquake and its associated aftershocks occurred on the Greendale fault, the only fault of the sequence that showed a surface rupture. Better understanding of the Canterbury Basin fault zone's structure is needed for future hazard analyses, one such example being the near-surface velocity structure. The number of ambient seismic noise studies has seen a dramatic increase in recent years. Cross-correlations between seismic station pairs can be approximated to their corresponding Green's functions, from which surface wave group dispersion curves can be computed. Most studies focus solely on vertical components as they contain fundamental-mode Rayleigh wave data, which is most commonly used to invert for S-wave velocity structure.

This project will use ambient noise correlation techniques to determine the velocity structure of Canterbury. Victoria University deployed a temporary seismometer network throughout the region to record the Darfield aftershock sequence. Thirteen stations were in operation from mid-September 2010 to mid-January 2011. Preliminary work using low frequency data found Rayleigh wave velocities between $1.5-2.9 \text{ km.s}^{-1}$ for 3-16 s periods. 1D S-wave models were computed at several locations, obtaining velocities between $2.5-3 \text{ km.s}^{-1}$ for the uppermost 3km of the subsurface. Comparisons of RR and ZZ functions computed for the VUW stations showed strong first higher mode Rayleigh waves propagating on paths parallel to ocean wave directions. This was interpreted as basement resonance. Cross-correlation functions of VUW and GeoNet data will be produced for all components of the data, creating nine cross-correlation functions per station pair, for a wider range of frequencies up to 100Hz, to investigate what extra information and velocity constraints can be obtained from high frequency data. Non-vertical components will be used to further examine higher mode content and characteristics of the noise source.

POSTER

**IMAGING THE DEEP HEAT SOURCE OF THE
ROTORUA GEOTHERMAL FIELD**

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Broad-band magnetotelluric (MT) data at fifty-two locations in and around the Rotorua geothermal field were recorded to determine the extent and deep structure of the geothermal system. Electrical resistivity images derived from the analysis of these data suggest that a magmatic system centred southeast Rotorua at about 6 km depth is the ultimate heat source for the geothermal field at Rotorua. The resistivity images suggest that the high temperature up-flow feeding the shallow part of the geothermal system and the thermal features lies just southeast of the Whakarewarewa thermal area.

ORAL

**TE PŪMANAWA – A NEW SCIENCE EDUCATION
INITIATIVE FOCUSED ON CURRICULUM
LEVELS 3 & 4**

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In 2013, we have been running a pilot science programme based at Shirley Intermediate School in Christchurch. The impact of the 2010-2011 Christchurch earthquakes on the residents of this low-decile school's catchment area has been significant. We have designed a series of modules intended to engage both teachers and students in a programme of science learning that is topical, exciting and that uses everyday items as the basis for both experiments and observation. For the two strands ('Material World and 'Living World), we have as far as possible integrated geological examples/materials as the exemplars that illustrate both scientific principles and the practical applications of science. Now that the trial is completed, what have we learned and what are our plans for the future?

ORAL

**DIGITAL IMAGERY AND LIDAR: NEW ZEALAND
AND ELSEWHERE**

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Recent years have seen dramatic changes in how we can view the Earth's terrain. Digital imagery that sees through vegetative cover to the ground surface, and software, which can manipulate the topographic representations allowing, detailed examination of specific terrain signals and anomalies. An added special feature is viewing the terrain stereographically (S-3D), which is substantially better than the commonly used shaded relief. These new digital tools are valuable for studying fault movement, erosion rates, fault locations and orientation (for siting water wells), debris landslide hazard identifications, and in identifying debris landslide accumulations.

This poster will project the digital topography of South Island, NZ at 8-meter resolution focusing on areas near Fiordland. 100 % of South Island will be available. I welcome attendees interested in South Island to search the imagery to see what can be discovered by using the software to exaggerate, highlight, define, and capture subtle topographic signals quantitatively (in S3-D).

In addition to South Island areas, specific USA sites will be presented. One striking image shows the submarine faulted and landslide-rich 10,000 foot face of the North American Plate viewed from offshore of the Cascadia Subduction Zone in Oregon. LiDAR imagery has allowed details not available with 10 meter resolution DEM's. An example is a time-lapse study in progress using LiDAR topography—compared with older topographic mapping—that may indicate higher sedimentation rates associated with erosion and debris slides from an impacted area. The presentation will show LiDAR's applications for hazard rating terrain by comparing actual failure slope angles with the remaining terrain to produce a conservative assessment map. Digital data from many areas of the Earth will be available for viewing.

POSTER

ZIRCON AND MONAZITE U-TH-PB, REE, O AND HF SIGNATURES IN WESTERN PROVINCE GNEISSES

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Zircon and monazite from Western Province paragneiss and orthogneiss units, mostly located within the Fraser and Granite Hill Complexes of Westland, were analysed for U-Th-Pb geochronology to constrain the ages of protolith rocks and metamorphic overprints. This was followed by the determination of zircon rare earth element (REE) concentrations, oxygen and hafnium isotopic compositions. Experiments performed *in situ* using a sensitive high-resolution ion microprobe (SHRIMP) and laser ablation multi-collector inductively coupled plasma mass spectrometer (LA-MC-ICPMS) allow better understanding of crustal growth on the Zealandia margin of Gondwana from the micron scale. Paragneiss zircons were likely sourced from widespread regional Greenland Group meta-sedimentary rocks of the Buller Terrane based on their typical 'Gondwana' age spectra. Detrital grains record variable REE patterns relating to magmatic and metamorphic crystallisation processes operating prior to and following Ordovician deposition. $\delta^{18}\text{O}$ and $\epsilon_{\text{Hf}(T)}$ values trace major phases of juvenile crust formation and subsequent reworking in provenance sources, signifying an increase in the recycling of compositionally diverse, evolved crustal materials through time.

Orthogneiss zircons relate to two intense episodes of magmatism that record similar REE concentrations. Devonian samples have elevated $\delta^{18}\text{O}$ and un-radiogenic $\epsilon_{\text{Hf}(T)}$, Cretaceous samples record more primitive $\delta^{18}\text{O}$ and radiogenic $\epsilon_{\text{Hf}(T)}$. Both orthogneiss suites can be explained by thorough mixing of mantle-derived magmas with Greenland Group rocks. The relative proportion of crustal contamination being ~20-50 % for the Devonian and ~10-40 % for the Cretaceous. Orthogneiss protolith materials were largely hybridised prior to and during zircon crystallisation, suggesting plutonic assembly over

limited structural levels. Both paragneiss and orthogneiss monazite are dominated by Devonian and Cretaceous ages, reflecting thermal pulses related to regional and localised granitoid intrusions. These results demonstrate the ability of zircon to retain detailed petrogenetic information through amphibolite-facies metamorphism with excellent fidelity.

ORAL

FILTERING OUT THE ASH: MITIGATING ASH INGESTION FOR EMERGENCY POWER GENERATORS

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The widespread distribution of volcanic ash can lead to a range of societal impacts. One of the most common impacts is flashover on insulators, following contamination by volcanic ash. Disruption of the power systems may lead to cascading disruption for dependent systems such as hospitals, water and wastewater treatment plants, and emergency services. Typically, large emergency power generator sets are used to provide emergency power supply for essential services. However, there has been little study of what impact ash fall exposure will have on generator performance. International experience suggests large generators can be rapidly disrupted when exposed to high concentrations of suspended or falling ash due to obstruction of air filters and radiators, causing overheating of the engine and shut down of the generator system.

Therefore, understanding a) what ash dose (as a function of suspended ash concentration, grain size and volume) will lead to generator failure and b) what mitigation strategies can be employed to avoid failure are required in order to ensure the reliable emergency power supply can be provided for lifelines. This research uses empirical laboratory experiments to investigate the use and maintenance of large generators to a range of volcanic ashfall types, simulating both proximal and distal ash fall exposure. It does this by investigating the application of temporary external filters to minimise the ingestion of volcanic ash into generator housings, and recommendations on the type and use of temporary filters including the rate of cleaning, loss of performance, and replacement. Initial testing results suggest temporary filters are effective at reducing ash ingestion, but significantly reduce airflow due to

ash blockage. Future work will investigate the most effective filters for different ashfall types and make recommendations for the operation and maintenance of generators during the event of volcanic ashfall.

POSTER

INVESTIGATING SUBMARINE CANYONS AND SEAFLOOR DEPRESSIONS ON THE OTAGO SHELF USING 3D SEISMIC DATA AND HIGH RESOLUTION MULTIBEAM BATHYMETRY

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The continental shelf along the east coast of New Zealand's South Island is a classic passive margin. Off the coast of Otago, the shelf is incised by a series of submarine canyons that lead out into the deeper water of the Bounty Trough. The sedimentary environment of the continental shelf in this region has been strongly influenced by dynamic current systems. Temperature and salinity gradients between inshore and offshore waters are significant and form the sharply delineated northward flowing Southland Current, which is continuous with the Subtropical Convergence. Numerous small seafloor depressions are found in the vicinity of these canyons, indicating a possible relationship between the formation of the depressions and fluid flow dynamics in the canyons. Recently acquired 3D seismic data collected by Anadarko and Origin Energy revealed a dense network of polygonal faults in the region that potentially act as fluid flow conduits to the seafloor. Mapping of these fault systems allows us to determine whether there is a significant relationship between faults in the subsurface and the location of overlying seafloor depressions. Additionally, the complex geomorphology of the submarine canyons can be seen in high-resolution bathymetric data recently collected by NIWA as part of the Oceans 2020 program. Incised canyon systems indicate the influence of focused dynamic fluid flow; however several of the canyons appear to have been abandoned which suggests that fluid flow may be intermittent. There is also evidence of sediment slumping on the slopes adjacent to the canyons, another potential factor in the formation of seafloor depressions.

ORAL

DETERMINATION OF NEOGENE MG/CA SEAWATER RATIOS AND SPECIES-SPECIFIC MG/CA CALIBRATIONS FOR EXTINCT FORAMINIFERAL LINEAGES

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A key facet of climate science is constraining the extents of past climates – because, in order to understand future changes to the state of the system, we have to understand past changes. However, as there is no direct temperature record throughout deep time, our knowledge is reliant on proxy indicators, and each of these proxies has its own inherent problems when extending them through geological timescales. Traditionally, benthic oxygen isotope records have been used to construct Cenozoic temperature histories; however, oxygen isotope paleotemperature estimates are largely reliant on assumptions of global ice volume and the ¹⁶O/¹⁸O ratio of the ocean. The application of the Mg/Ca paleothermometer escapes this issue, but is instead reliant on poorly-constrained estimates for the ambient Mg/Ca ratio of seawater throughout much of the Cenozoic. We present a pilot study measuring Mg/Ca ratios in foraminiferal lineages with overlapping ranges from the Recent through to the Miocene, in order to cross-calibrate species-specific precipitation effects of Mg/Ca in biogenic calcite. Utilising extant species with established Mg/Ca calibrations and long time ranges, the Mg/Ca seawater ratios are back-calculated through time, and then these data can be used to generate species-specific Mg/Ca calibrations for extinct taxa when cross-calibrated with overlapping species lineages and oxygen isotope records. This is an iterative process, allowing us to work backward, stepwise, through the Cenozoic. Samples have been selected from specific intervals of DSDP Site 593, which provides a near-continuous record of well-preserved planktic foraminifera assemblages, and well-constrained age models. The outcomes – species-specific Mg/Ca calibration for extinct foraminifera, and Mg/Ca seawater ratios through time – are widely applicable to Cenozoic climate studies, and will strengthen the accuracy of multi-proxy sea surface temperature records.

POSTER

**YOUNGER DRYAS ATMOSPHERIC RADIOCARBON
VARIATIONS AS ARCHIVED IN NEW ZEALAND
KAURI**

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The Younger Dryas (YD) stadial, from ~12.95 to 11.6 kyr cal BP, was an abrupt Northern Hemisphere cooling episode, disrupting the general warming trend from the Last Glacial Maximum to the Holocene. The YD represents the end of the last glacial period in the Atlantic region and was accompanied by several large, prolonged fluctuations in atmospheric radiocarbon concentration, resulting from either changes to production or segregation of radiocarbon between the various global carbon reservoirs. In addition, the YD is also an important period of time for radiocarbon calibration in that it links the master tree ring series (as presented in the international radiocarbon data set IntCal09) terminating at 12.56 ka cal BP, with the older floating ~1300 year Allerød Pine sequence beginning at ~12.64 ka cal BP. A floating 1450-yr-long New Zealand YD kauri chronology has been constructed from 37 trees, and spans the time interval ~12.86 – 11.7 ka cal BP. Radiocarbon analysis comprising 700 measurements from 144 decadal samples by three radiocarbon laboratories has produced a high resolution and highly accurate and precise radiocarbon data set. A radiocarbon wiggle match of the YD kauri data set against IntCal09 to establish accurate calendar ages reveals additional errors in IntCal09 between 12.6 – 12.0 ka cal BP.

In this paper, we will discuss the origin of the YD radiocarbon fluctuations and possible implications for ocean circulation re-organization theories, highlight errors in IntCal09 and show the best positioning of numerous floating German and Swiss tree-ring series.

ORAL

**BROADBAND GROUND MOTION MODELLING OF
A LARGE ALPINE FAULT EARTHQUAKE**

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The large September 2010 and the tragic February 2011 Canterbury earthquakes caused widespread damage by ground shaking and sand liquefaction in the Christchurch region. The Canterbury earthquakes are at a short distance from the Christchurch central business area and have a magnitude that is much smaller than the expected one of the Alpine fault (Mw=8.2). Caroline Holden had the privilege to work closely with Dr John Beavan on modelling many past large regional earthquakes, including the Canterbury earthquakes. This study presented here is the projection of this work now onto a potential future earthquake.

The Alpine Fault is a major geological feature in New Zealand. It is a dextral transform fault separating the Pacific plate on the east from the Australian plate on the west, crossing the South Island from Northeast to Southwest. The Alpine Fault is a potential source of major earthquakes in the near future. The return period of the fault is approximately 270 years, with no major event occurring over the last 294 years. Recent studies suggest that a magnitude Mw > 8 would be a realistic scenario for a future Alpine fault rupture. The Alpine fault is at a distance of 150km from Christchurch and there is a need to better assess the effect of ground shaking in Christchurch from this large event.

We have modelled deterministic broadband ground-motions in Christchurch from a magnitude 8.2 Alpine Fault event based on a range of techniques and scenarios. We present here our results in the form of acceleration time histories and response spectra, the latter being relevant to the engineering community.

ORAL

**NEW ZEALAND'S PARTICIPATION IN IODP:
RETROSPECT AND PROSPECT**

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New Zealand joined the Integrated Ocean Drilling Program (IODP) as part of the Australian and New Zealand IODP Consortium in 2008. Despite on-going struggles to come up with funds for the annual membership fee of ~\$300,000, we have had an extraordinarily high level of participation. Over five years, 12 NZ-based researchers or educators have participated in expeditions: 6 from Otago University, four from GNS Science, two from Victoria University and one from the National Aquarium. There have been three expeditions in the SW Pacific and one more on the Antarctic margin, in a region very relevant to our Antarctic research. The NZ public and economy has benefitted from three port calls of the *D/V JOIDES Resolution*, via >\$3M in port fees and provisioning costs and a wide range of public outreach activities.

The future of our participation looks bright. NZ scientists are lead proponents or co-proponents on several highly ranked proposals that stand a good chance of being scheduled within the next 4-5 years:

- The Hikurangi Subduction Margin Slow-Slip Multiphase Proposal (including riserless and riser drilling, and borehole monitoring)
- Tasman Frontier Proposal exploring linkages between SW Pacific subduction initiation and Paleogene climate change on the Lord Howe Rise
- Brothers Volcano Proposal, Gateway to the Sub-Arc Mantle, on the Kermadec Ridge
- Campbell Drift Ancillary Proposal to complement an existing Paleogene South Pacific Transect proposal, that traverses the Campbell Plateau and South Pacific to the east.

In addition to their science goals, all of these proposals have potential to have significant economic benefits for NZ by ground-truthing poorly known parts of our marine territory and drawing two premiere drilling vessels to our region, the US-run *JOIDES Resolution* and the Japanese *Chikyu*, both of which will be available for targeted exploration for petroleum and minerals. There are also several additional proposals involving NZ scientists that are currently being reviewed by IODP panels.

ORAL

**OCEAN CHANGE THROUGH THE PALEOCENE-
EOCENE TRANSITION: INSIGHTS FROM
COMPARISONS BETWEEN THE SW PACIFIC AND
NW ATLANTIC (IODP EXPEDITION 342)**

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As key regions for global thermohaline circulation, the present-day SW Pacific and NW Atlantic oceans have three primary features in common: a deep western boundary current flowing from pole to equator, a sub-polar cyclonic gyre of cool surface water and a subtropical anticyclonic gyre of warm surface water. In both regions the interplay between these three components has been closely linked to tectonic and climatic changes through the Cenozoic, including the opening of gateways and a progressive decline in atmospheric CO₂. For the SW Pacific, it seems likely that this interplay can be traced back to the early Cenozoic, perhaps even the Late Cretaceous. However, the origins of the NW Atlantic system are much less certain, partly because of the absence of high-latitude records. IODP Expedition 342 aimed to resolve this uncertainty by recovering an expanded record from Paleogene sediment drifts off Newfoundland (40°N paleolatitude).

Radiolarian microfossils and biosiliceous sediments are used to infer the relative influence of warm and cool watermasses in these two regions through the Paleocene-Eocene transition. In the SW Pacific, the boundary between these watermasses oscillates between a paleolatitude of 65° and 50°S. A southern watermass, characterised by endemic or cosmopolitan taxa and abundant biogenic silica, is most extensive in the Paleocene and Late Eocene. Tropical elements migrate south in the Early Eocene but fully tropical radiolarian assemblages are unknown south of 40°S in the Eocene. Tropical assemblages are recorded in the NW Atlantic sites at 40°N from Late Paleocene to Middle Eocene times. In contrast to the SW Pacific, the globally warm early Eocene is associated with radiolarian-rich biosiliceous sediments, suggesting pronounced northward expansion of an equatorial zone of high productivity. Conversely, siliceous microfossils are scarce in Late Eocene-Early Oligocene sediments from the Newfoundland sites, suggesting an oligotrophic setting within a subtropical gyre.

ORAL

**RAIN INDUCED UNSTABLE SLIDING – TASMAN
GLACIER, NEW ZEALAND**

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Alpine glaciers and ice caps are anticipated to contribute significantly to sea level rise over the coming century. This contribution will take place due to changes in surface mass balance and dynamic discharge. The potential for discharge acceleration has been highlighted as a major source of uncertainty in sea level rise prediction.

Glacier flow is commonly partitioned into three components: internal deformation, basal sliding, and subglacial deformation. Basal sliding and subglacial deformation rates have the potential to change rapidly, and observational data have established a clear causal link between subglacial water pressure and sliding velocity. When the glacier substrate is hard, the reduction in effective pressure caused by increasing basal water pressure has a direct effect on sliding velocity by reducing grain–grain contact and increasing zones of cavitation. When the glacier substrate is soft and deformable, reducing the effective pressure reduces the shear strength of the substrate. This results in enhanced sliding at the top of the substrate, and enhanced deformation at depths of decimeters to meters within the substrate.

Here we present the largest glacier accelerations in response to rainfall events ever observed. During times of heavy rainfall, Tasman Glacier in the Southern Alps of New Zealand accelerates to speeds that are over 40 times its normal speed. Peak speeds are maintained for periods of less than 48 hours before the glacier velocity returns to close to background levels. Continuous GPS deployed for 212 days on the glacier surface show that the velocity of Tasman Glacier is linearly proportional to 24-hour rainfall in the surrounding catchment. These observations greatly expand the range of glacier speed-ups in response to water inputs, and likely represent a state of unstable sliding.

POSTER

**PALEOSEISMOLOGY OF THE 2010 MW 7.1
DARFIELD (CANTERBURY) EARTHQUAKE SOURCE,
GREENDALE FAULT**

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The previously unknown Greendale Fault (GF) ruptured in the moment magnitude (M_w) 7.1 Darfield earthquake and produced the first historical surface rupture on the Latest Pleistocene gravel surface of the Canterbury Plains west of Christchurch, New Zealand. Surface displacements along the GF were measured with high precision using a combined approach of field mapping, airborne lidar, and terrestrial lidar. No unambiguous geomorphic evidence of a penultimate GF surface rupture was revealed from pre-2010 imagery.

In order to determine the displacement, timing and magnitude of paleo-earthquakes on the GF, we conducted trenching investigations across the central fault. Riedel shear fractures were one of the most conspicuous features of the surface rupture deformation zone. Subsurface trenching reveals faulted stratigraphy of gravels interbedded with thin sand and silt paleochannels. At one site, a shallow channel near the top of the sequence is offset 60 ± 10 cm right laterally and 9 ± 5 cm vertically across a discrete Riedel fracture, consistent with displacement measurements from overlying offset cultural features. An underlying channel is offset 120 ± 15 cm right-laterally and 21 ± 5 cm vertically, consistent with successive slip-at-a-point in both a penultimate earthquake and the Darfield earthquake. Data from a second trench site corroborate these findings and indicate lateral variation in the thickness of sediment deposited after the penultimate rupture. Optically stimulated luminescence dating of the channels yields an age of 22 ± 2 ka for the single-offset sand and 28 ± 2 ka for the twice-offset sand.

We conclude that the penultimate GF surface rupturing earthquake occurred across an actively aggrading, last glacial maximum, alluvial landscape between ca. 22–28 ka and was possibly of a similar M_w to the Darfield earthquake. The fault scarp was buried, and possibly eroded, following the penultimate event, such that no surface evidence of faulting was present at the study site prior to the Darfield earthquake.

ORAL

THE ¹³C-EXCESS: A NEW DUAL-ELEMENT STABLE ISOTOPIC APPROACH FOR PALAEO-ENVIRONMENTAL RECONSTRUCTIONS USING LAKE CARBONATES

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Stable isotope-based proxy methods enhance our ability to interpret past environments. In ancient carbonate lakes, these methods assume that the unmodified isotopic composition of meteoric water or local carbon reservoirs, or both, are recorded by authigenic minerals. Surprisingly, these assumptions have not been tested across wide-ranging environmental contexts. A review of globally distributed Quaternary lake carbonate oxygen isotope compositions reveals that lacustrine carbonate $\delta^{18}\text{O}$ values are not strongly, nor significantly, correlated with local meteoric-derived water compositions due to the modification of in-flow waters. These modifications are largely caused by surface water evaporation, and can result in dubious reconstructions of ancient hydrological conditions and water source effects such as the strength of prevailing air-mass trajectory, >3km errors in paleoelevation estimates, and unrealistic shifts in lake water temperature if not accounted for. However, evaporation induced shifts in surface water $\delta^{18}\text{O}$ are accompanied by similar magnitude shifts in $\delta^{13}\text{C}$ -DIC due to kinetic fractionations associated with CO_2 evasion. This positive covariation in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ may be used to de-trend lake carbonate compositions for the effects of surface water evaporation using a parameter recently defined as the '¹³C-excess'. This approach uses the isotopic covariant trend between in-flow waters and lake waters to better constrain ancient meteoric-derived water compositions. To demonstrate the potential strength of the ¹³C-excess approach over single element methods, we compare the paleoelevation estimates derived from lake carbonate compositions using both approaches. ¹³C-excess values are significantly correlated with mean up-slope hypsometric altitude with an error of $\pm 500\text{m}$, and application of the ¹³C-excess approach to Cenozoic lake carbonate records from the western U.S. Cordillera and central Otago both challenge and reinforce previous palaeo-environmental interpretations based on $\delta^{18}\text{O}$ alone. The ¹³C-excess approach is an exciting new approach relevant to disparate paleoenvironmental research topics, including

Quaternary climate change, uplift of mountain belts, and palaeohydrology.

ORAL

LARGE EARTHQUAKES AS A DRIVER OF EPISODIC SEDIMENT FLUX FROM AN ACTIVE MOUNTAIN BELT

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Large earthquakes are an important mountain building process responsible for both the addition of mass to mountain belts and its removal through erosion. Earthquakes drive erosion by triggering pervasive landsliding and increasing the susceptibility of slopes to failure during subsequent disturbance. Despite their importance, the magnitude and duration of landscape responses to earthquakes and their role in the long-term development of mountains is poorly understood. We use the sedimentary records of lakes Paringa, Mapourika and Moeraki to constrain the magnitude and duration of post-seismic landscape responses to sequential great ($M_w 8$) earthquakes on the Alpine Fault in range-front and trunk valley catchments of the Southern Alps. The lake sediments contain a detailed record of co-seismic, post-seismic and non-seismic deposits that are correlated to the Alpine Fault seismic cycle using high precision chronologies derived from Bayesian modelling of AMS radiocarbon dates. The greatest impact of Alpine Fault earthquakes occurs in small range-front catchments. Here the landscape response to Alpine Fault earthquakes persisted for on average 50 years following the last four Alpine Fault earthquakes. Landsliding on hillslopes during the landscape response resulted in a threefold increase in sediment flux from the range front. In larger trunk valley catchments, the sedimentary response to Alpine Fault earthquakes is more subdued and has a longer duration. The lake records indicate that Alpine Fault earthquakes are important drivers of episodic supply of sediment to channels, and play a significant role in the denudation of the Southern Alps.

ORAL

**MICROBIAL ARSENIC RESISTANCE MECHANISMS
IN CHAMPAGNE POOL, NEW ZEALAND: AN
ANALOG FOR EARLY EARTH?**

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Champagne Pool is an acidic, sulfidic hot spring with arsenic levels supersaturated with respect to orpiment precipitation. Hyperthermophiles with microbial arsenic resistance mechanisms influence and reflect the arsenic speciation in the hot spring, and give insights into the evolution of microbial arsenic tolerance. In this study, water and sediment samples for arsenic speciation and 16S rRNA gene pyrosequencing were taken from the inner pool, the rim, the outflow channel and the discharge of the outflow channel. Arsenic speciation in Champagne Pool is controlled by a low redox potential, which stabilizes arsenite (As(III)) as the main species, and a cumulative replacement of oxygen by sulfide in arsenic oxyanions to form thioarsenate species. At the shallow outflow channel, the appearance of methylated arsenic is correlated with a shift in microbial community structure from Bacterial to Archaeal dominance. Microbial community diversity increased from pool to rim and outflow channel, signifying a release of selective pressure from arsenic attributed to orpiment precipitation. The inner pool and rim contain thermophiles closely related to the family Thermodesulfobacteriaceae, which may influence the shift to Archaea at the outflow channel by controlling the concentration of sulfate. The correlation of archaeal relative abundance with arsenic methylation points to the presence of thermophiles possessing the rare *arsM* gene (or gene homologue) associated with arsenic methylation. These results suggest a close dependency between arsenic speciation and microbial diversity at otherwise stable conditions (pH, temperature, Eh) in Champagne Pool.

ORAL

VOLCANIC ACTIVITY ON TERRANE BOUNDARIES

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Many workers have noted the apparent lineations of volcanic cones and eruptive centres of Te Ika A Maui (North Island), New Zealand. Kear, (1964) and later Hayward (1976) identified islands off the eastern coast of the Coromandel Peninsula as the 'Rhyolite Line'. No causative agent for the lineation was identified at the time.

Extending the classification to include all types of volcanic activity identifies a feature at least 350km long, from Cape Brett, Bay of Islands to Motiti Island, off Tauranga. While seismic data compiled by Thrasher (1986) reveals that there is no apparent fault on the sea floor that would cause the lineation, comparison with published maps of the underlying terrane structure reveals a probable match with the eastern boundary of the Waipapa (composite) Terrane. Basement samples east of this lineation are sparse, but are not fully congruent with Waipapa (composite) Terrane.

Another volcanic lineation, the Kiritahi Volcanics, is similarly identified on the western shore of the Hauraki Depression. An extended line of volcanic activity is also traceable both north and south of this group, from Leigh to Pureora. Residual gravity mapping of the lower part of the extended chain provides evidence that this volcanic lineation occurs at a sharp change in the gravity field, corresponding with the western boundary of the Waipapa (composite) Terrane.

If this apparent link between volcanic lineations and the terrane boundaries is correct, this implies that these volcanics are not directly connected to the subductional processes of the Pacific Plate, but are the result of a separate process associated with tractional weakening of the inter-terrane boundaries.

