GeoSciences 2014

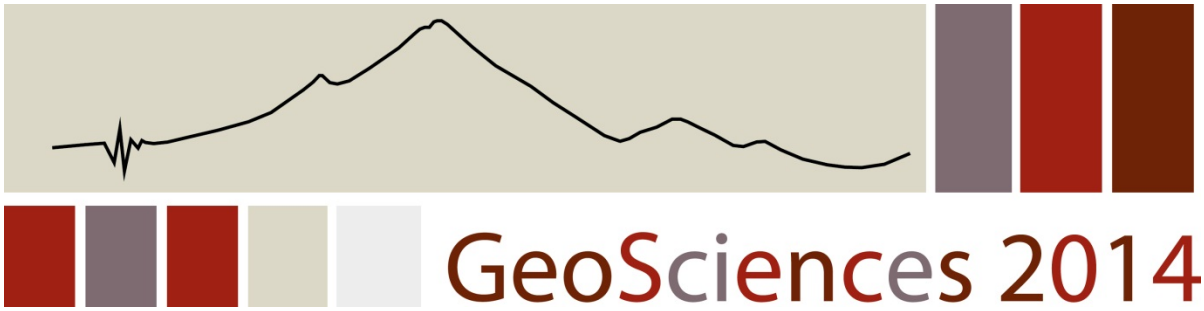
Annual Conference of the Geoscience Society of New Zealand
24th - 27th November 2014, Pukekura Raceway and Function Centre, New Plymouth

ABSTRACTS

Geoscience Society of New Zealand

Cover Photos:

Top Left: Mount Taranaki/Egmont Volcano, with the conference venue, Pukekura Raceway and Function Centre, in the foreground. Photo by Ken George, Absolutely Organised. Top Right: Examining volcaniclastic deposits on the track to Holly Hut, Mount Taranaki. Photo by Alan Palmer, Massey University. Bottom: Tertiary strata exposed in the cliffs at Pukearuhe Beach. Photo by Kyle Bland, GNS Science.



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ABSTRACT VOLUME

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MID-SHELF SUBMARINE CANYONS: IMAGING THE PROCESSES INVOLVED IN THE FORMATION AND EVOLUTION OF THE WAITAKI CANYON

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The sea floor off the coast of New Zealand's Otago region is characterised by a narrow (15-30 km wide) and shallow (<150 m deep) continental shelf incised by a submarine canyon system that feeds into the Bounty Channel further offshore. Although comprehensive bathymetric images of the area exist, there remain questions regarding the processes involved in the formation and evolution of these canyons. High-resolution seismic imaging of the subsurface will allow analysis of sedimentary structures in the vicinity of the canyons, which will shed light on the processes that led to their present configurations.

This research will develop a high resolution model of the sedimentary architecture in the vicinity of the Waitaki Canyon, one of the largest canyons in the system, using existing and yet-to-be-collected seismic data. This will provide insight into the processes that have led to the development of the canyon into its current form, as well as the processes that it is currently experiencing. Data from a number of sources are included: 2D and 3D seismic surveys from the oil and gas industry, multichannel boomer seismic data collected by the University of Otago's *RV Polaris II*, and high-resolution bathymetric images collected by NIWA.

Preliminary interpretations suggest that there has been migration of the Waitaki Canyon's upper channel through time, and that bulk movements (slumps) are likely to be a major factor in this. Other sediment transport processes, such as hyperpycnal currents and coast-parallel sediment transport due to marine currents, will also be investigated for their potential influence.

Furthermore, the role of glacio-eustatic sea-level fluctuations in the initiation and evolution of canyon systems will be assessed. This will be aided by the records from nearby exploratory wells, particularly the Cutter-1 well drilled near the head of the canyon in 2006.

STRUCTURE AND ANCIENT SIESMICITY IN THE MOOLIGHT FAULT ZONE IN THE MATUKITUKI VALLEY, WANAKA

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The Moonlight Fault Zone (MFZ) is a regionally important fault zone that has a complex geological history which despite its significance has been sparsely studied and as a consequence, is poorly understood. During the Miocene it underwent reverse movement which is intriguing as the MFZ is steeply dipping to the west, thus an "unfavourable" thrust fault, of which generally form at ~30^{o}, assuming an Andersonian stress regime.

Fieldwork in the West Matukituki Valley found that reverse movements along the MFZ juxtaposed intensely folded and massive greenschists to the west, against strongly foliated greyschists with intense chevron folding to the east. A range of fault rocks are present, including; networks of green cataclasite; solidified frictional melts (pseudotachylytes) which occur as thin (200 μm - 1mm) fault veins sub-parallel to foliation in the hanging wall greenschists, and rare injection veins branching into the host rocks and a thick (15 m) zone of fault breccia along the main fault trace which becomes increasingly foliated towards the fault trace.

A combination of optical microscopy, scanning electron microscopy and X-ray powder diffraction methods were used for analysis of these fault rocks. In the pseudotachylytes features such as flow banding, glassy margins and newly grown mineral phases are strong evidence for a prior melt phase. Breccias along the main fault trace become increasingly foliated (towards the fault trace) and contain an increasing amount of phyllosilicate phases (muscovite, chlorite and illite). The presence of these well aligned, phyllosilicate rich breccias along the fault trace has likely influenced the strength of the fault, as they have low friction coefficients (~0.4), which decreases stress along the fault plane. This decrease in stress increases the likelihood of failure and may account for slip on this unfavourably oriented fault.

A REMARKABLE MID-PLIOCENE VOLANT MARINE FOSSIL BIRD ASSEMBLAGE FROM THE SOUTHERN TARANAKI COAST

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The ocean has had a strong influence on the composition and evolution of the New Zealand avifauna. Whilst penguins are well known in the New Zealand Pliocene, the published record of volant birds is minimal with only a couple of bony-toothed bird (Pelagornithidae) fossils and a single shearwater (Procellariidae) cranium described. Here we detail new records of bony-toothed birds, albatross (Diomedeidae) and petrels (Procellariidae) from the Tangahoe Formation (Waipipian; Mid-Pliocene) of New Zealand's North Island that alter our ideas about the evolution and biogeography of not only New Zealand's marine avifauna, but give us a new insight into the timing of evolution of waterbirds worldwide. The Tangahoe Formation fauna lived during the most recent time in Earth's history when mean global sea temperatures were substantially warmer for a sustained period. Study of these fossils using CT scanning and modern medical imaging has enabled us to establish better than ever before the relationships of these fossils to modern taxa. We discuss the paleoenvironment of New Zealand during this biologically crucial epoch and how radical changes in climate, currents and biogeography that occurred in the Pleistocene may have affected the evolution of seabirds worldwide.

METALLOGENESIS ALONG THE MARGIN OF GONDWANA IN SOUTHERN NEW ZEALAND

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Major precious metal deposits are commonly located near repeatedly reactivated trans-lithospheric faults at active continental margins. These faults provided pathways for asthenospheric melts and fluids which help drive larger hydrothermal systems in the upper crust than would otherwise be the case.

In Fiordland and Stewart Island the Grebe Shear Zone (GSZ) and Freshwater Fault System (FFS) mark the Carboniferous margin of continental Gondwana. Transpressional deformation along both structures between 125-115Ma was likely preceded by extension between 320-130Ma when I and A-type granitoids, and high-K volcanic rocks were emplaced/erupted periodically near both structures. Three km-scale intrusion-related metalliferous hydrothermal systems have been delineated along the southern margin of the FFS in Stewart Island. At North Red Head 140Ma leucogranite hosts mineralogically complex veins containing Mo, Ag, Te, Bi, Au, REE, Zr, Y, U, Th, F and Cl-rich minerals. At "Hill 267m" intensely altered 300Ma leucogranite is riddled with miariolitic cavities that contain pyrite and molybdenite. Hydrothermal rutile in the granite contains W and Nb. On the east side of South West Arm 300Ma ilmenite-rich granite contains magmatic scheelite. Pyrite-rich blebs and biotite potassic alteration overprinting the same granite are associated with Mo, Te, Ag, Bi mineralization. More distal quartz veins cutting nearby 340Ma tonalite contain Ag, Pb, Au, Te mineralization. In Fiordland Cretaceous Cu, Pb, Zn, Ag mineralization at Dana Peaks and molybdenite at Pomona Island occur along or adjacent to the GSZ.

The Carboniferous margin of Gondwana and coincident younger faults mark a long lived discontinuity in the crust and sub-continental lithospheric mantle of NZ. Metalliferous granites and structurally controlled base metal mineralization formed sporadically along this discontinuity over a period of ~180Ma. The area which straddles this discontinuity is one of the more prospective sites for precious metal mineralization in NZ, consistent with the model outlined above which is now being applied to metal exploration globally.

SEDIMENT DEPOSITION, TECTONICS AND PETROLEUM GENERATION IN THE SOUTHERN TARANAKI BASIN

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The geology and petroleum systems in the Southern Taranaki Basin has been examined using 2D and 3D seismic reflection surveys tied to 35 exploration wells. These seismic lines image a Late Cretaceous to Recent sedimentary succession (<~80 Ma) that unconformably overlies Mesozoic basement with a total thickness of ~800 m to 8 km. Up to 15 seismic horizons have been interpreted throughout the southern basin and were used to generate regional 3D horizon models. The results presented here are based mainly on interpretations of individual seismic reflection lines and on structure contour, isopach, erosion and paleogeographic maps with temporal resolution of ~1-4 Myr since 23 Ma and ~5-10 Myr prior to the Miocene. The improved lateral and vertical resolution of these maps has led to a greater understanding of the area's geological and petroleum development. The sedimentary sequence comprises early transgressive strata (65-23 Ma) followed by Early Miocene and younger regressive units. Strata have been deformed by multiple phases of deformation dominated by Late Cretaceous-Paleocene extension, Miocene and younger shortening and, in the northern part of the basin, Plio-Pleistocene extension. North-trending anticlines and associated reverse faults appear to have generated minor topography which promoted northward flowing paleo-drainage systems during the Late Miocene. These paleocurrents indicate that the northern South Island, which was uplifted during the Neogene, was an important source of basin sediments during the Cenozoic.

BLOCK AND ASH FLOW PRODUCTION AT HIGH VISCOSITY LAVA DOMES

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A major hazard of viscous lava dome eruptions is the production of large block and ash flows, sourced from collapse of part, or all, of the dome. This collapse happens for a number of reasons such as the eruption rate, topography, vent morphology and the properties of the lava. Lava domes are a common volcanic landform in New Zealand, and will likely comprise part of the next large, rhyolitic eruption from within the Taupo Volcanic Zone. Identifying exactly how the variables affect the ability of a dome to collapse is crucial in predicting the hazard potential of a growing lava dome.

Here we present the findings of detailed field mapping of internal structures of lava domes from New Zealand and Guatemala, as well as experimental volcanology into changes in the porosity and permeability of an erupting lava dome, to compare and contrast the behaviour and collapse potential of these domes.

At Santiaguito volcano, Guatemala, dome or flow collapses occur at all stages of growth, triggered by flow front over-steepening or increases in extrusion rate. The largest block and ash flows are associated with the collapse of long, high volume lava flows during periods of high extrusion rate, and is coupled to the degree of degassing of the magma prior to extrusion.

At Ruawahia dome, New Zealand, multiple and widespread block and ash flow deposits surround the flanks of the volcano; clasts within these deposits shows evidence of post-collapse inflation, similar to lava found on the leading edge of the dome. Conversely, Ngongotaha dome, New Zealand, shows little to no block and ash flow production. In these cases, the crystal content of the magma controls the production of large cracks which enabled more efficient degassing, and the palaeotopography influences the likelihood of collapse of the dome.

CHALLENGES IN TEACHING UNDERGRADUATE GEOLOGY AND IMPROVING THE TRANSITION FROM 100 TO 200 LEVEL

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As a recent hire in the position of Senior Tutor in geology, my focus is both on lab and field based teaching. In particular this is guided by an overarching goal of linking the introductory 100 level courses (open to students of any background) to 200 level courses (only geology majors). Here, I will present my first impressions of teaching at these levels, as well as the challenges that I have encountered and changes to the courses that I have undertaken to improve learning and links between the courses.

Challenges that I have encountered include a low amount of retention of information from 100 to 200 level, leading to the necessity of re-teaching material covered in 100 level during 200 level labs or lectures. This low knowledge retention rate may have a run on effect of reducing self confidence in students own abilities, and may also be indicative of a culturally placed 'tall poppy syndrome' within New Zealand students. Universities are constantly trying to increase student numbers while simultaneously reducing time spent on marking or organisation and increasing research loads on lecturers. This may be hampered by a lack of interest or information on geology at pre-University levels, leading to few 'dedicated' geology students at 100 level.

The steep learning curve that students encounter at 200 levels leads to challenges during field trips which are part of the core degree structure. They require a high degree of self-motivation and reliance, as students are on their own in the field with minimal supervision (as compared to a lab setting). Improvements to these courses, such as streamlining of learning goals and improved pre-field trip training, may improve learning retention and reduce student stress during trips, potentially leading to benefits for other courses.

RADIOGENIC ISOTOPE CONSTRAINTS ON THE GLACIAL STATE OF ANTARCTICA AND PALEOCEANOGRAPHY OVER THE PAST 14 MILLION YEARS

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The long-lived neodymium, hafnium and lead (Nd-Hf-Pb) isotope systems are conservative water mass tracers with decadal to millennial residence times that are shorter than ocean mixing timescales. Their seawater isotopic composition reflects the age of continental crust being delivered to the ocean by glacial, fluvial and (to a lesser extent) aeolian processes, as well as continental weathering style. Thus, paleo-seawater Nd-Hf-Pb isotope records provide unique constraints on past continental weathering driven by global climatic conditions, reconfiguration of oceanographic circulation, and vigour of global thermohaline circulation. We have determined a continuous Nd-Hf-Pb isotopic record (ca. 3000 analyses) of paleo-deep waters (0-14 Myr; resolution = 100-400 kyr) from offshore eastern New Zealand (Deep Western Boundary Current – Antarctic Circumpolar Current). We have also determined their Pb isotopic composition at near-suborbital timescales (<20 kyr). The Nd isotopic record over the past 14 Myr is extraordinarily uniform and intermediate between North Atlantic (NADW) and Pacific deep waters – an observation that has led to the hypothesis that the Nd isotope composition of Southern Ocean deep waters is dominated by mixing between the Atlantic and Pacific oceans with reduced export of NADW in glacial periods. However, our data do not support this interpretation and instead are consistent with Southern Ocean deep waters having a Nd isotopic composition representative and overwhelmed by continental crust weathered from Antarctica. Moreover, Nd model and Pb-Pb "ages" of the paleo-seawater data are consistent with the mean age of Antarctica's continental crust. However, Pb-Hf isotopes show remarkable paleo-deep water variability related to incongruent weathering of Antarctica's continental crust over the past 14 Myr. These variations reveal the glacial state of Antarctica on timescales that vary from the mid-Miocene to present-day descent into the Icehouse World, through to Pliocene warmth immediately prior to onset of Northern Hemisphere glaciations,

and even over glacial-interglacial Quaternary transitions.

PRE-STACK DEPTH MIGRATION OF 05CM-04, IODP DRILLING, AND MARINE GEOPHYSICAL INVESTIGATIONS OF SUBDUCTION BEHAVIOUR AT HIKURANGI MARGIN

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Proposed International Ocean Discovery Programme (IODP) drilling and adoption of New Zealand as a GeoPRISMS focus site have led to a concentration of national and international resources and experiments that will be conducted in the next 5 years. The Hikurangi subduction margin offers a globally unique laboratory to investigate the physical controls on subduction earthquakes, including slow-slip events (SSEs), and tsunami. Indeed, the region offshore Gisborne may be the only place world-wide where well defined subduction interface SSEs occur at depths within range of current scientific drilling. Several multi-scale seismic surveys now form a comprehensive dataset along the entire Hikurangi margin (e.g. 05CM; RAU07; PEG09; SAHKE; SO191; TAN1114). These data are helping shape our knowledge about the along-strike changes in subduction slip behaviour, guiding precise locations for drill sites and informing later generation passive and active seismic experiments.

In particular, MCS reflection profile 05CM-04 is central to the drilling transect in IODP proposals to investigate slow-slip behaviour on the plate boundary offshore Gisborne. We present a pre-stack depth migration of 05CM-04 and inversion of magnetic data crossing the northern Hikurangi margin. The derived velocity and depth image provide a high-resolution geometry of the subducting plate and help constrain the location of earthquakes recorded on Ocean Bottom Seismographs (OBS). A larger array of OBS, Ocean Bottom Pressure sensors, and Ocean Bottom Electromagnetometers was deployed in May 2014 above the source of shallow SSEs at the northern Hikurangi margin (HOBITSS); roll-over of those instruments and deployment of GPS-Acoustic instruments is planned for 2015. Heat flow measurements will be acquired in 2015 in northern and southern Hikurangi, providing understanding of the subduction zone thermal structure. We also plan to mature proposals for regional 2D active source seismic on along- and across-strike profiles, and targeted 3D seismic surveying of the shallow SSE source region offshore Gisborne.