ORAL

**REALITIES OF SCIENCE AND RISK
COMMUNICATION: SOME EXPERIENCES FROM
THE 2010 DARFIELD AND 2011 CHRISTCHURCH
EARTHQUAKE RESPONSES**

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Following the September 2010 Darfield and February 2011 Christchurch earthquakes a small team of scientists was tasked with providing science and risk information to decision makers and the public.

Working within the Civil Defence Emergency Management (CDEM) framework, rather than as independent scientists, presented particular challenges. The CDEM management structure, strained by the enormity of the 2011 response, struggled to support the communication of science, and dissemination of information to the community was often delayed. Occasionally political factors also created delays or obstacles to open communication. In addition, alternative theorists provided another challenge in how best to manage rumours around earthquake causes and predictions. Effective messaging, particularly around risk, was an issue. People, who were often displaced and distressed, craved certainty, which couldn't be provided. While probability data produced were useful for technical users, many members of the public were focused on more simple questions like "how scared should I be?" and "when should I put things back on shelves?". Where possible we presented information in terms of relative risks, scenarios to be prepared for, and actions that people could take. We also needed effective communication methods while being limited by disruption to power and telecommunication networks. The main methods of communication were fact sheets (hard copy and pdfs on websites), and engagement with the community at public meetings held around greater Christchurch. We found that direct contact, mainly through community meetings, was the best means of conveying information. Being able to talk *with* people, rather than anonymously providing written information, put a face to the science and introduced the elements of listening and empathy, which people needed just as much as the technical information. This dialogue also enabled us to ascertain what people wanted to know, rather than assuming their needs, resulting in more effective messaging.

ORAL

**SILCRETE PLANT FOSSILS FROM LANDSLIP HILL,
SOUTHERN NEW ZEALAND**

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Miocene plant fossils comprising leaves, wood, bark, cones and seeds occur as randomly oriented, often three-dimensionally preserved fossils in silica-cemented fluvial quartz sandstones (silcrete) at Landslip Hill, near Pukerau. Recent collections have added to the diversity of plant morphotypes already reported from the silcrete. External moulds of logs are common, and wood is occasionally preserved. The silcrete fossils preserve several types of conifer, including leaves of *Agathis* (Araucariaceae) and shoots of *Libocedrus* (Cupressaceae) and *Dacrydium* (Podocarpaceae). Many types of angiosperm leaves are also present, with possible *Nothofagus* (Nothofagaceae), *Ixerba* (Escalloniaceae), *Metrosideros* (Myrtaceae), *Myrsine* (Myrsinaceae), and *Weinmannia* (Cunoniaceae), and a range of as yet unidentified morphotypes, including a banana-like monocot (?Musaceae). Fruits and seeds preserved as three-dimensional moulds include common, smooth, and deeply tri-lobed endocarps of the Australasian rainforest tree *Elaeocarpus* (Elaeocarpaceae). Numerous, well-preserved cones of *Gymnostoma* indicate that Casuarinaceae also formed an important component of the vegetation. The silcrete fossils from Landslip Hill indicate the past presence of local vegetation quite unlike that now found in the region. *Gymnostoma* is no longer present in New Zealand, but *Agathis* is an important canopy tree in northern North Island, while *Libocedrus*, *Dacrydium*, *Elaeocarpus*, and *Nothofagus* are found throughout modern New Zealand. Together, these identifications suggest a warmer climate and the presence of subtropical rainforest. The lack of evidence for leaf decay, along with the jumbled and damaged state many of these fossils suggests fluvial transport with rapid, shallow burial and fossilization.

POSTER

EARTHQUAKE RATES AND CHANGES ALONG THE HIKURANGI MARGIN

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We will examine how the rate of earthquakes varies along the Hikurangi Margin in time. The Hikurangi margin exhibits clustering behaviour intermediate between the frequent clustering of low magnitude (< 5) earthquakes of the Taupo Volcanic Zone, and clustering dominated by the aftershock activity of large magnitude earthquakes (> 6) exhibited in the South Island (both along the Alpine Fault, and in the Fiordland subduction zone). Several earthquake sequences along the Hikurangi margin have previously been shown to correlate with the occurrence of local slow slip events. We analyse these sequences, and some newly identified sequences that also appear to relate to slow slip events. We will explore variations in slow slip related sequences, and between triggered and non-triggered sequences. While the majority of seismicity along the Hikurangi Margin does not occur in distinct sequences, we estimate that 25% of all clustered earthquakes are associated with slow slip. Despite the fact that a high percentage of sequences are associated with slow slip, many slow slip events do not cause detectable sequences. The relationship between slow slip events and earthquake sequences has implications for both earthquake forecasting and hazard modelling.

POSTER

BENEATH CHRISTCHURCH IN 3D: WAYS OF PRESENTING NEW INFORMATION UPON WHICH TO BASE PLANNING AND ENGINEERING SOLUTIONS

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Damage from the Canterbury earthquakes has focused attention on ground conditions beneath Christchurch and the need to re-build the city. Planning and engineering decisions for re-building will require clear and comprehensive understanding of high quality information. As part of a new 3D Urban Mapping project at GNS

Science, various geomorphic, lithostratigraphic, chronostratigraphic and geotechnical data have been used to develop a 3D geological map of subsurface materials underneath Christchurch City, using Leapfrog software (www.leapfrog3d.com). Leapfrog builds geological models using implicit modelling, a 3D interpolation engine (FastRBF™) that allows rapid construction of 3D boundary models from input data. RBFs are a natural way to interpolate scattered data, particularly when the data points do not lie on a regular grid and when the sampling density varies. Modelled subsurface data include the pre-existing Environment Canterbury digital borehole log database which records lithological information to depths of up to 200-300 m. Subsequent to the Darfield earthquake a large number of boreholes and geotechnical soundings (mostly to depths of up to 40 m) provide high quality digital data across the central and eastern city. These subsurface data have been modelled separately in terms of stratigraphic unit, lithology and geotechnical characteristics, including soil behaviour type (SBTn) and density ((N1)₆₀). Models can easily be copied, updated, edited and compared providing reliability and confidence in the modelling process. The different models have been reconciled within a single 3D geological model that provides information on distribution and characteristics of materials from underpinning models. This model reveals different aspects of Christchurch city and its relationship with subsurface geology. Interpolated boundaries and volumes are valuable at the city block scale for a range of purposes, including planning, generalised geotechnical conditions, liquefaction susceptibility and potentially ground shaking amplification.

ORAL

THE 2013 SOUTHERN COOK STRAIT EARTHQUAKE SEQUENCE: SPATIAL VARIABILITY OF GROUND MOTION DUE TO SOURCE AND SITE EFFECTS

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The 2013 Cook Strait earthquake sequence produced the most significant ground shaking in the Wellington and Marlborough regions in recent decades. The sequence began on the 19th July at shallow depths offshore from Seddon. Two foreshocks of Mw5.5 and Mw5.8 preceded the Mw6.6 Cook Strait earthquake on the 21st July. The major events of the sequence showed a general

southwestward progression, with the Mw6.6 Lake Grassmere earthquake following on the 16th August, in the onshore region. Both Mw6.6 events involved strike-slip rupture of approximately northeast-southwest oriented fault planes.

Peak ground accelerations recorded during the sequence ranged up to 0.75 g in Seddon during the Lake Grassmere earthquake, and over 0.2 g in parts of Wellington during both major events. In central Wellington, a number of stations recorded spectral accelerations up to 20-30% of the current building design level for any given site class. Station VUWS close to the foreshore and areas of reclaimed land recorded spectra over 50% of the design level for periods 0.4 - 0.5 seconds. Whereas the Cook Strait earthquake rupture was bilateral, the Lake Grassmere earthquake involved southwest-to-northeast directed rupture, with directivity effects that led to increased ground motions in the Wellington area. Ground motions in Wellington were highly variable and strongly dependent on the local site conditions. We present a preliminary analysis of local ground motion effects in terms of amplification and polarization, using spectral ratios calculated for a range of Wellington stations spanning rock to deep soil conditions. We also investigate the potential to extract information from a spectral inversion technique to separate source, path and site influences on ground motion (used successfully following the Canterbury earthquake sequence).

POSTER

OLIGOCENE PALEO GEOGRAPHY (TE KUITI GROUP) OF CENTRAL-WESTERN NORTH ISLAND, NEW ZEALAND

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The Te Kuiti Group (Late Eocene to earliest Miocene) is an overall transgressive sequence of highly varied facies ranging from basal coal measures in fluvial environments to capping bryozoan limestones and marls in shelf to upper slope settings. Based upon a comprehensive re-evaluation of the lithostratigraphy and biostratigraphy of the Group, and upon the results of detailed facies analysis, a new series of 13 paleogeographic maps (Runangan to upper Waitakian) have been drawn that track the geological evolution of the Te Kuiti basin in central-western North Island, including the bounding basement highs. Two stages of contrasting basin

development are evident, each controlled by different tectonic regimes and with characteristic linked depositional systems. The first stage (Late Eocene to mid-Oligocene) of sedimentation occurred under regional extension marked by downwarping accompanied by minor normal faulting and regional onlap. The second stage (mid-Oligocene to earliest Miocene) involved sedimentation within a mild contractional setting expressed as reverse movement and basement uplift on the Taranaki and Manganui Faults and repeated phases of subsidence and mild inversion in the basin inferred from the occurrence and distribution of unconformities. Relative sea-level changes associated with the Te Kuiti Group succession appear to have been influenced more by tectono-eustasy than by glacio-eustasy. No single piece of evidence conclusively rules out complete marine submergence of the entire Te Kuiti basin by Oligocene seas, but collectively several properties strongly suggest the persistence of at least local or scattered basement paleohighs, including the occurrence of variable amounts of terrigenous sediment throughout the Group, the lateral distribution of formations and facies within the basin, and the sedimentary structural evidence for accumulation in an open to partly land-locked marine shelfal embayment or seaway under the influence of both strong tidal flows and storm wave sediment transport and by-pass.

ORAL

PMAP SERIES: A NEW PALEOENVIRONMENT AND PALEO GEOGRAPHY MAP SET FOR UNDERSTANDING THE NEW ZEALAND CENOZOIC

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We have developed a set of Paleoenvironment and Paleogeography maps for New Zealand (The PMAP Series) at 1 m.y. intervals through the Cenozoic. These maps are built upon base maps of the distribution of Paleozoic and Mesozoic basement terranes, changes in the distribution of which take account of the c. 800 km of right-lateral displacement through New Zealand during the past 27 m.y., for which a numerical model has been developed. This model is also used to relocate formations to the positions in a fixed-Australia frame of reference appropriate to the time they accumulated through sedimentary or volcanic processes. The Paleoenvironment maps are

supported by an extensive database that includes present location, stratigraphic age, lithofacies and environments of deposition for each Cenozoic formation, together with an extensive text file that details most of the information published about Cenozoic formations across New Zealand. The Paleogeography maps are a derivative of the Paleoenvironment maps and interpret the location of particular boundaries (e.g. coastline, shelf edge) and features (e.g. mountains, rivers, submarine fans). The maps have been animated and are considered to be a useful tool to transfer knowledge about the development of New Zealand through the Cenozoic for resource exploration and other purposes.

ORAL

TRAPPED IN AMBER – RECONSTRUCTING FOREST ECOSYSTEM BIODIVERSITY IN CENOZOIC NEW ZEALAND

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Organisms preserved in fossilized tree resin (amber) from numerous Old and New World localities are renowned for their exquisite preservation which allows novel insights into past terrestrial ecosystems. Until now, however, most fossiliferous amber deposits have been located on the former northern supercontinent Laurasia. Gondwanan fossiliferous amber deposits are comparatively rare, and Australasian occurrences are limited to the still largely unstudied Miocene (?) amber from the Cape York Peninsula of Australia. In New Zealand, amber is virtually ubiquitous in coal, lignite and some non-carbonaceous sediments throughout the South Island but until recently, no animal inclusions and only a few floral remains have been recognised. In an ongoing study, we have collected amber from Upper Cretaceous, Eocene, Oligocene, Miocene and Pliocene sites, including discrete blocks, rounded “amber-pebbles”, millimetre-sized drops, sometimes associated with wood, presumably of the resin producing trees, or as tiny resin plugs on leaf macrofossils such as *Halocarpus*. Preliminary study of these samples has revealed a spectacular range of well-preserved fossil inclusions, including (1), araucariacean wood, (2), fungal remains such as two-celled ascospores, numerous septate conidia, and mycelia of sooty moulds

(Capnodiales), (3), sheathed prokaryotic filaments, (4), arachnids such as mites and spiders, (5), springtails (Collembola), and (6), diverse insects from the orders Coleoptera, Diptera, Hymenoptera, Hemiptera, and Lepidoptera. These finds represent groups poorly represented in the fossil record of the Southern Hemisphere and, for the first time, attest to the paleontological potential of New Zealand amber inclusions to provide new insights into the biodiversity of past forest and forest floor ecosystems of Zealandia.

ORAL

A SEISMOLOGICAL INVESTIGATION OF THE KAWERAU GEOTHERMAL FIELD

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The Kawerau geothermal field is located east of the Kawerau township in the Bay of Plenty and covers an area of 19 – 35 km². It has been exploited for steam and geothermal energy since 1957 and currently has three abstracting companies operating within it. Now it hosts 15 production wells, 12 injection wells and 24 additional wells for monitoring purposes with the depths of these wells ranging between 950 – 2500 m for production wells and 300 – 3000 m for injection wells.

The investigation will incorporate earthquake relocations and ambient seismic noise imaging. Shallow local earthquakes recorded on the GeoNet network and Mighty River Power's private monitoring network over the last 5 years will be relocated using an existing velocity model and compared with local tectonics, injection sites, temperature structures and resistivity boundaries. With ambient seismic noise imaging we aim to delineate the shallow structure of the field and refine local velocity models. Recent geological models of the field will provide some constraints on the model as well as providing an interesting comparison point. We also plan to do a temporary seismometer deployment in the coming months to augment the existing network and improve the coverage for our ambient noise study.

POSTER

**DETERMINING THE PROVENANCE OF THE
MURIHIKU TERRANE USING IGNEOUS CLASTS
FROM JURASSIC AND TRIASSIC CONGLOMERATES,
CATLINS COAST, NEW ZEALAND**

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The provenance of the Murihiku Terrane has been investigated using petrography, geochemistry and geochronology on igneous, mainly plutonic, clasts found in rare conglomerates in the Catlins, southeastern New Zealand. Late Triassic (Oretian) conglomerates at Roaring Bay and Middle Jurassic (Temaikan) conglomerates at False Islet, Waikawa and Slope Point have been studied in detail. These are generally polymict, poorly sorted, pebble to cobble grade (uncommonly boulder). Rounded to subrounded volcanic clasts dominate with subordinate volcanoclastic, plutonic (15%) and rare metamorphic clasts.

The 18 plutonic clasts analysed range from diorite to alkali feldspar granite (59-79 SiO₂ wt%) and generally have subduction-related arc geochemistries. The majority are I-type but a small number have weak A-type affinities.

Zircons from 13 plutonic clasts have been dated by LA-ICP-MS at the University of Otago. All reported ages are pooled ²⁰⁸Pb-corrected ²⁰⁶Pb/²³⁸U ages (Ma) with 2s errors. The main clast age cluster is broadly Middle Permian (258 ± 4, 262 ± 3, 266 ± 3, 266 ± 4, 268 ± 2, 270 ± 4, 273 ± 3). In addition there are clasts with younger Triassic (218 ± 3, 241 ± 4) and Jurassic (170 ± 2, 188 ± 3), and older latest Carboniferous (299 ± 4) and mid-Carboniferous (332 ± 5) ages.

Many of the analysed clasts show similarities with units within the adjacent Median Batholith on the basis of their combined petrography, geochemistry and age characteristics. However, as yet, no appropriate source in the Median Batholith has been recognised for the clasts of Middle Permian age. Potential source(s) for these may include rare felsic plutonics in the Dun Mountain Ophiolite Belt or Brook Street Terrane. Alternatively, the source of the clasts may extend to the voluminous Mesozoic to Late Palaeozoic batholiths that occur in formerly contiguous eastern Australia and West Antarctica.

ORAL

**SHAKING UP AN INTRODUCTORY GEOHAZARDS
COURSE**

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In July 2010, a mixed team of geologists, education researchers and academic developers at the University of Canterbury embarked on a two-year project to revamp the teaching in undergraduate geology. Here we focus on a first year introductory geohazards course. We adapted methodology from the Carl Wieman Science Education Initiative (CWSEI) at the University of British Columbia. CWSEI emphasises a strongly data-driven approach to educational reform, adopting a “baseline” and “intervention” phase, led by people from the discipline. Data gathering consisted of classroom observations, pre- and post-instruction concept tests and pre- and post-instruction perception of science tests. We discuss the impacts of the earthquakes and course restructuring on students attitudes and learning. The February 2011 earthquake caused the University to close for considerable time, and the geologists and hazard managers in the department were out in the field lending their expertise to the city. As a result, baseline data gathering procedures and development of interventions for the next iteration of the course was disrupted, shifting the emphasis more to in-situ academic development. Several initiatives were taken to use the earthquakes as a teachable moment and improve student engagement, learning and perceptions of geoscience. In lectures, the focus moved toward answering the “how do we know this” question and the modelling of expert thinking. The field trip and workshop students moved focus towards more applied skills involved in disaster management rather than hazard identification. The data showed (1) that the experience of the earthquake significantly improved student learning as earthquakes and landslides showed greater gains than other hazards when measured on concept tests, (2) that student attitudes to Science and Society were significantly changed by the earthquakes, and (3) the use of in class exercises during the class significantly improved student engagement during the class.

ORAL

**LATE CRETACEOUS TO EARLY EOCENE FLORAS
AND PALEOCLIMATE FROM SOUTH ISLAND, NEW
ZEALAND**

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Quantitative methods of paleoclimate analysis based on the morphology of dicot angiosperm leaf fossils have been applied to at least a dozen NZ floras ranging from Cenomanian to Pleistocene in age. Broad trends show a mild temperate Late Cretaceous (PM2 pollen zone; Haumurian) cooling into the early Paleocene, warm subtropical conditions in the earliest Eocene, a warm temperate to subtropical Miocene and a cool temperate mid-Pleistocene. Here we review Late Cretaceous to earliest Eocene floras from South Island analysed using leaf morphology-based paleoclimate methods. We focus on the Late Cretaceous floras and will also present results from the earliest Eocene Otaio flora, South Canterbury. Two PM2 zone floras have been analysed to date – Pakawau Bush Road (Rakopi Formation) and Cameron's Pit (Taratu Formation). Temperature estimates from these floras suggested that Cameron's Pit flora lived in cooler conditions than Pakawau, and the leaves were morphologically more similar to earliest Paleocene floras. A beautifully preserved PM2 zone flora from Paparoa Coal Measures near Greymouth may help us understand these differences. The Greymouth flora is diverse with warm/wet elements such as drip tips on dicot leaves. Both gymnosperms and angiosperms are prominent components of the leaf flora; araucarian and podocarp leaves are common. Associated palynology assemblages will be compared to help assess how similar the Greymouth flora is to Pakawau and Cameron's Pit. The Otaio flora occurs in estuarine to non-marine coal measures of Broken River Formation. Palynology assemblages indicate that the leaf flora is Waipawan (PM3b zone). The presence of the dinoflagellate cyst *Apectodinium* suggests that the leaves were deposited during one of the *Apectodinium* acmes that occurred during, and soon after, the PETM. Morphological analysis of the dicot angiosperms has yielded warm temperature estimates which in combination with

mesothermal elements in the pollen assemblages suggest a humid subtropical climate.

ORAL

**JAROSITE SOLID SOLUTION IN ARSENIC-RICH
MINE WASTES, MACRAES GOLD MINE, NEW
ZEALAND**

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Jarosite ($\text{KFe}_3[\text{SO}_4]_2[\text{OH}]_6$) is one of the most common secondary minerals in oxidized mine wastes. As Jarosite contains ferric iron, dissolution and subsequent hydrolysis can produce acid. In arsenic-rich environments, sulfate in jarosite is partially replaced by arsenate and can be a significant source of dissolved As. Hence, the composition and solubility of jarosite is of importance when evaluating the environmental stability of mine wastes. Jarosite is one of the principal products of the pressure-oxidation autoclave system at Macraes gold mine, and is discharged to a tailings impoundment for long-term storage. Dissolved sulfate and arsenate concentrations in the autoclave both locally exceed 0.1 mole/L. Rare, coarse grained (~1 mm) jarosite crystals formed in mineral scales in the autoclave provide insight into the mineralogical nature of the jarosite waste. The jarosite crystals are zoned, with some zones having up to 12 wt% Al, as part of the jarosite-alunite solid solution series. Both the monovalent and trivalent sites in the jarosite have apparent deficiencies (~10 atomic %) because of hydronium ion substitutions. There is <0.3 wt% As substitution for S in the jarosite anionic site, despite abundant As in the autoclave system, because dissolved As decreases by several orders of magnitude during the latter stages of oxidation. Jarosite is intergrown with rapidly precipitating ferric arsenate, and most jarosite growth zones contain small (<20 μm) inclusions of ferric arsenate. The lack of structural As and only minor Na substitution limits the environmental destabilization effects of solid solution in the jarosite, and dissolution of the jarosite is expected to be slow. Dissolution rate is further limited by high dissolved sulfate in the tailings impoundment. Both jarosite and ferric arsenate dissolve incongruently in the surficial environment, yielding ferric oxides/hydroxides, and these efficiently adsorb As so dissolved As remains low (typically <10 mg/L) in the tailings impoundment waters.

ORAL

**DEFORMATION ZONE OF THE HURUNUI SEGMENT
OF THE HOPE FAULT, NEW ZEALAND, REVEALED
FROM LIDAR**

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A 29 km-long section of the 42 km-long Hurunui segment of the dextral-slip Hope Fault, concealed beneath beech forest, was investigated using high-resolution airborne LiDAR and field mapping. A large portion, i.e. 76% (c. 22 km), of the principal slip zone (PSZ) was clearly exposed on the LiDAR DEM. A Rose diagram weighted by the lengths of the PSZ strands shows that the Hurunui segment strikes between 070°-075° and is thus optimally oriented for dextral strike-slip within the regional strain field. Newly-discovered and previously-mapped fault strands reveal that an active and spatially-variable deformation zone of up to c. 500 m wide (average width = 200 m) is associated with the Hurunui segment. We examine the effect of factors such as deviation of surface fault strike from 070°-075°, thickness of the deposits covering bedrock, differential topography north and south of the fault, proximity to major river valleys, and age of the faulted landscape on the deformation zone width. Our results show that the deformation zone width has no systematic relationship with landscape age, but has significantly been influenced by topography and strike of the fault. North of the PSZ is higher in elevation and this is fairly concordant with a wider deformation zone, particularly near major river valleys, indicating that erosional unloading of the fault may result in deformation zone widening. Where strike of fault patches are within the range of 070°- 075°, the width of the fault deformation zone is confined into a discrete surface rupture up to c. 150 m. The strike and near surface dip of the fault are strongly controlled by topographic load. Estimated thickness of Holocene deposits, covering the bedrock, shows a partial relationship with width of the fault deformation zone and a linear relationship with fracture density. Our results strongly suggest that topography plays a major role in influencing the surface rupture morphology of fault deformation zones.

ORAL

**DEFORMATION TEMPERATURES OF
QUARTZOFELDSPATHIC GNEISSES BASED ON
MICROSTRUCTURES VS. MINERAL ASSEMBLAGES**

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Temperature is one of key elements for interpreting the rheology of deformed rocks. The estimation of deformation temperatures, however, is not straightforward in case of quartzofeldspathic lithologies such as metagranitoids, where syn-kinematic growth of new minerals is generally lacking. In order to better constrain deformation temperatures, we carried out microstructural and petrological analyses on the quartzofeldspathic gneisses in the Mt. Cheonggye area, Gyeonggi Massif, Korea. These gneisses underwent high-temperature ductile deformation of variable intensity. Metamorphic minerals include garnet and biotite with or without sillimanite (or kyanite) and cordierite.

Quartz ribbons are common and show interlobate grain boundaries and uncommon chessboard extinction, suggesting the operation of the subgrain rotation (SGR) and grain boundary migration (GBM) recrystallization and intracrystalline plasticity, respectively. K-feldspar porphyroclasts show the core-and-mantle structure, where the bulging and SGR recrystallization and the myrmekite formation are concentrated along their margin and pre-existing fractures. The majority of plagioclase forms the aggregate of polygonal grains, which is diagnostic of the foam texture. Diffusive subgrain boundaries and dissected grains suggest the SGR and GBM recrystallization, respectively. Overall, the deformation temperatures of 500–650 °C are inferred from the above microstructures.

The pseudosection modeling of a cordierite-bearing gneiss suggests a composite P–T path consisting of two clockwise segments. The low-P segment is characterized by the formation of cordierite mantling garnet. The coronitic cordierite has formed earlier than or coevally with major deformation whose P–T condition is constrained at 3–5 kbar and 650–750 °C. The latter is apparently higher than 500–650 °C inferred from the microstructures. This discrepancy could be attributed to the prolonged textural adjustment during the thermal relaxation, but a possible

underestimate of temperatures based on various microstructures cannot be precluded.

ORAL

**POSITIONING AN OPTIMAL DRILLING LOCATION
ON THE ALPINE FAULT IN THE WHATAROA VALLEY
WITH SEISMIC AND GRAVITY DATA**

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The South Island's Alpine Fault is one of the major transpressional structures on Earth. Paleoseismic evidence suggests that earthquakes of magnitude 7.9 occur every 200-400 years, with the last earthquake occurring in AD 1717. Determining the shallow structure of the fault is crucial for understanding the conditions that govern earthquake rupture. Therefore, the Deep Fault Drilling Project 2 (DFDP-2) drill hole planned for 2014 on the hanging wall of the Alpine Fault in the Whataroa Valley, provides a critical opportunity to study its behavior and seismogenic cycle. Seismic and gravity data collected since 2011 have been analysed to assist with the positioning of the drill hole.

The WhataDUSIE controlled-source seismic project, led by researchers from the University of Otago, TU Bergakademie Freiberg (Germany) and the University of Alberta (Canada), provided relatively high-resolution coverage (4-8 m geophone spacing, 25-100 m shot spacing) along a 5-km-long profile across the Alpine Fault in the Whataroa Valley.

In positioning DFDP-2, an understanding of the nature of overburden and valley-fill sediments is critical for drilling design. High-resolution seismic and gravity data images the uppermost part (1 km) of the hanging wall of the Alpine Fault and shows the glacial valley from the Last Glacial Maximum, which has been filled with 200-350 m of post-glacial sediments and outwash gravels. Considering uplift rates of 6-10 mm/yr on the hanging wall of the fault, 60-100 m of uplift has occurred in the last 10,000 years; the floor of the valley would have been as deep as about 350 m below sea level at the time that the ice withdrew. Basal sediments in the valley could therefore be either marine (connected to ocean) or lacustrine (separated from ocean). Once the original water body in the valley was filled, sediments would accumulate as outwash gravels above sea level.

POSTER

**PROBABILISTIC MODELLING OF SUBMARINE-
LANDSLIDE-GENERATED TSUNAMIS IN COOK
STRAIT**

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Cook Strait Canyon lies within ten kilometres of Wellington. Its sides are marked with scars from previous landslides which could have caused large local tsunamis. Palaeotsunami evidence also points to catastrophic past tsunamis in Wellington. Furthermore, the canyon's location in Cook Strait means there is inhabited land in the path of both forwards and backward propagating waves. Tsunamis induced by these submarine landslides pose a potentially devastating hazard to coastal communities and infrastructure. But major events are very uncommon and the historical record is not long enough to quantify this hazard. The dichotomy of infrequent but potentially devastating events makes realistic assessment of the hazard challenging. However, information on both magnitude and frequency is vital for planning and civil defence purposes.

The very local nature of submarine landslides means that there is no one scenario that can capture the hazard. As such it is necessary to consider a wide range of scenarios. Monte Carlo modelling provides a tool to synthesize geologic knowledge of landslides and their triggers with hydrodynamic knowledge of tsunamis and their propagation. Using this framework we can build an understanding of the overall hazard due to submarine-landslide-generated tsunamis within this region over different time frames.

Monte Carlo simulations require the modelling of many different scenarios. While it would be ideal to use fully three dimensional model including the landslide and the water and to run this from generation through to inundation this is not yet feasible. Limitations in computing power constrain us to initializing and running two-dimensional models. Many standard initialization methods, however, assume landslides on the continental shelf – no valid in this case. Thus we must first model the submarine landslide and then use this to initialize two dimensional tsunami inundation model. We will show how we develop these models and some preliminary results.

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ORAL

EDUCATION AND OUTREACH ON EXPEDITION 341-SOUTHERN ALASKA MARGIN

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Education and outreach on IODP Expedition 341-Southern Alaska Margin was conducted by two Education Officers; Alison Mote, Ann Richards School for Young Women Leaders in Austin, Texas and Carol Larson, National Aquarium of New Zealand, Napier. From 29 May to 29 July 2013 Expedition 341 scientists onboard the JOIDES Resolution focused on global climate change caused by the advance and retreat of glaciers, subsequent change in erosion rates, and mountain building events.

The *JOIDES Resolution* was an authentic context to teach about Earth processes and scientific methods. The education programme involved students, teachers and museum audiences taking a ship's tour with an educator using a Skype or ZOOM connection and an iPad. Videoconferences gave learners the opportunity to engage in live, research experiences with scientists and to discuss real-world geoscience events.

In this presentation, Expedition 341 Education Officer Carol Larson will give the highlights of the Education and Outreach programme. 54 videoconferences with primary, secondary schools,

home school groups, universities, museums, aquariums, science fairs and teacher summer workshops were conducted over two months. 1284 children and 712 adults took part in videoconferences with a range of scientists on topics including: plate tectonics, climate change, microfossils, technology, careers, and life on board a geological research ship. Audiences participated from England, USA, Australia and New Zealand.

Communication via Skype and an iPad brought pioneering science into the classroom. Social media was an effective mode of outreach delivery and included daily blogs for all ages from two educators, Facebook and Twitter posts. Simple competitions via Facebook created interest with some posts engaging 6,000 viewers. Education resources were written on board for the Deep Earth Academy/ Ocean Leadership website. Use of new communication technologies enabled spontaneous and memorable "live science experiences" from IODP Expedition 341.

ORAL

TARANAKI BASIN PETROLEUM SYSTEM SEAL CHARACTERIZATION

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A key element of any petroleum system are the seal rocks that cap the reservoirs. In order to assess what hydrocarbon column heights can be retained, a good understanding of seal properties is required. In the Taranaki Basin, seals comprise mudrocks. Two of the main, regional sealing mudrocks, the Turi and Manganui formations, have been selected in an attempt to produce a spatial and stratigraphic analysis of important seal characteristics. Mudrocks are seldom cored, either by conventional or side-wall methods precluding direct measurement of rock properties. Therefore, the properties of the chosen sealing formations are being determined from wireline logs. The wells for the study were chosen to cover as much of the Taranaki Basin as possible, and contain the 'best and most consistent' wireline datasets (including borehole image logs where possible), and that penetrate through both the Turi and Manganui formations. Prior to interpretation, quality control was undertaken on all wireline log data sets.

Three approximately NE-SW trending well transects sub-parallel to the Taranaki Basin axis and three NW-SE trending transects approximately

orthogonal to the basin axis, comprising a total of 22 wells are being used in the study. Preliminary results show distinct metre-scale variations in log responses in mudrock units, which vary with location with respect to palaeo-shorelines. While both the Turi and Manganui formation mudrocks display significant high-resolution heterogeneity stratigraphically, they also contain zones of similar properties. Variations in seal properties are plotted on palaeogeographic/palaeofacies maps to show lateral variations in seal rock character.

POSTER

**A REMARKABLE DIVERSE LATE OLIGOCENE
SUBTROPICAL FAUNA AND FLORA FROM COSY
DELL, SOUTHLAND**

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The fossil fauna and flora from a small quarry in basal Chatton Formation at Cosy Dell, near Waimumu, Southland has yielded a remarkable array of diverse and exceptionally well-preserved fossils derived from coastal forest, rocky shore, estuarine, sandy beach and shallow subtidal habitats. Nannofossil evidence confirms the age as Late Oligocene (25.4–24.4 Ma), close to the Duntroonian/Waitakian boundary. A poorly sorted lag of locally derived lithic boulders and cobbles from the underlying plant-bearing Jurassic Murihiku basement grades up into ~6 m of richly fossiliferous, locally concretionary pebbly shellbeds. The fauna is remarkable for its taxonomic richness and diversity, particularly of molluscs; it includes robust, thick-shelled bivalves and large gastropods (up to 15 cm in length), an abundance of juveniles, and aragonitic molluscs with nacreous shell and colour patterns preserved. More than 350 species of molluscs are present, including 10 chitons, the nautiloid *Aturia*, 90 bivalves, 250 gastropods, and 4 scaphopods. Basement-derived boulders carry oysters in life position; others were bored by pholadid bivalves. Other notable components of the biota include 127 ostracod species, 7 genera of barnacles, foraminifera, brachiopods, bryozoans, echinoderms (including *Fibularia*), solitary and

hermatypic corals, numerous otoliths and penguin bones. The palynoflora comprises more than 100 taxa including at least 16 ferns, 10 conifers, 8 monocots and numerous dicots, including Casuarinaceae, Cunoniaceae, Euphorbiaceae, Loranthaceae, Myrtaceae, Nothofagaceae (6 species), Proteaceae and Strasburgeriaceae. The macrofossil drift flora includes abundant teredinid-bored wood, and seeds including the tropical vine legume *Entada* (sea bean). Elongate limpets and mangrove creeper snails provide indirect evidence for seagrasses and mangroves. The abundance of large, warm-water species confirms a subtropical climate in southern New Zealand in the Late Oligocene. The boulder lags, abundance of wood, palynomorphs and seeds, and numerous intertidal and estuarine species indicate proximity to forested land adjacent to a rocky coastline and nearby estuary.

POSTER

**LATE OLIGOCENE PALEOGEOGRAPHY OF
SOUTHERN ZEALANDIA: SEDIMENTOLOGICAL AND
PALEONTOLOGICAL EVIDENCE FOR FORESTED
LAND, ESTUARIES, ROCKY AND SANDY SHORES**

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Southern New Zealand is a key region for establishing the extent of land during the maximum marine transgression in the Late Oligocene. Sedimentological evidence indicates emergent land on all basement terranes. One large island measuring about 140 km x 100 km on Otago Schist had shorelines near Kokonga and Naseby along the Canterbury Basin margin, Queenstown on the northeast margin of the subsiding Waiau-Te Anau Basin, and near Waikaia and Waikaka. A meandering river system drained south across Caples Terrane into the Pomahaka Embayment. The Pomahaka coastline was likely contiguous with the Catlins Block, a substantial 80 x 70 km region of uplifted Murihiku Terrane basement that probably extended south to Stewart Island. During sea level highstands the sea lapped onto indented ridges and valleys of the western coastline of the Catlins Block. Elsewhere on the East Southland platform, at Cosy Dell, a forested island with a river and estuary formed another rocky shore on Murihiku basement. Further south and west, the sea lapped on exposed basement rocks of Brook Street

Terrane at Bluff and near Pourakino, Longwood Range. At Dunrobin, upper Aparima River, rhodoliths and locally-derived blocks of basement indicate proximity to another Murihiku shoreline. On the west side of the Waiau-Te Anau graben, Oligocene rocky shorelines including that at Mt Luxmore formed on the Fiordland margin. Collectively, these islands covered an area of at least 20,000 km², about the same size as present-day New Caledonia. Late Oligocene sea level was relatively stable, rising and falling ~30 m, allowing periodic connection of the basement terrane islands separated by shallow drowned valleys. These substantial subtropical islands provided a variety of habitats able to support a diverse biota. Paleogeographic maps need to be redrawn to accurately represent the extent and physiography of southern Zealandia in the Late Oligocene to Early Miocene.

ORAL

A NEW DETAILED GLACIO-ERUPTIVE HISTORY FOR TONGARIRO NATIONAL PARK, NEW ZEALAND: RESULTS FROM MAPPING, GEOCHRONOLOGY, GEOCHEMISTRY AND GLACIOLOGY CURRENTLY UNDERWAY

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We discuss preliminary findings of a project developing an integrated glacio-volcanic history for Tongariro National Park, part of a collaboration with the Department of Conservation to publish the first detailed volcanic geological map and bulletin for the park (see Townsend et al., this volume). Considerable geological mapping and geochemistry has been conducted over past decades, but past moraine mapping has been limited; the frequency, extent and precise timing of past glacier fluctuations remained unknown. Consideration of the influence of glacial processes with primary volcanism has largely been absent.

Tongariro and Ruapehu volcanoes have been geomorphically mapped from aerial photos and fieldwork, showing extensive complex moraine and lava sequences over much of the area. Distributions of lava flows and pyroclastic deposits

have been heavily controlled by ice distributions during eruptions. We recognise widespread ice-contact textures including fine lateral columnar jointed lava (sometimes grading into till); intercalated stacked moraines and perched lavas, often with lobes of lava dipping and thickening into the valleys toward now-missing ice; lava tubes and sheets emplaced under ice; stalled lava flows inferred as bounded by valley-filling ice; Holocene valley bottom lavas mantling glacial features; and eruptive textures and landforms possibly due to sub-glacial volcanism.

New high-precision ⁴⁰Ar/³⁹Ar age dates are achieving ~1.2 kyr (1 s.d.) uncertainties on Holocene lavas and <1 kyr on c.40 kyr lavas. The tephra cover on moraines is being analysed in detail; stratigraphic constraints are being combined with cosmogenic ³He surface exposure dating on boulders in till to ascertain the relative and absolute timing of volcanic events and their relationships to past ice configurations. The dating is shedding new light on the timing of growth of late Pleistocene cones, and on Holocene lavas and their relationships to regional pyroclastic deposits. We are also integrating the large lahar ring plain into the glacio-volcanic history.

ORAL

HYDRODYNAMICS AND SEDIMENT TRANSPORT AT MANGAWHAI ESTUARY, NEW ZEALAND.

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Mangawhai estuary is a 4 km long, microtidal barrier-enclosed estuary comprised of a bifurcating channel and intertidal flats with mangrove stands in the middle to upper reaches. The estuary drains a small catchment and has minor fluvial input so is tide dominated. The aim of this study was to characterise the physical processes operating in the estuary because the expansion of mangroves seen in the past 50 years has been considered a problem by many locals, and a better understanding of such processes can aid in decision making. Hydrodynamic data was collected at Mangawhai during summer and winter at three sites: the harbour area in the lower estuary and the two arms of the upper estuary. Tidal range, timing, velocity, salinity, turbidity and total suspended matter (TSM) were recorded as well as the sedimentological properties of each site, and during summer a bathymetric survey of the lower

and middle estuary was conducted. Tides within the estuary are asymmetric and this trait increases moving landward. In summer, peak ebb velocities were stronger than flood at all sites to varying degrees, and ebb durations were also longer. In winter, the pattern of double ebb dominance was again exhibited throughout the estuary except at one of the upper estuary sites during spring tide. Mangawhai sediments are medium to coarse feldspar and quartz sands, even where mangroves are established. Concentrations of TSM are very low, and turbidity and velocity readings showed advection of suspended matter from higher estuary locations on each tide and no evidence for local resuspension. Current velocities are sufficient to entrain bed load sediment, so this is therefore the dominant sediment transport mechanism. This data set describes in detail the behaviour of different parts of the estuary and allows the testing of a number of models that describe the overall behaviour of estuaries.

POSTER

CHARACTERISATION OF CLAY ALTERATION OF THE INJECTION WELL NM9, NGATAMARIKI GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, USING SHORTWAVE INFRARED SPECTROSCOPY AND SELECTED WIRELINE LOG RESPONSES

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This paper presents an in depth analysis of the complex alteration assemblage within one well in the Ngatamariki Geothermal Field, Taupo, New Zealand. This 3544 m deep well intersects a sequence of sediments, tuffs and the only large intrusive body drilled in the Taupo Volcanic Zone. Our study builds on previous work describing the geologic sequence of this well by reanalysing and revising key intervals using shortwave infrared spectral analysis (SWIR) to characterise the clay alteration intervals, especially the presence of hypogene acidic alteration adjacent to the intrusive body. These data are compared to selected electric wireline logs which were run in the open-hole interval of NM9. Spectral analysis showed the distribution of clay minerals with depth with smectite occurring down to ~773 m,

interstratified illite-smectite at ~773-863 m and illite at depths >863 m. A pyrophyllite alteration zone was recognised at 2353-3053 m, with spectrally recognised pyrophyllite and kaolinite. An interval of paragonitic illite occurs above the intrusive body at 1900 m.

The type and distribution of clay minerals, assuming they are in equilibrium with the modern system, is closely tied to the temperature distribution of a geothermal reservoir. Furthermore, the distribution of smectite in wells forms a key validation for the interpretation of the magnetotelluric survey used to image the extent of the clay cap. Our study has shown that SWIR is a rapid, cost effective and accurate means of identifying hydrothermal alteration, especially clay type minerals. When used in conjunction with more traditional methods, such as XRD and thin-section analysis, SWIR allows us to easily build detailed datasets which support our understanding of the permeability structure of a geothermal reservoir. Furthermore, in the case of NM9 the SWIR analysis has allowed us to accurately map the extent of the relic alteration halo associated with the diorite-tonalite intrusion.

POSTER

DETAILED ANALYSIS OF GREENDALE FAULT GROUND SURFACE RUPTURE DISPLACEMENTS: HOW MUCH VARIATION CAN YOU GET?

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Surface fault rupture of the Greendale Fault during the M_w 7.1 4th September 2010 Darfield Earthquake is by far the best documented ground surface rupture in New Zealand and probably the world. As such, it provides an important opportunity to describe in detail the distribution of surface rupture displacement of an active fault, both along and perpendicular to strike, and to explore displacement measurement uncertainties. In this study we compare dextral displacements measured using 13 different datasets at ~100 sites along the fault, and by different people at 18 sites. Over 350 new displacement measurements using different datasets were added to ~150 previously published and, disturbingly, show a large range of variation at a single site (up to ± 2.2 m about a median value of 4.9 m). This is surprising given that displacement at any given site was, by definition, a

unique amount (i.e., it is not natural variability). No systematic variations can be detected between measurements from different datasets, with position along the fault, with displacement, or with fault zone width. Instead, the variation appears to mainly be a function of the resolution of the datasets, with higher variability corresponding to larger uncertainties assigned to the remote sensing datasets (Orthophoto and Airborne Lidar) than the field-based datasets (Tape and Compass, RTK GNSS, and Terrestrial Lidar). Measurements by different people (n~530) also produced a surprisingly large range of variation at a single site (up to ±3.8 m about a median value of 3.0 m). There are no systematic differences between measurements made by individuals. The variation in measurement uncertainty at a single site, along with the documented variability in displacement along-strike and width, have implications for the measured and natural uncertainty in characterising single event displacement for active faults which have ruptured in the geological past.

ORAL

GETTING THE MOST FROM GEONET

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In the last few years GeoNet has changed dramatically, mostly due to the implementation of the automatic earthquake location system SeisComP3. Changing the earthquake location system has consequently altered the earthquake catalogue, used by many researchers. GeoNet's public profile has also been raised due to recent large earthquakes near populated cities.

SeisComP3 is developed by the GEOFRON Program at Potsdam and adapted to New Zealand, using a 3D velocity profile for the country. All earthquakes are automatically located and posted to the website without human interference. A geohazards duty officer is notified immediately and reviews any earthquake larger than magnitude 4.5. During the day the duty officer will also periodically review smaller earthquakes that may have been felt by New Zealanders. This new automated system means that during a busy aftershock period – like the recent Cook Strait Sequence – a more complete picture of the aftershock sequence can be identified in real time, rather than waiting weeks for analysts to look at the smaller quakes. As a consequence of the change in earthquake location system, GeoNet has

overhauled its website. The changes are mostly aimed at the public, but changes have also been made to the earthquake catalogue search. Earthquake parameters such as azimuthal gap, distance to station, and number of stations used to calculate magnitude can also now be retrieved. GeoNet's network of strong motion, seismograph, and continuous GPS stations is also still being expanded. Stations around the north and central South Island will be rolled out in the coming few years.

ORAL

FOLIATION FANNING IN THE HANGINGWALL OF THE ALPINE FAULT, CENTRAL SOUTHERN ALPS

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Seismic reflection data suggest that the Alpine Fault dips at ~60° at ~15 km depth, and that this dip shallows with further increase in depth. In the central Southern Alps, the dominant (Mesozoic-aged, syn-peak metamorphic) foliation in the Alpine schist near the Main Divide is a weak chlorite zone fabric that is mostly vertical or steeply NW-dipping, while striking slightly anticlockwise of the fault. At ~8 km from the fault, the foliation is higher grade (biotite zone) and typically dips 70-80° SE. This change in dip may result from up-to-the-west ductile backshearing across the footwall ramp of the Alpine Fault.

At <3-4 km east of the fault, outside the Cenozoic Alpine mylonites, the foliation shallows to a moderate SE dip, and rotates clockwise to a mean strike of ~055. This gradual fanning is well documented in a water project tunnel near Wanganui River. Across the mylonites, at <1.5 km from the fault, the mean foliation has commonly been assumed to be near-parallel to the fault. If so, the fault dips ~63 ±2° (1σ) at Tare Stream, 42° ±9° near Whataroa River, and 47 ±11° at Harold Creek. Due to their structural position, these sites would appear to be little affected by near-surface fault segmentation. By contrast, foliation near the oblique-thrust segments at Stony Creek, Hare Mare Creek, and NE of Whataroa River shallow across the mylonites to reach minima of ~30 ±10° at the fault. Such "rolling over" occurs across a

width of ~1 km, suggesting a similar depth to the level of fault segment branching.

Foliation fanning in nonmylonitic rocks may reflect Cenozoic, dextral-reverse simple shearing (“drag”) in the hangingwall of the Alpine Fault. If so, a finite shear strain of >3.0 would be needed to explain it, however transpressive ductile thinning of the fault zone could also contribute.

ORAL

TECTONIC GEOMORPHOLOGY OF BANKS PENINSULA FROM COSMOGENIC NUCLIDE EXPOSURE DATING

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The 2010-2011 Christchurch earthquake sequence has focussed attention on the tectonics of the Canterbury region, particularly the need to elucidate the long-term behaviour of faults buried beneath the glacial-outwash gravels of the Canterbury Plains. Here we explore potential tectonic signals recorded in Banks Peninsula geomorphology, as documented by bedrock exposure ages determined by cosmogenic ³He nuclide dating, to inform the tectonic history of the region. Our initial work focussed on dating paleo rockfall deposits at Rapaki Bay, to constrain previous episodes of extreme ground motion. Multiple rockfall boulders were most recently deposited at approximately 8 ka, with little evidence of younger rockfall until 2011, indicating displacement of large boulders is rare at this site. Further investigations focused on the long-term erosion rate of the volcanic rock in this region, which multiple ridgetop and cliff face bedrock samples bracket at a relatively slow rate of approximately 0.01 mm/yr.

An outstanding question following the earthquake sequence is whether Banks Peninsula is subsiding, stable, or uplifting. Multiple techniques have historically been used to address this problem, with conflicting results. Central to the debate are putative marine terraces around Banks Peninsula, approximately 8-10 m asl, and reportedly cut during the last interglacial high stand, ~120 ka. Samples are currently being analysed to assess the age of representative elevated marine platforms, to determine the vertical motion of Banks Peninsula relative to fluctuations in sea level.

ORAL

INCREASED MANTLE HEAT FLOW WITH ON-GOING RIFTING OF THE WEST ANTARCTIC RIFT SYSTEM INFERRED FROM CHARACTERISATION OF PLAGIOCLASE PERIDOTITE

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The lithospheric, and shallow asthenospheric, mantle in Southern Victoria Land are known to record anomalously high heat flow but the cause remains imperfectly understood. To address this issue plagioclase peridotite xenoliths have been collected from Cenozoic alkalic igneous rocks at three localities along a 150 km transect across the western shoulder of the West Antarctic rift system in Southern Victoria Land, Antarctica. There is a geochemical, thermal and chronological progression across this section of the Antarctic rift shoulder from relatively hot, young and thick lithosphere in the west to cooler, older and thinner lithosphere in the east. Overprinting this progression are relatively more recent refertilising events. Melt depletion and refertilisation was relatively limited in the lithospheric mantle to the west but has been more extensive in the east. Thermometry obtained from orthopyroxene in these plagioclase peridotites indicates that those samples most recently affected by refertilising melts have attained the highest temperatures, above those predicted from an idealised dynamic rift geotherm, or Northern Victoria Land geotherm and higher than those prevailing in the equivalent East Antarctic mantle. Anomalously high heat flow can thus be attributed to entrapment of syn-rift melts in the lithosphere, probably since regional magmatism commenced at least 24 Myr ago. The chemistry and mineralogy of shallow plagioclase peridotite mantle can be explained by low degrees of melt extraction followed by a series of refertilisation events. These include: addition of a basaltic melt; metasomatism involving addition of a subduction-related component; and addition of average calcio-carbonatite. Melt extraction and refertilisation mainly occurred in the spinel stability field prior to decompression and uplift. In this region mantle plagioclase originates by a combination of subsolidus recrystallisation during decompression within the plagioclase stability field and refertilisation by basaltic melt.

ORAL

INTERPRETING AIRBORNE GEOPHYSICAL DATA IN CENTRAL OTAGO: NEW INSIGHTS INTO STRUCTURE, LITHOLOGY AND MINERALISATION

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The 2007 central Otago airborne geophysical survey provided an excellent magnetic and electromagnetic data set with considerable potential to improve understanding of regional and local geology. A new geological mapping program complemented by the new geophysical data is focussed around the Middlemarch area where Rakaia Terrane Otago schist is intruded and overlain by Waipiata Volcanics and locally covered by Quaternary sediments. The geophysical data combined with aerial photography and field mapping is improving delineation of lithological contacts and structural off-sets that are difficult to define with traditional surface outcrop mapping alone. For example, the edge of alluvial fan deposits derived from the Rock and Pillar Range is defined both laterally and at depth by electromagnetic data, and can be differentiated from adjacent Taieri River alluvial deposits. The surface extent of Waipiata Volcanics is being re-defined, as are potential zones of igneous alteration halos. New units of magnetite greenschist, whose presence was first suggested from interpretation of the aeromagnetic survey, have also been mapped, and the geophysical data have helped show these units plunge shallowly to the north-west beneath much of the Taieri valley. Mapping suggests the magnetite-greenschist units are linear, rod-like features rather than planar, and may have formed in the hinge areas of isoclinal folds during metamorphism. The magnetite greenschist units have the potential to mark the internal architecture of the greyschist and record significant structural offsets, to an extent unknown prior to the geophysical survey. The occurrence of historic Au and Sb mining on the edge of these unmapped magnetite greenschist units warrants further investigation into their potential as fluid pathways for mineralisation. This mapping project highlights the potential to use the new geophysical data set to redefine the geological interpretation of central Otago.

POSTER

FRACTURE CHARACTERISATION IN GEOTHERMAL RESERVOIRS USING ACOUSTIC BOREHOLE IMAGES AND CORES

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The successful development of a geothermal reservoir requires a thorough characterisation of lithology, alteration, structure (i.e. faults, fractures and veins) and *in-situ* stress. The determination of the location, orientation, connectivity and aperture of the permeable structures from small drill cuttings and rare drill-cores is particularly challenging. Acoustic image logs acquired by borehole televiewers (BHTVs) help with this investigation by providing an oriented image of the borehole wall. BHTV logs have been collected in high temperature wells from a number of geothermal fields in the Taupo Volcanic Zone (TVZ), New Zealand, using a recently developed high temperature ($\leq 300^{\circ}\text{C}$) BHTV tool. Welding zones, dykes, formation boundaries, faults, fractures and *in-situ* stress features have been successfully identified in BHTV logs using a new interpretation workflow adapted to the hydrothermally altered volcano-sedimentary formations, and correlated to drill-cuttings. The BHTV logs provide direct observations of the structures in the geothermal fields and can be particularly useful in highly fractured zones where drill-core recovery is commonly poor. In the andesite-hosted, fractured reservoir of the Rotokawa Geothermal Field (TVZ), drill-cores display a high diversity of fracture characteristics (e.g. mineralisation, relative orientation, connectivity), and an abundance of thin (<3 mm-wide) veins and fractures. We demonstrate in this presentation how high resolution observations from drill-cores with BHTV logs interpreted using an interpretation workflow adapted to the geothermal environment can enhance the characterisation of structures in geothermal reservoirs. In the next phase of this research, statistical analysis of fracture spacings and apertures, and an evaluation of fracture connectivity will be used to generate predictive fracture models of the Rotokawa Geothermal Field.

ORAL

REKOHU RESEARCH PROJECT AND PRE-HISTORIC EAST-POLYNESIAN ADAPTATION TO CLIMATE.

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East Polynesians successfully settled every island group of the Pacific as far south as New Zealand. To achieve this last great human migration Polynesians adapted a portable economy and technology set derived largely from the Western Pacific. The rapid, successful human colonisation of Eastern Polynesia resulted in profound impacts on the flora, fauna and landscapes of all major islands and island groups.

The technical challenges to successful, early Polynesian colonisation were substantial in the New Zealand archipelago at the cool-temperate margins of southwestern Polynesia. The investigation reported here is concerned with the last, and arguably most difficult place to be permanently settled by Polynesians in the New Zealand region: Rekohu of the offshore Chatham Islands. A holistic approach utilises archaeology, anthracology, palynology and ethnographic records to reassess earlier ideas of how the Moriori, the first people of Rekohu, modified the environment and adapted ancestral Polynesian ideas and technologies. The results of this research demonstrate the resilience and technical skills of early Polynesian settlers to successfully adjust to a new climate zone.

Central to the success of Moriori settlement was the translocation of *Corynocarpus laevigatus* from New Zealand to Rekohu and the management of the coastal broadleaf forests. The results of the project indicate that the management of fruiting *Corynocarpus* trees was a core economic activity with major implications for questions of Moriori socioeconomic development. This investigation also highlights the sensitivity of *Corynocarpus* on Rekohu to adverse wind exposure. The evaluation of possible historical effects of increased westerly wind flows on forest structure and fruiting has implications for late Holocene climate modelling and our understanding of human resilience to climate change.

ORAL

SURVEYING AND DATING LAKE WAKATIPU STRANGLINES TO ASSESS FOR TECTONIC AND GLACIAL ISOSTATIC UPLIFT

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Glacial-rebound signals have not previously been identified or isolated from tectonic processes in the New Zealand landscape. This contrasts with other parts of the world where glacial-unloading has caused tens to hundreds of meters of uplift and increased fault activity. The aim of this research was to quantify the magnitude and timing of post-glacial lake-level changes and deformation of the previously-glaciated Lake Wakatipu basin, New Zealand. Tilting of abandoned shorelines up to 43 m above the modern water-level have previously been used to indicate tectonic uplift gradients and evidence of faulting in the region. Accurate measurement of the magnitude and timing of tilting would provide a unique attempt to extract a glacial-rebound signal from the tectonically-overprinted New Zealand landscape. The shoreline ages were assessed with optically stimulated luminescence (OSL) and Schmidt hammer exposure-age dating of a flight of alluvial terraces directly correlated with the shorelines. The ages suggest formation of the lake by $\sim 17.1 \pm 2.6$ ka, which is assumed to be the approximate age for formation of the highest and most prominent preserved shoreline. Paleo-shoreline profiles were surveyed along the lake using differential GPS, real-time kinematic GPS, and airborne LiDAR datasets. The shoreline profiles were correlated based on elevation and numerically cross-correlated to assess potential progressive offset. The results reveal negligible elevation differences for all of the shorelines, in conflict with previous suggestions of shoreline tilting and fault offset. Uplift has not been recorded by paleo-shorelines of Lake Wakatipu over the last ~ 17 kyr. It is possible that relatively small ice volumes, unresponsive crust and mantle, in combination with a small ice thickness gradient and long isostatic wavelength can explain why a glacial-rebound signal is not evident. However, it is more surprising that a tectonic uplift signal is also absent. These results invite further investigation of the tectonics of the Wakatipu area, and of other glaciated areas to test if the glacial-rebound signal

(or lack thereof) is consistent throughout the South Island.