COMMUNICATING SCIENCE - THE "THIN ICE" EXPERIENCE

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"Thin Ice – the inside story of climate science" is a 73 minute feature documentary released in 2013. our original aim was to make a popular film in which climate scientists told their story directly to the public. In 2007, when filming began, climate change had become a serious issue, and we thought that if climate scientists could tell their own story directly to the public, their credibility would be obvious and action would surely follow.

The initial team comprised just Simon Lamb, an Oxford geologist with film-making experience, his friend David Sington, a London-based film producer, and Peter Barrett, a Victoria University academic with a concern for the future of the Antarctic ice sheet. Between late 2006 and the end of 2009 Simon had filmed over 100 hours of interviews in Antarctica, the Southern Ocean, New Zealand, England and Germany, including interviews with key US scientists. The film and a supporting website finally came together for Earth Day, April 22, 2013, with screenings at 200 sites

around the world. Responses made it plain we had struck a chord.

Key features of the film are the human face it gives climate science and scientists, and the conclusion that our societal goal should be zero carbon emissions. It also conveys a message of hope. Since the film's release it has been screened by invitation at over a dozen film festivals. In addition director/producer/photographer Simon Lamb has been awarded the 2104 Athelstan Spilhaus Award for Science Communication from the American Geophysical Union. It is now being distributed world-wide with subtitles in 8 languages by Green Planet Films marketing it to educational institutions world-wide. We are also working toward a 56 minute version for US public broadcasting for screening in 2015. For more on the film and project see www.thiniceclimate.org and www.greenplanetfilms.org.

PREDICTIVE SUBMARINE SUBSTRATE MAPPING IN THE ACTIVE VOLCANIC ENVIRONMENT OF THE KERMADEC ARC, NEW ZEALAND

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The Kermadec arc is a region of high geological and biological interest as it is home to a magmatically and hydrothermally active volcanic front. Geological mapping of the substrate in this region can aid characterisation of the volcanic and tectonic histories of the seamounts, providing insight into subduction processes. Substrate information is also essential for predicting the distributions of biological assemblages, as an aid to understanding and protecting unique communities.

However, direct mapping of the seafloor via imaging and sampling is time consuming, expensive, and limited in terms of coverage. Predictive substrate mapping using backscatter and bathymetry data obtained from multibeam echo sounder (MBES) systems enables large areas to be mapped comparatively inexpensively and with greater and more complete coverage. In order to achieve such maps, it is first necessary to have a sound understanding of the backscatter response to the various substrates that occur in volcanic arc environments, along with the bathymetric controls on substrate distributions. These relationships can be established with the use of ground-truth data, which can also be used to test the applicability of models developed for one seamount to other seamounts within the region.

In this study we investigate the relationships between substrate and MBES data for three Kermadec arc volcanoes (Rumble II West, Rumble II East and Brothers), and use logistic regression analysis and c-means clustering to construct predictive substrate maps for these regions. Video footage of the seafloor obtained using a deep towed image system is used as a ground-truth. The incorporation of bathymetric derivatives was found to improve the predictive capacity of regression models substantially compared to the use of seafloor backscatter alone. A fine-scale bathymetric position index, aspect eastness, and slope were found to be particularly significant predictors for identifying hard vs soft substrates.

PAPAROA COAL MEASURES: A FAULT BOUNDED BASIN BUT WHICH SIDE?

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The Late Cretaceous – Paleocene Paparoa Coal Measures of the Greymouth Coal Field have been variably modelled as deposited in a half-graben rift basin (Nathan et al 1986, Newman & Newman 1992, Ward 1997, Kamp et al 1999), a transtensional rift basin (Ettmuller et al 2006), and a sag basin with no basin bounding fault (Suggate 2014). In all cases where a fault was postulated it was located on the eastern side of the basin (Montgomerie - Mt Davy faults) based on isopach maps of the coal-bearing strata from drillcore. However, field work by Gage (1952) revisited by Suggate (2014) has suggested that these faults were not the primary basin bounding faults, particularly during the latest Cretaceous – Paleocene, and that strata thinned to the east.

In the central and eastern portions of the basin, coal-bearing Rewanui and Dunollie Formations have been interpreted as deposited by small sandy meandering creeks flowing west and southwestward into the Goldlight lake with peat-

forming mires in the floodplains. New research on the correlative conglomerate facies has highlighted their importance in the northwestern part of the basin. At 12 Mile Beach, the combined thickness of the Rewanui-Dunollie conglomerates is >800m with the intervening Goldlight lake absent. The basal contact is erosional and contains rip-up clasts of the underlying Waiomo lake mudstones. The lower strata are poorly sorted boulder conglomerates fining up to moderately sorted cobble conglomerates upsection. They are interpreted as steep alluvial fans that change to lower gradient braided rivers through time. Imbrication measurements show paleoflow was toward the southeast.

Thick alluvial fan conglomerate deposition in the west indicates high relief likely created by a basin bounding fault. This is associated with thinning and fining to the east with basin centre lacustrine deposits grading eastward to coal-bearing meandering river deposits typical of half-graben rift basin geometry.

USING GEOMORPHOLOGY TO PREDICT THE DISTRIBUTION OF LIQUEFACTION

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The 2010 Mw 7.1 Darfield earthquake and large aftershocks caused up to ten episodes of liquefaction in the eastern Christchurch suburb of Avonside. Field mapping, LiDAR, and aerial photography are used to identify 4872 surface liquefaction features including lateral spreading fissures and aligned sand blow vents within Avonside. Quantitative metrics of liquefaction features including fissure length, orientation, and density are combined with estimates of liquefaction induced horizontal and vertical ground deformation to derive a land damage metric (LDM) for a suite of 164 polygons throughout the study area. LDMs are compared with the geologic, topographic, and geomorphic conditions of each polygon to seek relationships between intrinsic properties and liquefaction-induced ground damage. Elevation (as a proxy for water table depth) and proximity to modern river banks or abandoned terrace risers play first-order roles in controlling LDM variability. Near surface geology plays a secondary role in influencing the location of lateral spreading fissures. On the scale of the study site, variability in the spatial distribution of the liquefiable layer appears to be small compared to LDM variations. Geomorphic and topographic variability in areas underlain by sediments highly susceptible to liquefaction provide important clues relevant to land use planning and microzoning.

A CATALOGUE OF HIKURANGI, NEW ZEALAND, SLOW SLIP EARTHQUAKES

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Slow Slip Earthquakes, also known as “silent earthquakes”, are episodic events similar to earthquakes that involve the release of accumulated strain, but over periods extending from days to months, rather than seconds. They account for a significant portion of strain release in plate boundary zones.

One aim of the project is to develop methods for the routine processing of GeoNet continuous GPS (cGPS) data for determining the location, moment, mechanism and duration of Slow Slip Earthquakes (SSEs) along the Hikurangi margin, and the uncertainties of these quantities. The primary result will be a catalogue of SSEs that is as complete and homogenous as possible for this period. A secondary aim is to investigate apparent differences in character between events in the NE (short and frequent) as compared with those in the SW (long and infrequent) of the North Island.

The relevant cGPS data from 2000 to 2014 have been processed and approximately 150 events have been identified and categorised, although not all of these may comprise SSEs. A map of secular velocities split into components due to SSEs and due to SSE-free displacements raises questions concerning current interpretations of the tectonics of the Raukumara Peninsula and the Wairoa domain.

Forward modelling of surface displacements produced by movement on buried faults suggests that commonly-used inversion techniques, based on the assumption of an homogenous half-space below the ground surface, could, in some circumstances, be significantly over-estimating or under-estimating the apparent magnitude of the source mechanisms.

This paper will present an overview of results obtained to date.

GRAIN GROWTH KINETICS FROM EXPERIMENTS USING SUPERFINE ICE

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Grain growth is the increase in mean grain size in polycrystalline materials when exposed to low stress and high temperature conditions, and is described by the mean field equation: $D^n - D_0^n = kt$. Where D is the mean grain diameter after time t, D_0 is the initial mean grain diameter and k is the product of intrinsic diffusivity and the Arrhenius relationship of temperature. The growth exponent n reflects the microscale physics of the grain growth process, and is poorly understood in geologic materials including ice.

Knowing the growth exponent for ice is important to the interpretation of ice-core grain size data. High n values mean that the range of grain-sizes converge more rapidly with time. For example, zones of anomalously small grain size that may be generated by localized creep could be made less significant by grain growth and part of the history of the ice sheet will be missed. Growth exponents in ice are traditionally set at 2, corresponding to one theoretical grain-growth model; some new data confirm values of 2 for clean bubble-free ice but suggest that they are closer to 4 for ice with a very small bubble content. Estimation of n-values from ice cores or experiments have often been limited by very small differences between D and D_0 so that there are potentially large errors in n that cannot be deconvolved from errors generated by uncertainty in the thermal history.

This study uses a new approach; two samples that differ only in grain-size are subjected to a single thermal history cancelling out uncertainties in the thermal history and allowing n to be calculated by the relative grain growth of the two samples. To give well-constrained n values the approach requires very fine-grained starting materials. To date we have made progress in generating starting materials, testing the experimental approaches and collecting pilot data. Preliminary experiments give n values of 2 for clean bubble-free ice.

P-T-t-D EVOLUTION ACROSS A PALEOZOIC GREENSCHIST TO AMPHIBOLITE FACIES TRANSITION IN GREENLAND GROUP ROCK IN SOUTH WESTLAND

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A superb prograde metamorphic sequence in the Greenland Group is exposed in the Collie Range in South Westland. Metamorphic grade progressively increases over a 6 km transect, from lower greenschist facies slates and greywackes near the coast to microcline-bearing amphibolite facies gneisses immediately northwest of the Alpine Fault. Four textural-mineralogical zones are defined. These span chlorite-sericite-albite to microcline-oligoclase/labradorite assemblages and record progressive recrystallization throughout. Whole rock analysis indicates a mobility of X (loss) and Y (gain) with increasing grade. Textural Zone I rocks are greenschist facies argillites and greywackes that were folded into macroscopic folds and contain an S_1 schistosity. In Textural Zone II rocks, which are upper greenschist-lower amphibolite facies but contain abundant detrital minerals, porphyroblastic biotite that overprints S_1. Textural zone III records near complete recrystallization and weak crenulation cleavage. Textural zone IV rocks are completely recrystallized and contain metamorphic segregation.

In TZ III and IV amphibolites, two generations of muscovite occur. Syn-kinematic muscovites define a penetrative foliation that is overprinted by

coarse poikiloblastic muscovites that represent rehydration-mediated retrogression of microcline.

P-T conditions for the S_2 assemblages were obtained by a combination of Ti-in-biotite geothermometry and phengite geobarometry. Peak metamorphism in the amphibolite facies TZ IV occurred at ~ 620˚C and 4 kbar, whereas TZ III records temperatures of ~ 540˚C and 3.5 kbar. The metamorphic textures observed are interpreted to show that an early regional axial-planar S_1 cleavage associated TZ I is overprinted by porphyroblastic biotite in TZII and by increasing intensity of S_2 fabrics in TZ III and IV. These results are tentatively interpreted to show that the metamorphic sequence in the Collie Range represents a tilted section, with the highest grades exposed closest to the Alpine Fault. The change in the metamorphic fabrics is interpreted to record initial shortening and macroscopic folding (TZ I) at >371 Ma, followed by an elevated heat-flow at ~340 Ma perhaps due to crustal thinning. Thermal relaxation caused coarse muscovite and biotite porphyroblasts to overgrow the amphibolite facies assemblages.

A KINEMATIC SOURCE MODEL OF THE M 6.3 FEBRUARY 22 2011 EARTHQUAKE IN CHRISCHURCH, NEW ZEALAND

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A simple, kinematic model of the rupture of the M6.3 February 22 2011 earthquake in the city of Christchurch, New Zealand provides insights into the factors influencing observed ground motions. The model is based on a squared 9 km x 9 km fault dipping 75^0, striking 64^0 and rupturing with a thrust mechanism. The fault is embedded in a velocity model consisting of one layer over a uniform half-space representing the stiffest soil deposit and the bedrock underneath, respectively (Brown, L.J.; Weeber, J.H. 1992). The free-surface of the soil layer is assumed to be flat, however, the bedrock interface (initially at 900 m depth) pinches out as a 3-D cosine shaped free-surface topography up to 225 m high, representing Banks Peninsula.

Numerical modelling of the rupture shows that the observed strong ground motion is mainly due to two factors: the coherent rupture of a section of the fault of 25 km^2 area, with average 3.5m slip, 116^o rake and 3.1 km/s rupture velocity, and the presence of the shallow layer of sediments immediately overlying the fault. The discretization of the whole fault into several subfaults each with prescribed values of slip in the range 0.4-3.5 m, and variable rise time, allows parametric study of the ground motion using several rupture scenarios. The model with the coherent rupture described above best reproduces the high (1.2 g -1.8 g) accelerations observed at stations in the footwall and hanging wall of the fault. The topography does not appear to contribute significantly to the high accelerations observed in the near field, but it might produce Rayleigh waves propagating away into the basin. This is in agreement with particle motion surface wave analysis of the measured seismograms that reveals the contribution of Rayleigh wave energy to the observed long-period ground motions. Furthermore, arrival times of the Rayleigh wave energy are consistent with predicted travel times from our basin velocity model.

THE CLAY CREEK LIMESTONE: STRATIGRAPHY, DEPOSITIONAL ENVIRONMENT, AND CONSTRAINTS ON LATE MIOCENE-EARLY PLIOCENE DEFORMATION ASSOCIATED WITH THE SOUTHERN HIKURANGI MARGIN

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Studies of the structure and tectonic history of the southern Hikurangi Margin (e.g. Cape et al, 1990; Nicol et al, 2002) provide evidence for an episode of intense tectonic shortening and deformation during the Late Miocene or Early Pliocene. However, the stratigraphy associated with this time interval is often complex and poorly-understood, and few details of Late Miocene paleogeography are currently known in the Wairarapa (Beu, 1995). The Clay Creek Limestone is ideally positioned to provide a record of Late Miocene-Early Pliocene shortening and deformation associated with the southern Hikurangi Margin. It is a coarse-grained coquina limestone of Late Miocene age that outcrops irregularly over an estimated area of 50 km^2 on the northern margin of the Aorangi Range. At some

locations, it directly overlies Mesozoic greywacke and argillite, while at others it overlies Miocene sandstone or mudstone. A more detailed understanding of the stratigraphy of the Clay Creek Limestone and adjacent units is necessary in order to better constrain the timing and style of Late Miocene-Early Pliocene deformation. Our study aims to produce a detailed stratigraphic and paleoenvironmental interpretation of the Clay Creek Limestone and associated units, using techniques such as field mapping, measuring key sections, and biostratigraphic analysis of macro- and microfossil samples. We will present preliminary results and images from our study.

RICE - ROOSEVELT ISLAND CLIMATE EVOLUTION PROJECT - A NEW, INTERMEDIATE DEPTH ICE CORE RECORD FROM COASTAL ANTARCTICA

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RICE is a collaboration between New Zealand, Australia, Denmark, Germany, Italy, People's Republic of China, Sweden, U.K., and U.S.A. The overarching aim of the project is to help evaluate the stability of the Ross Ice Shelf and West Antarctic Ice Sheet in a warming world.

The team recovered a 763m deep ice core from Roosevelt Island during the 2011/12 and 2012/13 field seasons supported by Antarctica New Zealand and the USAP. The core was drilled using the newly built New Zealand intermediate ice core drilling system, which is based on the design of the Danish Hans Tausen drill.

Roosevelt Island, an ice dome grounded 200m below sea level, is situated at the northern tip of the Ross Ice Shelf, which flows around it. The dome has a maximum elevation of 550m above sea level and exhibits a well developed Raymond Bump. Average annual snow accumulation is 20cm ice per year. The RICE core was drilled in the vicinity of the topographic and Raymond Bump divides. The core was processed at the New Zealand Ice Core Research Facility during May to July 2013 (0-500m) and May to August 2014 (500-760m).

The record has been dated using annual layer count, volcanic markers, and correlated to WAIS via an exceptionally high resolution match between the WAIS and RICE continuous flow methane measurements. Geophysical measurements (radar and strain rate measurements) provide information on the thinning history of the island and further help to constrain the age model. The RICE core provides a high resolution record of the deglaciation history in the Ross Sea region and a lower resolution record extending to >60ka.