ORAL

**EAST ANTARCTIC CLIMATE AND ICE SHEET
EVOLUTION: RESULTS FROM IODP EXPEDITION
318**

**R. McKay & the IODP Expedition 318 Science
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This talk will present a summary the major scientific achievements of the IODP Expedition 318 to Wilkes Land off shore of East Antarctica, drilled in 2010. A history of climate and ice sheet evolution from the warm greenhouse of the Eocene to the present icehouse of the East Antarctic Ice Sheet will be presented. The principal goals were:

1. To establish the timing and nature of the first arrival of ice at the Wilkes Land margin inferred to have occurred during the earliest Oligocene (reflecting Oligocene isotope Event 1 around ~34 Ma),
2. To reconstruct the nature and age of the changes in the geometry of the progradational wedge interpreted to correspond with large fluctuations in the extent of the East Antarctic Ice Sheet and possibly coinciding with the transition from a wet-based to a cold-based glacial regime,
3. To obtain a high-resolution record of Antarctic climate variability during the late Neogene and Quaternary,
4. To obtain an unprecedented ultrahigh resolution (i.e., annual to decadal) Holocene record of climate variability.

A total of 7 cores were drilled on the continental shelf and rise of the Wilkes Land margin and ~53 m.y. of Antarctic history were recovered. These cores reveal the history from an ice-free "greenhouse Antarctica" with a subtropical vegetation, followed by late Eocene cooling and onset of the first EAIS glaciation, and the subsequent waxing and waning of Late Cenozoic ice sheets. Finally, an unprecedented "tree ring style" record in the form of a 180 m thick laminated diatom ooze was also recovered, and documents seasonal resolution oceanographic and climatic conditions since the last deglaciation.

ORAL

**LANDSLIDES GENERATED BY THE M_w 6.5 JULY 21,
2013, COOK STRAIT AND M_w 6.6 AUGUST 16,
2013, LAKE GRASSMERE EARTHQUAKES, NEW
ZEALAND: A RECONNAISSANCE REPORT**

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The recent Cook Strait and Lake Grassmere earthquakes produced strong ground shaking in central New Zealand, with shaking felt from Auckland to Dunedin. The extent of landsliding generated in central New Zealand in these earthquakes, however, was at the lower end of the expected range for shallow earthquakes of these magnitudes. Steep cliffs cut in Neogene sedimentary rocks, especially on the coastal bluff near Cape Campbell were the sites of many landslides during both the Cook Strait and Lake Grassmere earthquakes. A peak horizontal ground acceleration (PGA) of 0.75 g was recorded within 10 km of the coast during the Lake Grassmere event. The same station recorded a PGA of 0.21 g during the more distant Cook Strait event. Landslides up to an estimated 100,000 m³ were triggered on the highest of the coastal mudstone cliffs. The inland Needles Creek area, 4 km WNW of Ward, was particularly hard hit in the 16th August earthquake. Many disturbed boulders on terrace surfaces there suggested >1 g vertical ground acceleration, but some may have been overturned by cattle. Many landslides were triggered from terrace edges cut into fluvial valley fill. Most were extensive shallow debris slides and falls which stripped a thin cover of stony regolith, commonly failing along stock tracks that followed the terrace edge.

In southern North Island PGAs reached 0.1–0.2 g in both events and the only landslides seen there were some small debris falls in wave-cut deposits of unconsolidated fill at Kaiwharawhara Point in Wellington Harbour.

ORAL

**TIMING AND NATURE OF FLUID FLOW AND
MINERALIZATION OF ONEKAKA SCHIST IN NW
NELSON, NEW ZEALAND**

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Timing and conditions of metamorphism and mineralisation of Onekaka Schist, an amphibolite facies Early Paleozoic constituent of the Takaka Terrane, is currently under investigation. The Onekaka Schist is a Late Ordovician unit composed of graded quartzites and rare meta-conglomerates that appears to young southeast from Pariwhakaoho River to Anatoki River in northwest Nelson. Preliminary pressure-temperature calculations indicate peak metamorphism occurred at 5-7 kbar and 600°C, with kyanite-bearing quartz veins imposed upon this fabric.

The structural history is subdivided into three events; *D1*->*S1*: development of prograde metamorphic lepidoblastic biotite+quartz+muscovite+plagioclase foliation. *D2*->*S2*: crenulations overprint the *S1* foliation in mechanically weaker pelitic units accompanied by syntectonic garnet growth. Leucosome-like feldspar-quartz lodes containing Cu-Fe-S mineralisation (pyrite, pyrrhotite, bornite and chalcopyrite) formed under amphibolite facies conditions. *D3*->*S3*: a greenschist facies overprint composed of porphyroblastic chlorite+epidote+muscovite. A second generation of Cu-Fe-S veins with chlorite-rich alteration zones were imposed perpendicular to the foliation. The Onekaka Schist is exposed at the same stratigraphic level as the Onehau Granite and is located near the Median Batholith. The Cretaceous granites may be responsible for the observed mineralisation. Regional folding of the Onekaka Schist and overlying Parapara Group, but undeformed Onehau Granite, indicates folding has occurred between the Triassic-Cretaceous. Research in 2014 will be focused upon: dating peak metamorphism and the timing of mineralisation using zircon geochronology; geochemical thermodynamic modelling to determine element mobility; and field mapping to discover the extent of mineralization and link small scale structures into a regional framework.

ORAL

**A CAMBRIAN TO HOLOCENE STRATIGRAPHIC
FRAMEWORK FOR ZEALANDIA**

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Thirteen new high-level stratigraphic units are proposed, mainly for broad groupings of Late Cretaceous to Holocene cover strata. Along with existing names, these place all of New Zealand's onland and offshore Cambrian to Holocene, plutonic, volcanic, sedimentary and metamorphic rocks, and unconsolidated deposits in a single, unified scheme:

Zealandia Supersuccession

Aotearoa Megasuccession

Aoraki & Maui Successions

Waka Megasuccession

Waitomo, Kahurangi & Kawatiri Successions

Rūaumoko Volcanic Province

Whakaari, Horomaka & Maungataniwha Supersuites

Austral Superprovince

Eastern Province

Torlesse, Caples, Maitai, Murihiku, Brook St & Drumduan Terranes

Western Province

Takaka & Buller Terranes, Tuhua Intrusives

The Northland-East Coast Allochthon and the Haast Schist are also accommodated. The twenty three high-level units are fundamentally tectonostratigraphic but provide a concise, geologically meaningful, overarching hierarchical framework for the c. 1000 medium-level lithostratigraphic units that are in contemporary use. The provinces and terranes of the Cambrian-Early Cretaceous basement rocks are well established. The new high-level names for the cover rocks correspond to parts of the Late Cretaceous-Paleogene rift-transgressive sequence (Waka Megasuccession) and the Neogene regressive sequence (Aotearoa Megasuccession); volcanic rocks are treated separately (Rūaumoko Volcanic Province). The benefits of this proposed scheme include convenience and economy of description of broad stratigraphic units, and more efficient database searching based on stratigraphic names.

ORAL

SUBMARINE CANYONS FEEDING THE HIKURANGI CHANNEL

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The head of the 2000 km-long Hikurangi Channel initiates from 10 major submarine canyons between Banks Peninsula and southern Wairarapa. For the first time the seafloor geomorphology of feeder canyons into the Hikurangi Channel are completely imaged with multibeam bathymetric data. New data collected under the Oceans-2020 program, combined with existing published and unpublished data, complete c. 50,000 km² 25m-resolution continuous coverage of the head of the Hikurangi Channel. The new multibeam data provides an excellent framework for interpretation of multichannel seismic data (e.g. Peg-09), archived sediment core analysis, and associated studies within the upper Cook Strait and Kaikoura canyons. We are progressing towards understanding modern and glacial-cycle sedimentary activity, large scale geomorphic evolution by tectonic deformation and mass failure, and placing constraints on the age of the canyon-channel system. Analogies from high-resolution imaging and monitoring of canyons on the Californian margin help to understand how this world class example of a large marine canyon-channel functions. Climatic, tectonic and oceanic forcing are all apparent as controlling factors.

ORAL

SPATIAL AND TEMPORAL PATTERNS OF PLEISTOCENE BIOGENIC SEDIMENT ACCUMULATION IN THE GULF OF ALASKA

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Reconstructing the timing and nature of past changes in aquatic productivity in the Gulf of Alaska (GoA) can shed light on the primary processes driving biogeochemical cycling over geologic timescales. Today, Fe is an important micronutrient that limits primary productivity in surface waters beyond the continental shelf in much of the GoA. However, we have a relatively poor understanding of how Fe-delivery processes influence primary production over glacial-interglacial timescales. Here, we present sedimentologic and physical property data from IODP Expedition 341 and identify intervals where diatom ooze and diatom-rich mud lithofacies are prevalent during the Pleistocene. We obtained high-quality sediment cores from the Surveyor Fan (Site U1417) and from a small slope basin at the edge of the continental shelf (Site U1419). In general, greenish gray diatomaceous ooze and diatom-rich mud is found in beds ranging in thickness from 20 to 150 cm, interbedded with gray mud that commonly contains limestones. Ooze is occasionally found immediately overlying volcanic ash. Compared to non-biogenic mud, diatomaceous sediments are generally characterized by lower magnetic susceptibility, natural gamma ray, bulk density, and higher b* color reflectance. At Site U1417, we observe a frequent occurrence of diatomaceous ooze during the middle Pleistocene relative to the early and late Pleistocene. At Site U1419, two prominent ~5 m thick intervals of ooze are found at the top of the core and centered at 90 m composite depth. Between these intervals are numerous 20 cm thick intervals of biogenic sediment that were likely deposited during the late Pleistocene. Biogenic intervals observed at both sites may be related to increased productivity driven by a combination of the aforementioned processes, but additional chronological and geochemical constraints are needed to rule out the role that changing sedimentation rates and/or silica dissolution play in controlling the distribution of ooze in these records.

ORAL

**IMPLICATIONS OF RUPTURE COMPLEXITY FOR
FORECASTING OF REGIONAL TSUNAMI IN NEW
ZEALAND**

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It has been demonstrated that the wave field of tsunami generated local to New Zealand (usually defined by travel times of less than one hour) strongly depends on the distribution of slip across the generating earthquake's rupture interface. Although methods for inverting this distribution exist, their performance (resolution and speed) in part depends on the capabilities of the seismic and/or GPS sensor network used for monitoring. Currently GEONET's performance is being evaluated with respect to this capability. However, at the moment we need to assume that the slip distribution is unknown at the time of the event. This effect poses a significant difficulty for forecasting the impact of the tsunami.

The rupture process of large subduction zone earthquakes will also have an influence on the distribution of wave heights at the coast for regional tsunami. Although the time available for determining the distribution of slip and the rupture kinematics increases with increasing distance, the resolution of the sensor network local to New Zealand is most likely not sufficient to perform the task (e.g. for tsunami originating in the Tonga-Kermadec subduction Zone).

The ground shaking caused by such earthquakes may not be strongly felt and a natural warning cannot be guaranteed to be adequate. Within the range of regional tsunami travel time only limited information about the nature of the tsunami source will be available through global earthquake monitoring bodies (e.g. USGS or PTWC). Initially this is only an estimate of the magnitude and the hypocenter.

We have investigated as an example, how variations in the rupture process and magnitude uncertainties impact on the prediction of wave heights in the wider Auckland coastal region, using hypothetical scenarios representing subduction zone earthquakes for different locations and magnitudes along the Tonga-Kermadec trench.

ORAL

**THE TIME-SPACE RELATIONSHIP BETWEEN
HINTERLAND EVOLUTION AND SEDIMENTARY
PROVENANCE OF THE UPPER CRETACEOUS
ACCRETIONARY COMPLEX IN THE SHIMANTO
BELT, KII PENINSULA, SW JAPAN**

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For understanding the time-space relationship between the provenance of sediments supplied to a trench and its hinterland evolution, a combined method of microfossil analysis and detrital-zircon U-Pb dating was carried out in Kii Peninsula, Southwest Japan. The Matoya Group including its equivalents in Kii Peninsula are one of the best-exposed sequences of Cretaceous accretionary complexes that are extended along the Pacific side of Southwest Japan (the Shimanto belt). These complexes have been assumed to represent trench-fill deposits derived from the eastern margin of the ancient-Asian continent. Mudstones and a medium-grained sandstone were sampled from three horizons at bottom, middle and top along a representative succession of the Matoya Group; two samples for microfossil analysis collected from the bottom and top mudstones, and the remaining sample for U-Pb dating yielded from the middle sandstone. Results are as follows: the bottom and top mudstones are respectively correlated to the Lower Campanian (ca.84-80Ma) and the Upper Campanian (ca.76-72Ma), and five age groups of zircon can be recognized from U-Pb dating of the middle sandstone. The abundant age groups of zircon consist of the younger sources that are concentrated in 110Ma, 100-90Ma and 87-79Ma (82.5Ma on average), whereas the least abundant age groups are significantly older, indicating 1800Ma and 220Ma. Among the above, the youngest U-Pb age of zircon is stratigraphically and chronologically concordant with microfossil ages of the mudstones, showing that the sediments derived from a contemporaneous magmatic arc (Ryoke granitic belt) were directly supplied to the subduction zone during the trench-fill sedimentation (around 80Ma). In addition, sediments containing zircons of 110-90Ma definitely predate the main phase of the trench-fill sedimentation and consequently make recognition of the existence of a slightly older magmatism. This data set possibly provides a model that the sediment supply to the subduction zone occurred in multiple ways.

POSTER

**DISPLACEMENT RATES ON THE WAIRAU FAULT;
IMPLICATIONS FOR PLATE BOUNDARY
DEFORMATION IN THE NORTHERN SOUTH ISLAND**

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The Wairau Fault is part of the strike-slip Marlborough Fault System (MFS) which presently accommodates ~80-90% of plate boundary deformation in the northern South Island of New Zealand. The Wairau Fault is the northern continuation of the Alpine Fault which is widely inferred to have initiated in the Early Miocene. Its ~150 km strike-slip displacement of the Esk Head basement terrane suggests that the Wairau Fault is also millions of years old, although little data have previously been available to estimate the age or the long-term (>18 kyr) displacement rates of the fault. Here we use ages and offsets from displaced fluvial surfaces, glacial moraines and a Pleistocene conglomerate (Porika Formation) to estimate displacement rates on the Wairau Fault over time intervals from 2 ka to 2.5 Ma. For time intervals <6 kyr displacement rates varied from <1 to 9 mm/yr, although were most often between 2 and 5 mm/yr, with this variability attributed to variability of inter-event times and slip for individual earthquakes arising in part from fault interactions. By contrast, displacement rates over longer time intervals (> 6 kyr) were ~3-4 mm/yr and may not have varied significantly since 2-2.5 Ma. These uniform long-term displacement rates indicate that the present along strike decrease in displacement rates on the Alpine/Wairau faults have been in operation for at least the last 2 Ma and do not support suggestions that the locus of high shear strains migrated southwards within the MFS during this time. We propose an alternative model in which the plate boundary in the northern South Island has been located in the region now occupied by the MFS for millions of years with initiation of new faults (e.g., Hope and Awatere faults) being part of a strain localisation process and occurring at the expense of vertical-axis rotations.

ORAL

**ORGANIC ENRICHMENT & SEDIMENTATION IN
DEEP-SEA POCKMARKS & DEPRESSIONS, SOUTH
CHATHAM RISE**

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Sea-floor depressions ranging in scale from 10-1000's of metres in diameter have recently been discovered on the upper southern flank of the Chatham Rise. These features are potentially formed by fluid and/or gas hydrate (methane) release at the sea-floor. A voyage this year (RV *Sonne* SO-266) investigated more fully the structure and fluid systems associated with these "pockmarks" and also provided an opportunity to determine whether infaunal community structure and function differed inside and outside the seafloor depressions. Sediments were collected using a multi-corer (10 cm-diameter tubes) in water depths ranging from 500 to 1000 m from which we incubated sediments to determine benthic metabolism, sampled for macro- and meio-fauna and sectioned to determine sediment properties in the upper layers. Preliminary results indicate differences in the grain-size and chemical characteristics within the large km-scale depressions, related to the preferential accumulation of organic-rich sediments compared to the surrounding sea-floor. This organic enrichment was reflected in elevated benthic activity as measured by increased sediment oxygen consumption. We also measured higher benthic activity in smaller-scale circular pockmarks (10's of metres) on the southwestern flank of the Chatham Rise. Fluid and/or gas expulsion appears to be ephemeral in the southwestern pockmark fields, with no evidence of active methane expulsion detected during the voyage. Seismic reflection data from the larger depressions indicate that while fluid processes were a factor in the geological past, recent erosional and depositional activity, potentially related to the development of current systems within the Subtropical Front, has effectively capped the direct escape of methane-charged fluids to the modern-day sea-floor. Thus, it appears that sea-floor communities are structured more by recent sedimentation processes than previous gas and/or fluid expulsion events.

ORAL

HOLOCENE SEDIMENT TRANSPORT ON THE NORTH CANTERBURY CONTINENTAL SHELF

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The North Canterbury Shelf is a highly complex and dynamic, rapidly evolving depositional environment. The study of continental shelf sediment transport, allows for predictions of source sediment for submarine canyons like the Kaikoura Canyon which feeds the Hikurangi Trough. This study aims to characterize the sediment delivery pathways on the Canterbury shelf between Banks Peninsula and Kaikoura, from the last glacial maximum to today. The study utilised surface samples, shallow cores, bathymetry data, 3.5 kHz seismic reflection data and a regional oceanographic modelling system.

A multi-raster sediment distribution map, sediment budget and sediment transport model detail: the extent, characteristics, rate of erosion, rate of deposition, sediment pathways and seasonal variations in the transport mechanisms, of the post-glacial sediments on the North Canterbury Shelf. The seafloor sediments on the inner shelf, up to 15 km offshore from Pegasus Bay north to Kaikoura are dominated by coarse sand and gravel. The hydraulic regime cannot support transport of this coarser material further offshore and it is transported north via long shore drift to Kaikoura Canyon.

The post glacial sediment wedge takes the form of a wide sandy-mud bank and extends north from the northern shoreline of Banks Peninsula, reaching a maximum thickness of 43 m on the mid-shelf, 40 km offshore central Pegasus Bay. The northerly dominant currents are accelerated around the constricting Banks Peninsula. Suspended load is transported north around Banks Peninsula is deposited in a zone extending north from Banks Peninsula as it loses momentum.

The outer shelf consists of medium sand to gravel sized sediments. The outer shelf sediments are largely relict material reworked with finer modern sediments. The Pegasus, Okains and Pukaki canyons have become dormant since the last glacial maximum. The rise in sea level since the last glacial maximum has created oceanic conditions unable to supply sufficient sediments.

POSTER

THE HYDRAULIC RESPONSE OF SCHIST LANDSLIDES TO REGIONAL EARTHQUAKES IN CENTRAL OTAGO

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The long-term record of groundwater measurements made in landslides in the vicinity of the Clyde Dam, Central Otago, provides an exceptional data set with which to investigate earthquake-induced hydrogeologic behaviour of compartmentalised groundwater systems. The Clyde Dam groundwater monitoring network consists of >250 piezometers installed in boreholes, which are used to monitor artificially lowered water table; of these, 25 instruments have responded repeatedly to large ($M_w > 6$) regional earthquakes since 1993. An extensive network of tunnels within and beneath the landslides contains V-notch weirs measuring groundwater discharge, these have also recorded large groundwater pulses in response to regional earthquakes. The magnitudes of earthquake-induced water level changes vary from site to site, and are typically of the order of 10^{-3} – 10^{-2} m, but some reach nearly 10^0 m. The timings of the peak piezometric pressure changes also vary by site, and are typically 10^{-1} – 10^1 hours after the earthquake. Recovery periods vary greatly and in some records are truncated by the responses to subsequent earthquakes. Water level fluctuations are spatially systematic, and consistently positive or negative throughout the study area for each triggering earthquake. Increased flow rates recorded in the tunnel weir data begin almost coseismically and exhibit recessions lasting 10^1 – 10^2 hours. Cumulative discharge volumes associated with each earthquake range from 100–1200 m³ for the Nine Mile Downstream slide area where the tunnel volume is 0.002% of the landslide mass, having a tunnel surface area of 43300 m². Earthquake-induced hydrological responses differ in both their magnitudes and temporal characteristics from storm-related responses. Analysis of the focal mechanisms of regional seismicity reveals that Clyde Dam is located in the compressional (P) quadrant of those earthquakes triggering a hydraulic response. The next phase of this research will address the relationships between the magnitude, onset, and duration of hydraulic responses and the characteristics of the seismic wavefields that induce them.

ORAL

GEOLOGIC HAZARDS IN HUNGARY

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Hungary is in Carpathian basin in Middle Europe, it has mountain ranges of medium heights and large plains. The geologic environment is variable; the oldest rocks are different types of sandstones from Ordovician period, but on the surface or near the surface are rocks from Cenozoic Era mainly Pliocene deposits and Pleistocene loess. Types of geologic hazards are similar everywhere. The priority order are determined by the country's natural (geographic, geologic, climate) capability and anthropogenic impacts. The last is becoming more and more important.

Hungary is threatened by a medium level of earthquakes, 5-20 events a year, and their magnitudes are very rarely more than 6.5. Other 'vis maior' geologic hazard events numbers are between: 100-150, but in a strong rainfall year, like 2010, we registered 640 events. For example, we had a red-mud flood which killed 10 people, four large landslides, the biggest of which moved about 500,000 m³ of landmass, 123 smaller landslides, 285 different type bluff topples and slides and 229 wine cellar collapses under public areas, streets, roads, squares and breaking the public utilities.

In Hungary the cellar collapses are a specialised problem. In the old times, people did not have a fridge, they had to deepen cellars for holding a stock of food and wine. The settlements continuously changed their geographical position after different historical events that happened in the last 1000 years, so the entries of cellars are forgotten. Nowadays, when the roads are used by 10-40 ton vehicles, we dig 3-4 m deep trench for public utilities above cellars, they collapse.

There are 3245 different settlements in Hungary, from these, 958 have experienced some kind of geologic hazard event in last 100 years. I will show some examples in my presentation.

ORAL

PLENARY: C, FE, H₂O, T, t & LIFE

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Whether focusing on a particular metal, isotope, and/or gas, I am drawn to projects that investigate temporally-dependent, water-rock/mineral interactions over a range of pressures and temperatures. Additionally, these projects investigate how the presence of life may play an integral role with regards to the development of minerals/rocks/ores/soils/wines. From near-surface processes to the depths of the mantle, I will cover a few examples examining the complex relationship and interdependence of C, Fe, H₂O, T, t and life from the start to hopefully not the finish.

ORAL

PALEOBIOGEOGRAPHY OF EOCENE RADIOLARIANS FROM THE SOUTHWEST PACIFIC

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By the end of this century, atmospheric CO₂ is predicted to increase to up to 1000 ppmv leading to significant global warming. To identify the consequences of extreme global warming on marine biota, a look into the past may help to understand the complex climate system and its implication on marine life. During the Eocene, several extremely warm episodes, called hyperthermals, have been identified and associated with very high pCO₂ exceeding 1000 ppmv. This project investigates the effect of extreme global warming events on fossil radiolarian assemblages and their distribution in the Eocene and aims to further advance the tools for Paleogene climate reconstruction. High-resolution study of radiolarian assemblages will be conducted, focussing on the MECO (Mid-Eocene Climatic Optimum) and post-MECO cooling interval (42-32 Ma). The focus on the middle Eocene is because it appears to be a radiolarian-rich record throughout the SW Pacific region, whereas radiolarians occur less consistently and are often poorly preserved in the early Eocene. Therefore, sample material from different DSDP/IODP sites from the high-latitude southwest Pacific (DSDP Site 277, ODP Site 1121, Campbell Plateau), onshore

New Zealand (Canterbury and Marlborough), and Lord Howe Rise (DSDP Leg 21) will form the main part of the study. Published records from the equatorial eastern Pacific (IODP Leg 320) and West Atlantic (ODP Leg 207, Demerara Rise), and the North Atlantic (IODP Leg 342) will also be incorporated into the paleobiogeographic analysis. The first approach will be the identification of warm and cold-water radiolarian taxa from DSDP Site 277 to investigate the faunal turnover at the late Eocene/Oligocene boundary and to set these results in a wider paleoceanographic context.

POSTER

POSITIONZ-PP, DEVELOPING AN ONLINE GPS PROCESSING TOOL FOR EARTH SCIENTISTS IN NEW ZEALAND

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This paper describes progress in the development of an online GPS processing application capable of producing coordinates with 1-2cm accuracy with 2 hr of data anywhere within the North and South Islands. This system was developed to process NZ user supplied GPS data which has been observed in 'static' mode. While there are other services available, LINZ decided to create its own system to produce coordinates in the NZGD 2000 datum. The GPS processing engine identifies and acquires RINEX data for the three best PositionZ stations to act as control, acquire appropriate IGS orbit files and initiate GPS processing using the Bernese GPS package. This step generates a set of ITRF coordinates at the epoch of observation which still must be transformed to the reference epoch of NZGD2000. Because of New Zealand's location on the Pacific Australian plate boundary, models of tectonic deformation are necessary to correct coordinates for tectonic deformation that have occurred between the epoch of observations and the reference epoch (2000.0). The PositionZ-PP system makes use of two subroutines for this purpose. The first (the Station Predictive Model) uses parameters determined from a least square analysis of the time series from PositionZ CORS network to correct coordinates for changes associated with the secular velocity, seasonal (annual and semi-annual) cycles, offsets caused by equipment changes and co-seismic displacements,

decaying post-seismic signals and slow-slip events. This subroutine determines accurate coordinates PositionZ CORS network at the epoch of observation. The second subroutine (the new Zealand Deformation Model) uses a gridded model of the secular velocity field and the co-seismic displacement associated with any earthquakes to transform the coordinates associated with the user RINEX data to NZGD2000 at epoch 2000.0. Both of these subroutines are based on models that were originally developed by John Beavan.

POSTER

POST SEISMIC DEFORMATION AFTER THE 2010-2012 CHRISTCHURCH EARTHQUAKE SEQUENCE

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This paper summarizes the on-going post-seismic deformation from the 2010-2012 Christchurch earthquake sequence measured with continuous GPS (cGPS) sites, plus three surveys of a ~30-station GPS network observed between January 2012 and January 2013. Results indicate that post seismic deformation is ongoing over two years after the 2010 Darfield earthquake and over a year after the last major earthquake in the sequence; however, the rate has decelerated by up to 50%. Displacement rates of individual GPS sites are 10 mm/yr or smaller and are not all significant, but coherent patterns of displacement are nevertheless evident in the data. The vectors indicate dextral shear along an extension of the rupture plane of the Darfield Earthquake and show a very clear ~6-10 mm/yr of east-northeast motion for sites in the northern part of Christchurch relative to Banks Peninsula in the south. The pattern of deformation appears to be centred in the region between the rupture planes of the 2010 Darfield earthquake and the 22 February 2011 earthquake. The deforming region overlaps with the eastern end of the rupture plane for the Darfield earthquake but is not measurable further west. Towards the east, the rate of deformation decreases towards the east coast.

Monitoring the post-seismic deformation after the 2010-2012 Christchurch earthquake sequence is important both for what it can tell us about the causes of the earthquake sequence and for its

possible implications for the seismic hazard for the region. For this reason we plan a program of continued monitoring combined with modelling to better characterize the post seismic deformation and understand its cause.

ORAL

**PLENARY: ENVIRONMENTAL AND MEDICAL
GEOCHEMISTRY IN URBAN DISASTER SCENARIOS**

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In addition to the physical damages, casualties, injuries and psychological effects they cause, urban disasters can also produce large volumes of hazardous materials. These disaster materials can be geogenic (e.g. volcanic ash, landslides), geoanthropogenic (e.g., polluted flood sediments, smoke and ash from wildland-urban fires), and anthropogenic (e.g. industrial chemical releases, dusts and debris from building collapses, and smoke and ash from building or industrial fires). Environmental and medical geochemists can collaborate with hazards, emergency management, and public health experts to: characterize the physical, chemical, and microbial makeup of disaster materials; fingerprint and assess relative contributions of materials from multiple sources; elucidate how environmental processes modify disaster materials; monitor, map, and model the dispersal and evolution of disaster materials in the environment; characterize pre- and post-disaster environmental conditions; help understand exposure pathways and toxicological implications of disaster materials for urban populations and ecosystems; and, help identify appropriate disposal options for disaster materials to minimize additional health impacts or exposures. Environmental and medical geochemists can also contribute substantially to interdisciplinary urban disaster scenarios, which are increasingly used by hazards experts to help governments and communities prepare for future disasters. This presentation, growing from the outstanding efforts of many collaborators, will summarize urban environmental and related health implications of several such scenarios. These include the Southern California ShakeOut (which modeled the impacts of a hypothetical 7.8 magnitude earthquake on the southern San Andreas fault), ARKStorm (which modeled the impacts of a hypothetical weeks-long winter storm hitting southern and central California), and a

California teletsunami triggered by an Alaskan offshore earthquake. Helping understand the plausible sources, types, environmental behavior, and health implications of natural and anthropogenic contaminants and pathogens that are involved in these disaster scenarios will ultimately enhance preparedness for and resilience to environmental and health consequences of future disasters.