Here we present the first data spanning the entire record and offer initial conclusions.

EVOLUTIONARY CHANGE WITHIN THE LATE NEOGENE PLANKTONIC FORAMINIFERAL LINEAGE *TRUNCOROTALIA*

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This study aims to document detailed evolutionary change within a single planktonic foraminiferal lineage over time. Planktonic foraminifera are useful tools for studying evolution as their tests are easily preserved in deep sea environments. Cores collected by the Deep Sea Drilling Project (DSDP) contain continuous records of deposition, which offer excellent opportunities to study evolutionary change within lineages. The lineage

of interest here is classed within the *Truncorotalia* genus: the ancestor-descendant pair *Truncorotalia juanai* and *Truncorotalia crassaformis*. This species pair was chosen as they are relatively common within the studied DSDP cores. Additionally, the evolutionary transition from *Truncorotalia juanai* to *Truncorotalia crassaformis* occurred over the Miocene-Pliocene boundary constrained the study to between 5.9 and 4.5 Ma. Using closely sampled collections of *Truncorotalia* from approximately continuous sedimentary records from DSDP cores, we studied populations of these species.

Abundant and extremely well-preserved specimens of the end member species and any intermediate forms were collected from the DSDP Sites 593 and 593-A. Specimens were sampled every 100 ka between 5.9 and 4.5 Ma. Where possible, at each interval 120 specimens were identified and collected. These specimens were imaged using the AMOR foraminiferal imaging system at Basel Natural History Museum in Switzerland. Digitised outlines of these images were decomposed to a series of Fourier coefficients using a Fast Fourier transform. The relationships between populations or shapes were subsequently quantified using principal component analysis. The preliminary results presented here suggest that the evolutionary change between *Truncorotalia juanai* and *Truncorotalia crassaformis* was very gradual, with each intermediate form grading into the next. There is no evidence of abrupt species changes, or species sorting, within this data set.

DINOSAURS, DISASTERS, AND THE POWER OF THE PLANET! SCIENCE OUTREACH FOR COMMUNITIES FROM A CROWN RESEARCH INSTITUTE PERSPECTIVE

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GNS Science believes that effective communication of science, and community engagement, are critical parts of doing business for New Zealand's Crown Research Institutes. With financial support from the Todd Foundation, we developed and very successfully ran two community-focussed educational events in Hawke's Bay and Taranaki. Based around a regionally-focussed theme, these two "Geocamps" were designed to awaken the enquiring scientist within children and adults through immersion in the creative, curiosity-driven, hands-on, problem solving process of real science. The Geocamp initiative was developed and implemented due to a perceived lack of science awareness in the general public, and an apparent lack of recognition of the value of science in NZ. Science isn't just about white lab coats and test tubes!

Each Geocamp comprised a two-week long field-based course for intermediate school-aged students and, very importantly, their teachers: our aim has been to "get the kids enthused, and teach the teachers." Participants learned basic (geo)science concepts using an observational and inquiry-driven approach, and then presented aspects of their learnings to their wider communities: the aim was to make the Geocamp experience as close to doing "real science" as possible. The success of the Geocamps is highlighted by teaching projects now implemented at some of the participating schools.

The Geocamp model is readily and easily transferable to any facet of science, to all age groups, and to any geographic area. We have now successfully adapted and implemented the concept for adults in on-going marae-based wananga in collaboration with Ngati Kahungunu in greater Hawke's Bay, where the educational focus is on climate change, petroleum exploration, and natural hazards. The same hands-on style of learning is being applied in these 3–4 day long wananga, with participants gaining a greater appreciation of how science "works", and the fundamental role that science plays in New Zealand.

FEEDING APPARATUS AND PHYLOGENETIC RELATIONSHIPS OF OLIGOCENE EOMYSTICETIDAE FROM NEW ZEALAND REVEAL EARLY EVOLUTION OF FILTER FEEDING IN BALEEN WHALES (MYSTICETI)

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The Eomysticetidae are a recently recognized family of archaic, purportedly toothless baleen whales. Named eomysticetids such as *Eomysticetus whitmorei* (Oligocene, USA) and

Yamatocetus canaliculatus (Oligocene, Japan) are characterized by an elongate and incipiently narrow rostrum, a plesiomorphic braincase with a well-developed sagittal crest and large temporal fossae, and an elongate slightly bowed mandible with unfused mandibular symphysis and "pan bone". New fossils from New Zealand representing a new genus and species of eomysticetid (OU 22044, 22075, 22163 from the Waitaki region), reveal new details of the feeding apparatus of the earliest toothless mysticetes. Palatal foramina indicate the presence of baleen posteriorly, but are absent from the rostral terminus – suggesting that baleen was absent (or poorly developed) anteriorly and forming a "subrostral gap" analogous to right whales (Balaenidae). A well-developed glenoid fossa indicates primitive retention of a synovial temporomandibular joint (TMJ), which in concert with a delicately constructed mandible, precludes dynamic lunge feeding exhibited by modern balaenopterid whales. The incipiently kinetic rostrum of eomysticetids is more elongate and narrow than any extant mysticete other than skim feeding right whales (Balaenidae). The possible absence of anterior baleen in concert with an anteriorly elongated rostrum would permit water to flow unidirectionally through the oral cavity in a manner similar to right whales without inflicting extreme stresses upon the delicate TMJ; balaenids also possess a synovial TMJ. A cladistic analysis of over 65 mysticete taxa coded for 362 morphological characters recovers a monophyletic Eomysticetidae (including *Eomysticetus*, *Yamatocetus*, *Micromysticetus*, and several new genera of Eomysticetidae from New Zealand) positioned as the earliest diverging toothless mysticetes, agreeing with all previously published studies. Because eomysticetids are the earliest obligately filter feeding mysticetes, our results indicate that skim feeding represents the primitive mode of filter feeding amongst baleen whales.

TIMING, SPATIAL DISTRIBUTION, AND ORIGIN OF PALEO-ROCKFALLS IN THE RAPAKI AREA OF THE PORT HILLS, CHRISTCHURCH, NEW ZEALAND

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More than 1,500 paleo-boulders have been mapped to determine the timing, spatial distribution, and origin of prehistoric rockfall deposits in Rapaki. Paleo-boulders consist of two dominant lithologies: volcanic breccia and fine-grained basalt. We propose that boulder volume is strongly influenced by layer/bed thickness and degree of pre-existing jointing within the source rock. The volcanic breccia comprises the majority of larger boulders (50 boulders > than 10.0 m^3), while boulders consisting of the finer-grained basalt rarely exceed 2.0 m^3. Mapping shows that volcanic breccia boulders exhibit the longest run-out distances but, unlike modern boulders generated during the 2010-2011 Canterbury Earthquake Sequence, we find no paleo-boulders present in the Rapaki village. This may provide important evidence that forest present on the mountainside prior to Maori and European settlement reduced boulder run-out distances.

Exploratory trenches have been excavated adjacent to and behind several of the paleo-boulders to identify sediments deposited before and after boulder emplacement. Single grain OSL dating of these bounding sediments will provide temporal constraint for boulder emplacement and associated shaking (i.e. paleo-earthquake).

Field observations suggest a correlation exists between boulder surface roughness and age, which could be used to determine timing of pre-historic shaking events. Older surfaces show greater removal of finer-grained host matrix material and increased exposure of larger, more resistant, volcanic clasts. High-resolution point clouds have been generated for twenty of the Rapaki paleo-boulders using photogrammetry and SFM (structure-from-motion) software, with the aim of producing a roughness metric for each of the dated surfaces. Early efforts indicate that measuring the 'rate of change of slope' for each surface will prove most effective in quantifying the observed differences in surface roughness.

MODELING TOOLS FOR THE REAL-TIME EVALUATION AND HISTORICAL RECONSTRUCTION OF TSUNAMI EVENTS IN NEW ZEALAND

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We assess tsunami hazards in New Zealand through a review of historical accounts, analysis of water level and current speed data and detailed numerical modeling. The tsunamis of 2010 (Chile) and 2011 (Japan) were recorded on tide gauges throughout New Zealand, providing a rich water level data set for model comparison and calibration. Furthermore, a current meter at the entrance to Tauranga Harbor also captured these tsunamis providing a unique current speed data set augmented by several concurrent water level records. This information was used to calibrate numerical models using the ComMIT modeling tool. A sensitivity study for tsunamis generated from around the Pacific Rim indicates the relative hazards from different source regions. Deterministic scenario modelling of significant historical tsunamis provides a quantitative estimate of the expected effects from possible future great earthquakes. These models were tested in April 2014 after the Mw 8.2 earthquake offshore of Iquique, Chile – an event of particular concern given that the August 1868 Arica earthquake generated a tsunami of ~7 m in Lyttelton Harbor as well as runup of up to 10 m in the Chatham Islands. As the April 2014 event unfolded, it was initially unclear if an evacuation or other emergency response would be necessary in New Zealand. Models run in real time, using sources based on inverted tsunameter data and finite fault solutions of the earthquake, suggested that a damaging far-field tsunami was not expected and emergency response teams and port authorities were advised that is was safe to stand down. These results were ultimately confirmed when the tsunami was recorded in Lyttelton Harbor with a maximum amplitude of ~15 cm. Nevertheless, this event reminded us of New Zealand's far-field tsunami exposure as well as the hazard from sources in South America and the Peru/Chile border region in particular.

PALEOCLIMATIC AND PALEOCEANOGRAPHIC RECORDS FOR NEW ZEALAND AND THE SOUTHERN OCEAN FOR THE LAST 60 KA – CONTRIBUTIONS TO THE SOUTHERN HEMISPHERE ASSESSMENT OF PALEO-ENVIRONMENTS (SHAPE) PROJECT

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The aim of SHAPE is to take an integrated approach towards reconstructing and understanding the evolution of the Southern Hemisphere climate. The project continues the momentum that was started with Australasian-INTIMATE (Integration of Ice, Marine and Terrestrial records). The timescale has been expanded with the aim to provide good, high resolution climate records from 0-60 ka (the limit of radiocarbon dating) and thus incorporating the abrupt millennial scale climate change events evident in the Antarctic ice cores during Marine Isotope Stage 3 (MIS3).

Here we provide a collection of proxy records for this extended time period for New Zealand and the Southern Ocean. These will be compared with other regions of the Southern Hemisphere and paleoclimate model simulations.

TARANAKI AND KING COUNTRY BASINS JUXTAPOSED DURING THE EARLY MIOCENE: SEISMIC EVIDENCE FROM THE MERCURY BASIN, NORTH TARANAKI

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The Mercury Basin is an Early Miocene (Waitakian-Otaian) depocentre that has been mapped using marine 3D seismic acquired by Kea Oil and Gas Ltd in 2013. It is located in North Taranaki, east of the Taranaki Fault yet west of the Tongaporutu Basement High. Closest stratigraphic controls are in the offshore Mokau-1 and Pluto-1 wells, but neither of these encountered the Early Miocene succession , up to 1500m thick in the Mercury

Basin, which is better correlated with the Mahoenui basin-floor flysch of the King Country Basin. Sedimentation ended during the Late Otaian when the Basin was uplifted from bathyal water depths and subsequently eroded through canyon incision; (this uplift being coeval with inversion of the Mahoenui east of the Ohura Fault). Reverse movement occurred on west verging thrust faults, the lowest and oldest being the Taranaki Fault. Further east thrusting continued throughout the mid Miocene creating the Tongaporutu High over which the Late Miocene Herangi Unconformity rests upon Murihiku Basement.

This paper looks at the seismic and other evidence for the age, depositional style and paleogeography of the Mercury Basin. A question is posed as to how the 1500m basin subsidence on the hanging wall of the Taranaki Fault occurred here during the Early Miocene when elsewhere the eastern margin of the Taranaki Basin was undergoing compression?

It is concluded that the Mercury Basin is unique in providing a snapshot of the juxtaposition of the Taranaki and King Country Basins during the Early Miocene, thus constraining the timing of west-east shortening along the Taranaki Fault Zone and the creation of the Tongaporutu Basement High.

Despite lack of seismic control along the coast between Pukearuhe Bay and Tongaporutu, it is tempting to propose that the entire Mt Messenger sequence (Tt) exposed in the stratotype at White Cliffs was deposited within this major canyon (some 10km wide by 300m deep).

Displayed are some of the interpreted seismic sections and 3D time slices which demonstrate the canyon termination of widespread reflectors corresponding to the basin-floor facies at the base of the Mt Messenger. The canyon shoulders are traced northwards into Pluto-1 and west into Pohokura-1 for youngest age control.

Canyons have been previously recognised within the overlying Urenui Formation (e.g. Wai-iti Beach) but the scale of the present discovery is of quite a different magnitude. Questions arise as to the longevity of the canyon and the nature of the controlling tectonic and/or eustatic processes. Earlier work by GNS has highlighted the extremely high estimated rates of sedimentation and rapid sedimentological facies variation within the upper Mt Messenger; now the abrupt transition from 'basin-floor' to 'slope-fan' may be understood within the confines of major slope progradation and canyon formation during the Tongaporutuan stage.

CANYON ON THE MOUNT: A NEW LOOK AT THE TYPE SECTION OF THE MT MESSENGER FORMATION

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Interpretation of 3D seismic acquired offshore north Taranaki by Kea Oil and Gas Ltd in 2013, in conjunction with onshore seismic (KEA55-13-1 to -4) shot over the Mt Messenger Range in the same year, has identified a major canyon which down cuts several hundred metres from within the upper Mt Messenger Formation through the Herangi Unconformity onto Murihiku Basement. The offshore data shows the comparatively steep northeastern flank of the canyon trending to cross the coastline some 3km south of the Tongaporutu River mouth (near Waikiekie stream). The southwestern canyon margin is mapped to cut the Pukearuhe-1 well at 682mAHKB, while further inland the thalweg passes close to Uruti-1.

GEOCHEMICAL FINGERPRINTING OF TITANOMAGNETITE PROVENANCE IN IRONSANDS ON THE WEST COAST OF THE NORTH ISLAND

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Previous studies on the provenance of titanomagnetite in ironsands on the west coast of the North Island have indicated that the ironsand was derived from erosion of Cenozoic volcanic rocks, mainly the andesite volcanoes of the Taranaki area. Ilmenite is a minor component in the Waikato North Head ironsand deposit and in the coastal sands north of the Waikato River mouth, which suggests input from Taupo Volcanic Zone (TVZ) sources because TVZ ignimbrites contain minor ilmenite in addition to titanomagnetite. Geochemical analyses of titanomagnetites in Taranaki and TVZ volcanic rocks show that those from Taranaki andesites have higher MgO and generally slightly higher V_2O_3 and Cr_2O_3 than TVZ ignimbrite titanomagnetites,

and that a MgO-MnO plot clearly distinguishes between the two sources. Previous analyses of titanomagnetite in ironsand deposits at Taharoa, Raglan and Waipipi, and our electron probe analyses (EPMA) of samples south of the mouth of the Waikato River, all lie in the Taranaki andesites field on the MgO-MnO plot. Our EPMA analyses of beach sand samples north of the Waikato River mouth show that some of the titanomagnetite grains (about 10% of the grains analysed) plot in the TVZ rhyolite-ignimbrite field; as do analyses of titanomagnetite in pumice clasts from the lower Waikato River. This is consistent with the high MgO titanomagnetites and associated ilmenites being derived from the TVZ via the Waikato River after 22 ka ago when the Waikato River changed course from flowing into the Hauraki Gulf to its present position.

VIEWING INSIDE EXPERIMENTAL PYROCLASTIC FLOWS

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Pyroclastic density currents (PDCs) are amongst the deadliest flows on Earth and are commonly produced by volcanoes worldwide. Direct observations of the flows are extremely rare and intrusive measurements inexistent. The Pyroclastic Flow Generator built at Massey University allows the limitations encountered with natural flows to be overcome through its ability to simulate PDCs with controlled initial conditions and to view and measure internal flow properties. Hence, from safe laboratory investigations, calibration data can be obtained that can be introduced into numerical models to enhance their validity and improve their efficiency in hazard predictions.

The Pyroclastic Flow Generator produces experimental flows by fully controlled column collapse and is able to generate the full range of column dilutions with natural pyroclastic material. We report results of a systematic series of experiments producing flows that reached velocities of up to 30 m/s and runout distances of up to 30 m. We will present high speed movies and non-invasive sensor data that allow the characterization of the transformation of a homogeneous volcanic column into a vertically and longitudinally stratified flow able to produce similar deposit facies to those observed in nature.

In the scenario of a collapse of a dense column (5-15% particle volumetric concentration), the PDC generated is a dense suspension that rapidly sediments particles into a dense underflow (40-50% particle volumetric concentration) able to progressively detach and behave separately from the more dilute and fully turbulent upper parts of the flow. Different regions of the flow will be detailed in terms of particle volumetric concentration, velocity profiles, particle transport mechanism, and turbulent eddies across the flow runout. From the results of the large-scale experiments, we introduce our model of the formation and evolution of pyroclastic flows.