ORAL

**USING TURBIDITES SEDIMENTOLOGY AND
DEPOSITIONAL SYSTEM TO INFER EARTHQUAKES
FREQUENCY, MAGNITUDE AND SOURCES ALONG
THE HIKURANGI MARGIN OVER THE LAST 16KYR**

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Sedimentary cores collected in the Poverty, Ruatoria and Matakaoa morphological re-entrants, along the northern Hikurangi Margin, contains a high density of turbidites. Their geographic origin on the margin and petrographic composition, provide hints as to whether the turbiditic events were triggered by earthquake shaking. Age models for all events generated using Oxal probabilistic software, tephra and radiocarbon ages, range from 170±140 to 18,150±140 yr BP. Overall, 30 depositional turbidite events were identified independently in Ruatoria, 19 in Matakaoa, and 73 in Poverty. Forty-one events are synchronous along the entire margin (margin events) and interpreted as originating from the upper continental slope in response to earthquake-triggered slope failures between 387±170 and 16,446±310 yr BP. Using the location and seismotectonic characteristics of 26 identified offshore faults, the extent of the seismically-triggered turbidites and assuming that peak ground accelerations must reach 0.1 g simultaneously in all source areas across the margin to trigger synchronous slope failures, we inferred that synchronous slope failures were triggered by the rupture of three offshore faults, each capable of generating Mw 7.3 to 8.4 earthquakes. Two earthquake sources are crustal reverse faults and one is the subduction interface.

Overall, we establish a calendar of 41 Mw \geq 7.3 earthquakes with a return time of 150 \pm 50 yr over the last \sim 16,000 yr on the northern Hikurangi margin. Twenty earthquakes affected the three re-entrants simultaneously and are interpreted as Mw \geq 7.5 plate interface events with return time of 550 \pm 50 yr, and capable of triggering exceptionally voluminous turbidity currents. Return times deduced from turbidite chronology is similar to that estimated for the three faults, and onland paleoseismic evidences corroborate our interpretation. Return time of subduction earthquakes suggest alternating periods of intense activity with low magnitude earthquakes separated by periods of relative quiescence characterized by rare but high magnitude earthquakes.

POSTER

THE 2009 SOUTH PACIFIC TSUNAMI REVISITED

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The 2009 South Pacific tsunami was the most destructive tsunami to hit the South-west Pacific for at least 90 years, and possibly much longer than that. Over 180 lives were lost, and many houses and business were destroyed. The damage was distributed across three countries: Samoa, American Samoa, and Tonga.

The earthquake that caused the tsunami was unusual in many respects. It consisted of two nearly-simultaneous ruptures, one on an outer-rise fault, and the other on the subduction interface. These earthquakes occurred in an area that was previously considered to be relatively safe from large local tsunami, as geodesy indicates that the subduction interface should be largely uncoupled.

The physical properties of the tsunami inundation were greatest on the Tongan Island of Niutopotapu. There the maximum tsunami height was 17 metres above sea level, and the maximum flow depth approximately 15 metres above the ground. The tsunami inundated 46 percent of the island, and completely stripped away large areas of dense forest. Fortunately the side of Niutopotapu that was most affected was uninhabited, otherwise the casualties would have been much greater.

This presentation will review the process by which John Beavan and colleagues established that two near-simultaneous earthquake ruptures occurred, using tsunami water level data, geodetic data, and seismic data; and how this was independently

discovered by Thorne Lay and colleagues using seismic imaging. We will also discuss why it was that Niutopotapu was so strongly affected, and what the implications of this event are for tsunami hazard in the South Pacific.

ORAL

NEW TOOLS FOR CENOZOIC POLLEN ANALYSIS – INTERACTIVE KEY AND RANGE CHARTS

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The New Zealand Fossil Spores and Pollen Catalogue (online at <http://www.gns.cri.nz>) documents >830 species of fossil spores and pollen from the New Zealand region recorded in scientific literature. It includes a detailed synonymy for each taxon, and key illustrations. We have produced an interactive taxonomic key for the >330 Cenozoic taxa that appear in the Catalogue, using the original published descriptions and any emendations. This interactive taxonomic key is constructed using the 'Delta' platform and is accessed using the freeware 'Intkey' interface. Unlike traditional hierarchal keys, an interactive key allows the user to identify specimens by selection of morphological character states in any order. An estimate of the stratigraphic range of each taxon has also been made by counting the number of times per New Zealand Stage that each taxon has been recorded in the New Zealand Fossil Record File (FRED). Some caveats must be remembered when using such range estimates: individual FRED entries have not been checked, either for taxonomic accuracy or reasonableness of individual age determinations, and no consideration has been given to any sampling biases in the FRED database. Corrections and suggestions for improvement are most welcome.

ORAL

NEW ZEALAND CRETACEOUS MIOSPORE BIOSTRATIGRAPHY AND NON-MARINE CORRELATIONS

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Recent biostratigraphic results from petroleum exploration and studies of key sections have revised correlations and enabled subdivision of

some long-standing Cretaceous miospore zones (Raine 1984, Crampton et al. 2004). Successive first appearance datums of *Peninsulapollis gillii*, *Forcipites sabulosus* and *Nothofagidites senectus* mark upper divisions of the PM1 zone (Mangaotanean-Early Haumurian, Turonian-Middle Campanian), while first appearances of *Tricolpites lilliei*, *Clavifera rudis*, *Quadraplanus brossus*, and *Tripunctisporis maastrichtiensis* + *Beaupreaidites* n.sp. mark divisions of the PM2 zone (late Early-Late Haumurian, Middle Campanian-Maastrichtian).

Highlights of a new correlation chart of Cretaceous non-marine strata are presented. In the Taranaki Basin, the deltaic Taniwha Formation is of Motuan-Ngaterian age (TS zone, Late Albian-Cenomanian), but has been encountered only in the Te Ranga-1 well; elsewhere, drilled sections of the widespread Rakopi Formation coal measures are mostly of Late Haumurian age (PM2 zone), with Early Haumurian (PM1 zone) encountered only in the far offshore region (Tane-1 well) and adjacent to the Taranaki Fault (Rimu/Kauri fields). Succeeding shallow marine sedimentation of North Cape Formation was interrupted by regressive episodes which saw renewed coal measure deposition in more inshore areas during the mid Late Haumurian and at the close of the Cretaceous.

In the Canterbury Basin, the oldest palynologically dated strata are fluvial conglomerates associated with the 112 Ma Shag Valley Ignimbrite in the Waihemo Fault zone (Tulloch et al. 2009): these contain a palynoflora of Korangan age (LB2 zone, late Aptian or early Albian). The Horse Range Formation away from the Waihemo Fault comprises marine-influenced lower coastal plain sediments of Piripauan-Early Haumurian age (upper PM1 zone), and is disconformably overlain by the widespread Taratu Formation coal measures of Late Haumurian (PM2 zone) age. In outcrop, the Kyeburn Formation and Monro Conglomerate, and in offshore wells the partly marine Clipper Formation span parts of the Motuan to Early Haumurian interval.

POSTER

AN AEROMAGNETIC-CONSTRAINED SUB-QUATERNARY GEOLOGICAL MAP OF THE WEST COAST REGION

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The West Coast region of the South Island has significant deposits of Quaternary sediment that mask underlying basement geology, particularly in low-lying areas. The airborne geophysics survey released in August 2013 has revealed many features that refine the known surface geology and provide insight into the composition and stratigraphic association of subsurface geology beneath the Quaternary cover. These features have been compiled with the QMAP Seamless GIS 1:250 000 geological map into a derivative sub-Quaternary geological map of the West Coast.

Both the mineral prospective Ordovician Greenland Group and the Late Devonian to Early Carboniferous Karamea Suite granitoids that intrude them have very subdued magnetic responses and collectively they are inferred to underlie much of the Quaternary sediments and other Cenozoic sedimentary rocks across the region. Cretaceous Rahu and Separation Point Suite granitoids are interpreted to be the cause of most of the relatively high magnetic intensity anomalies in eastern parts of central Westland. The biotite zone greenschist facies and higher metamorphic grades of the Alpine Schist have elevated magnetic intensity compared their lower grade protoliths.

ORAL

USING FLORAL PROXIES TO RECONSTRUCT LATE EOCENE TO LATE MIOCENE TERRESTRIAL PALEOCLIMATES IN SOUTHERN NEW ZEALAND

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Southern New Zealand is located at the convergence zone of the subtropical and

subantarctic oceanic fronts. In the Late Eocene southern New Zealand was situated at ~55°S; by the Miocene it had moved to its current latitudinal position at ~45°S. This relatively stable position makes the terrestrial climate of southern New Zealand crucial in understanding the development of the subantarctic front. Six sites were analyzed using floral climatic proxies: Pikopiko (36–34 Ma), Cosy Dell (25 Ma), Foulden Maar (23 Ma), Shale Creek (19–15 Ma), Double Hill and Kaikorai Valley (both 12–11 Ma). Quantitative climate proxies such as the Climate Leaf Multivariate Program (CLAMP) and Bioclimatic Analysis were used to estimate mean annual temperature, warm and cold season temperatures, annual precipitation, and humidity.

Mean annual temperatures cooled from 20.0–22.8°C in the Late Eocene to 17.7–19.8°C in the Late Oligocene, 18.4–20.1°C at the Oligocene-Miocene boundary and 18.2–19.5°C in the Early Miocene. At Kaikorai Valley close to the Middle-Late Miocene transition temperatures had dropped to 13–15.8°C whereas at Double Hill, CLAMP analysis gives temperatures of 17.4–20.2°C, although Bioclimatic Analysis estimates are 11.5–19.3°C. Cooler temperatures at the Middle-Late Miocene transition resulted from lowering of winter temperatures; summer temperatures were similar to those of the Early Miocene. Precipitation rates were relatively stable from the Late Eocene to the Late Miocene (1500–2200 mm).

From floral proxies it is evident that the climate cooled from subtropical in the Late Eocene to temperate by the Late Miocene even as Zealandia moved northwards. The Late Eocene was characterized by high temperatures and humidity, which concords with the view that higher latitude rainforest had less evaporation and possibly a near permanent cloud cover. Near the Middle-Late Miocene boundary the subantarctic front started influencing southern New Zealand winter weather patterns.

ORAL

THE AVON-HEATHCOTE ESTUARY AS A RECORDER OF COSEISMIC VERTICAL DEFORMATION

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The Mw 6.1 Christchurch earthquake of 22nd February 2011 produced coseismic ground deformation in the Avon-Heathcote Estuary, presenting a unique opportunity to measure deformation and potential geological signatures against a known earthquake event. Three-monthly surveys of inter-tidal plants and invertebrates, microbiota and sediments have been conducted since June 2011 at four locations within the Avon-Heathcote Estuary. These surveys track response of flora and fauna to ground deformation, allow quantification of uplift or subsidence at each location, and indicate the likely geological signature of this modern event to better enable interpretation of pre-historical events. The intertidal plant community has responded to coseismic deformation with seaward or landward shifts, with the glasswort *Sarcocornia* used as the indicator of pre-deformation highest spring tide level. In the southern estuary subtle uplift has occurred and new and healthy *Sarcocornia* form a new zone seaward of their pre-earthquake limit. In the northern estuary significant subsidence has occurred and the *Sarcocornia* zone has shifted landward. Foraminiferal data indicate living tests are responding to changed conditions, but the widespread occurrence of sand volcanoes has introduced prehistoric marine and estuarine foraminifera to modern sediments. Surface sediments are responding to localised geomorphology and do not show a consistent response to deformation. Comparison of estuary deformation data and differential LiDAR maps reveals the soft sediments of the estuary show either uplift that is less than that indicated by LiDAR for adjacent land area (southern estuary), or only subsidence where adjacent land area shows subtle uplift (northern estuary). This uplift signal dampening is a response to shaking-induced compaction of unconsolidated sediments. Where uplift is recorded in the geological record this may be muted by soft sediment compaction, potentially leading to an underestimation of the hazard. Conversely both near and far-field shaking may produce soft sediment compaction therefore

subsidence records may record both local and regional seismic events.

ORAL

**THE IMPORTANCE OF FAULT SIZE FOR
SUBSEQUENT INVERSION, SOUTHERN TARANAKI
BASIN, NEW ZEALAND**

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Fault reactivation is observed in many basins worldwide and has been extensively studied, yet the details of how earlier displacement accumulation impacts on later faulting is often unresolved. We address this question using seismic reflection data (25,000km of 2D and 4,000km² of 3D seismic data with up to 16 interpreted seismic horizons tied to 35 wells), from the Southern Taranaki Basin, which contains sedimentary rocks up to 8km thick that record multiple phases of faulting and folding since ~85Ma. As is common in New Zealand many early formed Late Cretaceous to Palaeocene normal faults in the Southern Taranaki Basin were inverted during Miocene shortening. We find that all normal faults with maximum vertical displacements over 300 milliseconds (TWTT) were inverted while faults smaller than this were not. In the majority of cases, the entire length of the initial normal fault was inverted with the approximate location of the maximum displacement and the proportion of the total (basin wide) strain budget accommodated on the fault being similar between deformational episodes. These observations suggest that few new large (>300 milliseconds) faults were initiated in the Miocene and that the size (displacement and length) of each normal fault is a key determinant for whether it will be reactivated and for the size of the subsequent reverse fault. It is proposed that larger normal faults (>300 milliseconds) are reactivated along their entire lengths at the onset of shortening with the reverse fault system largely utilising the pre-existing system from an early stage. Under these conditions a hierarchy of fault length was established rapidly and longer faults accrue a greater proportion of the total strain budget perhaps because their greater dimensions or weakness locally promotes strain localisation at the expense of smaller faults in the system or the creation of new faults.

ORAL

**THE TECTONIC CONTEXT OF THE 2013 COOK
STRAIT EARTHQUAKES**

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The Cook Strait earthquakes of 2013 July 13 (Mw 5.5) and July 21 (Mw 5.8, 6.6), and the nearby Lake Grassmere earthquake of August 16 (Mw 6.6), lie in a region of recurrent seismicity marking the transition along the Hikurangi Margin from normal subduction in the southern North Island to continental subduction in the northern South Island. North of Cook Strait, 80% of the current plate motion is accommodated by repeated slip at the plate interface. In contrast, south of Cook Strait almost all of the plate motion is accommodated in the overlying plate. The Cook Strait earthquake sequence also occurred at the southern edge of the currently strongly coupled part of the plate interface, as revealed by GPS observations. Previous detailed studies of the small earthquake distribution in this region using double-difference relocation show that events in the mid crust form lineations along the strike of the subduction zone. This is evidence for significant creep on pre-existing faults. The Cook Strait earthquakes occurred during an episode of slow slip in the Kapiti region, which is at the down-dip edge of the strongly coupled part of the plate interface. They can similarly be interpreted as stress corrosion at the southern edge of the strongly coupled part of the plate interface, albeit in a region where the pore fluid pressure ratio (λ) is less, allowing a mixture of brittle failure and creep. This explains the swarm-like nature of the sequence. A southward decrease in λ is consistent with the dehydration history of the underlying Hikurangi Plateau. This southward decrease in λ is also a key driver in the tectonic transition across Cook Strait, from repeated, localized slip at the plate interface in the southern North Island to upper crustal deformation with a shallow brittle-plastic transition in the northern South Island.

ORAL

**PROLONGED CANTERBURY EARTHQUAKE
SEQUENCE LINKED TO WIDESPREAD WEAKENING
OF STRONG CRUST**

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The larger events of the 2010-2011 Canterbury, New Zealand, earthquake sequence had disproportionately large energy magnitudes (M_e) relative to their moment magnitudes (M_w), and produced the strongest shaking ever measured in New Zealand. The pattern of faulting was very complex, and the aftershock sequence has lasted a long time. Here we investigate what role crustal structure has played in this unusual earthquake sequence, through detailed 3-D tomographic imaging of P-wave velocity (V_p) and the ratio of P-wave to S-wave velocity (V_p/V_s). The Canterbury region is underlain at ca. 10 km depth by mafic crust of the Hikurangi Plateau, a large igneous province subducted under the edge of Gondwana ca. 100 million years ago. Faulting occurred in greywacke rocks welded to this underlying, strong plateau, producing a very energetic mainshock rupture (M_w 7.1, M_e 8.0). A prominent feature of the V_p/V_s image at the depth of maximum slip during the mainshock is a region of extremely low V_p/V_s (< 1.60), centred on the surface fault break. This compares with a pre-earthquake V_p/V_s of 1.71. We interpret this reduction as the fresh rupture front producing widespread cracks around the fault zone. Strength recovery following this widespread weakening of the crust may explain the 172 day delay between the mainshock and the largest aftershock (M_w 6.3), which caused widespread destruction in Christchurch City.

POSTER

**PRECURSORY SIGNALS AND FORECASTS OF THE
COOK STRAIT AND LAKE GRASSMERE
EARTHQUAKES**

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There was high seismic activity in the vicinity of the July and August 2013 magnitude M 6.5 Cook Strait (South) and M 6.6 Lake Grassmere earthquakes in the years preceding their occurrence. A precursory

scale increase (a medium-term increase in the rate of occurrence of minor earthquake) occurred before these earthquakes, as for most other major earthquakes in New Zealand and other well-catalogued regions. The precursory scale increase had its onset in late 1997. In all, 22 earthquakes with magnitude $M \geq 4.5$ occurred between the onset and the Cook Strait (South) main shock. In contrast only five earthquakes with $M > 4.5$ occurred in the prior period of similar length. The largest precursors were an M 5.7 earthquake 3 days before and an M5.8 event one day before the Cook Strait main shock.

The Every Earthquake a Precursor According to Scale (EEPAS) medium-term forecasting model showed the vicinity of the main shocks as a likely location for the occurrence of an M6.5 earthquake from 2004 through to the time of their occurrence. Because of the strong burst of foreshock activity in the three days prior to the Cook Strait (South) main shock, short-term clustering models also showed high probability gains in the source region of this earthquake at the time of its occurrence.

ORAL

**DOME OR FLOW: A CHARACTERISATION AND
ANALYSIS OF LAVA DOME FACIES, SANTIAGUITO
VOLCANO, GUATEMALA**

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Structures and textures of lava dome facies reflect underlying magmatic and eruptive processes. We mapped and classified the lithologies, textures and facies of Santiaguito Lava Dome sequence, Guatemala. In addition, we examined the historical eruption record to constrain the temporal relationships and effusion rates of the different flow units. Spines or short blocky lava flows are generally dense and crystalline and erupted at low effusion rates. These occur at the beginning and end of an eruption sequence from different linear vents on the dome. Long lava flows are generally more porous and erupt at high effusion rates in the middle of eruption sequences from larger vents. Over time the composition changed from dacite to andesite. We interpret that spines form from high viscosity dacitic magma at low effusion rates allowing degassing and crystallisation in the conduit prior to eruption. Long lava flows form from lower viscosity magmas, either andesites, or dacites that erupted at high effusion rates experiencing less degassing and crystallisation.

Effusion rate and degassing appears to control the viscosity of the magma. An eruption cycle begins with an explosive eruption followed by the slow extrusion of a viscous spine and lava flows of increasing length. The end of eruption cycles is marked by slow effusion rates and spines blocking vents causing the subsequent eruption cycle to initiate from a different vent. Dome collapses are more frequent during high effusion rates and from lava flows than compared to spines. Characterisation of extrusion cycles and an understanding of the changing facies are essential for hazard recognition at lava domes worldwide.

POSTER

DEEP ATLANTIC CIRCULATION DURING THE WARM PLIOCENE: A NEW RECONSTRUCTION FROM THE IODP ARCHIVES

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Earth last experienced sustained global warmth within the range predicted for the 21st century during the late Pliocene. To understand climate during this interval, the U.S. Geological Survey's PRISM Project has reconstructed global conditions at 3.264-3.025 Ma, identifying a prominent warm surface anomaly with increased evaporation in the North Atlantic. Warm anomalies propagate southward into the deep ocean to 46°S, suggesting that enhanced overturning circulation may have been responsible for southerly penetration of North Atlantic Deep Water (NADW). However, paleotemperature is not diagnostic of water mass origin, and some model simulations predict transient decreases in 21st century NADW production, presenting a contrasting picture of future climate.

Here, we present a synthesis of Atlantic deep ocean circulation during the PRISM interval, using the neodymium isotopic composition (ϵ_{Nd}) of fossil fish teeth as a proxy for water mass source and the $\delta^{13}C$ of benthic foraminifera as a proxy for water mass age. We utilize new and previously published data from 11 DSDP and ODP sites in the North

Atlantic and along southern depth transects from equatorial Ceara Rise, mid-latitude Walvis Ridge, and South Atlantic Meteor Rise/Agulhas Ridge. We identify the ϵ_{Nd} fingerprint of northern component water (NCW) at all four equatorial sites, indicating a Pliocene water column structure similar to today. In contrast, southern mid-latitude water column structure was significantly different in the Pliocene. Abyssal depths in the Walvis Ridge region are currently bathed in southern component water (SCW). However deep sites were influenced exclusively by NCW during the PRISM interval, while the shallowest site, in the core of NADW today, was instead influenced by SCW. The South Atlantic transect provides further evidence for deep ocean restructuring in the warm Pliocene. Although NADW bathes the Meteor Rise region at intermediate depths today, our southernmost Pliocene depth transect preserves an unequivocally SCW fingerprint.

ORAL

RECONSIDERING BASIN GEOMETRIES OF THE WEST COAST: THE INFLUENCE OF THE PAPAROA CORE COMPLEX ON OLIGOCENE RIFT SYSTEMS

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Geological models of the West Coast Region rely on E-W cross sections emphasizing the persistent influence of predominantly NNE-SSW trending structures as both normal (Palaeogene) and reactivated reverse (Neogene) faults. Recent work on Oligocene stratigraphy and carbonate sedimentology along the Paparaoa Range suggests that inherited topography from an older (Late Cretaceous) orthogonal, WNW-ESE oriented fault set associated with the Paparaoa Core Complex was also a controlling factor on basin geometry and sedimentary fill. This is most evident along the north eastern (Inangahua) and western (Punakaiki to Westport) flanks of the Paparaoa Range where Oligocene strata are well preserved. A NNE-SSW cross-section across this area illustrates a relationship between thin Oligocene strata and a basement high created by low angle (normal) detachment faults that formed the Paparaoa Core Complex. Oligocene strata thicken rapidly in the direction of hanging wall movement, outwards from this basement high. Facies variations correspond with changes in thickness; thinner

sections are typically algal grainstone and cross-bedded grainstone facies and thicker sections contain deeper water wackestone and packstone facies. These variations in thickness and palaeotopography run perpendicular to the axis of current palaeogeographic models of the region such as the Paparoa Trough (Nathan et al. 1986) and highlight an additional complexity to West Coast Oligocene palaeogeography. Based on these findings in the Oligocene record, we propose that accurate interpretation and reconstruction of the Challenger Rift System needs to incorporate both core complex-related and younger Cretaceous and Tertiary faults. This revelation also begs the question as to what degree these inactive structures have influenced other aspects of the West Coast Tertiary succession. Furthermore, the potential for inactive faults to continue to influence the character and geometry of rift systems and the resulting sedimentary fill has implications for Palaeogene basins across much of New Zealand as well as similar overseas examples.

ORAL

THE ORIGIN OF SOLUTES WITHIN THE GROUNDWATERS OF A HIGH ANDEAN AQUIFER

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This paper investigates the origin of solutes within the groundwaters of the Monturaqui-Negrillar-Tilopozo (MNT) aquifer system within the high Andes of the Atacama Desert that discharges into the Salar de Atacama. Key questions include the relative significance of volcanic hydrothermal processes and evaporitic brine recycling over solute supply as well as the pathways of solute ingress to the MNT aquifer system. Groundwaters were analysed for elemental (major, minor and trace) and isotopic ($\delta^{18}\text{O}/\delta^2\text{H}$; $\delta^{13}\text{C-DIC}$; $\delta^{34}\text{SO}_4$; $^{87}\text{Sr}/^{86}\text{Sr}$) constituents to which various hydrochemical and multivariate statistical methods have been applied. Groundwaters are all classified as thermal and show increasing temperatures (27 – 35°C) and concentrations of HCO_3^- (4.4 – 10.4 mmol/L DIC) with increasing proximity to Volcano Socompa associated with an increasing mass flux of steam and magmatic CO_2 ($p\text{CO}_2 = 0.02 - 0.11$ atm; $\delta^{13}\text{C-CO}_2 = -9.3$ to -3.6% (PDB)) boiled off a

deep hydrothermal reservoir. Superimposed upon this gradational and relatively smooth spatial increase in heat and mass flow is a sharp, structurally controlled, increase in TDS (826 – 3,632 mg L^{-1}) and a concomitant change in $\delta^{34}\text{SO}_4$ (+0.79 to 4.9 ‰ (CDT)) and $^{87}\text{Sr}/^{86}\text{Sr}$ values (0.707375 - 0.706859) associated with the inflow of evaporitic solutes. Evaporitic inputs are chemically and isotopically distinct from localised secondary hydrothermal derived solutes with major, minor and trace element data suggesting an origin within a highly oxidising, alkaline, evaporitic lake receiving dilute inflows enriched in volcanic/fumarolic sulfur mineralisations probably from volcanoes Socompa, Salín or Pular that delimit the eastern topographic extent of the aquifer system. The conceptual model presented in this paper proposes that basal leakage of evaporitic brines from active salar(s), within the high altiplano, are actively entrained by sub-regional groundwater flow and conveyed to the MNT aquifer system where they mix with solutes derived from localised secondary hydrothermal gas-water-rock interaction. This work provides detail on the origin and processes controlling the solute composition of groundwater inflows to the Salar de Atacama within the volcanically active and hyperarid Atacama Desert and may be of significance to conceptual models of evaporitic brine evolution, recycling of evaporitic brines and hydrothermalism in arid regions.

ORAL

THE CONDITIONS AND TIMING OF AMPHIBOLITE FACIES GREENLAND GROUP METAMORPHISM IMMEDIATELY SOUTH OF THE REEFTON GOLDFIELD, WESTLAND

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The general structure of the Reefton Goldfield, Westland, is one of upright to steeply inclined macroscopic folds and faults that trend north-south within the Ordovician metasedimentary Greenland Group. These structural features, along with one of the most significant historically mined sites in New Zealand (the auriferous Blackwater mine), should project southwards directly into the Waipuna Valley in the Upper Grey River. The Greenland Group has now been mapped throughout the Waipuna Valley, but it is distinct from the goldfield in two ways. Firstly, in contrast to the goldfield, mapping reveals that the

Greenland Group has been invaded by abundant granitoid dikes, stocks and plutons. Bulk rock chemistry suggests correlation with Rahu Suite granitoids. Secondly, Waipuna Valley Greenland Group is subtly higher metamorphic grade. These rocks contain a sequence in which detrital (quartz, feldspar) and low metamorphic grade features (chlorite, white mica) are progressively recrystallized to greenschist to amphibolite facies assemblages. The highest-grade rocks co-inside with a low-angle ductile shear zone, here named the Waipuna Shear Zone. Peak metamorphism reached ~600-650oC, significantly higher than the adjacent Reefton Goldfield (~400oC). The highest-grade rocks, exposed over a small area in the center of the valley, are staurolite-bearing schists, gneisses and mylonites. Monazite and zircon U-Th-Pb dating, reveals that the metamorphism and associated deformation occurred in the mid Cretaceous, contemporaneous with the emplacement of the granitoid bodies. We interpret these geological features to indicate that the Cretaceous Waipuna Shear Zone has juxtaposed low-grade and deeper-crustal sections of Greenland Group. This is consistent with widespread mid Cretaceous extensional tectonics and Rahu Suite magmatism. The field relationships imply that this fault zone may project beneath the Reefton Goldfield. These dates demonstrate a Cretaceous age for metamorphism directly south of the goldfield, and hence that this was a time of fluid flow that could have facilitated mineralisation.

POSTER

CIVIL DEFENCE EXERCISE TE RIPAHAPA – A REALISTIC SCENARIO FOR A RUPTURE OF THE ALPINE FAULT

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Following the devastating Canterbury earthquake sequence, there has been a strong drive in New Zealand to increase awareness and resilience to earthquakes. As a result, Canterbury CDEM Group initiated a South Island-wide exercise to test the emergency response to a strong earthquake affecting the entire island. Currently, the Alpine

Fault is thought to present the most severe seismic threat to the South Island with the potential for an M8 earthquake. Thus a scenario for an earthquake on this fault was developed for the exercise. Using evidence from previous identified ruptures, it is inferred that a rupture of the Alpine Fault will involve its whole 400 km length most likely initiating on the central segment. Surface displacements will reach a maximum of 8 m horizontal and 2 m vertical resulting in an M8 earthquake. Modified Mercalli intensity shaking is expected to reach a maximum of MM10 in the epicentral region with MM9 along the entire rupture length; up to 75% of people in the South Island will be subjected to MM6 or greater shaking. Empirical evidence from historic earthquakes suggests that landsliding will affect an area >34,000 km² with >50,000 individual landslides. The morphology of the Southern Alps indicates that many of these landslides will block river systems resulting in landslide dams and 'quake lakes'. Numerous historical examples have been identified throughout the South Island as well as geologic and geomorphic evidence for pre-historic blockages. Subsequent rainstorms will reactivate landslide deposits in the form of debris flows. Landslides entering lakes or fiords may generate landslide tsunamis with Milford Sound a particular concern. Aftershocks are expected to last for >5 years with the largest magnitude aftershock expected to be ~M7. An Alpine Fault earthquake therefore has the potential to generate widespread consequences with its impacts lasting for an estimated 40 years.

ORAL

LIKELY IMPACTS TO CRITICAL LIFELINES FROM AN EXPECTED ALPINE FAULT EARTHQUAKE

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The Alpine Fault is currently thought to present the most severe seismic hazard to New Zealand's South Island with the potential for an M8 earthquake sometime in the next 100 years. A recent Civil Defence and Emergency Management exercise sought to simulate the natural and infrastructural impacts of such an event. Herein we

present the anticipated impacts to the critical lifelines networks derived from a process of expert elicitation. These networks include the State Highway, rail, hydroelectric power, and telecommunications networks. The State Highway network is expected to be substantially affected with ~40% of the network experiencing MM7 or greater shaking. State Highway (SH) 6 is particularly exposed, crossing the fault rupture in multiple locations and with ~65% of its length exposed to MM7 or greater. The Alpine Passes are equally exposed, with each crossing the fault rupture and being particularly susceptible to devastating landslides. As a result it is expected that SH6 will be completely impassable along its entire length within the West Coast region while each of the major Alpine Passes will be blocked by fault rupture and landslides. The hydroelectric power network is anticipated to be similarly affected however, none of the major dams are exposed to shaking intensities large enough to generate damage. Nevertheless, ~20 major transmission substations experience MM7 or greater shaking which is sufficient to cause damage, while transmission lines for the West Coast region follow the blocked Alpine Passes. The result is a loss of power to the entire West Coast region which is expected to last weeks to months. The mobile telephone network is robust with transmitting towers able to withstand large shaking intensities. Nevertheless, a loss of power will result in a loss of cell reception when back-up generators run out of fuel.

POSTER

INTEGRATED WORKFLOW FOR MODELLING BASIN-SCALE PETROLEUM SYSTEMS: A CASE STUDY FROM OFFSHORE TARANAKI BASIN

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This poster presents an integrated workflow for modelling Taranaki Basin petroleum systems aimed at visualising basin evolution and hydrocarbon accumulation within the entire basin by depth, area and through geological time (4D). The size of the study area (74,209 km²), integration of large datasets over a nine-year timeframe, use of multiple software types, and a multi-disciplinary approach present a number of technical

challenges. Examples of data applications are presented for the hydrocarbon-producing Kupe and Tui-Maui-Maari areas (4,155 and 8,723 km², respectively).

The six-step workflow builds on a consistent naming convention, developed for stratigraphic boundaries recorded in wells, seismic data, seismically interpreted geological horizons and faults. It provides a co-ordinated approach to interrogating large amounts of independent data, and the derivative maps and models are the base for detailed petroleum exploration. Lessons learned may serve as guidelines for similar scale, regional projects.

POSTER

SEISMIC CHARACTERISTICS AND PALEO- DEPOSITIONAL ENVIRONMENTS OF THE MID TO LATE CRETACEOUS SECTION IN THE GREAT SOUTH BASIN

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The Great South Basin is one of several frontier areas for hydrocarbon exploration in New Zealand and since 2005 has been the focus of renewed exploration interest from major petroleum companies. This study aims to identify and map sequence boundaries, characterise seismic facies and produce a series of updated paleogeographic maps to assist understanding of regional hydrocarbon potential.

Major sequence boundaries have been identified in seismic sections based on stratal terminations and mapped throughout the basin. Production of isochron maps and seismic facies characterisation aids understanding of sediment dispersal patterns and preparation of paleogeographic maps. Seismic facies are characterised based on seismic amplitude, reflection continuity and geometry of reflection packages. These facies are further calibrated with wells for age, gross lithology and paleobathymetric controls.

The Cretaceous succession can be divided into four seismic sequences. The lower two sequences are mainly fault bounded and were deposited in a syn-rift phase. The upper two sequences reflect a change in basin character from rifting to a post-rift thermal sag phase. Facies identified and depicted on paleogeographic maps include non-marine sand, non-marine to marginal marine source rocks, shoreface/marginal marine sand, shelf facies and

slope facies (mostly mudstones and siltstones). Most of the non-marine reservoir facies display variable seismic amplitudes, with chaotic to less continuous reflectors. Non-marine source facies, mainly coals and coaly mudstones, are characterised by high amplitude and low to moderately continuous reflectors. Often these units are amalgamated with non-marine sands. Shoreface/marginal marine sands are characterised by high amplitude and discontinuous reflectors. Shelf facies are mainly variable in amplitude, with continuous parallel reflectors that often onlap underlying strata. Slope facies are often low to moderate in amplitude and highly continuous parallel reflectors.

ORAL

SEISMICITY, VELOCITY STRUCTURE AND STRESS FROM BROADBAND SEISMIC RECORDINGS AFTER THE 4 SEPTEMBER 2010 M7.1 DARFIELD EARTHQUAKE

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We deployed broadband seismometers to record aftershocks of the 2010 M7.1 Darfield earthquake, and combined our data with that from permanent GeoNet and portable GNS Science stations. We jointly invert for three-dimensional P-wave and S-wave velocities and hypocentral locations, using data for 2840 aftershocks recorded at 36 temporary and permanent seismic stations. These relocations delineate eight individual faults active prior to the Feb. 22 earthquake. Two of these faults are in the Christchurch region, one of which corresponds to geodetically determined rupture plane of the Christchurch earthquake.

We estimate focal mechanisms and shear-wave splitting (SWS) parameters and we estimate the stress field orientation from inversions of focal mechanisms. The tectonic stress field has an average maximum horizontal compressive stress orientation of SHmax=116±18°, forming an angle with the average strike of the Greendale Fault of c. 25°. However, near the Greendale Fault, SHmax rotates so that along the middle section of the fault it is sub-parallel to the fault strike (93.6±13.1°, 100.8±11.5° and 100.8±12.6°)

indicating that the fault may be frictionally weak, in an Andersonian sense. SWS fast directions (ϕ) generally match nearby SHmax, suggesting stress-aligned micro-cracks. But ϕ estimates at two stations near known and inferred faults are sub-parallel to these faults and differ greatly from nearby stress orientations, indicating structure-dependent anisotropy.

Multi-component ambient noise cross correlation allows the basement resonance frequency in the Canterbury region of New Zealand to be determined based on the horizontal to vertical amplitude ratio (H/V ratio) of the first higher-mode Rayleigh waves. At periods of 1–3 s, the first higher-mode is evident on the radial–radial cross-correlation functions but is almost absent in the vertical-vertical cross-correlation functions. A one-dimensional regional velocity model incorporating a c. 1.5 km-thick sedimentary layer fits both the observed H/V ratio and Rayleigh wave group velocity.

ORAL

SEDDON EARTHQUAKE AFTERSHOCK STRUCTURAL INVESTIGATION

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The Southern Cook strait earthquake sequence near Seddon, containing the M=6.5, 21 July and M=6.6, 16 August 2013 earthquakes included the largest shallow earthquakes to strike the Wellington region since 1942. This earthquake offers a rare opportunity to take advantage of naturally occurring seismic sources to determine the structure of the subducting plate. We deployed a line of seismometers along the Kapiti (west) coast in the Wellington region and the Awatere Valley in the South Island. Including existing temporary and permanent stations, it stretches 250 km at a spacing of 10 km. We will use refracted and reflected arrivals from the earthquakes to image the subducting plate

interface and to refine the upper plate structure along its strike. This line will complement the cross-strike image of the subducting plate that we have determined from the SAHKE controlled source experiment. It will help to determine if the underplating seen in the SAHKE line continues throughout the region. Furthermore it may help us to determine the structure of the southern end of the Pacific Plate. The line will be out for at least three months to take advantage of the numerous earthquakes in the middle of the line but also to be able to record ones to the north and south that are likely to occur. The location of the line relatively close to the epicentres will also allow us to be able to provide more input to the aftershock source studies and studies of slow-slip, with possible attendant triggered earthquakes, occurring in the area. Finally, reduced detection threshold may help to determine if there is triggered microseismicity on the faults in the region.

POSTER

TEXTURAL, VOLATILE AND REDOX EVOLUTION OF PYROCLASTIC BASALT FROM THE 1963-67 ERUPTION OF SURTSEY, ICELAND

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Processes observed during the extremely well documented eruption of Surtsey, Iceland (1963-67), highlighted that magma-water interaction affects eruption dynamics. Although 2013 marks the 50th anniversary of this canonical eruption, many specific aspects of Surtseyan eruption dynamics, and magma-water interaction in general, remain only qualitatively described. For example, eruptions or phases thereof are often referred to as “phreatomagmatic”, without any discussion or identification of specific geometries and interactive volumes of the magma-water interaction involved. Moving toward a more quantitative understanding requires that all types of information: observational, textural, geochemical, and thermodynamic, be combined. In this work, we address the starting conditions of the magma involved in the eruption.

We present an analysis of Surtsey’s basalt that draws on several cooperative but different techniques. Firstly, we use major (EPMA) and trace

elements (LA-ICPMS) in olivine hosted melt inclusions to characterize the magma source conditions. Secondly, we use volatile (H₂O + CO₂ + S + F + Cl) concentrations in inclusions, olivine embayments, and matrix glasses to track multi-element degassing during magmatic ascent. Because degassing dynamics have feedback relationships with evolution of magma’s porous network, we investigate degassing signatures in light of 3-D x-ray computed microtomographic (μ-CT) imaging of the erupted tephra’s internal pore networks, and apply lattice-Boltzmann flow modelling to determine permeability of these pore networks. Finally, we determine inclusion, embayment and matrix glass redox states by applying a S-Kα peak shift routine (EPMA) to link with the degassing scenarios.

Together, the data presented here provide us with a solid platform on which to build more robust and quantitative models of shallow – to – emergent, subaqueous explosive volcanism.

POSTER

SIMULATION OF SEISMIC-WAVE PROPAGATION THROUGH THE LAKE TAHOE BASIN, CALIFORNIA-NEVADA: A SCENARIO APPROACH TO PROBABILISTIC SHAKING HAZARD

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Large normal faults, capable of producing greater than magnitude 7.0 earthquakes, are responsible for the formation of the Lake Tahoe basin in California and Nevada. Recent paleoseismic research indicates that at least four large ~M7 earthquakes have occurred during the Holocene on the West Tahoe-Dollar Point fault, with the most recent event (MRE) occurring on the Incline Village fault ~ 500 B.P.; it also appears that the Stateline–North Tahoe fault may have had synchronous ruptures with the West Tahoe–Dollar Point fault at roughly 7800 B.P. and 11,500 B.P. Uplift and erosion over the past several million years has resulted in a structural basin with thick sedimentary fill, which significantly enhances ground motions. Moreover, portions of the basin have undergone significant anthropogenic modifications such as the Tahoe Keyes, a complex of 1500 homes sited on reclaimed Upper Truckee

estuary material. Seventy-five shallow shear wave measurements made using the SeisOpt® ReMi™ method (© 2013 Optim) enable more accurate modelling of ground motions in the Tahoe basin, with a focus on the South Shore region. A 5.4-km-long deep ReMi™ array measured Vs to >1 km depths. Combining the Vs data with existing and new gravity measurements produced a 3-D model that served as the basis for numerical simulations of the likely earthquake scenarios. Ground motions modelled using Nevada ShakeZoning, a physics-based method incorporating geotechnical information and basin shape determined from geophysical methods, show unexpectedly strong shaking intensities and long durations within small sub-basins. Modelling indicates strong, sustained shaking in the basin, threatening several communities, and suggesting a possible trigger for the huge McKinney Bay submarine landslide. Annual rates of exceedance maps show the highest rates of exceedance are strongly correlated with basin shape.

ORAL

MULTIPHASE OROGENIC GOLD MINERALISATION IN THE REEFTON GOLDFIELD, NZ

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Multiple styles of mineralisation form structurally controlled orogenic gold deposits in the Reefton Goldfield, Westland. Syn-metamorphic mineralisation initiated along regional scale shear zones that lie subparallel to axial surfaces of upright macroscopic folds. Shearing was synchronous with the development of metamorphic sulphides, primarily arsenopyrite and pyrite, both of which have been variably rotated. Sideritic carbonate porphyroblasts are locally altered to chlorite and phengite in zones up to 100 m from the shears. Alteration halos extending in the host Greenland Group rocks are enriched in As, Fe, S and Si with minor Au. Early quartz veins are strongly deformed, locally folded and cut by black stylonitic veins containing sulphides and native gold. These early quartz veins were emplaced before the rocks were exhumed above the brittle-ductile transition. The quartz veins are overprinted by brittle shear zones and a generation of quartz-ankerite veins. Alteration associated with this phase of mineralization consists of the formation of stibnite, arsenopyrite, pyrite and significant Au

(>>1g/t). The mineralisation styles record a progression from late metamorphic ductile shearing through to post-metamorphic brittle fracturing, and are broadly distinguished by two different generations of arsenopyrite. Metamorphic arsenopyrite forms rhomb-shaped grains that are fringed by quartz-filled pressure shadows. Post-metamorphic arsenopyrite forms acicular prisms that are disseminated in wall rock and fault gouge. Stibnite is abundant as infill fractures, open space cavities and massive veins in the post-metamorphic mineralisation stage. Gold in the currently mined Globe-Progress shear is primarily associated with brittle deformation event, whereas gold in the Blackwater Birthday Reef is associated with early ductilely deformed quartz veins.

POSTER

FLUID FLOW IN FAULT ZONES FROM AN ACTIVE RIFT

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Faults can profoundly influence the flow of groundwater and hydrocarbons. The geometry and hydraulic properties of fault zones are investigated for Mesozoic greywacke basement and Miocene sandstone from ~37 km of tunnels in the southern Taupo Rift, New Zealand. Localised ground water inflows occur almost exclusively (≥~90%) within, and immediately adjacent to, fault zones. Fault zones in the contrasting lithologies comprise fault rock, small-scale faults, and fractures with thicknesses of 0.01 to ~110 m approximating power-law distributions and bulk permeabilities of 10⁻⁹-10⁻¹² m². Variability in fault zone structure results in a highly heterogeneous distribution of flow rates. Within basement ~80% of the flow rate occurs from fault zones ≥10 m wide, with ~30% of the total localised flow rate originating from a single fault zone (i.e. consistent with the golden fracture concept). No simple relationships are found between flow rates and either fault strike or hydraulic head, with ≤50% of fault zones in any given orientation flowing. A general positive

relationship does however exist between fault zone thickness and maximum flow rate. Higher flow rates from larger fault zones may arise because these structures have greater dimensions and are more likely (than smaller faults) to be connected to other faults in the system and the ground surface. Given the heterogeneous nature of fault zone structure, size and length, predicting the precise location of interconnected high permeability rock within fault zones will be challenging.

ORAL

**EOCENE NANNOFOSSIL BIOSTRATIGRAPHY OF
THE HAMPDEN BEACH & MID-WAIPARA
SECTIONS, CANTERBURY BASIN, NEW ZEALAND:
PRELIMINARY RESULTS**

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This study examines how calcareous nannofossils were affected by two periods of extreme global warmth during the Eocene: the Early Eocene Climatic Optimum (EECO, ~50 Ma) and the Middle Eocene Climatic Optimum (MECO, ~40 Ma). During these intervals, global sea-surface temperatures increased by almost 5°C above background, resulting in significant perturbations in planktonic biota. Species turnover and changes in geographic distribution of nannofossils across these intervals can be used to test proxy-based climate reconstructions for the SW Pacific. Here we report preliminary results based on nannofossils from two Canterbury Basin sections that span these intervals. The Hampden Beach section (North Otago coast) provides one of the most complete onshore records of the Paleocene to Upper Eocene in the southern Canterbury Basin. This sequence comprises ~208 m of claystone, siltstone and glauconitic sandstone of the Kurinui and Hampden Formations. Samples from the mid-Waipara River section (North Canterbury) were collected from ~66.5 m of Ashley Mudstone.

Preliminary analyses indicate that these sections span the lower to uppermost middle Eocene (Mangaorapan to Kaiatan), although part of the Porangan may be missing at mid-Waipara. Preservation of nannofossils in both sections is variable, especially within the basal sequences.

Overall, the nannofossils in the Hampden section are better preserved than at mid-Waipara, particularly through the Bortonian, which includes a diverse assemblage of holococcoliths that are rarely preserved in fossil assemblages. Key index fossils present in both sections include *Discoaster lodoensis*, *Nannotetrina* spp., *Reticulofenestra umbilicus*, and *Reticulofenestra reticulata*. *Discoaster sublodoensis*, which is very rare in New Zealand sections, occurs sporadically in the Hampden section and offers an opportunity to better calibrate the New Zealand timescale to the international timescale. Future work will focus on detailed analysis of assemblages in both sections to develop a chronostratigraphy integrated with other fossil groups and paleomagnetism and to observe assemblage changes linked to climate fluctuations.

POSTER

**CONJUGATE STRIKE-SLIP FAULTING DURING THE
2010-12 CANTERBURY EARTHQUAKE SEQUENCE:
BRITTLE VERSUS DUCTILE CONTROL?**

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When faults form under triaxial compressive stress ($s_1 > s_2 > s_3$) in the brittle upper crust or are resheared at optimal orientations, they tend to occupy planes containing the s_2 direction lying at 25-30° to s_1 ('Andersonian' faulting). This is because the coefficients of internal friction for intact rock and sliding friction are similar. The dihedral between conjugate fault sets (seen in map view when $s_v = s_2$ in an 'Andersonian' wrench regime) is then typically 50-60°. By contrast, ductile strike-slip shear zones form along vertical planes of maximum shear stress lying at $\pm 45^\circ$ to horizontal s_1 , giving orthogonal conjugate shear zones. The 2010-2012 Canterbury earthquake sequence ruptured a segmented polyplanar fault system, arising in part from structural inheritance. The major dextral strike-slip rupture along the Greendale Fault lies at c. 30° to the regional s_1 direction ($115 \pm 5^\circ$), and a conjugate set of inferred left-lateral aftershock lineaments trend 140-150°, defining a 55-65° dihedral between the conjugate sets. Much of the sequence thus results from frictional reactivation of near-optimal conjugate faults in the regional stress field. Intersection areas between the conjugate strike-slip sets (e.g. north of Sumner) are zones of intense aftershock activity from criss-cross faulting that impedes

throughgoing ruptures and induces high stress-drops. However, It is noteworthy that the dominant strikes of subvertical nodal planes for aftershocks are 070° (subparallel to the Hope Fault) and 160°, parallel to maximum shear stress planes, implying there may also be some ductile or kinematic control of higher level brittle fault structures. Other regions (e.g central Honshu, southern San Andreas fault) are characterised by orthogonal systems of conjugate strike-slip faults. Whether conjugate sets of strike-slip faults are 'Andersonian' or orthogonal may reflect fault maturity. Analysing such structural systems may give insights into how low-displacement strike-slip fault systems evolve into larger displacement structures.

ORAL

DEPOSIT CHARACTERISTICS AND EXPLOSIVE ERUPTION PROCESSES OF BLUE LAKE CRATER, TONGARIRO

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Blue Lake is a volcanic crater-lake situated at the northern end of the Tongariro Volcanic Complex. It is one of at least 11 vents that have been active on Tongariro since approximately 25 ka. The most recent eruption from Blue Lake Crater is thought to have occurred around 10 ka, although its volcanic geology and eruption history is one of the least documented of the young Tongariro vents. The stratigraphy, geomorphology and facies characteristics of the deposits within and proximal to Blue Lake Crater have been mapped and documented in a series of stratigraphic logs. We present a geological map of the eruptives that surround Blue Lake Crater, and establish the eruption history, eruption dynamics and emplacement processes.

The inner wall and rim of the 800 m-wide crater is comprised of a succession of agglutinated andesitic spatter deposits (which are often coherent and banded), and scoria lapilli to bomb and block fall deposits. The Rotopaunga massif, which rises ~130 m above the northern rim, provides the thickest section constructed of at least four, up to 8 m-thick welded agglutinate units, overlain by a succession of scoria and spatter beds that extend northwards on the outer flank towards the Te Maari vents. These fall beds display great variation in the degree of sorting, grain size and welding. A 5 m-thick lava flow extends over 500 m beyond the

eastern rim of Blue Lake Crater into the Mangahouhounui valley. Petrographic analysis shows that the deposits are plagioclase-dominant, two-pyroxene andesites with rare olivine found within the upper scoria fall units. The deposits of Blue Lake are consistent with those of intense Hawaiian-style fire-fountaining eruptions, a common style among the young Tongariro vents (e.g. Red Crater and North Crater).

ORAL

THE TECTONIC EVOLUTION OF THE GREY VALLEY TROUGH

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Towards the end of the 19th century, oil was found to be seeping out of the ground near Kotuku, North of lake Brunner. Since this discovery, petroleum companies have taken great interest in revealing the subsurface structure of the basin in order to discover economic oil reservoirs. Thanks to the large volume of pre-existing seismic and borehole data collected, we gain a detailed view of how a section of the Australian crust has responded to the transpressional plate boundary evolving directly adjacent to it. This study integrates surface mapping, borehole, seismic, and newly released aerial geophysics data using the 3D kinematic structural geology modelling software MOVE. The result provides insights into the full temporal record of the plate boundary since its inception, something that is poorly understood for the greater West Coast region. Specific findings suggest that early in the Alpine Fault's evolution, a much broader scale of serial partitioning (thrust/strike-slip segments 5-10 km long) developed, with deformation becoming localised to its present fault trace in the time since.

POSTER

CALCIUM CARBONATE: WORLD'S BEST BIOMINERAL?

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There are at least 277 known carbonate minerals, of which 158 are 'pure' carbonates and 65 are 'simple' carbonates, formed with just one or two cations and the carbonate anion. Simple carbonates form in five types of crystal structures: triclinic, monoclinic, orthorhombic, trigonal, and hexagonal. Cations range in atomic weight from 13.88 (Li) to 207.20 (Pb). Crystal ionic radius ranges from 75 pm (Fe) to 149 pm (Ba). These minerals are usually of moderate hardness (1.5-4.5 on the Moh's scale) and density (2.09 to 6.56 g/cm³). A detailed analysis of physical and thermodynamic properties of twelve simple carbonate minerals shows that the two principal polymorphs of CaCO₃ (aragonite and calcite) have a number of special characteristics which might explain their role as common and widespread biominerals.

ORAL

EARTH SCIENCE VIRTUAL FIELD TRIPS

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LEARNZ virtual field trips provide opportunities for students in New Zealand schools to engage with experts in remote locations. The resulting student experiences are framed within the New Zealand curriculum and recently have included sampling water in Ruapehu's crater lake, following faults deep underground, using geospatial tools to locate underground services, chipping fossils from a clay cliff in the Waipara Gorge and spotting petroleum installations across Taranaki from the air. Fulfilling the intention and aims of the curriculum's Planet Earth and beyond achievement objectives is a challenge for many teachers who lack experience and confidence in science generally, and have little knowledge of New Zealand geology specifically. LEARNZ field trips provide a means for enriching student learning in an area woefully underrepresented, while giving teachers an opportunity to do what they do best, to facilitate student inquiry. The LEARNZ field trip model is based on the premise that learning takes place

when critical thinking is combined with relevance. The critical analysis of background material, the relationships developed over time with experts and the powerful use of still and moving imagery allow for intellectual and emotional student engagement. This presentation will explore what a LEARNZ field trip looks like, how it is supported by its stakeholders and why it is now used in 80% of New Zealand schools.

ORAL

EVIDENCE FOR A MANTLE DISCONTINUITY BENEATH MT COOK BASED ON CRUSTAL STRUCTURE, GRAVITY ANOMALIES AND SEISMICITY

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Recent geophysical data from the central South Island outlines a sharp mantle – crust discontinuity with a SW-NE azimuth. We argue that the discontinuity is due to the interaction of the SW and NE verging Pacific and Australian lithospheres, with the "seam-zone" being directly beneath Mt Cook.

Since 2009, we have run a bore-hole seismograph array (SAMBA) in the central Southern Alps. Seismicity is distributed throughout the upper crust except within a region of inferred high fluid pressure between depths of 7-30 km. Deeper mantle earthquakes are located at depths exceeding 50 km. These mainly occur to the south of Mt Cook and have strike-slip and reverse focal mechanisms with steeply dipping fault planes. At 15-50 km we locate a vertically distributed zone of seismic tremor, although these locations are uncertain to ±15 km. The northern extent of the tremor zone terminates abruptly just north of Mt Cook.

To the south of Mt Cook crustal thickness increases yet mean elevation decreases, in defiance of the rules of local isostatic balance. A Bouguer and isostatic gravity low dominates south of Mt Cook and extends as far south as Wanaka. We attribute the deep gravity low, and crustal thickness-topographic variation, to a pull from below due to active mantle lithospheric thickening. P-wave

teleseismic delays also require mantle thickening directly beneath the zone of maximum crustal thickness.

Our tentative interpretation of all the above observations is that mantle lithospheres of both the Australian and Pacific Plates are colliding head-on beneath central South Island and thickening in a uniform manner. We suggest the leading edge of the Australian lithosphere extends north to beneath the Mt Cook region, and this is the reason for the contrasting seismicity patterns north and south of Mt Cook.

ORAL

DEEP CRUST AND MANTLE STRUCTURE BENEATH WELLINGTON

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In 2010-11 an active source seismic experiment (SAHKE) was carried out across the Wellington region. Both active and passive seismic methods were used to establish a model of the crustal structure and upper mantle structure beneath SAHKE (Henrys et al, 2013). We recorded 12 x 500 kg dynamite shots on ~ 1000 recorders placed at 100 m spacing from coast to coast. These data contain excellent returns from the subduction zone at two-way travel times of 7-15 s, but we also recorded coherent reflection energy down to 30 s two-way-travel-time on vertical recorders and 47 s on horizontal recorders. The deepest reflections define a westward 17 degree-dipping zone at ~ 100 km deep that is possibly the base of the subducted Pacific plate. The westward dip on this 100 km deep reflector matches that for the top of the plate.

The other deep reflection zone dips eastward across the shot gathers and is typically seen at two-way travel times of 18-25 s on the vertical phones. We also see the same event as a Vs arrival on horizontal phones at two-way travel times of 34-47s. When migrated these reflections define an east dipping reflector that is within the mantle of the overriding Australian plate, and the surface

projection of the reflector is ~ 80 km west of the Kapiti coast. i.e. roughly beneath a location ~ 20 km east of D'Urville Island. We suggest serpentine within the mantle as the cause of these reflections, which is consistent with the observation of the reflector producing a strong S-wave return. Further support for serpentine comes from the observation that when the reflector is projected to the surface it corresponds to the Taranaki Fault zone, where sporadic outcrops of serpentine have been mapped.