GEOTHERMAL-INDUCED MICRO-SEISMICITY : A CRACKING GOOD STORY

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Often we hear stories of the potential adverse effects from hydraulic fracturing undertaken for energy purposes. Examples include groundwater contamination from coal-seam gas wells or deep waste-water disposal wells (from casing failures). Geothermal energy developments have resulted in many cases of triggered micro-seismicity, benefitting fluid transmissivity, but without significant adverse effects. Although there have been no documented cases of severe damage or pollution from high-pressure geothermal fracture stimulation or continuous fluid injection/production, there remains an issue of hazard perception. This varies with location because of differences in familiarity with natural seismicity. To help address the perception issue, the positive side of the story deserves an airing.

In New Zealand, several producing geothermal fields have triggered micro-seismicity, others haven't (eg. Ngawha, Ohaaki). The favoured mechanism is an indirect effect of increased fluid-flow on fracture networks. Seismic failure can be triggered on favourably-oriented fractures, through micro-stress perturbations from thermal, chemical, or pressure transients. Although the

fluid flow is driven by pressure gradients through the fractures, the perturbing stress transients are largely induced by cooling contraction. The transients locally unlock asperities on pre-stressed fractures.

In some geothermal fields levels of natural seismicity are relatively low, and induced seismicity has not been observed, despite prolonged periods of pressure and temperature change from fluid production and injection. An explanation is that the local reservoir stress conditions are probably not close enough to critical. Therefore, reservoir fractures are not, in these cases, poised for failure in the event of small stress perturbations.

The positive benefits and practical applications of induced seismicity include information constraining the reservoir simulation models: a) locations of permeable upflows, b) depth of the brittle-ductile transition zone, and c) locations of fault-bound compartments within geothermal reservoirs. Active fracturing enables the transmissivity to be maintained by countering mineral scaling. Long-term energy extraction is thereby enhanced.

SILICICLASTIC LITHOLOGIES RECOVERED IN DREDGE SAMPLES FROM REINGA BASIN

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The Reinga Basin northwest of New Zealand is a 75 000 km^2 frontier basin with typical water depths in the range 500 - 2500 m. The region is contiguous with the Northland and the petroleum-producing Taranaki basins to the east and south, respectively. In November 2013, an 18-day survey on board the *RV Tangaroa* (survey TAN1312) acquired dredge samples and multi-beam data from 38 sites. Rock samples were collected using a 0.45 x 1.2 m diameter steel rock dredge at locations selected on the basis of seismic and/or multi-beam data.

A range of rock types were dated using foraminifera, palynomorphs, radiolaria and macrofossils, and indicate a broad range of Late Cretaceous to Recent ages. Some of the younger ages are likely to represent infillings of borings at the margins of samples, or modern ooze.

Siliciclastic stratigraphic units include quartz and feldspar-rich sandstones similar to other arkosic sandstones of Zealandia, such as the Coverham and Wallow groups of Marlborough and the Hoiho Group of Great South Basin, and to the Rakopi and North Cape formations of Taranaki Basin. In the survey area, they comprise well to poorly sorted, very fine- to coarse-grained, quartzose and feldspathic (plagioclase and K-spar) rich, micaceous sandstone. Some samples contain volcanic (basaltic) lithics. Preliminary analyses based on mineralogy alone suggest some of these rocks could be excellent reservoir sandstones. Late Cretaceous to Eocene mudrocks are laminated to non-laminated, calcareous to non-calcareous, very fine sandy mudstones. They are similar to Whangai and Waipawa formations of the northern and eastern North, and eastern South Islands. Affinities can also be drawn with Late Cretaceous to Eocene mudrocks of New Caledonia. Carbonate rocks recovered from TAN1312 are described in a separate talk by Mark Lawrence et al.

A MULTI-PROXY HOLOCENE PALEOCLIMATE RECONSTRUCTION FROM THE SUB-ANTARCTIC AUCKLAND ISLANDS

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Sediment cores recovered from fjords along the eastern margin of the sub-Antarctic Auckland Islands (51°S, 166°E) are well-located to record changes in oceanic circulation and precipitation-induced catchment erosion, related to Holocene variability in the strength and position of the Southern Hemisphere westerly winds. We recovered a 5.75m core from Hanfield Inlet that is composed entirely of brown marine mud and silt, and contains terrestrial organic matter that has been washed in from the fjord catchment. Based on the entrance sill depth of the fjord (10 mbsl), our knowledge of regional sea level rise, and the lack of lacustrine sediments at the base, we infer that the base of the core is early Holocene in age.

Benthic foraminiferal assemblages (125-500µm fraction) in surface and downcore samples are dominated by three species, *Nonionellina flemingi, Cassidulina carinata* and *Quinqueloculina seminula.* These species are either shallow infaunal or infaunal. We will combine a radiocarbon chronology with stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope geochemistry of benthic foraminifera *Nonionellina flemingi, Bolivina* cf. *earlandi, Trifarina angulosa, Bulimina marginata* f. *marginata* and *Cibicides* species (all identified from Rose Bengal stained box-core samples) to reconstruct water column fluctuations associated with frontal migration. These results will compliment bulk sediment C and N concentration and isotope measurements that monitor terrestrial organic matter delivery to fjord sub-basins over the past 12,000 years. We will attempt to track Holocene changes in sea-surface temperature using the $\delta^{18}O$ of planktic foraminifera *Globigerina falconensis* and *Globigerina bulloides,* and by measuring the distribution of alkenones produced by coccoliths identified in sediment core smear slides.

THE EFEFCT OF UNCERTAINTY IN EARTHQUAKE FAULT PARAMETERS ON THE MAXIMUM WAVE HEIGHT OF A TSUNAMI

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We have run several thousand tsunami propagation models in order to determine the effect of uncertainty in an earthquake's rupture parameters (specifically strike, dip, rake, depth and magnitude) on the maximum wave height of the tsunami that it creates. We have shown that even for the simple case of a tsunami propagating over flat bathymetry, the Coefficient of Variation (CoV) of the maximum wave height was a complex function of the choice of rupture parameter, distance and azimuth. For example, if the strike of the fault was varied, the CoV was at maximum on either side of the tsunami beam, but if the dip was varied the CoV was at a maximum along the strike of the rupture. We then created maps of the skewness of the distribution of the maximum wave height. They also showed a complex dependence on the choice of the rupture parameter, azimuth and distance. Finally, we have examined the effect of a realistic bathymetry on CoV and skewness by mapping them for three hypothetical earthquakes on different types of subduction zones (Kermadec, Java and the Solomon Islands). These examples showed that the areas of shallow bathymetry in either the local or far field can also make a significant difference to both the CoV and skewness of the distribution of maximum tsunami wave heights at a point.

COMPOUND-SPECIFIC D/H RATIOS OF LIPID BIOMARKERS AS A PROXY FOR HOLOCENE CLIMATE AND HYDROLOGY, FIORDLAND, NEW ZEALAND

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The latitudinal position and strength of the Southern Hemisphere westerly winds (SHWW) plays a critical role in global CO_2 air-sea flux and the distribution of rainfall in the southern mid-latitudes. Strengthening and southward shifting westerlies are thought to be reducing the efficiency of the Southern Ocean carbon sink, which has direct implications for modern atmospheric CO_2 concentrations. Southern New Zealand intersects the northern margin of the SHWW belt, where a direct relationship exists between annual precipitation and zonal wind speeds. Reconstructing past hydrological variations from the southwest of the South Island (SWSI) can provide a regional record of climatic response to changing SHWW. A 5.4 m sediment core spanning the last 11.5 ka was recovered from South Mavora Lake, Southland. Magnetic susceptibility, bulk organic C and N isotopes and concentrations, and lipid biomarker (C_{21}-C_{33} *n*-alkanes) concentrations, distributions, and hydrogen isotope values (δD) serve as proxies for change in lacustrine productivity, relative proportions of terrestrial and aquatic input, and hydrology. Modern meteoric water isotope values ($\delta^{18}O$, δD) collected over a

12-month period show 3‰ summer and winter seasonality in SWSI, providing a modern-day assessment of isotopic response to climate. Downcore interpretation of data suggests a period of increased precipitation, rapid warming, and greater autochthonous input from 10.2-9.0 ka. From 9.0-4.6 ka, elevated *n*-alkane concentrations indicate increased terrestrial input, increased aquatic productivity, and a warm/relatively humid climate. From 4.6 ka to present a predominance of long-chain *n*-alkanes, declining $\delta^{13}C_{org}$ and magnetic susceptibility, and increasing C/N values, signal decreased precipitation and lake productivity that may be associated with late Holocene cooling. We will present these findings along with ongoing work measuring the δD of intermediate (C_{21}-C_{27}) and long-chain (C_{29}-C_{33}) *n*-alkanes. These results will allow reconstruction of lakewater evaporation and help provide a record of westerly driven hydrological change in SWSI.

IMPROVING ENVIRONMENTAL RECONSTRUCTIONS – A CASE STUDY FROM POST-GLACIAL SW PACIFIC OCEAN

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Modern observations together with palaeo-reconstructions provide insights into the mechanisms and outcomes of polar/tropical influences in the SW Pacific since the Last Glacial Maximum (LGM). During the LGM, Subantarctic and Polar fronts of the Antarctic Circumpolar Current (ACC) migrated north towards the Tasman Sea concomitant with shifts of the Subtropical and Tasman fronts. This was a response to shifting westerly zonal winds under evolving pole-equator temperature gradients. Off eastern NZ that migration was influenced by the regional bathymetry. ACC fronts compressed against the western boundary presented by Campbell Plateau to strengthen the ACC and an offshoot that passed through a gap in the western boundary to enhance the cyclonic Bounty Gyre and form a jet along the eastern North Island. As a result, subantarctic surface waters dominated the upper ocean facilitated by a weakened and possibly diverted subtropical inflow to northernmost NZ. As zonal westerlies returned south, polar influences declined and the subtropical inflow via the eastward Tasman Front and to a lesser extent, the Subtropical Front, dominated the Holocene Optimum.

That trend of polar contraction and tropical expansion continues today, but probably at an accelerated rate in response to temperature gradients affected by greenhouse gases and the "ozone hole". Since the 1940s, observations show a marked expansion of the subtropics as westerly storm tracks shift south and the South Pacific Gyre spins up. Off eastern Australia, the extension of the East Australian Current strengthened over 350km southward resulting in the subtropical colonisation of previously subantarctic habitats off Tasmania. Those Australian developments potentially reduced the Tasman Front inflow but that may be offset by an increase in the Subtropical Front linking Tasmania with southernmost New Zealand, as evinced by reconstructions of the last interglacial period. Despite the ongoing subtropical expansion, Antarctica maintains a strong influence on modern NZ climate as far as the central North Island.

SHEAR-WAVE AUTOMATIC PICKING AND ANISOTROPY MEASUREMENT AT RUAPEHU VOLCANO

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An automatic shear-wave picking program and an automated shear-wave splitting measurement tool (MFAST) are combined to build a possible near-real time application for monitoring local stress fields around volcanoes. Over-pressured magma chambers underneath volcanoes can change stress on the surrounding ground, leading to changes in the anisotropic structure of the rock and shear-wave splitting. Monitoring the stress evolution in time could be a key element of eruption forecasting. Here we present a fully automatic system using an adapted version of Diehl et al. [2009] shear-wave picking program on seismograms provided by the New Zealand GeoNet catalogue and having an origin time and location based only on P picks. The best automatic picks are processed by MFAST which computes the corresponding shear-wave fast direction *fast*, and splitting delay time δt, interpreted respectively as the principal direction of stress underneath the station and the amount of anisotropy integrated

along the wave ray-path. We applied our system to nine years of local earthquakes recorded at seven stations around Ruapehu volcano, New Zealand. Results are compared against MFAST measurements coming from manual S picks when available and show less than 10° difference for 90% of *fast* measurements and less than 0.05 s difference for 95% of δt measurements. Shear wave splitting from automatic S arrival times are slightly more consistent than those from manual arrival times. Nine years display of δt values shows a possible cycle-skipping behavior and a strong correlation with the shear-wave initial polarization computed by MFAST.

LOW-FREQEUNCY EARTHQUAKES REVEAL PUNCTUATED SLOW-SLIP ON THE DEEP EXTENT OF THE ALPINE FAULT

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We present our recently developed catalogue of low-frequency earthquakes (LFEs) associated with the deep extension of the transpressional Alpine Fault beneath the central Southern Alps of New Zealand. Our database comprises a temporally continuous 36 month-long catalogue of 8760 LFEs within 14 families derived from data collected on the SAMBA seismic deployment from 2009-2012. To generate this catalogue, we first identify 14 primary template LFEs within known periods of seismic tremor and use these templates to detect similar events in an iterative stacking and cross-correlation routine. The hypocentres of 12 of the 14 LFE families lie within 10 km of the inferred location of the Alpine Fault at depths of approximately 20–30 km, in a zone of high P-wave attenuation, low P---wave speeds, and high seismic reflectivity. The LFE catalogue consists of persistent, discrete events punctuated by swarm---like bursts of activity associated with previously and newly identified tremor periods. LFE rate increases are also detected after large regional earthquakes including the 2009 Dusky Sound (Fiordland), 2010 Darfield (Canterbury) and the larger events in the Christchurch sequence. The magnitudes of the LFEs range between ML – 0.8 and ML 1.8, with an average of ML 0.5. We find that the frequency-magnitude distribution of the LFE catalogue both as a whole and within individual families is not consistent with a power law, but that individual families' frequency-amplitude distributions approximate an exponential relationship, suggestive of a characteristic length-scale of failure. We interpret this LFE activity to represent quasi-continuous slip on the deep extent of the Alpine Fault, with LFEs highlighting asperities within an otherwise steadily creeping region of the fault.

SEISMOLOGICAL CHARECTERIZATION OF THE DFDP-2 DRILL-SITE AND SURROUNDINGS, WHATAROA VALLEY, CENTRAL ALPINE FAULT, NEW ZEALAND

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Detailed analysis of the seismicity and seismic velocity structure of the crust surrounding the central Alpine Fault is being undertaken in conjunction with a broad range of other scientific activities under the auspices of the Deep Fault Drilling Project (DFDP). Real-time analysis of seismicity within c. 20 km of the DFDP-2 drill-site using RTQuake will be performed prior to and during the drilling operations utilising data from a recently telemetered temporary network of seismometers surrounding the drill-site. Additionally, records obtained since 2008 have been re-analysed using standard earthquake detection techniques (sta/lta) and manual picking, and detection via cross- correlation waveform matching. The results of this analysis are being integrated with newly developed P- and S-wave tomographic velocity models to refine hypocenters and

earthquake magnitudes in the vicinity of the DFDP-2 and elucidate spatiotemporal patterns of seismicity. Seismicity near DFDP-2 is sparse and of low magnitude: analysis of seven months' data recorded by an extensive network in 2013 including four shallow borehole seismometers within 1.5 km of the drill-site revealed fewer than 40 earthquakes within 10 km of the DFDP-2 drill-site. Of these, all but two earthquakes (M=2.6 and M=1.7 located c. 6 km northwest and c. 3.5 km north of DFDP-2 respectively) were deeper than 2 km and all but five were deeper than 3 km. Preliminary cross-correlation detection work using 14 template events and one year's continuous data reveals on-going clustered activity. In particular, many newly detected events are observed close to a c. 10 km-deep cluster near Gaunt Creek known to produce fault zone guided waves. This demonstrates that waveform matching works well even when waveform complexity is high and highlights the potential for using repeated earthquakes occurring on or near the Alpine Fault to study temporal changes in fault zone properties late in the earthquake cycle.

SHEAR VELOCITY OF THE ROTOKAWA GEOTHERMAL FIELD USING AMBIENT NOISE

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Ambient noise correlation is an increasingly popular seismological technique that uses the ambient seismic noise recorded at two stations to construct an empirical Green's function. Applications of this technique include determining shear velocity structure and attenuation. An advantage of ambient noise is that it does not rely on external sources of seismic energy such as local or teleseismic earthquakes. This method has been used in the geothermal industry to determine the depths at which magmatic processes occur, to distinguish between production and non-production areas, and to observe seismic velocity perturbations associated with fluid extraction. We will present a velocity model for the Rotokawa geothermal field near Taupo, New Zealand, produced from ambient noise cross correlations. Production at Rotokawa is based on the "Rotokawa A" combined cycle power station estab- lished in 1997 and the "Nga Awa Purua" triple flash power plant established in 2010. Rotokawa Joint Venture, a partnership between Mighty River Power and Tauhara North No. 2 Trust currently operates 174 MW of generation at Rotokawa. An array of short period seismometers was installed in 2008 and occupies an area of roughly 5 square kilometers around the site. Although both cultural and natural noise sources are recorded at the stations, the instrument separation distance provides a unique challenge for analyzing cross correlations produced by both signal types. The inter-station spacing is on the order of a few kilometers, so waves from cultural sources generally are not coherent from one station to the other, while the wavelength produced by natural noise is greater than the station separation. Velocity models produced from these two source types will be compared to known geological models of the site. Depending on the amount of data needed to adequately construct cross-correlations, a time-dependent model of velocity will be established and compared with geothermal production processes.

OCEAN REDOX DYNAMICS DURING THE END-PERMIAN EXTINCTION AND EARLY TRIASSIC RECOVERY

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The Permian Triassic mass extinction is widely regarded as the most severe of the Phanerozoic extinctions. The event was associated with major carbon cycle disruption, not only at the Permian Triassic Boundary (PTB) but also for the entire

Early Triassic. These disturbances are recorded in the $\delta^{13}C$ record of both carbonate and organic carbon, which show a series of positive and negative carbon isotope excursions (CIEs) throughout the Eary Triassic. These fluctuations are also linked to minor extinctions in the Early Triassic and a delay in total species recovery until the Middle Triassic. One leading hypothesis invoked to explain these changes is oceanic anoxia, which provides a kill mechanism that is also potentially linked to observed changes in the carbon isotope record. Multiple anoxic events have indeed been identified in various sections around the world. However the link between the globally recorded CIEs and the development of anoxia is not clear, with no consistent relationship emerging.

Here we present a new record of anoxia from the Arabian platform using Fe-S-C systematics. This mixed sequence of continental margin carbonates and clastics records a shelf to basin transect for the PTB and Early Triassic, which demonstrates the distinct CIEs mentioned above. The use of Fe-speciation in tandem with carbon isotopes places the local record of anoxia in a global context, thus helping elucidate the timing, development and stability of anoxia.

Our data show sustained anoxic, non-sulphidic (ferruginous) conditions across the PTB for both slope and basin settings. Subsequently anoxia appears restricted to the positive CIEs. Here, non-sulphidic conditions were again dominant, which is in contrast to a growing body of evidence indicating euxinic conditions for the PTB. S-isotope systematics provide further insight into controls on the observed environmental conditions at this time. Together, our approach provides a detailed examination of ocean redox variability during this interval of extreme environmental disturbance, thus enabling a greater understanding of C-cycle feedbacks and biological consequences.

UNRAVELLING THE INFLUENCE OF CONTINENTAL LEVERING ON PALAEO SEA-LEVEL CHANGES AROUND NEW ZEALAND

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Recent research has identified previously unobserved complex spatial variations in the timing and magnitude of sea-level changes around the New Zealand coast since the end of the last glaciation. It has been hypothesised that this spatial and temporal variability in sea-level change is driven by the isostatic response to the load placed on New Zealand's continental shelf by meltwater derived from melting ice sheets. This process is known as continental levering.

Following the end of the last glaciation the meltwater from melting ice sheets placed a load on New Zealand's continental shelf. This load caused the shelf to flex downwards, displacing the underlying viscous material of the Earth's mantle. Coastal margins respond to this loading and consequent mantle displacement with complex spatial variability, reflecting the local and regional configuration of the coast and continental shelf. Some locations experience uplift as a result, while other locations experience subsidence. For example: our modelling predicts that in the Manawatu-Wanganui region, as the meltwater-loaded continental shelf was flexed downward, onshore areas above sea level were levered upward by up to 1 m over the past 10,000 years. In contrast, in Northland northerly locations subsided up to 10 m during the past 10,000 years as the tip of the Northland peninsula is surrounded by downward-flexing continental shelf, with the amount of subsidence progressively reducing towards the south. We predict that these complex vertical land movements will contribute considerable spatial and temporal variability to reconstructions of sea-level changes covering the last 10,000 years. While the contemporary effects of vertical land motion on sea-level change have been investigated, the effects on sea-level changes over the past 10,000 years are very poorly understood, and are often not accounted for.

SEDIMENTOLOGY OF THE PAPAROA COAL MEASURE LACUSTRINE MUDSTONES: IMPLICATIONS FOR SYN-DEPOSITIONAL TECTONICS

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Sedimentary facies analysis was undertaken on the lacustrine mudstones of the Greymouth Coalfield with a specific focus on the northwest section of the coalfield.

Sedimentology of the mudstones and surrounding transitional facies outlined the discrepancy between current models of the basin and interpreted field observations. On the northwestern margin of the coalfield, the Rewanui and Dunollie Coal Measures consist of over 1000m of cobble to boulder conglomerate with large mudstone rip up clasts at the basal contact between the Rewanui Coal Measures and the Waiomo Mudstone. The Goldlight Mudstone, classified as a massive mudstone in the central part of the coalfield up to 150m thick, here grades laterally into the Rewanui Coal Measures with the occurrence of mouth bar and debris flow deposits, coupled with thin turbidites. At this same location, the Waiomo Mudstone displays abundant turbidites and conglomerate lenses as well as occasional drop stones found near the top of the section.

Conversely, on the eastern margin there is a lack of thick conglomerate and the Goldlight and Waiomo mudstones instead grade to coal and carbonaceous claystone with the presence of organic rich siltstone and occasional laminae inferred to be from low gradient turbidites. TOC and HI results have shown that the mudstones can have high organic material within them, indicating that the lakes were stratified and leading to the preservation of organic material.

This evidence suggests that alluvial fan deltas with occasional debris flows infilled the lake to the west while the eastern margin was dominated by marshy shorelines and small deltas from meandering rivers. This leads to an interpretation of a highly asymmetrical lake where the western margin is significantly steeper than the eastern margin. This suggests that the steeper side of the basin was also to the west rather than the east.

CONSTRUCTING AN ALPINE FAULT PALEOSEISMICITY RECORD FROM SLUMPED LACUSTRINE DEPOSITS IN THE CASCADE RIVER VALLEY, SOUTH WESTLAND, NEW ZEALAND

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Extending along the West Coast from offshore Caswell Sound to the Matyr River, the Southern Alpine Fault has the potential to produce major earthquakes of magnitude 7 or greater during dominantly strike-slip motion. Paleoseismic records of these earthquakes indicate recurrence intervals of 300 – 400 years over the last 1,300 years. The tectonically complex Cascade River Valley follows the trace of the fault. In the valley two outcrops of proglacial lacustrine silt are exposed along the river, within which, deformed (folded) rhythmites bound by planar laminated rhythmites have been identified.

Initial radiocarbon ages of 14,400 and 13,300 ^{14}C yr BP have been obtained from terrestrial plant material isolated from samples near the base of one outcrop. Given the age range and laminae density, these dates suggest that the rhythmites are varves, but additional radiocarbon dates and CT-scans will be used to confirm this. Radiocarbon ages linked with varve counting will be used to determine the timing and recurrence interval of earthquake events during this period.

Outcrop observations and x-ray computed tomography (CT) have shown a variety of fold geometries, all of which show some degree of asymmetry. Deformed horizons are interpreted to be seismites formed by slumping. Earthquake shaking triggers an increase in pore fluid pressure, which destabilises the submarine slope causing failure and the release of silt into the sedimentary system. As silt is transported by downslope shear it is deformed in distinct layers. Displacement of volumes of silt into the basin also causes the formation of seiche waves that apply shear stress to lake floor sediments causing further deformation. Deviations in magnetic susceptibility and magnetic remanence declination observed underneath and within deformed horizons may also be a result of earthquake shaking. Data from these different proxies will be presented and

compiled to generate a record of earthquake shaking from the Southern Alpine Fault.

EXPLORATION OF FORMER AVIAN BIODIVERSITY THROUGH ANCIENT DNA PRESERVED IN EXCAVATED BULK-BONE

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Understanding the role of human colonisation on island biodiversity can be useful for understanding the tempo and mode of extinction processes. Fossils from small-bodied fauna including birds and fish are often fragmentary and difficult to identify, however these taxa likely made up a large proportion of subsistence diet. Taxonomic identification may be aided using Ancient DNA techniques. For example, when collectively pooled for extraction as a bulk-bone sample, the DNA of morphologically unidentifiable bones may be sequenced to reveal valuable phylogenetic or taxonomic information. This study presents bulk-bone metabarcoding data from several New Zealand and Hawaiian sites, with aims to reveal unrepresented and rare small-bodied fauna, clarify avifauna biodiversity loss and compare assemblages over time. Our results reveal extinct, extirpated and endangered taxa. Results can be useful in interpreting faunal responses to human colonisation, how humans historically used the landscape, understand extinction and reintroduction events and infer how biodiversity responded to anthropogenic influences.

THE GEOLOGY OF PEGASUS BASIN BASED ON SEISMIC DATA, WITH INSIGHTS FROM OUTCROP CORRELATIVES IN SOUTHERN WAIRARAPA AND NORTHEASTERN MARLBOROUGH

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Acquisition of high quality 2D seismic data by the New Zealand Government in 2009-10 (the PEG10 Survey) sparked new interest in Pegasus Basin, an offshore frontier basin situated east of central New Zealand.

Covering an area of at least 75,000 km^2, the basin developed as a contiguous entity with the East Coast and Raukumara basins along the Gondwana subduction margin during Permian to mid-Cretaceous time, only becoming a separate physiographic feature since inception of the modern plate boundary at the start of the Neogene. The basin fill comprises Early Cretaceous syn-tectonic strata overlain by up to 8000 m of Late Cretaceous – Recent passive margin rocks. What differentiates the Pegasus from other basins is a lack of Neogene convergent tectonic overprint and relatively little deformation.

Although no wells have been drilled in the Pegasus Basin, strata exposed onshore in southern Wairarapa and eastern Marborough provide useful analogues for the sedimentary fill of the basin.

Using field observations including measured sections, detailed description of sedimentary features and sample collection for reservoir petrology, in combination with seismic interpretation of the PEG10 survey, this study provides a more complete understanding of the geology of the Pegasus Basin. Reservoir petrology of appropriate geologic facies will shed light on provenance and quality of strata that may be found offshore, and identified in seismic.

Initial petrographic analyses of sandstones from Glenburn Formation (Late Cretaceous), Mungaroa Limestone (Paleocene), the Whakataki Formation (Early to earliest Middle Miocene) have revealed that intergranular porosity (estimated visually) is highest in Neogene sandstones, and is lacking within Cretaceous and Paleogene sandstones, which do have minor fracture porosity.

Mapping indicates up to 1700ms TWT of Miocene – Recent sediments overlying a bright amplitude reflector interpreted to represent Oligocene carbonates.

IN SITU COSMOGENC ^{10}BE IN PYROXENES

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Cosmogenic nuclides provide an efficient way to quantify many Earth surface processes. Terrestrial cosmogenic nuclides are produced from the interaction of secondary cosmic radiation with target atoms in Earth materials. These cosmogenic nuclides accumulate over time and allow us to calculate how long a rock or land- surface has been exposed at the Earth's surface, independent of the crystallisation age of the rock. One of the most commonly used systems is ^{10}Be produced in-situ in minerals from the interaction of cosmic rays with oxygen. Meteoric ^{10}Be is produced in the atmosphere by the same production reactions, and can be strongly adsorbed onto mineral surfaces. In order to calculate accurate in-situ cosmogenic ^{10}Be exposure ages, it is essential to remove the contribution from meteoric ^{10}Be. While this is relatively simple for quartz, reliable methods have not been designed for most other minerals.

We adapt a cleaning method proposed previously [1] to remove the meteoric ^{10}Be from pyroxene grains, allowing calculation of accurate in-situ produced ^{10}Be exposure ages for mafic rocks. We have tested this method using pyroxenes from an already dated glacial moraine on Mt. Ruapehu on the North Island of New Zealand.

Our results will open new avenues for in-situ cosmogenic ^{10}Be dating, which have previously relied predominantly on quartz, rather than pyroxenes that are subject to weathering in the surficial environment. Using this pyroxene cleaning method, the minerals are crushed small enough to expose the pits that contain the meteoric ^{10}Be, allowing us to leach it out. Because pyroxenes contain more major cations than quartz, standard separation techniques cannot be employed. We have optimised cation exchange chemistry for the larger cation masses of the mafic minerals. This method provides a useful terrestrial cosmogenic nuclide system to incorporate into cosmogenic exposure age studies in mafic settings.

[1]Blard et al. (2008). Quaternary Geochronology 3, 196-205.

DOES MY POSTERIOR LOOK BIG IN THIS? THE EFFECT OF PHOTOGRAPHIC DISTORTION ON MORPHOMETRIC ANALYSES

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Geometric morphometric studies often use photographs to capture raw shape information, rather than directly measuring specimens. Digital photographs (theoretically) provide a consistent data-collection method, and can be readily distributed to researchers worldwide. However, photographs of objects are not necessarily perfect representations of them. A camera lens distorts the image when a photograph is taken, and the extent of the distortion will depend on factors such as the make and model of the lens and camera, and user-controlled variation such as the zoom of the lens, aperture, and shutter speed. Any morphometric study that utilises data digitised from a photograph will therefore have shape variation introduced to the dataset simply by the photography. The shape variation introduced is systematic and predictable and, if not accounted for, can lead to misleading results, suggest clustering of specimens in ordinations without biological basis, or induce artificial over-splitting of taxa. Here, we illustrate the nature and magnitude of the error that can be generated within a 30-specimen dataset of Recent New Zealand Mactridae (Mollusca; Bivalvia) using only a single camera and camera lens (Nikon D800, Nikkor 24-85 mm *f*2.8-4.0). We provide recommendations for ways of better quantifying, reducing, and correcting this error.

NEW TOOLS, OLD SHELLS: SYNCHROTRON MICRO-CT RECONSTRUCTION APPLIED TO THE PALAEOBIOLOGY OF CRETACEOUS-PALEOGENE OSTRICH-FOOT SNAILS (GASTROPODA, STRUTHIOLARIIDAE)

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Biological shape reflects ancestry, ecology, and life habits, making shape analysis (morphometrics) of fossils relevant to many fields of geoscience, including biostratigraphy, phylogenetic analysis, evolutionary studies, and palaeoenvironmental analysis. In animals such as molluscs, which grow by adding new shell without destroying earlier-formed shell, shape analysis can also reveal details of growth and development. However, the capture of shape information can sometimes be challenging, particularly when specimens of interest are not conveniently flat and two-dimensional. Snails are extremely common fossils, with both biostratigraphic and palaeoenvironmental utility; but their shape variation is hard to capture in a consistent, systematic way.

Struthiolariid snails are morphologically variable and have an interesting evolutionary history, as they appear to have originated in New Zealand and spread around the Southern Hemisphere in a number of discrete colonisation events. Untangling the aspects of their shape that are heritable and indicative of phylogeny from those that are moulded by immediate environment is not a trivial problem. Compared to external morphology, internal shell features are likely to be relatively conservative and may provide important new data for evolutionary analyses. External morphology is acted upon by the environment and may be useful as a palaeoenvironmental indicator. Even when the specimen is optimally preserved with a complete shell, capturing the internal and external shapes of an organism that grows in a spiral fashion, and is full of sediment, is difficult. High-resolution micro-computed X-ray tomography is a potential solution, allowing the digital reconstruction not only of the external shell, but also of the internal matrix-filled space where the animal lived. These shape data can then be analysed using the quantitative tools of morphometrics.

In this paper we present preliminary results and images from work undertaken at the Australian Synchrotron to illustrate the potential of this method as a tool for palaeobiological research.

NEW ZEALAND LATE EOCENE FLORAS – WAIAU AND BALLENY BASINS, WESTERN SOUTHLAND

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Sites such as Messel and Eckfeld provide remarkable windows through which to study both plant and animal life in the Northern Hemisphere during the Eocene. Now, Middle to Late Eocene sites in New Zealand and Australia are providing a view of Southern Hemisphere high-latitude mesoforests from lake and river deposits and extensive coal deposits representing Eocene swamps. Although there are few animal fossils from these deposits, Late Eocene sites in southern New Zealand at a paleolatitude of ~50^{o}S indicate high floristic diversity. At Pikopiko, a petrified *in situ* forest includes leaf beds containing diverse fern macrofossils, suggesting that they dominated the understorey in the Eocene just as they do in modern New Zealand forests. The macrofossils are dominated by Lauraceae and Myrtaceae, but there is also a range of tree species and several palms, including a *Calamus*-like rattan, but no *Nothofagus* leaves. Fossil pollen at the site includes Casuarinaceae, Sapindaceae and Euphorbiaceae, together with several Proteaceae and *Nothofagus* (*Fuscospora* and *Brassospora*) pollen types. Abundant associated fossil epiphyllous fungi also provide evidence for high, year-round rainfall and a relatively warm and humid climate. In contrast, largely coeval floras near Puysegur Point (Balleny Basin, southwest Fiordland) and Blackmount (Waiau Basin), although similarly diverse, contain abundant *Nothofagus* macrofossils (both deciduous and non-deciduous leaf forms), together with several species of Lauraceae and a range of other rainforest families. This indicates

that there was regional diversity and heterogeneity in the floras despite apparently relatively uniform low paleo-topography. When incorporated with paleoclimate evidence from the Northern Hemisphere, these southern New Zealand sites show that floras with mesothermal characteristics persisted at high paleolatitudes until the Late Eocene.