POSTER

USING FRAGILE GEOLOGIC FEATURES TO PLACE CONSTRAINTS ON LONG TERM SEISMIC HAZARD

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Marginally-stable rock outcrops and precariously-balanced rocks are collectively termed 'fragile geologic features' (FGFs) and have potential utility for seismic hazard assessment. Establishing the date at which the feature became fragile, usually resulting from irregular erosive wasting of the outcrop, and estimating the amount of seismic shaking necessary to induce its failure, indicates the minimum time elapsed since those shaking conditions were last attained. Key to FGF studies has been the development and ongoing improvements in accuracy of surface exposure dating of rock outcrops using cosmogenic nuclides such as ¹⁰Be. The most notable research effort so far on FGFs was for a proposed nuclear waste repository site in Yucca Mountain, Nevada, USA. Despite the cancellation of the Yucca Mountain project in 2008, there is continuing interest in using FGF studies to provide better constraints on seismic hazard models for engineering applications. A field-based review of previously studied and dated FGF sites in southern California is being undertaken under the auspices of the Southern California Earthquake Centre and is showing that there is a distribution of fragilities across the FGFs. In contrast, previous studies tended to highlight the most fragile FGFs. An emerging view is that constraints on long term seismic hazard should be based on the more representative fragilities observed, rather than relying on the most fragile features. Quartz-rich schist tors in the dry climate of central Otago are ideal for surface exposure dating and FGFs are

reasonably common there. FGF studies underway in central Otago, and also at paleo sea-stack sites in central California, are aimed at establishing a range for fragilities in order to provide defensible constraints on seismic hazard, and where possible compare these results to data from other methods, such as trenching and dating of earthquake fault-rupture events.

ORAL

PALEO GEOGRAPHY OF THE TARANAKI BASIN REGION DURING THE LATEST EOCENE TO EARLY MIOCENE AND IMPLICATIONS FOR THE “TOTAL DROWNING” OF ZEALANDIA

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Latest Eocene–earliest Miocene strata in the Taranaki Basin provide important new regional paleogeographic and tectonic constraints not available from onshore outcrops. Six paleogeographic maps of the Taranaki Basin and surrounding areas (~142,000 km²), have been produced utilising extensive well, seismic reflection, and outcrop data. These data record three broad periods of sedimentation in the eastern and southern Taranaki Basin region characterised by: variable transgression and initial deformation (c. 40–30 Ma), maximum transgression with moderate deformation (c. 30–21 Ma) and regression with accelerated deformation (<21 Ma). Local sedimentation patterns were influenced by reverse faulting which produced depocentres and topographic highs, particularly adjacent to the Taranaki Fault System. Reverse faulting commenced as early as c. 40 Ma and may signify the onset of incipient subduction beneath the North Island. In common with other parts of New Zealand the Taranaki Basin region reached maximum marine inundation in the Waitakian (c. 23 Ma). However, the deposition of thick clastic sediments in eastern parts of Taranaki Basin, as well as in other regions of central Zealandia, such as the East Coast and Murchison basins, suggests the presence of a significant non-marine hinterland supplying sediment to the basin throughout the Oligocene and Early Miocene, and is inconsistent with total Oligocene drowning of Zealandia.

ORAL

OVERVIEW OF THE TASMAN FRONTIER, OFFSHORE NW NEW ZEALAND

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The Tasman Frontier region is a vast submerged continental fragment of over 3,000,000 sq km between Australia, New Zealand and New Caledonia. It hosts a number of unexplored sedimentary basins, some of which may share a common geological origin with the Taranaki and Gippsland basins, where petroleum production is established. The region may also host important clues to regional and global paleoclimate, tectonics, and paleobiogeography. We present a status report on work that was started as a collaborative initiative between GNS Science, Geoscience Australia, Service Géologique de Nouvelle-Calédonie (SGNC-DIMENC), Agence de Développement Economique de la Nouvelle-Calédonie (ADECAL), and Institut français de recherche pour l'exploitation de la mer (IFREMER); but now involves a much broader group of scientists.

The Tasman Frontier seismic-reflection database is a compilation of 100,000 line km of digital seismic reflection data from the region that were able to be made publicly available, as at March 2012. Data can be obtained as GNS Science Report 2012/01, or freely copied from a colleague that already has it.

Since release of the database, three geophysical voyages have been scheduled in the next two years, and an IODP proposal has obtained favourable feedback. If we can obtain additional site-survey data, then this may become the first official NZ-led IODP leg ever. An overview of existing understanding and future plans will be presented.

ORAL

**APPROACHING GEOSCIENCES OF NEW ZEALAND
FROM THE CONTINUOUS GRAVITY
MEASUREMENT**

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Modern geodesy consists of three areas (positioning, Earth rotation, and gravity field) called as the three pillars of geodesy. In global, the accuracy of current measurement systems allows time variations to be observed in all three areas. In New Zealand, the GNSS networks (PositionNZ and GeoNet) and VLBI station (Warkworth 12-m) are contributing the positioning and Earth rotation areas for the global geodetic services (IGS and IVS). Unfortunately, New Zealand does not have the gravimeter that can provide time variations like Superconducting gravimeter and Absolute gravimeter. The gravity measurement is necessary for a scientific understanding of the Earth and it can provide a wealth of information about the shape of the earth, the position of the continents, as well as the water and mineral contents of the ground underneath our feet.

In this presentation, we insist that New Zealand must have a continuous gravity measurement point which can provide the reference gravity values and the time variations. New Zealand is located on the plate boundaries, is seismically active, subject to crustal deformation and volcanic activity. The continuous gravity data will provide knowledge of New Zealand tectonics, knowledge that will contribute to the prediction of natural disasters, risk assessment, new early warning system etc. Also, from point of view of the worldwide distribution, New Zealand is very important point. The continuous gravity data will contribute to some global studies, including polar motion, seismic normal modes, searches for inner-core and core modes, analyses of the free core nutation.

We will show the reason why we need the continuous gravity points, the expected scientific result, and the benefit for the society. Also, we will summarize the current situation of New Zealand gravity study and will introduce our proposing project of absolute gravity measurement in New Zealand.

ORAL

**THERMO-TECTONIC HISTORY OF SOUTHEAST
CHINA SINCE THE LATE MESOZOIC: INSIGHTS
FROM DETAILED THERMOCHRONOLOGICAL
STUDIES OF HONG KONG**

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Fission-track (FT) analyses on apatite and zircon from igneous rocks are used to establish the thermal history of Hong Kong since the late-Mesozoic magmatism associated with the Yanshanian Orogeny. These rocks form part of a tilted nested caldera complex, in which voluminous ignimbrites and their granitic roots are now exposed side by side. Crystallisation ages of these rocks range from 164 to 140 Ma, yet these Middle Jurassic to Early Cretaceous igneous suites yielded ZFT ages of 140 to 60 Ma. These findings show that zircons have been partially to fully reset, indicating post emplacement heating to temperatures of possibly up to 250 °C. U-Pb ages of detrital zircons from late-Early Cretaceous sediments demonstrate that the source was the proximal igneous rocks. The ZFT ages on these sedimentary sequences show the same heating event, hence the same thermal history, as the source rocks. However, sediments of Eocene age contain a range of detrital ZFT ages similar to that of the reset ages from the older sequences, suggesting that their source was the newly exhumed igneous rocks and Cretaceous sediments. Reset AFT ages of the igneous suites range from 83 to 22 Ma. Thermal modelling of these data revealed a 2-stage cooling / exhumation since about 80 Ma: a relatively rapid cooling between 80 and 60 Ma, followed by a slower cooling through to today. The data are interpreted as the result of the onset of post-magmatic arc collapse in southeast China after approximately 120 Ma, when significant amounts of sediments were eroded from the volcanic province. We link the rapid cooling to tectonic uplift and related erosion. This possibly signals the end of large-scale continental rifting and shifting of focus of extension prior to opening of the South China Sea.

POSTER

EVOLUTION OF THE EARLY CRETACEOUS LARGE SILICIC MAGMATIC SYSTEMS IN HONG KONG, SOUTHEAST CHINA RECORDED IN ZIRCON TRACE ELEMENT PATTERNS

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Four temporally distinct late-Mesozoic magmatic episodes have been identified in Hong Kong, with paired volcanic-plutonic assemblages that are now exposed side by side through faulting and uplift. The youngest of these systems generated at least one 'super-sized' ignimbrite eruption at 141-140 Ma. We use ion probe trace element analyses on zircons from 10 samples, representing 5 eruptive units and 5 sub-volcanic plutons of this magmatic episode, to track its evolution. Cathodoluminescence (CL) imagery of zircons shows that each unit yields distinct zircon populations showing varying growth patterns and zonings, suggesting a complex and diverse evolution history. Trace element concentrations, combined with comparison of core-rim variations, in zircons from the oldest 141 Ma trachydacite lava, show that the zircon cores were inherited from a relatively more-evolved melt, and then grew their rims in a less-evolved, hotter magma. Subsequent eruptions of rhyolitic lava and ignimbrites, including that of the "super-sized" High Island eruption, display similar variations in trace element concentrations in zircons, which are distinct from that of the trachydacite lava. The post-High Island rhyolite lava yields zircons that were crystallised from slightly less-evolved material, suggesting possible rejuvenation of the magmatic system. Two sub-groups of the sub-volcanic plutons can be identified based on the signatures of trace element in zircon. Zircons from the 'granitic' subgroup defines a tight fractionation trend in Eu/Eu^* versus Hf concentration that is characteristically different from that of the volcanic units, and corresponding to feldspar fractionation during melt evolution. On the contrary, the 'quartz monzonitic' sub-groups yield zircons with more scattered Eu/Eu^* values and trace element concentrations, but are generally overlapping with that of the volcanic units. This possibly implies a closer genetic linkage of the eruptive units with the 'quartz monzonitic' plutons.

POSTER

DEVELOPING EDUCATION AND OUTREACH AT GNS SCIENCE

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GNS Science is unique amongst the CRIs in employing a full time teacher/educator to communicate with the public and engage with schools. The purpose of this outreach programme is to promote greater understanding and appreciation of New Zealand geoscience. Apart from the publication of popular book titles on New Zealand geology, GNS Science outreach includes presentations to schools and community groups, running workshops and field trips, advising museums, creating web based NZ earth science information and producing videos.

A survey of earth science teachers was conducted in 2008 to gain feedback about their needs and preferences for teaching resources and support. A repeat survey in 2013 showed a shift in awareness and use of the resources available, as well as useful directions for further development. In this presentation, Julian Thomson will illustrate some examples of his outreach activities and thoughts about "where to from here?"

ORAL

DRILLING INDUCED FRACTURES IN COAL: STRESS AND CLEAT AZIMUTHS, AND PERMEABILITY

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It is useful to obtain cleat azimuths from exploration drilling for future CSG production, and gas drainage prior to underground coal production. It is also useful to know the angle between maximum horizontal stress and (face) cleat, as this can influence permeability. Where face cleat is at high angles to maximum horizontal stress, coal seams can be expected to have relatively low permeability. In contrast, where face cleat is at low angles to maximum horizontal stress, coal seams can be expected to have relatively high permeability. The orientation and dip of structures (sedimentary and tectonic) can generally be obtained from an image log (resistivity or acoustic) as the trace of the structure on a circular borehole produces a sinusoidal curve; the minima records dip direction and the height allows measurement of dip. In vertical drill-holes the apparent dip of

cleat is generally vertical, there is no sinusoidal trace indicating continuity of the structure around the borehole, and it is not possible to correlate images of vertical multiple cleats. Hence cleat azimuth in these circumstances cannot be determined from a scanner image.

The combination of the presence of drilling induced petal fractures in coal core from a vertical drill-hole, and the availability of breakout images in a scanner log, permit the determination of cleat azimuth, and the angle between present-day maximum horizontal stress and cleat azimuths. Breakout is perpendicular to the direction of maximum principal horizontal stress. The strike of petal fractures is parallel to maximum horizontal stress. The basis of the method of determination is that the azimuth of apices of the intersection of curvi-planar drilling induced petal (and related) fractures on the core perimeter is the same as the azimuth of breakout on the bore-wall (and scanner image).

ORAL

NEW GEOLOGICAL MAP OF TONGARIRO NATIONAL PARK –AN UPDATE

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Detailed mapping of Tongariro National Park is well underway and we here present the draft map. This joint project involving DoC, VUW and GNS is to produce a 1:50,000 scale geological map in early 2015. Mapping units have primarily been constructed using geomorphology, with compilation and amalgamation of published and unpublished data. We are using ArcMap 10[®] to visualise and categorise more than 1350 XRF data for lavas, both in map space and in X-Y multivariate parameter space, which allows us to better-define geochemical fields. In some cases individual flows can be correlated, but typically units are amalgamated into (informal) geochemical groups, formations or members. Many samples have been evaluated and reassigned to units different from those previously mapped. We are also using ArcMap to construct digital models of ancient terrain for ice-flow modelling by “removing”

younger lava flows from contour data and re-gridding.

The new mapping shows that about 1/3 of Mt Ruapehu comprises glacial deposits. We construct a detailed and precise stratigraphy for the volcanoes from new Ar-Ar dates on lavas and new ³He cosmogenic dating of pyroxenes from moraine boulders. We correlate dated lavas and glacial deposits on the mountain with a well-established ringplain stratigraphy.

We recognise many cases invoking the interaction between lava and ice, especially on Mount Ruapehu, including lava quench-textures and flow morphology. The model suggests that during glacial stages, growth of volcanic edifices is not laminar, and is instead dominated by radial lava flows emplaced adjacent to major glacial valleys. These flows stack up along ridge tops, commonly moraines, and become isolated once the ice retreats, as recorded at Mount Rainier, Washington State, USA.

POSTER

IODP EXPEDITIONS 343 AND 343T, THE JAPAN TRENCH RAPID DRILLING PROJECT (J-FAST) YIELD NEW INSIGHTS INTO THE MECHANICS AND STRUCTURE OF SUBDUCTION THRUST FAULTS

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The $M_w=9$ 2011 Tohoku-oki earthquake ruptured to the Japan Trench, with very large coseismic slip occurring on the shallow part of the décollement. A significant consequence of the large slip was generation of a devastating tsunami. To better understand the controls on rupture propagation and slip, the plate boundary décollement, and over-riding and subducting plate materials near the trench were investigated by downhole logging and coring, and a temperature observatory was installed, during Integrated Ocean Drilling Project Expeditions 343 and 343T (the J-FAST project) from May-July 2011.

Analysis of samples and data arising from these expeditions has already yielded new insights into subduction thrust mechanics. In particular, the very smectite-rich shallow décollement materials are demonstrated experimentally, and by the very small temperature anomaly generated during slip,

to be extremely frictionally weak ($m \sim 0.05-1.0$). They could also have experienced thermal pressurisation resulting in additional coseismic weakening. These properties allowed an energetic rupture that had initiated deeper on the subduction thrust to accomplish very large slip in the surface during a near total stress drop earthquake!

Examination of the structure of the décollement materials reveals a range of fabrics exhibiting evidence shear was localised in zones ranging from 5 m to $\ll 1$ mm thickness. The range of fabrics are tentatively interpreted to have developed at a range of strain rates, from creep to seismic slip.

I will discuss these overarching scientific findings, and outline how NZ-based research is helping to characterise the structure of the wedge, décollement, and subducting plate. This research used samples provided by the Integrated Ocean Drilling Program (IODP). Additional funding was provided by the Australian-New Zealand IODP Consortium (ANZIC).

ORAL

PROCESSES RESPONSIBLE FOR ORBICULAR GRANITOID FORMATION IN THE BONNEY PLUTON, ANTARCTICA

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Orbicular granitoids are geological oddities, characterized by orbs with a peculiar texture that typically consists of concentric shells of felsic and mafic minerals dominated by the radial and tangential growth of elongate crystals surrounding a core of variable nature. Within the Bonney Pluton, southern Victoria Land, Antarctica, a diverse range of spectacular outcrops of orbicular granite occur, and the study of these granitoids has provided a unique insight into the processes responsible for orbicule formation, and the processes that operate within late-stage magmas. The diversity of orbicule types found in the Bonney Pluton is attributed to the dynamic and complex interplay of magmatic processes operating within the pockets of melt where the orbicules formed. Petrographical and geochemical evidence indicate that the orbicules formed in small pockets of H₂O-rich silicate melt that was extracted from the

crystallizing and fractionating Bonney Pluton magma and concentrated along the pluton margins. A superheating event caused by mafic magma injection removed most nuclei from the melt, and lead to a delay in crystallization and subsequently undercooling of the melt. These conditions favoured rapid and dendritic crystal growth around the few remaining nuclei in the melt (i.e. phenocrysts, xenoliths, mafic enclaves, broken orbicules). The alternation between hornblende-rich and plagioclase-rich 'shells' were caused by fluctuations in the composition, H₂O-content, temperature and P_{H_2O} at the crystallizing orbicule boundary layer in response to pulses in the movement of magma, competition between crystallizing phases, episodic vesiculation, degassing and/or second boiling.

POSTER

PETLAB DATABASE 2013 & BEYOND

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PETLAB (<http://pet.gns.cri.nz>) is an online nationally significant database that contains locations, descriptions and/or analyses of 183,000 rock and mineral samples collected by government, university and industry geologists. PETLAB is operated by GNS Science with data also contributed by Auckland, Waikato, Massey, Victoria, Canterbury, and Otago universities. The majority of the catalogued samples in PETLAB are from New Zealand and its EEZ, but Australia and Antarctica are also well represented.

Over the years there have been numerous large datasets added to PETLAB including Geochron database, Geophysics Division rock properties, detrital zircon, GANOVEX Antarctic, limestone, sedimentological lab, heavy mineral and DEVORA (Determining Volcanic Risk in Auckland) samples. There have also been numerous incremental interface improvements including NZTopo50 and QMAP layers, irregular polygon searches on the webmap and hotlinking to GIS applications. Most recently we have added the ability to search by formal hierarchical stratigraphic name, achieved by connecting PETLAB to the New Zealand stratigraphic lexicon (STRATLEX) database.

However the current PETLAB data licencing model, user interface, and data input and output methods have remained essentially unchanged since PETLAB

went live on the web in 2004. Furthermore the list of 63 rock and mineral names used in PETLAB were introduced by John Reed for punched cards in the early 1960s. To those who use it regularly, PETLAB operates efficiently enough and is an extremely useful research tool. But now is an appropriate time to take stock of all these aspects, freshen up the interface, improve functionality and attract more users. To this end we have developed and are circulating a questionnaire that will help us address these issues and prioritise improvements.

At the poster display people will be able to have hands-on experience using PETLAB, as well as pick up and turn in questionnaires. We welcome any comments.

POSTER

INTEGRATING MATERIAL RESPONSE AND GEOMORPHIC PROCESSES USING NUMERICAL MODELLING

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The western Southern Alps of New Zealand are shaped by high rates of relative motion across the Australian/Pacific plate boundary in conjunction with a dynamic climatic regime and consequent rapid rates of landscape evolution. The resulting system is tightly linked and it is difficult to model one component without the other. To understand the dynamics of the system we use a formulation, the Failure Earth Response Model (FERM), which incorporates the response to tectonic and geomorphic forcings within a single framework. FERM relies on two basic assumptions about the 3D stress state and material rheology at the Earth's surface: (1) Both tectonic (e.g., faulting) and geomorphic (e.g., fluvial or glacial incision, landsliding) material displacement occur when local forces overcome local resistance, and (2) Large displacements, whether tectonic or geomorphic in origin, change Earth material properties resulting in a long term strain memory imposed onto the topography. FERM enables us to determine for each point at the surface the stress state generated by far field tectonic processes, topography and surface processes acting upon that point. It also allows consideration of contributions

from other processes including seismic accelerations and fault damage.

Here we focus on the FERM description of potential for landsliding in a region of high seismic activity, adjacent to the Alpine Fault. Located just west of the Alpine Fault with a catchment that extends across the Alpine Fault and ~10 km back into the high mountains of the Southern Alps, Lake Moeraki contains a sedimentary record of Alpine Fault earthquakes and landscape processes. We model the Moeraki catchment to provide constraints on landslide generation from different relief regions, rock types and following seismic perturbations.

ORAL

GEOTECHNICAL INVESTIGATIONS FOR CHRISTCHURCH INFRASTRUCTURE REBUILD

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The Stronger Christchurch Infrastructure Rebuild Team (SCIRT) is responsible for the rebuild of Christchurch horizontal infrastructure, bridges and council owned retaining walls. The geotechnical investigations team has undertaken approximately 800 intrusive investigations to delineate the parameters for the design engineers to develop the robust designs needed in the seismically active environment that is now Christchurch. Typical case studies representing the horizontal infrastructure, bridges and retaining wall investigations dispel the premise of layer cake geology and the importance of site specific investigations for robust design.

Investigations for the Bridge Street bridge in New Brighton were undertaken to determine the depth to gravel with the strength necessary to support the jacking of the bridge back to plumb and provide support for the bridge during future seismic events. Multiple boreholes revealed the changing environment of the Riccarton Gravel Formation with non clast supported gravel and sand horizons. The boreholes also indicated a Springston Formation gravel unit with a flowing artesian pressure within the Christchurch Formation.

Mt Pleasant Road required retaining wall repairs/replacement. Logistics for the investigations were hampered due to access limitations to private land. Initially two boreholes identified the depth to rock. Geophysical methods identified that rock was deeper than expected and

another two boreholes were drilled to groundtruth the depth to rock.

The geotechnical site specific investigations methods have proven and support the necessity for geological investigation techniques which include the paring of different methodologies to provide a robust characterisation of the site. As SCIRT is tasked with the implementation of resilient infrastructure by 2016 the geotechnical investigations provide the essential groundtruthing for the cost effective, time efficient rebuild.

ORAL

GEOSCIENCE LEARNING AND CONCEPTUAL RECONSTRUCTION THEORY

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This presentation briefly describes the science education domain of conceptual reconstruction (Duit & Treagust, 2012) and how it might apply to geological thinking. Conceptual reconstruction (CR) in this context refers to how we learn and conceptualise concepts such as plate tectonics, the geological time scale, 3D modelling of the subsurface and biological evolution. Conceptual change involves how concepts can be moved (not exchanged) from ignorance and naivety to sophistication. No one enters a new sphere of learning without carrying the baggage of pre instructional knowledge in all its many forms. Initiating successful scientific conceptual change follows a complex pathway of historical, social, developmental and motivational interactions between institutions and individuals. For example, rather than providing factual information for regurgitation, one goal of an educational and accompanying assessment programme might be to move an immature concept of the 'water cycle' for example, to a more 'scientific' conceptual status. The ultimate goal of conceptual reconstruction theory, from a multi perspective position, is to find ways in which learners can best learn science, and in particular, geoscience. Conceptual reconstruction also has application to institutional management of change. Examples of conceptual change within a geological context are provided (Cheek, 2010; Francek, 2013) with a summary of possible ways in which effecting conceptual change might be addressed.

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ORAL

SEISMOMETERS FOR NEW ZEALAND SCHOOLS

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Earthquakes form some of the more dramatic expressions of the dynamics of our planet. The sudden release of stress built up slowly by tectonic or volcanic processes often has far-reaching consequences, and can be measured (in classrooms) around the world. This is one reason why designing and building seismometers has been a popular school activity, and why different versions of "seismometer in schools" projects thrive in the USA, Australia, and Europe. It is aim to set up a New Zealand chapter of seismometers in schools. We present a cheap, robust and easy-to-build seismometer to measure seismic displacements in the vertical direction called the TC1. Its components are easy to obtain and assemble, yet the resulting instrument is accurate enough to record earthquakes from around the globe. The part list and building instructions of the TC1 seismometer are freely available online. Assembling the system naturally involves students in a number of concepts in physics and engineering, while upon completion seismic recordings trigger discussions about the dynamics and internal structure of the Earth. The discussions are fostered by Service Learning, and shared in the network of TC1s.

ORAL

**LIQUEFACTION (MINOR) GENERATED BY THE M_w
6.5 JULY 21, 2013, COOK STRAIT AND M_w 6.6
AUGUST 16, 2013, LAKE GRASSMERE
EARTHQUAKES, NEW ZEALAND: A
RECONNAISSANCE REPORT**

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The 2010-2011 Canterbury earthquakes generated wide-spread liquefaction in low-lying, Holocene coastal, estuarine and riverine settings; and heightened awareness throughout New Zealand, possibly globally, and certainly within the insurance sector, of the ruinous impacts of liquefaction. The recent Cook Strait and Lake Grassmere earthquakes also produced strong ground shaking in low-lying, Holocene coastal, estuarine and riverine settings. However, the extent of liquefaction generated in central New Zealand by these two earthquakes was substantially less than that generated in Canterbury by similarly sized, and close, earthquakes in the Canterbury sequence. Lake Grassmere is the most proximal site to show evidence of liquefaction during the Cook Strait and Lake Grassmere earthquakes. A peak horizontal ground acceleration (PGA) of 0.75 g was recorded within 10 km of Lake Grassmere during the Lake Grassmere event, but only a few sub-aqueous sand boils were observed near the eastern shore of the lake. Along the Opawa River, near its confluence with the Wairau River, a 300 m length of river bank along the inside of a meander bend experienced liquefaction and lateral spreading during the Lake Grassmere earthquake, but not the Cook Strait event. The total amount of horizontal spreading was up to several decimetres, with most of this occurring within 10-20 m from the river bank. Liquefaction ejecta was composed predominantly of fine sand, but in some instances, medium sand dominated. Silt drapes capping sand boils were only rarely present. A PGA of 0.14 g was recorded within ~9 km from the site; the same station recorded a PGA of 0.07 g during the Cook Strait event. More distant from the earthquakes, reclaimed land of a port facility in Wellington Harbour experience ground damage with evidence of liquefaction in both earthquakes. Recorded PGAs within 1 km of the site were 0.1-0.2 g in both events.

POSTER

**EXAMINING CRYSTAL FABRICS IN FINE-GRAINED
ICE: CRYO-EBSD AND SHEAR DEFORMATION
EXPERIMENTS**

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Over the past few years, cryogenic electron backscatter diffraction (Cryo-EBSD) has been increasingly used to examine microstructures in both natural and experimentally deformed ice samples on a micron-scale. Experiments that investigate grain size-sensitive behavior require working on fine-grained ice. These samples present a number of experimental challenges. Issues that present particular difficulties include stable mounting of ice samples, transport of mounted samples and producing a planar, frost-free and damage-free surface. Recent work at the new Otago Ice Deformation Lab has led to the development of a number of experimental methods that help overcome these challenges and enable routine EBSD analysis of fine-grained ice. A brief outline of these experimental methods and some EBSD results will be presented. Shear deformation experiments on polycrystalline ice are being developed in order to further explore the relationships between deformation and processes of recrystallization. Self-contained, refrigerated (via cooled silicon oil) deformation units fitted with digital controllers are being designed and tested for deformation experiments on polycrystalline ice. Methods of analysis, from time-lapse photography to random-point tracking, are being explored for monitoring strain in real time. Longer-term objectives involve using ultra-sonic transducers to monitor the change in the acoustic anisotropy of ice during deformation. Under shear strain, polycrystalline ice can develop a c-axis preferred crystal orientation fabric. It has been observed that these fabrics develop as a result of flow in grounded terrestrial ice. These experiments will be designed with the objective of quantifying the relationship between deformation fabrics and englacial seismic reflectivity observed in thick grounded ice sheets.

ORAL

HIGH-RESOLUTION BULK PYROLYSIS OF MID CRETACEOUS TO EOCENE ROCKS IN THE RERE-1 WELL, EAST COAST BASIN: EVALUATION OF SOURCE ROCK POTENTIAL AND MATURITY

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Despite the high prospectivity of the East Coast Basin, no commercial discoveries have yet been made. The Waipawa (Late Paleocene) and Whangai (Campanian–Paleocene) formations remain the most prospective source rocks, but older Cretaceous rocks could also have contributed hydrocarbons to the numerous seeps and stains documented throughout the region. This study seeks to test this hypothesis for the Gisborne area by providing a high-resolution evaluation of source rock potential and maturity for mid Cretaceous to Early Eocene rocks in the Rere-1 exploration well. Bulk pyrolysis measurements were made of 215 washed cuttings with a 3–15 m sampling interval from 1959 to 4239 m well depth. The basal units of the Wanstead Formation (Eocene) are thermally immature, contain Type III and IV kerogen and have fair potential for gas generation only. The Waipawa Formation was not distinguished in bulk samples. The Whangai Formation is thermally immature to early mature and has fair to good potential for generating oil and gas. The Karekare Formation (Albian–Santonian) has likely entered the oil window. It contains Type III and IV kerogen and has poor to fair potential to generate gas only. This formation is highly homogeneous at the scale of 3–15 m and lacks distinct intervals with more favourable generative potential. These results indicate that none of the formations investigated in Rere-1 are likely to have contributed significantly to known oil seeps and stains in the vicinity of the well. These determinations were made with consideration of the effects of organic-based, drill mud additive that has contaminated all of the Rere-1 sample cuttings. On-going investigations of each formation are being conducted to assess the origin of the organic matter, be it terrestrial and/or marine.