LAVA-ICE INTERACTION ON A LARGE COMPOSITE VOLCANO: A CASE STUDY FROM RUAPEHU, NEW ZEALAND

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Ice exerts a first-order control over the distribution and preservation of eruptive products on glaciated volcanoes. Defining the temporal and spatial distributions of ice-marginal lava flows provides valuable constraints on past glacial extents, and is crucial for understanding the eruptive histories of such settings. We present a case study of effusive ice-marginal volcanism from Ruapehu, a glaciated andesite-dacite composite cone in the southern Taupo Volcanic Zone, New Zealand.

Flow morphology, fracture characteristics and $^{40}Ar/^{39}Ar$ geochronological data indicate that lavas erupted between *ca*. 51 and 15 ka interacted with large valley glaciers on Ruapehu. Ice-marginal lava flows exhibit grossly overthickened margins adjacent to glaciated valleys, are intercalated with glacial deposits, and are commonly ridge-capping due to their exclusion from valleys by glaciers. Fracture networks produced via interaction with ice and associated meltwater define the margins of these lava flows. New and existing $^{40}Ar/^{39}Ar$ eruption ages for ice-marginal lava flows indicate that glaciers extending to 1300 m above sea level were present on Ruapehu between 51–41 ka and 27–15 ka.

Younger lava flows located within valleys are characterised by blocky flow morphologies and fracture networks indicative of only localised and minor interaction with ice and/or snow, especially in their upper reaches at elevations of 2600–2400 m. Based on regional paleoclimate reconstructions that indicate rapid warming from *ca*. 18 ka, valley-filling lavas are interpreted as post-glacial flows that were emplaced after glaciers had largely retreated. An $^{40}Ar/^{39}Ar$ eruption age of 9 ± 3 ka (2σ error) determined for a valley-filling flow on the northern flank of Ruapehu indicates that glaciers had retreated to near-historical extents by 12 ka.

THE MORPHOLOGY AND PHYLOGENY OF THE MOST COMPLETE KEKENODONTID, OU 22294, WITH OBSERVATIONS ON THE FEEDING ECOLOGY OF LATE OLIGOCENE ARCHAECOETES

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Kekenodontids represent a group of Late Oligocene enigmatic toothed whales from the Waitaki region, New Zealand. Until recently, the family Kekenodontidae included only one species, *Kekenodon onamata*, based on fragmentary material. This, and a lack of more complete specimens, led to taxonomic ambiguity: do kekenodontids belong within the paraphyletic Archaeoceti (primitive toothed whales) or in the Neoceti (Odontoceti, Mysticeti)? OU 22294 represents an informative new species of kekenodontid, and includes a nearly complete skull, both periotics, teeth, a fragmentary mandible, and associated postcrania from the Kokoamu Greensand of Awamoko Valley. Phylogenetic analysis identifies OU 22294 as a sister-taxon to the Neoceti, making it the latest-diverging archaeocete. Past research showed that the more-basal basilosaurid archaeocetes went extinct around the Eocene/Oligocene boundary, possibly from competitive displacement by early Neoceti. Kekenodontids now represent the first recognized Oligocene archaeocetes, which lived well past the first appearance of Neoceti. Further, fossil odontocetes and mysticetes occur with kekenodontids in the Kokoamu Greensand, raising questions about niche partitioning between the three groups. Primitive features of the skull and dentition in OU 22294 suggest a macrophagous raptorial form of predation as in basilosaurids, whereas odontocetes and mysticetes had more-derived feeding strategies (echolocation and filter-feeding, respectively). However, some features in OU 22294 (such as a less-attenuated rostrum and wider-spaced cheek teeth, and published isotopic data from tooth enamel) suggest feeding on multiple, smaller prey items at a low trophic level.

Microwear analysis should elucidate the extent to which OU 22294 pierced and grasped its prey, or filter-fed in a manner similar to the crabeater seal (*Lobodon carcinophaga*). If demonstrated in OU 22294, this would represent a third instance of filter-feeding in marine mammals, in addition to mysticetes and lobodontine seals.

WHO IS EDUCATING WHO? SMALL-SCALE DELIBERATIVE ENGAGEMENT WTH THE TARANAKI COMMUNITY AROUND THE HYPOTHETICAL SITING OF A CARBON CAPTURE AND STORAGE FACILITY (CCS)

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Carbon Capture and Storage (CCS) is relatively new to the portfolio of responses to climate change, and is still earning its 'social licence to operate'. It is associated with a number of public perceptions of risk, such as the vulnerability of storage sites to seismic events, catastrophic leakage and groundwater contamination. As yet, there are no plans to deploy the technology in New Zealand, but the Taranaki region would be a likely region for CO_2 storage, due to its oil and gas industry, potential storage reservoirs, and skilled local workforce. This provided an opportunity for very early, small-scale deliberative engagement with local stakeholders (urban community, farmers and landowners, local iwi, local/regional council, and the oil/gas industry) in May-June 2013.

This paper analyses the value of this engagement process for upstream conflict identification and problem-solving. After a focus on the local context, climate change and energy, single-stakeholder group discussions pivoted around a future fictional scenario. An introduction to CCS was followed by the opportunity for participants to conduct their own research and participate in self-guided question-and-answer sessions with a GNS scientist, before producing a 'group viewpoint'. The project culminated in a final small-scale, multi-stakeholder deliberative forum, where group representatives were involved in solution-focused decision-making around risk, information/communication needs and risk management. Whilst the scientists were acknowledged 'experts' in their field, all participants in the research could be termed what Collins and Evans (2001) called 'experience-based experts', both in their respective vocational fields and the complex geography of the local region. With an emphasis on listening as well as talking, the engagement process was an opportunity for mutually-based learning from all parties involved, from which emerged a set of ways to move forward in the event of the need for CO_2 storage arising in this region.

MANTLE GEOCHEMISTRY BENEATH SOUTH WESTLAND, NEW ZEALAND: A STUDY ON PERIDOTITE XENOLITHS FROM HAAST PASS

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Peridotite xenoliths entrained in alkaline magmas can preserve a record of processes that affected them in the lithospheric mantle. In the Burke River in the Haast area, the Alpine Dike Swarm entrained a variety of spinel facies peridotites that are predominantly of harzburgite composition. A large proportion of the spinels in these rocks form distinctive orthopyroxene-clinopyroxene symplectites and represent the decompression of garnet peridotite followed by equilibration in the spinel facies at some point in the past. Spinel Cr# and olivine Mg# indicate that high degrees of partial melting removed essentially all of the primary clinopyroxene, and likely some of the orthopyroxene, in these peridotites. However, the mantle has been overprinted by metasomatism, with two types inferred from the geochemistry of secondary clinopyroxene. The first type, affecting most of the peridotites, is carbonatite metasomatism as indicated by low Ti/Eu, high Th/U and high LREE of the clinopyroxene. The second event, only affecting some peridotites, is silicate metasomatism as indicated by high Ti and LREE concentrations in clinopyroxene. As the peridotites were devoid (or very close to devoid) of clinopyroxene prior to metasomatism, the isotopic ratios of these grains should closely represent the composition of the metasomatic agents. Clinopyroxene radiogenic isotopes are comparable to that of the HIMU mantle reservoir. HIMU-like ratios have also been recorded in the host Alpine Dike Swarm, which suggests that the dike swarm could share a similar source to the metasomatic agent, or could be derived from melting of the HIMU-enriched mantle lithosphere.

MICROSTRUCTURAL EVOLUTION OF CALCITE FAULT GOUGE DEFORMED IN EARTHQUAKE-LIKE LABORATORY EXPERIMENTS

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Earthquakes often rupture through carbonate rocks in the upper crust, It is important to understand microstructures produced during faulting in carbonate rocks to help to identify the mode in which particular carbonate-bearing faults may have slipped in the past (i.e. seismically during an earthquake or aseismically during creep). This is relevant for earthquake hazard analysis and it is also an important first step in using fault rock microstructures to quantify fault mechanical behaviour (e.g. dynamic stresses, frictional heal anomalies).

This study involves a microstructural analysis of calcite fault gouges experimentally-deformed under "earthquake-like" conditions (slip velocity <1 ms^{-1}; displacements <5 m; normal stresses < 30 MPa). The specimens were deformed in the Slow to High Velocity Rotary-Shear frictional Apparatus (SHIVA) at the INGV, Rome. Three samples made of pure calcite gouge were analysed in this work. The samples were deformed in a ring-shaped (external/internal diameters of 55 mm and 35 mm) gouge sample holder. Scanning Electron Microscope images were collected of the three deformed samples using polished thin sections cut approximately parallel to the slip direction and perpendicular to gouge layer boundaries. Using representative SEM images, grain boundaries were manually traced and grain boundary maps were analysed using Image SXM.

Three distinct microstructural domains were identified in the deformed calcite gouges; 1) plastically deformed layers of gouge recrystallization, 2) transitional layers with partial recrystallization and 3) brittly deformed layers. The plastically deformed layer becomes thicker with increasing mechanical work (and heating) and grains also evolve in this layer to become more elongate and aligned parallel to gouge layer boundaries, resembling calcite mylonites in higher-temperature creep experiments. Grain sizes in the plastically deformed layer generally decreases as slip rate increases, but the data indicate some late stage grain growth and polygonizaltion, probably reflecting grain annealing immediately following the experimental slip pulses.

MICROSTRUCTURAL AND THERMOBAROMETRIC CONSTRAINTS ON ALPINE FAULT ZONE KINEMATICS AT MID-CRUSTAL DEPTHS

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Despite an inference of nominally steady-state deformation in many ductile shear zones, mylonitic rocks commonly contain heterogeneity in the form of compositional layering, grain size variation and the presence of rigid porphyroclasts. In this contribution, we analyse the link between rheology, kinematics and microstructure in mylonitic samples containing quartz layers deflected around garnet porphyroclasts during ductile deformation at mid-crustal depths in the Alpine Fault Zone. We present data from optical analysis of quartz microstructures, grain size and CPO quantification by electron backscatter diffraction (EBSD) and titanium-in-quartz (TitanIQ) thermobarometry. During shearing around rigidly rotating garnet porphyroclasts, quartz undergoes progressive grain size reduction in response to a local increase in stress and strain rate. C-axis maxima rotate around the kinematic vorticity axis and record a local increase in the ratio of simple to pure shear, leading to an increase in the asymmetry of quartz c-axis pole figures.

Ti concentrations reveal quartz deformation temperatures in the range of 500°C, which we propose record the cessation of grain boundary migration during exhumation. Owing to the rapid rates of microstructural change in quartz observed in this study, we propose a modified geotherm for the central Alpine Fault Zone, in which a transition in the geothermal gradient occurs at 11 km depth to place the 500°C isotherm at the brittle-ductile transition. We conclude that microstructures in layers deflected around rigid porphyroclasts can provide valuable information on deformation kinematics in ductile shear zones.

BUILDING GEOLOGICAL MODELS OF NEW ZEALAND'S PEGASUS BASIN AND ITS GAS HYDRATE SYSTEM: TOWARDS A BETTER UNDERSTANDING OF GAS HYDRATE FORMATION PROCESSES

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The Pegasus Basin, on the southern end of New Zealand's Hikurangi margin, developed as a passive margin from the end of subduction along the Chatham Rise around 105 Ma to the initiation of the modern plate boundary around 25 Ma. Seismic reflection data acquired in 2009 and 2010 show well-developed bottom-simulating reflections (BSRs) throughout the basin and also indications for deeply-sourced fluid migration.

We have used the seismic data, together with previously published age constraints, to identify and map key stratigraphic horizons from the ancient subduction margin on the East, through the sedimentary basin, and up onto the modern subduction margin on the West. Although the lines are sparsely spaced across the basin, key stratigraphic horizons can be traced with confidence throughout the basin. We have used BSRs to map the extent of the gas hydrate system throughout the basin. Together, these chronostratigraphic interpretations and gas hydrate indicators are enabling us to construct a 3D geological model of the basin that will be converted to depth using seismic velocities from the available data. The geological model will provide the basis for modelling fluid flow processes through the basin and ultimately to simulate gas hydrate formation using Petromod. We will present the latest results of this project and outline the implications for gas hydrate formation in the Pegasus Basin.

GEOCHEMISTRY OF AUCKLAND ISLAND LAKE SEDIMENTS: RECORDING LATE HOLOCENE CHANGES IN THE SOUTHERN HEMISPHERE WESTERLY WINDS

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The Southern Hemisphere Westerly Winds (SHWW), a zonal wind field in the Southern Hemisphere mid-latitudes, are one of the primary controllers of air-ocean CO_2 flux in the Southern Ocean. As the winds shift poleward and intensify, upwelling of CO_2-rich deep ocean water is enhanced, and the ocean's role in reducing the rate at which anthropogenic CO_2 accumulates in the atmosphere is diminished. Furthermore, the strength and latitudinal position of the SHWW control storm tracks in the Southern Hemisphere and directly influence precipitation patterns in the South Island of New Zealand. However, past variability of the SHWW is poorly understood. Tracking past changes in the winds across a range of Southern Hemisphere latitudes could help to infer potential future changes in the wind field due to rising global temperatures. There are few terrestrial records of past SHWW variability, particularly at Sub-Antarctic latitudes where landmasses are scarce and the modern westerly maximum is located. Lake sediment cores from the Auckland Islands (50°S) provide an opportunity to study Holocene SHWW variability in this crucial gap. A high-resolution record of recent environmental change on the Auckland Islands has been compiled from short sediment cores from three lakes using multiple physical and geochemical methods. The sediments collected are diatom- and plant macrofossil-rich and contain no carbonate. Biogenic silica wt.% varies between 5-20%. Physical properties measured using a Geotek core logger include p-wave velocity, gamma density, magnetic susceptibility, and colour spectrophotometry. We will discuss downcore variations in bulk stable carbon and nitrogen isotopes, wt.% biogenic silica, n-alkane distributions, and compound-specific hydrogen isotopes, and how these changes relate to SH climate during the latest Holocene. Ultimately, these sediment records will provide a useful comparison to lake and fjord records from the South Island, allowing us to build a regional perspective of Holocene shifts in the SHWW.

THE ANITA ULTRAMAFICS: AN ULTRA-DEPLETED SLICE OF NEW ZEALAND'S SUBCONTINENTAL LITHOSPHERIC MANTLE

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New Zealand's lithospheric mantle is relatively old and compositionally heterogeneous, with fertile and depleted domains that have early histories decoupled from the overlying Palaeozoic-Tertiary continental crust. Our contribution has been to study the Anita Ultramafics – a *c.* 1 km wide x 20 km long and remarkably fresh orogenic peridotite massif located close to Milford Sound in the mountains of Fiordland. The unit is composed of porphyroclastic dunite and harzburgite. Spinel-pyroxene symplectites indicate the former presence of garnet peridotite, although the massif now contains spinel facies assemblages. Several geochemical traits indicate extensive melt extraction (olivine Mg# ≈ 92.5, spinel Cr# ≈ 70, orthopyroxene maximum Al_2O_3 ≈ 1 wt%), and a composition very similar to cratonic lithosphere. Such extreme melting likely requires the fluxing of peridotite by hydrous fluid to lower the local solidus. The Anita Ultramafics are therefore interpreted to be depleted residues from extensive melting in the mantle wedge above a subducting slab.

Despite its depleted composition, the peridotite massif has been subtly metasomatised. Abundant hydrous minerals (hornblende, tremolite, chlorite, talc, bowenite) indicate interaction with water-bearing fluids. Some of these minerals represent hydration during exhumation (tremolite, chlorite, talc and bowenite), but hornblende appears to represent an earlier metasomatic event. We constrained the nature of this initial metasomatism using mineral trace element and Sr, Nd, Pb and Hf isotopic analysis. Coupled Eu and Sr positive and negative anomalies indicate the influence of plagioclase, despite this mineral being absent. We suggest that this ultramafic massif records a tectonic history involving decompression from garnet facies to spinel-plagioclase facies, with a loss of plagioclase via melting, and then final exhumation.

WHAT LIES BENEATH? THE GEOCHEMICAL EVOLUTION OF THE EAST OTAGO MANTLE

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Harzburgitic and lherzolitic mantle xenoliths entrained in the Miocene by the alkali basalts of the Dunedin Volcanic Group and emplaced in East Otago, New Zealand, have 'locked-in' the intricate history of the sub-continental lithospheric mantle (SCLM). Geochemical analysis of 36 peridotite samples from three neighbouring localities in East Otago reveals a remarkable degree of heterogeneity within the SCLM. Different realms of the SCLM have experienced diverse degrees of depletion by partial melt extraction and this has been followed by, in some cases significant, light rare-earth element (LREE) enrichment. Interrogation of clinopyroxene trace element geochemistry suggests mantle metasomatic processes are responsible for this enrichment, with carbonatite melts the most likely metasomatic agent, while the influence of silicate melts cannot be ruled out. Radiogenic isotope systematics (Sr, Pb) indicate the East Otago SCLM has an enriched HIMU-like composition similar to the alkali basalts erupted during Cenozoic intraplate volcanism. Samples which have experienced the greatest degree of metasomatism have a narrow isotopic range compatible with HIMU-like compositions. It is suggested here that the HIMU-like signature observed in the East Otago SCLM is of metasomatic origin. Based on orthopyroxene-clinopyroxene trace element equilibrium diffusion modelling it is thought that this metasomatic event occurred at least 100 Ma ago, while Zealandia was contiguous with Gondwana. The presence of HIMU-like isotopic signatures in the mantle beneath West Antarctica and Eastern Australia may indicate a pervasive metasomatic event with a common HIMU-like metasomatic agent.

BUILDING A HIGH-RESOLUTION DISTAL TEPHRA RECORD FROM MULTIPLE SITES AROUND MT. TARANAKI, NORTH ISLAND, NEW ZEALAND

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Based on new coring at four new sites in northern and eastern Taranaki, and an integration of past coring, analysis and dating studies, this project aims to produce the most detailed eruption record yet for Mt. Taranaki. With sites containing sedimentation records spanning from 36,000 years to the present, we have already built one of the longest high-resolution volcanic eruption records from any volcano in the world. Here we present the latest results from new coring sites collected over the last 12 months. Swamps and present and paleo lakes at Tariki, North Inglewood, Midhurst and Eltham are located under the known main dispersal axes of major tephra falls. Extending from soil-stratigraphy studies, the swamp/lake sites provide a deposition/preservation environment well suited for trapping fine-grained and thin deposits, characteristic of small to medium scaled eruptions (Volcanic Explosivity Index 2-3). By applying a multiple-parameter approach to andesitic tephra correlation we are able to determine long-term changes in frequency, magnitude and geochemical composition of Taranaki eruptions. Titanomagnetite phenocrysts have proven to be the most useful candidates for geochemical purposes, since andesitic glass shards have highly heterogeneous compositions caused by microlite growth and are more strongly affected by weathering. The scope and location of the coring sites will also allow us to develop a new record of paleo-wind directions and provide the basis for correlation of tephras from Taranaki to deposits recorded in Auckland and the Central North Island. By linking magma chemistry to eruption size and style records, we aim to improve hazard forecasts at Taranaki and increase awareness and preparedness for future hazards in this region.

THE GEONET CGPS NETWORK AND ITS POSSIBLE CONTRIBUTION TO A LOCAL TSUNAMI EARLY WARNING SYSTEM

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Tsunamis induced by nearby large offshore earthquakes are one of many natural hazards New Zealand is facing. International studies demonstrated the effectiveness of using real-time GPS data in Tsunami Early Warning Systems. The displacement recorded by real-time cGPS stations can be used to gain insights into the earthquake source and its tsunamigenic potential within few minutes from the event.

GNS-Science and GeoNet are currently evaluating their early warning capabilities in case of a tsunami being generated by an event on the Hikurangi subduction zone with a focus on weakly-felt slow-rupture earthquakes (Mueller et al., this session). The 1947 earthquake and tsunami offshore Gisborne served as template. As part of this project we analysed to what extent the cGPS network is capable of detecting the ground displacement simulated in a set of time-dependent models. 1HZ GPS data from a selection of 54 stations were post-processed and epoch-by-epoch 1Hz "earthquake free" time series have been obtained. In the same area, 4 PositioNZ-RT sites were processed in real time. The noise of post-processed and real-time solutions has been assessed and compared to the set of time-dependent displacement simulations (Ristau & Kaneko, this session). Results show that: a) the noise frequency and amplitude contents are similar over the 54 stations; b) the real-time outputs are generally twice as noisy as the post-processed solutions; c) the simulated displacements on near-field stations should be detectable by using the real-time processing strategy.

If all the cGPS stations on the East Coast were streaming 1Hz data, and the data were processed in real time, we would be able to rapidly detect and measure with reasonably good accuracy the displacement caused by a large earthquake within few minutes from the origin time. This study provides practical guidelines for upgrading the GeoNet network to a real-time network.

POCKMARKS OF THE CHATHAM RISE AND FURTHER SOUTH

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The availability of modern multibeam swath-bathymetry data in the New Zealand region has led to the widespread recognition of fluid-escape structures or "pockmarks".

Very large (> 20,000 km^2) pockmark fields discovered along the south-western Chatham Rise slope (Davy et al. 2010) were grouped aerially into pockmarks ranging from approximately 200 m wide x 5 m deep to some giant pockmarks, 12 km wide x 200 m deep – the largest known pockmarks world-wide. It was proposed by Davy et al. that the pockmarks all have a gas-hydrate source with dissociation at peak stadial glacial low stands (giant pockmarks) and during post-glacial warming (200 m wide pockmarks). The 500 m isobath occurrence for the upper limit of small 500 m diameter pockmarks was one of the principal factors in the Davy et al [2010] gas hydrate interpretation.

The distribution and associated features of pockmarks on the Chatham Rise margins, Canterbury slope and Inner Bounty Trough are described, contrasted and related to regional crustal structure. The presentation will also draw on some of the highlights from a 2013 seismic survey by R/V Sonne to the Chatham Rise (Bialas et al. 2013) investigating the nature of pockmarks already reported and discovering fresh giant pockmarks and their associated unusual sub-seafloor plumbing. As a companion survey (Bialas et al. 2013) designed to detect methane presence in the water column or sub-seafloor found no evidence of methane presence, the possible nature of fluids causing seafloor pockmarks are discussed.

EARLY MIOCENE FOSSILS INFORM ON THE EVOLUTION OF NEW ZEALAND'S AVIFAUNA – A WORLD VIEW

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Worldwide, Early Miocene (23–16 Ma) avifaunas provide an important evolutionary framework for understanding avian dynamics and faunal changes linked to climatic and geological factors occurring over the last 23 million years. This is because this interval immediately predates the major transitions traditionally associated with the Miocene (i.e., geologic, climatic, faunal and floral changes) that influenced the evolutionary history of terrestrial vertebrates. The only Miocene terrestrial fauna known from Zealandia is that of St Bathans, in Central Otago (Altonian, 19–16 Ma). New Zealand's Recent terrestrial vertebrate fauna is famously dominated by birds, a pattern that was also reflected in its composition during the Early Miocene. Recent and ongoing paleontological research has provided important insights into the composition and taxonomic diversity of the St Bathans avifauna, as well as into the antiquity of New Zealand's endemic avian lineages, and possible colonisation patterns resulting in New Zealand's iconic Quaternary bird fauna. In this overview we outline these recent advances and provide a phylogenetic and biogeographical framework linking NZ's past and present avifaunas. Furthermore, we compare this Early Miocene assemblage with that of coeval avian fossil localities worldwide, many of which are characterised by unusual biogeographical occurrences linked to the different environmental conditions in the past, suggesting that the distribution of certain lineages of birds today does not necessarily reflect ancient patterns. Although much data for Gondwanan Early Miocene avian localities is still lacking, we note that, similar to Australia and contrary to patterns observed in the Northern Hemisphere, the long interval of geographical isolation has contributed to the high

level of taxonomic endemism associated with New Zealand's terrestrial faunas.

PRELIMINARY RESULTS FROM RECENT SURFACE RUPTURES ALONG THE SOUTH WESTLAND FAULT ZONE, A MAJOR SOURCE OF SEISMIC HAZARD PROXIMAL TO THE PLATE BOUNDARY, SOUTH ISLAND, NEW ZEALAND

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Understanding the earthquake potential from active faults is critical for understanding seismic hazard. On the South Island of New Zealand, much attention has been focused on the plate boundary Alpine Fault thought to generate major earthquakes, although limited attention has been focused on the onshore faults adjacent to the Alpine Fault that are important sources of seismic hazard and sources of geomorphic change. The South Westland Fault Zone (SWFZ) may be responsible for some of the paleoseismic records previously attributed to the Alpine Fault and through study of the SWFZ, we may better understand plate boundary behaviour. We discovered the first Quaternary exposure of the SWFZ that shows evidence for repeated, reverse-style surface ruptures with ~ 2 m of vertical motion per event from Late Pleistocene to present based on offsets we documented in alluvium. Ongoing dating will provide insight into event timing. Based on the regional Quaternary geology and deformation we document proximal to the SWFZ, the SWFZ is indeed active and presents both earthquake as well as surface rupture hazards in South Westland. Prospecting with cone penetration testing (CPT) helped us map the strike of the fault in the subsurface based on offset units, which appears to be sub-parallel with the Alpine Fault. Important ly, the vertical offsets we document demonstrates repeated activity, while mapping and logging results show that the zone of surface deformation is up to 200 m around the SWFZ, which will clearly impact existing and planned infrastructure proximal to this fault during the next event. Our preliminary results suggests that decoupling paleoseismic records from perhaps up to Mw 7.5 earthquakes from along the SWFZ from Mw 8 earthquakes along the Alpine Fault will help us to better understand plate boundary behaviour and better understand frequency of strong ground motions irrespective of source.

JUMPING TRACK: WHY DOES LAHAR AVULSION OCCUR?

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Lahars have commonly been described as rapidly flowing mixture of debris and water. From a rheological perspective the behaviour of these sediment-laden flows are not consistent with other water dominated floods. Lahars are a common occurrence on Mt. Ruapehu, with more than 50 events since 1861 AD recorded in the Whangaehu Valley alone. Within this historic record three lahars have been recorded as either bifurcating from the normal stream path or avulsing into a neighbouring catchment e.g. the hazardous 1995 lahar that avulsed into the Waikato Stream/Tongariro River from the Whangaehu.

The March 2007 Lahar was a result of a Crater Lake out-break from the breach of a tephra dam created during the 1995-96 eruptions. Just over eight km from source part of the lahar overtopped the main channel and continued down a distributary called "Chute". This avulsion process is well documented at Mt. Ruapehu and a number of volcanoes, however the rheological, geomorphic and sedimentological processes behind this behaviour is currently poorly understood. In this research we assess different sedimentological and geomorphic signatures that could possibly cause lahars to avulse. Sediment deposits along a section of the Whangaehu River were analysed to determine if there is a sedimentological signature that causes avulsion. LiDAR data pre and post the March 2007 lahar has been examined to determine geomorphological properties of the channel and infer rheological influences on the lahar. In conjunction with this an ArcGIS model has been developed to combine these sedimentological and geomorphic factors that influence flow avulsions. The model is primarily based on the sensitivity of flows to various channel morphologies, however scenarios have been developed to simulate the effects of sediment

deposition on the channel morphology. The variations in these factors have revealed the primary causes of lahar avulsion in the Whangaehu Valley, Mt. Ruapehu.

LIQUEFACTION HAZARD IN THE TARANAKI REGION

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We present a regional-scale assessment of the liquefaction hazard in the Taranaki Region. Liquefaction hazard combines the susceptibility of the soils of the region to liquefaction and the likelihood of strong enough ground shaking occurring to trigger liquefaction. This allows assessment of liquefaction hazard — the probability of a given severity of liquefaction occurring in a given timeframe.

Significant liquefaction hazard in Taranaki is limited to only a few areas. The primary reason for this is the fortuitous lack of young, non-cohesive fine-grained sediments in areas where the groundwater table is close (within 1-5 metres) of the ground surface.

The liquefaction hazard was compiled and mapped principally based on published 1:250,000 scale geological mapping (QMap which is compiled from geological mapping at a scale of 1:50,000) and the GNS National Seismic Hazard Model. The liquefaction classifications assigned to the different map units were tested through the analysis of a geological database of 900 boreholes in the region. The liquefaction hazard derived from the borehole and the geological mapping were generally in agreement. However, in some cases there were discrepancies between borehole interpretations and the hazard determined from map units. The liquefaction hazard maps produced in this study identify areas where detailed site evaluation of the liquefaction hazard is warranted.

STUDENT PERCEPTIONS OF GEOLOGIC NOTE-TAKING WITH IPADS

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During fieldwork, students and professionals record information and hypotheses into their geologic notebook. In a pilot study, students (n=11) on an upper-level volcanology field trip were given iPads, with an open-source geology note-taking application (GeoFieldBook) and volunteered to record notes (i.e., digital notes) during a day at the Tongariro Volcanic Complex and the Orakei Korako geothermal site.

The digital notes were compared to hardcopy notes from earlier parts of the fieldtrip and students were interviewed several weeks after to reflect on using this technology. The notes and interviews were reviewed and evaluated with the aim of describing their experiences with an emphasis on perceived benefits and challenges of hardcopy and digital note-taking.

Students indicated that digital note-taking resulted in “quicker” transcription of notes, which they translated to improved “efficiency” and the ability to collect more data. Students also had differing views of the *utility* and *purpose* of notes (data collection, hypothesis-making, for research or for industry, etc.). Some major perceived disadvantages with digital note-taking included that the iPads are expensive and fragile (not field-hardy) and they felt that the software was limiting to structural measurements (not aimed explicitly at volcanology information). Additionally, the software does not allow for sketching capabilities, which several students mentioned as a disadvantage to digital note-taking.

More student experiences will be collected in order to further support and improve note-taking strategies and geologic reasoning in the field.

LAKE OHAU: A 17,000 YEAR SEASONALLY-RESOLVED RECORD OF CLIMATE CHANGE

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Seismic profiles show a ~70 m thick sedimentary sequence exists beneath the southeast arm of Lake Ohau (44°10'S, 169°49'E; 500 masl) that we believe contains a 17,000 year record of regional environmental change. Coring the full 70 m record by our research team is anticipated for February 2015. To date a series of ~6 m long cores collected from the same location contain mm-scale sediment couplets. The couplets are defined primarily by differences in grain size based on colour, x-ray, ITRAX µ-XRF and laser grain size analyses. A chronology for these cores has been developed from ^{210}Pb and ^{137}Cs profiles, as well as ^{14}C ages and pollen biostratigraphy, which show our cores span the last 1200 years at an average accumulation rate of 5mm/yr. The high sedimentation rate confirms the couplets are deposited on annual timescales. Intriguingly, over this time period there is a strong positive correlation between century-scale changes in Lake Ohau core colour and reconstructed indices of the Southern Annular Mode (SAM) from numerical models, Antarctic ice cores and southern hemisphere mid-latitude (SHML) tree rings. At these latitudes SAM exerts a major control over the flow of westerly winds and precipitation patterns. Thus our initial results point to the SAM being a key determinant of decadal to century scale changes in South Island precipitation. However, in order to closely examine the relationship between precipitation, lake sedimentation and hemispheric climatology we are undertaking a detailed monitoring study of the lake and comparing hindcast climatology with our existing core stratigraphy. Our ability to examine climate change at seasonal resolution over millennia holds a key to understanding the likely future importance of highly variable climate modes (SAM, ENSO, IPO) to SHML climate. We discuss how this research can be used to inform near-term projections of New Zealand's future climate.

LATE OLIGOCENE TO PLIOCENE ANTARCTIC CLIMATE AND OCEANOGRAPHIC RECONSTRUCTIONS USING MOLECULAR AND ISOTOPIC BIOMARKER PROXIES

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Atmospheric CO_2 reconstructions ranged between 500 and 300ppm across intervals of significant climate and environmental change from the late Oligocene to the Pliocene, indicating that major climate thresholds were passed during periods of relatively modest CO_2 variation. This implies the Earth's climate system is highly sensitive to feedbacks associated with changes in global ice sheet and sea-ice extent, as well as terrestrial and marine ecosystems. This study focuses on several key intervals during the evolution of the Antarctic Ice Sheet, in particular the Oligocene/Miocene boundary, at which the East Antarctic Ice Sheet expanded to close to or greater than present day volume, and the Mid-Miocene Climate Optimum (MMCO ~17-15 Ma), a period of global warmth and moderately elevated CO_2 (350->500 ppm) which was subsequently followed by rapid cooling at 14-13.5 Ma. Modelling of global climate, vegetation, and ice sheet extent has tried to reconcile the various feedbacks that occurred during these intervals. However, modelling studies are limited by a lack of geological data of hydrological processes and high latitude temperatures.