ORAL

INTERTIDAL FORAMINIFERA OF THE AVON-HEATHCOTE ESTUARY; RESPONSE TO COSEISMIC DEFORMATION AND POTENTIAL TO RECORD LOCAL HISTORIC EVENTS

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The Avon-Heathcote Estuary, located in Christchurch, New Zealand, experienced coseismic deformation as a result of the February 22nd 2011 earthquake in Christchurch. This is reflected in subsidence in northern parts and uplift in the south, in addition to sand volcanoes which forced up sediment throughout the estuary floor altering estuary bed height and tidal flow. This first part of this research project aims to quantify the change in modern foraminifera distribution caused by the coseismic deformation from the February 22nd 2011 earthquake by analysis of faunas immediately post deformation and 2 years post deformation with a comparison to earlier pre 2011 foraminifera distributions. Modern transect data show foraminiferal distributions similar to those of current New Zealand models for intertidal and salt marsh faunas. When February 2013 faunas are compared to June 2011 faunas foraminiferal zones have shifted landward or seaward as predicted according to uplift or subsidence. A distinct feature of June 2011 faunas is the occurrence of reworked prehistoric marine species in some samples that have been introduced by liquefaction processes. The second stage of this project, yet to be initiated, will collect a sediment core and the modern distribution used to establish foraminiferal history in the Avon-Heathcote Estuary. Foraminifera are sensitive to tidal height and salinity and they may record past seismic deformation. Sampling the core for foraminifera, grainsize, trace elements and carbon material (or pollen or caesium) will help to build a story of estuary development as well as past coseismic deformation events.

POSTER

CHRISTCHURCH FIELD DATA FOR ROCKFALL MODEL CALIBRATION

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The Canterbury earthquakes of 2012-2011 triggered devastating rockfalls in the Port Hills in Christchurch, over 8000 boulders resulted in fatalities and severe building damage. Detailed and defensible rockfall hazard analysis is needed to guide planning decisions in response to these rockfall events rockfall modelling is commonly used for this. Calibrating a rockfall model requires a robust data set of past rockfall events, including deposit location and size, in addition to dynamic information such as rock jump heights and velocities. Such information is often obtained from expensive rock rolling studies; however the dynamics of an event can be estimated from the runout terrain and impact scars.

In this study a 3D rigid-body rockfall model was calibrated using mapped boulder sizes and shapes at two sites, and velocity estimates obtained from impact scars of individual trajectories using a high resolution post-rockfall digital terrain model. The impact scar locations, length and depth of penetration into the loess soil cover were mapped. Two methods were used to estimate boulder velocities. The first crudely estimates the velocity based on the vertical free fall potential between the rockfall shadow line and the terrain surface, and a velocity correction factor to account for friction. The second assumes a parabolic trajectory between the impact scars giving an indication of both jump height and velocity.

Maximum runout distances produced a shadow angle of 23° in the areas mapped. The first method suggests velocities can reach up to ~26 m s⁻¹ and maxima concentrate in gullies and steep terrain. On average the distance between impact scars was 23 m, from which jump heights up to 4 m are estimated. While a first calibration of the rockfall model was possible by matching simulated to mapped deposit locations, many results initially showed unrealistic velocities and jump heights. The calibration has been refined using additional dynamic data to ensure a defensible rockfall hazard analysis.

ORAL

LARGE SLOW SLIP EVENTS AT THE HIKURANGI MARGIN IN 2013—DID SLOW SLIP TRIGGER THE COOK STRAIT EARTHQUAKE SEQUENCE?

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The Hikurangi margin was the site of 3 large slow slip events (SSEs) during the 2013 period. These include: (1) a recurrence of the deep (30-50 km depth) long-term Kapiti SSE that began in January 2013, (2) a large, shallow (Mw 6.8, <15 km depth) SSE on the central Hikurangi subduction thrust beneath Hawke Bay in February 2013, and (3) a large, shallow (Mw 6.6, <12 km depth) SSE offshore Gisborne. At the time of submission of this abstract, the Kapiti SSE is still ongoing, and we present evidence that the July/August 2013 Cook Strait earthquake sequence may have been promoted by stress changes from the ongoing Kapiti SSE. Previous Kapiti SSEs occurred in 2003 and 2008, confirming a 5 year recurrence interval for these SSEs. The February SSE at the central Hikurangi margin is the largest SSE observed to date on the portion of the subduction thrust beneath Hawke Bay, involving 1.5-2 cm of horizontal displacement of cGPS sites, and it is among the largest shallow (<15 km depth) SSEs ever observed on Earth. It was also accompanied by a swarm of earthquakes in the Hawkes Bay region. Most of the slip beneath Hawke Bay occurred within a 2 week period, but continued steady slip north of the main SSE region is ongoing (as of September 2013). In July this year, the shallow SSE offshore Gisborne occurred in an area where four Ocean Bottom Pressure recorders are currently deployed by Tohoku University to capture vertical seafloor deformation in Hikurangi SSEs. A more extensive deployment of US and Japanese Ocean Bottom Seismometers and seafloor pressure recorders is planned offshore Gisborne for early next year. These 3 SSEs further demonstrate the remarkable diversity of slow slip behavior at the Hikurangi margin, particularly in terms of recurrence, depths, duration, and magnitudes.

ORAL

MODELLING WATER WAVE IMPACT IN LAKE TAUPO BY WAIHI LANDSLIDES

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Over the past 230 years the Waihi Fault scarp at the southern end of Lake Taupo has been the source of at least three major landslides, e.g., those in 1780, 1846 and 1910. The 1846 landslide, killing around 63 people, is probably one of the most devastating landslides in the recorded history of New Zealand.

It is known from historical accounts that both the 1846 and 1910 landslides entered into Waihi Bay, causing wide-spread water disturbances in Lake Taupo. The 1910 landslide was reported to have initiated a tsunami up to 3 meters high and even to have swept to the opposite shore of the lake.

In this study, we will couple a wave propagation and runup model with a variety of wave generation approaches for Waihi mass failure scenarios similar to that of the 1910 landslide. The landslide-generated water waves in Lake Taupo will be simulated numerically and the pattern of wave evolution and impact will be analysed and compared to the available historical records. This investigation will help to understand the pattern and scope of the potential impact of waves in Lake Taupo caused by Waihi landslides, and will also provide a quantitative basis for hazard mitigation of similar events in Lake Taupo.

POSTER

CONSTRAINTS ON THE EROSION AND UPLIFT HISTORY OF THE SOUTHERN LAKES FROM APATITE AND ZIRCON FISSION-TRACK AGES

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Apatite and zircon fission-track (FT) ages have been used extensively throughout South Island to constrain the Cenozoic vertical kinematics of the Pacific plate (Tippet and Kamp, 1993). These studies show that crustal shortening as displacement on the Alpine Fault largely controls rock uplift in the Central Alps. However, this pattern breaks down around the Southern Lakes, where the width of the high exhumation zone

increases and discrepancies exist between thermochronological and geological estimates of unroofing. This study focuses on the uplift history of the Rakaia terrane in the region of Lakes Wanaka, Hawea and Wakatipu, an area where these discrepancies are most apparent.

Here we present new apatite and zircon fission-track ages for 21 samples from the Haast schist around the Southern Lakes to further constrain the Cenozoic vertical kinematics. Ages in this study were calculated using the external detector method, but initial age calculations established that in the case of very low uranium content in sample grains, this method may produce artificially young FT ages. We believe this may be the cause of the large number of zero apatite ages previously produced (Tippet and Kamp, 1993) for samples around Lake Wanaka that do not match geological observations (e.g. the Pisa Range and Matukituki Valley). In order to investigate such artificially young ages, we develop a method utilizing LA-ICP-MS to re-calculate AFT ages in low uranium samples and re-examine the exhumation history of the Southern Lakes. Some of these new ages have led to a better understanding and appreciation of the role of faulting in accommodating crustal shortening.

Reference

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POSTER

SEDIMENTARY PHOSPHOROUS RELEASE IN TE ROTO O WAIREWA/LAKE FORSYTH

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Te Roto o Wairewa/Lake Forsyth is a small, hyper-eutrophic, coastal lake on the south side of Banks Peninsula in Canterbury. Blooms of nitrogen-fixing cyanobacteria occur regularly in summer, and it is suspected that dissolved phosphorous (P) availability may be a key factor in bloom development. Analysis of dissolved and particulate P loads delivered to the lake via tributaries during different flow regimes confirmed that most P enters in particulate form, with flood events playing a major role in delivering particulate P to the lake. The Okuti and Okana Rivers provide the majority of particulate P input to the lake. However, these external loads of P cannot account

for the magnitude of observed fluctuations in P concentrations in the lake water column. We hypothesize that the release of P sequestered in near-surface lake sediments can both explain these fluctuations and, under the right conditions, trigger and sustain rapid increases in primary productivity leading to bloom formation. An understanding of the mechanisms that release dissolved P into the water column, and the factors that favour such mechanisms, is therefore critical to the formulation of good management responses to eutrophication of this lake. Sequential extraction of lake sediments indicates that there is a large reservoir of P that could be released under the variable pH and DO conditions observed in lake water; a finding supported by pore water analysis. Seasonal changes in the speciation and core depth distribution of sedimentary and porewater P were observed, and changes in the near-surface sedimentary and porewater P were also apparent during bloom periods. Kinetic EDTA extractions and geochemical modelling are being used to confirm the phases binding P to the sediment, and to quantify the effects of changes in porewater chemistry on this binding process.

ORAL

GRAIN SIZE ANALYSIS OF CATACLASITES WITHIN THE OTAGO SCHIST

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The mechanisms that occur during earthquakes and how these are represented in the fault rocks are not well understood. As cataclastic fault rock is formed, there is an evolution of particle size distribution and formation of differing particle shapes. Particle size reduction mechanisms can be used to predict what occurs during cataclasis and the processes behind particle reduction, which may be directly related to the energy that is released within a fault zone. While there have been numerous studies investigating particle size distribution within fault zones, we examine the relationship of grain size and shape with the mechanisms during cataclasis from a brittle fault zone at Reid Stream, southeast of Dunedin. Using high-resolution imaging capabilities on a Scanning Electron Microscope, we produced particle maps that distinguish grains according to their size and shape. These maps were constructed for the main cataclasite components: quartz + feldspar and mica. Preliminary results reveal that the particle

size distribution falls within the range proposed by Blenkinsop (1991); however, future work is intended to compare the particle distribution with the mechanism of deformation and thus assess the energy released during a fault rupture.

References

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ORAL

GLACIER CRYOCONITE GEOCHEMISTRY AND ITS EFFECT ON INTERRED BIOTA

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Cryoconites are small, but numerous, aquatic aquaria enclosed in the surface ice of glaciers, which collectively make up an important part of the liquid water and biomass of inland Antarctica. In Victoria Land, they are typified by cylindrical holes, less than 1m diameter and approximately 0.5m cm deep, in the glacier surface and are formed when solar-heated surface sediment melts down into the ice. They may freeze solid in winter but partially melt during summer while retaining a 10-20cm ice cover. The geochemistry and microbial diversity of Victoria Land cryoconites has been studied over a range of latitudes, elevations and distance from open seawater; on the Darwin and Diamond Glaciers (Lat 80°S), the upper and lower Koettlitz Glacier (Lat 78°S), and the Wright Glacier (Lat 77°S). The chemistry of the liquid water is highly variable, showing a range of pH (<5 to >11), conductivity (<0.005 to >4 mS/cm) and chemical composition, particularly in regard to the relative abundance of the anions. Major anion dominance shifts from SO₄ and NO₃ inland, to Cl-dominated in cryoconites closer to open seawater; a trend particularly evident on the Koettlitz Glacier. The high pH cryoconites also have a higher proportion of carbonate ion. Isotopes (tritium, oxygen and deuterium) confirm the origin of the water in the cryoconites as old glacial ice, rather than the recent surface snow. Bacteria-specific automated ribosomal intergenic spacer analysis

(ARISA) of the sediments from these cryoconites indicated that bacterial diversity varied as a function of pH and cryoconite size. However, cyanobacteria community composition was not influenced by cryoconite size, pH or geographic location, suggesting a high degree of tolerance to environmental conditions and transportation mechanisms. The implications for cryoconites as refugia for both bacterial and cyanobacterial species during glacial maxima are significant.

ORAL

GEOCHEMISTRY OF CARBONATE ALTERATION RELATED TO MIOCENE GOLD DEPOSITS AND THE ALPINE DIKE SWARM IN THE SOUTHERN ALPS OF NEW ZEALAND

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In New Zealand's Southern Alps, Miocene orogenic gold deposits are found in the Shotover Valley, and which formed contemporaneous with the emplacement of the lamprophyric Alpine Dike Swarm. Although the two geological features have very little spatial overlap, there are striking similarities:

- The orientations of the gold-bearing structures and the lamprophyre dikes are very similar. Gold occurs in NW-SE and W-E striking veins and silicified breccias. Dikes and diatremes in the Southern Alpine Dike Swarm also generally trend NW-SE or W-E.
- Geological and fluid inclusion data suggest that the gold-bearing veins formed at shallow crustal depths. Mariolitic cavities in the magmatic setting indicate that these structures also formed at a shallow crustal depth.
- Most prominently, both systems show evidence for extensive, structurally controlled flow of CO₂ rich fluids. This resulted in the formation of Fe rich-carbonates, which are found in veins and in the wall rock replacing some of the original minerals such as chlorite and epidote. We are in the process of examining the nature and origin of these carbonate-rich fluids and assessing whether there is any genetic connection between the two geological settings. Results from strontium isotope and trace elements data, obtained in situ using LA-ICP-MS, indicate several sources for the carbonate forming fluids

in the Alpine Dike Swarm, with one end member probably related to carbonatites found elsewhere in the Alpine Dike Swarm. On the other hand, the Shotover carbonates have ⁸⁷Sr/⁸⁶Sr ratios generally higher than the Dike Swarm and appear to have a more radiogenic source. This may be a result of dilution by the host rock (Otago Schist), which is highly radiogenic.

ORAL

TRIALLING PASSIVE REMEDIATION SYSTEMS FOR TREATMENT OF SEVERE AMD: A CASE STUDY FROM BELLVUE MINE, WEST COAST, NEW ZEALAND

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Bellvue Mine is an abandoned underground coal mine on the West Coast of the South Island, New Zealand, that discharges acid mine drainage (AMD) into nearby Cannel Creek. A research project is currently underway to examine the background geochemistry at the site, passive treatment of AMD in general, and how the science of AMD treatment can be applied at Bellvue Mine. This involves monthly testing to understand the background geochemistry of AMD at the site and the chemistry of the receiving waters above and below the discharge from Bellvue. Typically the pH of the AMD is 2.57, the dissolved Fe concentration is 110 mg/L, the dissolved Al concentration is 48 mg/L, while Ni, Zn, and Mn are enriched to between 0.02 and 1.2 mg/L (all dissolved). The AMD flows out of a pool in the collapsed mine adit. In the mine pool the iron is in a ferrous or reduced form but the AMD becomes aerated after discharge by a 57 m cascade and iron is oxidised into ferric form as it moves downstream. Several small-scale trial passive treatment systems are being installed, including a limestone leaching bed, two mussel shell reactors, an anoxic limestone drain, a bioreactor, and a diversion well. These systems are designed to increase pH, precipitate iron and aluminium oxy-hydroxide minerals, and remove trace elements from the AMD. Selection of a passive treatment system requires knowledge of

the background chemistry as well as geochemical modelling and field testing to determine the most effective treatment systems and methods of remediation. The systems will be sampled on a weekly basis for at least eight months.

ORAL

THE LARGE VOLUME (> 1290KM³), PERMIAN, RHYOLITIC, ORA FORMATION, NORTHERN ITALY: NEITHER MONOTONOUS NOR STRONGLY ZONED

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The 277 – 274 Ma Ora Formation, Italy, preserves > 1000 m of vertical section through its intra-caldera succession, providing an extraordinary opportunity to detail its chemical architecture, gain understanding of the eruption evolution and insights into the pre-eruptive magma system. Juvenile clast phenocryst and free crystal data, together with bulk-rock chemistry and single mineral data, show the Ora Formation ignimbrite succession is rhyolitic (67.95% – 77.73% SiO₂), has a stable main mineral population (volcanic quartz + sanidine + plagioclase + biotite), is crystal-rich (Ø43%), with variable phenocryst contents in juvenile clasts. Although the ignimbrite succession is largely similar, subtle but detectable lateral ranges in major and trace elements and modal mineralogy are identified.

The Ora Formation is comprised of multiple lithofacies, dominated by four densely welded ignimbrite lithofacies. Ubiquitous welding precludes juvenile clast chemical analysis; instead biotite can be used to discriminate between deposits at a large scale. Lithofacies analysis indicates the majority of the erupted material ponded within two caldera depressions, separated by a relict basement ridge, with late-stage outflow of material into the extra-caldera setting (<230 m). Chemical analysis through vertical stratigraphic sections reveals subtle compositional heterogeneity, but no large-scale systematic zonation.

Lateral chemical and mineralogical data analysis records a normal compositional evolutionary trend across the deposit from the Southern to Northern

intra-caldera successions, to northern extra-caldera succession. This is shown by a subtle increase in mean SiO₂, decreases in mean Fe₂O₃, MgO, Na₂O and in modal biotite (Ø7.3 – 1.2%), plagioclase (Ø15.9 – 5.6%), and total free crystal abundance (Ø47 – 37%), and finally, a lateral biotite compositional change from magnesium- to iron-rich. We propose that caldera collapse and eruption commenced in the south and progressed northwards, forming two pene-contemporaneous caldera depressions. We interpret that the Ora Formation was sourced from a heterogeneous, weakly compositionally zoned magma chamber.

ORAL

REVISED ESTIMATES OF HIKURANGI SLOW SLIP USING FEM-GENERATED GREEN'S FUNCTIONS

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Slow slip events (SSEs) occur along nearly the entire Hikurangi subduction margin adjacent to the North Island, New Zealand. The occurrence of both shallow and deep SSEs and the change in locking behavior observed along the Hikurangi Margin provide a unique opportunity to examine the factors controlling seismic and aseismic behavior. It is therefore critical that our slip estimates are as accurate as possible. Existing SSE slip estimates use geodetic data and an elastic half-space dislocation model to infer the slip distributions for these events. Two recent developments provide the potential to obtain more accurate estimates for these events. First, a New Zealand-wide seismic velocity model (Eberhart-Phillips et al., 2010) allows us to accurately represent the effects of complex variations in elastic properties. Second, a revised interface geometry has been developed (Williams et al., 2013), allowing us to represent more accurately the interface on which events are assumed to occur.

We use the finite element code PyLith to generate Green's functions for the entire Hikurangi interface, and use these in place of the elastic half-space Green's functions used previously. We do our work in two stages. In the first stage, we replace the existing geometry for the Hikurangi interface with the new geometry, allowing us to isolate the changes due purely to revised geometry. In the second phase, we use the FEM-generated Green's functions in the DEFNODE

inversion program, which allows us to isolate the changes that are due to changes in the assumed elastic properties. In this initial work, we apply the method to two Hikurangi SSEs: one deep event and one shallow one. The differences observed for these two events will allow us to evaluate the relative importance of interface geometry and assumed elastic structure for future SSE slip inversions.

ORAL

THE NORTHERN TONGAN SUBDUCTION-ARC AND MULTI-GEOHAZARD RISK IN THE SAMOAN REGION: HONOURING THE CONTRIBUTIONS OF JOHN BEAVAN TO OUR PRESENT UNDERSTANDING

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The Samoan Islands region is exposed to multi-geohazard risk resulting from its proximity to the northern Tongan subduction-arc (NTSA) which lies about 100–200 km south. Historical records spanning a few hundred years indicate that the NTSA is the main source area for seismic and tsunami hazards in this region. Evidence for long-term tsunami hazards also exists in the geologic record, with the largest likely event possibly associated with an NTSA source mechanism. Post-erosional volcanism has also been suggested to be associated with activity at the NTSA. Further, it has been recognized as being a potential long-term seismic source for triggering large-scale flank-collapses and subsequent tsunamis. Here we discuss the importance of the NTSA with respect to its apparent influence on multi-geohazard risk in this region, particularly when coupled with climatic influences. We highlight the importance of the contributions of John Beavan to our understanding of the hazard characteristics and long-term implications associated with the NTSA. We suggest that the NTSA is likely the dominant tectonic control on geohazards in the Samoan Islands region, and that further research is needed to elucidate the processes and hazard coupling effects on risk. This understanding would help contribute to developing strategies that aim to reduce the long-term vulnerability and increase resilience to NTSA associated hazards.

ORAL

DEVELOPMENT OF CRITICAL INFRASTRUCTURE FRAGILITY FUNCTIONS FOR VOLCANIC HAZARDS

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Approximately 10% of the world's population lives within 100 km of historically active volcanoes. Consequently, considerable critical infrastructure is at risk of being impacted by volcanic hazards, where critical infrastructure includes: electricity and wastewater networks; water supply systems; transport routes; communications; and buildings. Damage and/or disruption to these critical services can negatively affect society. To minimise the risk to infrastructure, a detailed understanding of how different infrastructure components interact with volcanic hazards is required. Here we present a methodology and schematic fragility functions for critical infrastructure performance in response to lava flows, lahars, pyroclastic density currents and tephra falls.

Impacts to infrastructure are documented from various sources within the literature, including: field observations, eye witness accounts, laboratory experiments, numerical simulations and expert opinions. This data is not utilised to its full extent and only limited detail analysis has been undertaken. To this end, we are using this data to develop fragility and functionality functions to assess critical infrastructure vulnerability to volcanic eruptions by quantifying relationships between hazard intensity and loss/function.

We compiled impact data from the literature into a database, permitting direct comparison and the establishment of common impact trends and critical thresholds. We then use this data to inform the creation and development of fragility and functionality functions. We have present schematic curves developed using critical thresholds and where this is lacking, expert opinion. Improvements in accuracy will occur iteratively with the addition of new experimental data and robust expert opinion. We consider appropriateness of hazard intensity parameters, as there is a balance between hazard model outputs and parameters controlling infrastructure damage. Our fragility functions, with the addition of new data, will aid in volcanic risk estimations and assist with the implementation of risk mitigation strategies.

POSTER

THE FORMATION OF FE-RICH SUBSURFACE CRUSTS ON WHITE ISLAND, NEW ZEALAND

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Epithermal alteration is capable of modifying the mineralogy and physical characteristics of the overlying volcanic deposits. The formation of subsurface precipitates may influence porosity, permeability and gas flux in volcanic and hydrothermal systems. Understanding the formation of these precipitates may provide insight into gas and hydrodynamics at similar volcanically active sites. At White Island, NZ, the Fe-rich crusts are prevalent in the central crater floor at a depth of less than one meter and are observed in the side walls of the crater. Here we access the crater floor Fe-rich crusts to understand their development and potential effect on volatile flux. Based on Raman, XRD and SEM analyses, the Fe-rich crusts are composed of jarosite (natrojarosite), goethite and schwertmannite. The conditions and fluids directly related to these layers are characterized by an average temperature of 31.6°C, pH of 1.4 and Eh of 168.8mV as well as having 390mg/L Fe and 900mg/L SO₄ in solution. The evolution of the Fe crusts is directly related to dynamic interactions involving the upward flux and flow of gases and fluids in relation to mixing with meteoric water and the atmosphere. In addition to the inorganic geochemistry of this system, microbes and diatoms have been identified in these crusts. Microbial activity may contribute to the formation of the precipitates and/or enhance the kinetics at which the Fe-rich deposits are forming; however, the extent of microbial activity contributing to this process is still being evaluated. Based on preliminary analyses, the Fe-rich layers are less permeable than the surrounding layers where the resulting decrease in permeability could influence the dynamics of gas and fluid flow and/or lead to over-pressurisation (i.e., an eruption) of the epithermal system.

ORAL

VERY HIGH-RESOLUTION MULTICHANNEL BOOMER SEISMIC ACQUISITION

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Very high-resolution marine seismic profiling with Boomer sources provides important information about a vast variety of geological structures and therefore contributes to unveil processes in the shallow marine environment. We present examples from several different places around New Zealand surveyed with NIWA's high-resolution, shallow-water seismic acquisition system and demonstrate the potential of this type of data if acquired and processed with care.

NIWA's system consists of a boomer seismic source and a GeoEel streamer. The source is a 300 Joule Applied Acoustics AA201 boomer plate towed from a CAT200 catamaran. The digital Geometrics GeoEel seismic streamer has 16 channels with a group spacing of 1.5625 m and two hydrophones per group. Real-time data and quality control are performed during acquisition allowing for storage, real-time display and printing of a selected range of control parameters. Navigational information coming from a DGPS is normally used for line display but is also immediately written to the seismic data for later use in processing. The system can be operated from small to mid-sized vessels, e.g. NIWA's RV Ikatere and RV Kaharoa, which makes it a fast, efficient and affordable geophysical tool.

Traditional single channel data is compared to the multichannel data processed with a newly developed processing scheme which effectively suppresses water column reverberations and thus greatly enhances the quality of the seismic sections. With sometimes more than 50m penetration and a vertical resolution of about 0.2 to 0.3m Boomer seismic investigation helps in particular to visualise sedimentary structures related to neotectonic processes and resolves features from a few centimetres to several metres. Example studies are widespread and include investigation of sediment deposits at canyon heads in relation to submarine landslides, resource location and estimation, as well as fault detection and characterisation.

POSTER

GRAINSIZE DISTRIBUTION OF ALPINE FAULT CATACLASITES

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The NE-SE-striking Alpine Fault accommodates most of the convergence between the eastern Pacific and western Australian Plates. Very rapid exhumation (~5-10mm/yr) of the fault hanging wall its 'central section' at Stony Creek, near Franz Josef township, has exposed a sequence of mylonites, ultramylonites and cataclasites. Here, and in other nearby Alpine Fault outcrops, the cataclastic zone ranges in thickness from 2-20m.

The exhumed fault rocks preserve structures resulting from fault processes that occurred at depth. Study of the structures present may help us gain an understanding of the kinematics and processes that acted within these fault rocks. The focus of this particular study is to examine cataclastic material from in and around the principle slip surface of the Alpine Fault. We hope to determine if there is a systematic relationship between particle size and particle shape distributions, and the processes that form and deform these particles. The main mechanisms that may have resulted in formation of these particles from a more intact protolith include cataclasis (by comminution or grain chipping) and alteration. I hypothesise that the gouge comprising the 'fault core' or 'principal slip zone (PSZ)' holds a record of seismic slip. If this material has a systematic grain shape and size distribution, we may be able to calibrate this relationship to the seismic process and thus make predictions of the seismic behaviour of comparable materials.

Samples collected from Stony Creek will be examined using both 2D and 3D methods. 2D methods include electron backscatter images obtained in a scanning electron microprobe. 3D methods include μ CT imaging and synchrotron-scale CT imaging. Images have been analysed using image software (Adobe Photoshop, ImageJ and a Matlab-based algorithm) following established methods (Scott, 2012). Using these techniques information such as the area and perimeter were measured from each grain in an image area; from these we calculated fractal dimensions 'D' of the particle size and shape distributions. We will

discuss comparison of these data to microstructural observations.

References

Scott, Hannah. 2012. Cataclasite within the Alpine Fault Zone. *Otago University*, 2012

ORAL

MONITORING ROCK FALLS IN YOSEMITE VALLEY USING SEISMIC AND INFRASOUND

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Seismic and infrasound instruments were deployed in Yosemite Valley to monitor for rock fall activity. The objective was to determine whether seismic and infrasound sensors are capable of detecting the small and medium-sized rock falls that are common on Yosemite cliffs, and if so, what could be learned about the triggering or dynamics of the rock falls from the geophysical data. Data were collected continuously at a rate of 500 or 1000 samples per second over the course of two winter seasons, primarily targeting the Middle Brother Cliff formation. Data analysis yielded not only information on rock falls, but also other physical phenomena such as rain, earthquakes, wind, infrasound from Yosemite Falls, snow avalanches, and human-caused noise. A total of twelve to seventeen rock falls were recorded, out of which only eight were reported by eyewitnesses. All of the detected rock falls were located in the target area at Middle Brother, except for one unusually large event. The Ahwiyah Point rock fall, 6.5 kilometers away, buried 300 meters of trail, leveled hundreds of trees, and sent off seismic waves that were detected at distances up to 350 kilometers on 28 March 2009. This rock fall was studied in detail using high-resolution photography and laser scanning in addition to the seismic data. Analysis and results from the monitoring effort as well as the detailed analysis at Ahwiyah Point are presented.

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