This study will produce new proxy climate reconstructions using terrestrial and marine organic biomarkers from Antarctic drill cores and outcrop samples that span from the Oligocene/Miocene boundary up to the Pliocene, including the MMCO, and the subsequent cooling event that followed. Variations in *n*-alkane abundances and concentrations will be used to identify changes in the distribution of terrestrial vegetation. These and other biomarkers will be analysed to determine biomarker syngeneity and abundances across a range of lithologies. Bacterial ether-lipids will be analysed to determine terrestrial mean annual temperatures and soil pH (via the methylation and cyclisation indexes of

branched tetraethers – MBT and CBT, respectively). Tetraether-lipids of Crenarchaeota found in marine sediments sampled from continental shelves around Antarctica will be used to derive sea surface temperatures using the TEX_{86} index.

THE NEW 1:1 000 000 GEOLOGICAL MAP OF NEW ZEALAND

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In 1865, the year the New Zealand Geological Survey was established, James Hector produced the first geological map of New Zealand at a scale of about 1:2 000 000. In 2015, the 150th anniversary, a new 1:1 000 000 Geological Map of New Zealand will be printed, and a provisional copy is presented here. The new map is based on the recently completed QMAP 1:250 000 scale Geological Map of New Zealand and incorporates the advances in understanding of New Zealand geology that came from it. It also includes geology of the Kermadec and Subantarctic islands, which were not included in QMAP coverage.

The small scale of the map dictates a chronostratigraphic emphasis where geological units are distinguished primarily by age of deposition or emplacement. Sedimentary units are differentiated and coloured according to their depositional age, with overprints used to distinguish those deposited in non-marine and coastal environments. Late Cretaceous and younger igneous rocks are coloured shades of red to pink, rather than the colours assigned to sedimentary units of comparable age. Metamorphic rock units are portrayed according to their known or inferred protolith age; Haast Schist rocks have overprints differentiating textural metamorphic grade. Major allochthonous units are distinguished by having a diagonal white stripe overprint on the underlying protolith colour. Basement sedimentary rocks are portrayed according to age and tectonostratigraphic terrane affinity. Most known active faults are shown, but of necessity only selected "inactive" faults are shown. The map will be published as two sheets, North and South islands, with detailed geological legends; an illustrated explanatory text will come later. Digital vector data for the map are already available on DVD, and the digital map can be accessed through the GNS website and web servers.

SATELLITE RADAR ANALYSIS OF POSTSEISMIC GROUND DEFORMATION ASSOCIATED WITH THE 2010-2011 CANTERBURY EARTHQUAKE SEQUENCE

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We measure and interpret ground deformation that occurred during and after the 2010–2011 Canterbury earthquake sequence using satellite radar interferometry observations. The dataset includes 11 COSMO-SkyMed (CSK) acquisitions in an ascending orbit from October 2010 to February 2011, 19 CSK acquisitions in a descending orbit between February and November 2011, and 66 TerraSAR-X (TSX) acquisitions in a descending orbit between February 2011 and May 2014. The data are analysed to assess postseismic deformation following the 4 September 2010 Darfield (Canterbury) earthquake, coseismic deformation related to the December 2010 aftershock swarm, and approximately three years of postseismic deformation following the 22 February 2011 Christchurch earthquake. The surface deformation data are interpreted using a variety of geophysical models including afterslip and poroelastic rebound to understand the role of competing processes in governing deformation at different points in the earthquake sequence.

DISTINGUISHING STORM AND SEISMOGENIC TURBIDITES IN LACUSTRINE RECORDS FROM THE SOUTHERN ALPS, NEW ZEALAND

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Precisely dated lacustrine sediments from lakes adjacent to active plate boundaries have the potential to yield records of the frequency and magnitude of landscape perturbations. However, distinguishing earthquakes from other perturbations such as floods and non-seismically generated mass wasting remain challenging impediments to the development of lacustrine paleoseismology. In this study we have used lakes located along the strike of the Alpine fault in the South Island of New Zealand to develop a precisely dated chronology that records seismic shaking from episodic rupture of the fault and high magnitude storm events. Storm deposits can be distinguished from seismic shaking deposits on the basis of the layer sequence, thickness, frequency and the regional extent of perturbations. Earthquake deposits consists of 150 to 200mm thick turbidites that are interpreted as coseismic mass wasting deposits formed by the collapse of lake margin and delta sediments during seismic shaking. These deposits lack soft sediment deformation and liquefaction structures because the lakes are adjacent to the Alpine fault and experience catastrophic collapse of subaqueous slopes during earthquakes. The seismic deposits are overlain by stacks of 2 to 100mm thick hyperpycnites that represent landscape responses to seismic shaking. These deposits are generated by sediment liberated by seismic shaking and transported to the lakes during floods within ~50 years of the earthquakes. These deposits are overlain by alternating organic-rich and inorganic silt beds that record relatively long periods between major earthquakes (c 200yrs) when the landscape is in a quiescent state interrupted by episodic delivery of sediment from precipitation-driven landsliding and flooding. We conclude that distinguishing flood and seismic deposits depends on building a robust and independently testable depositional model that couples landscape responses to perturbations with lacustrine processes.

SEEKING THE LOST MAMMALS OF ZEALANDIA

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Land mammals are known in Gondwana from the Middle Jurassic onwards. Given the other likely passengers on Zealandia, as it broke away from Gondwana, land mammals were probably there too. Yet, modern New Zealand lacks indigenous ground-dwelling mammals, and no conclusive fossils have been reported. (An early Miocene mammal find from Manuherikia Group includes bones similar to those of a megachiropteran bat.) We report the search for land mammals from loosely-cemented shallow marine sedimentary rocks that could be sieved at <1 mm: the Chatton Formation (late Oligocene), and the Otaio Gorge Sandstone (early Eocene), both from eastern South Island.

Shelly sands of the near-shore Chatton Formation produced a few chondrichthyan (shark, ray) teeth and many teleost (bony fish) otoliths from 300 kg, but no land vertebrates. The Otaio Gorge Sandstone yielded tens of thousands of teeth and bone fragments >0.8 mm size from 1320 kg of loosely cemented molluscan coquina and cm to dm cross-bedded, glauconitic, very fine quartz sandstone and siltstone, with *Ophiomorpha* burrows. The reported age is Waipawan or Mangaorapan (~56-49.2 Ma). Material was picked under the microscope or under a magnifying lens. Almost all the vertebrates are chondrichthyan or teleost teeth and bone fragments; no land mammal remains have been identified. However, one isolated tooth, with a high, lingually recurved conical crown (height ~18 mm, basal diameter ~8.5 mm), may be crocodylian. There are no keels, but indistinct mesiodistal ridges. The surface is unornamented, and shows subvertical microwear. Growth lines are visible in the broken basal section adjacent to a bluntly subconical pulp cavity and in SEM of a polished section; enamel microstructure

is unrevealing. If crocodylian, this is the first record from Zealandia older than about 18 Ma. It confirms that tetrapod remains other than penguins can be recovered from older Cenozoic strata.

TROPICAL INFLUENCE ON MIOCENE NEW ZEALAND

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Foulden Maar is an Oligocene/Miocene maar volcano located near Middlemarch, Otago. The crater is filled with ~100 m of annually laminated diatomite which represents a continuous, very high resolution record of ~100 kyr duration. The diatomite is dated to the period 23.03-22.93 Ma, and is coeval with the peak and rapid deglaciation phases of the Mi-1 Antarctic glaciation event. Spectral analysis of physical properties (density, reflectance, colour) and organic geochemical (δD, $\delta^{13}C$) records from the deposit reveals orbital-scale frequencies, chiefly obliquity, as well as an 11-kyr cycle. The 11-kyr cycle corresponds to the half-precession cycle which has a strong influence on insolation only at and near the Equator. The appearance of this tropical cycle in mid-latitude Miocene New Zealand is unexpected, and suggests a teleconnection between the tropics and New Zealand at this time. One possible mechanism for this teleconnection is ENSO variation, which originates in the tropics and is known to affect New Zealand climate at the present day. Significant ENSO-scale (2-8 year) variation is present in the high-resolution colour records from Foulden Maar, and is expressed chiefly by changes in lamina thickness (interpreted as a proxy for diatom productivity). If ENSO variation is indeed the mechanism for the transmission of the half-precession cycle to the mid-latitudes, it should be modulated on an 11-kyr scale. A new project, funded by the National Science Foundation, is currently underway to investigate this hypothesis by means of further geochemical proxies and measurement of lamina thickness.

BRITTLE DEFORMATION AND FAULTING IN FOLIATED BASEMENT ROCKS OF COASTAL OTAGO, NZ

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Fault and fracture networks in foliated basement rocks control the strength, fluid flow properties and seismogenic behaviour of the crust. Understanding faulting patterns in foliated basement rocks is important because much seismicity (e.g. in the south island of New Zealand) occurs within basement rocks and basement faults are commonly linked to the formation of major ore bodies (e.g. in central Otago). Strongly foliated schists (and greywackes) are extremely well exposed across extensive, clean outcrops along coastal sections in Otago, providing an important opportunity to study the nature of brittle deformation and faulting and how they are influenced by rock anisotropy.

Using high-resolution aerial photography, lineaments (n=6625) with lengths of a few metres to c. 200 m were mapped along the 16.5 km-long coastal platform between Taieri Mouth and Chrystalls Beach, Otago, to provide regional-scale context for future fieldwork. Significant patterns noted in the lineament data include strong preferred orientations trending 50-70° and 120-140°. Comparison to regional-scale faults in the Otago region (as recognised on GNS QMAP) shows a strong correlation between the coastal lineaments trending 120-140° and a set of NW-SE striking regional faults. However, many faults in the Otago region, including the nearby Akatore Fault, trend NE-SW (30-40±10°), an orientation that is conspicuously absent in our coastal lineament analysis. Preliminary fieldwork indicates that identified lineaments correspond to first-order (continuous faults up to a few metres wide, filled in some cases by breccias), second-order (faults up to tens of centimetres wide, vein-filled) and third-order (small-displacement faults and veins associated with breccias) features. Extensive structural and geochemical analysis will be undertaken to establish cross-cutting relationships amongst the various lineaments sets as well as the

nature of brittle faulting and veining (e.g. P-T conditions of faulting, fluid sources, influence of schistosity on fault patterns).

THE HIKURANGI SUBDUCTION SYSTEM AS SEEN BY SURFACE WAVES

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Seismic velocities in the earth can be used to infer the 3D geometry of structures arising from plate tectonics. Moreover, the additional information contained in the azimuthal dependence of wavespeed (azimuthal anisotropy) can in certain circumstances be seen as a marker of current and historic strain. Because the depth sensitivity of a surface wave is dependent on its period, broadband wavespeed information can also be used to solve for 3D velocity structure. Based on these principles, we invert surface wave dispersion data to calculate isotropic and anisotropic velocities between 6 and 50 second periods in North Island, New Zealand. This is a region with a subduction system including back-arc spreading as well as upper plate block rotation. We generate interstation empirical Green's Functions from stacked ambient noise cross-correlations recorded from station pairs of the GeoNet network and temporary experiments. Measurements of fundamental-mode Rayleigh-wave dispersion are made using multiple filtering and frequency-time analysis and manual selection of the dispersion curves. This collection of dispersion curves is then inverted for lateral variations in both isotropic and azimuthally anisotropic wavespeeds at discrete periods. Each discrete period provides a different depth sensitivity range, yielding information on depth dependence of the velocity variations. We then use the suite of isotropic solutions to develop a 3D shear wave velocity model. We define an anomalous region of slow velocities accompanying trench-perpendicular fast propagation under the east coast, near the shallow Hikurangi subduction zone. The structure appears at periods of about 21 seconds and is most prominent at periods of about 28 seconds. Toward the western North Island, farther from the trench, the isotropic group velocity and shear wave velocity is relatively fast with the fast-propagating axis parallel to the trench direction. The isotropic dispersion curves extract from our model are strongly suggestive of a thin (<10km) low velocity zone within or above the subducting slab which is also present in our 3D shear-wave model.

INTRAPLATE BASALTIC VOLCANISM ACROSS ZEALANDIA AND THE HIMU CONUNDRUM

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Intraplate volcanism across Zealandia, SE Australia, the Ross Sea Embayment and Marie Byrd Land, Antarctica defines a magmatic province characterised by basalts where many show high $^{206}Pb/^{204}Pb$ (19.5 – 22.5, HIMU), $^{87}Sr/^{86}Sr$ ~ 0.7035±0.01, Light Rare Earth enrichment ((Ce/Yb)n > 10), and convex-upward mantle normalised incompatible element multi-element patterns, peaking at Nb-Ta. Moreover, trace element abundances and ratios (e.g. Zr/Nb, Ba/Zr, Y/Zr) resemble those Ocean Island Basalts (OIB) and are distinct from MORB, suggesting derivation from an enriched (OIB-like) source.

Using geochemical data from Auckland Islands, Carnley Volcano as an exemplar, this talk will explore the petrogenesis of primitive basalts from the Auckland Islands. Our preferred model envisages partial melting across the asthenosphere – lithosphere boundary, leading to an aggregated melt column where the asthenospheric source is modelled by Primitive Mantle [1] and subcontinental lithospheric mantle (SCLM) by Depleted MORB Mantle [2] enriched by addition of 1% Carbonatite (from Hoernle et al, 2002, CMP, 142). Partial melting progresses from the garnet stability field into the spinel field and evolution of primitive, near primary, basalts is controlled by olivine (ol) + clinopyroxene (cpx) fractionation and subsequently, ol + cpx + plagioclase. This model is driven by “edge – driven” convective flow [3] induced along the trailing edges of the Zealandia, Antarctic, and SE Australian lithospheric plates and ultimately linked to the break-up of Gondwana and formation of the Southern Ocean and Tasman Sea. In the convective flow model, the trailing edge of a lithospheric plate experiences thermal and

mechanical (detachment?) erosion along the interface with convecting mantle, leading to heating and decompression partial melting. In this scenario, SCLM is the source of the HIMU signature, an argument supported by peridotite xenoliths that reveal both cryptic and patent (rare amphibole) metasomatism.

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THE PALEOECOLOGY OF THE ESTUARINE UPPER OLIGOCENE POMAHAKA FORMATION, OTAGO, NEW ZEALAND

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The upper Oligocene (Duntroonian) Pomahaka Formation, one of the few paleo-estuarine deposits known from New Zealand, crops out along the Pomahaka River and Waikoikoi Stream near Tapanui, West Otago. Sediments include lignite seams interbedded with fossiliferous muds, silts and occasionally sands. A drill core indicates that the entire sequence may be up to 90m thick. The Pomahaka Formation rests unconformably on Caples Terrane basement of low metamorphic grade and is overlain by the glaucony-rich Chatton Formation. Unusual well-preserved fossils not found elsewhere are present in the muddy and silty sediments. Shellbeds are up to 1 m thick and different molluscan-dominated assemblages occur at different horizons. Bivalves include *Hormomya, ?Barbatia,* two oysters *(?Crenostrea and Crassostrea)*, *Hinemoana acuminata, cf. Potamocorbula* and two new species of venerids, *Tellinota n.sp.* and *?Eumarcia n.sp.* Gastropods include the small neretid *Clithon(?) pomahakaensis* with extraordinary colour markings, *Batillaria pomahakaensis, Melanopsis pomahaka, Batillona amara, Maoricrypta, Pomahakia aberrans*, together with new species of *Potamopyrgus* and the freshwater genus *Melonoides.* Small drillholes, possibly made by the predatory gastropod *?Xymene*, are present in many molluscs. A species of a lobster-like decapod and trace fossils were found in concretions. Vertebrate fossils include a cheloniid-like (turtle) xiphiplastron, shark teeth of the family Odontaspididae (sand tigers), and bony fish remains. Plant fossils include numerous seeds, amber, leaves and *in situ* tree stumps up to 53 cm in diameter. Foraminifera include *Elphidium excavatum*, and species of *Trochammina* and *Haplophragmoides*, unlike any modern New Zealand species: they suggest that most of the molluscs lived in a sheltered, brackish, mid-high tidal estuarine paleoenvironment. The neretid *Clithon(?) pomahakaensis* and the turtle plastron plate suggest that sea temperatures were at least marginally subtropical.

A METHOD FOR SOURCE ROCK EVALUATION BY WELL LOGGING DATA IN TIGHT RESERVOIR-CASE STUDY FROM SANTANGHU BASIN OF WESTERN CHINA

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The abundance, quality and distribution of source rock are vital for predictions of oil and gas accumulation zones of tight reservoir. Methods of quantitation of TOC and source rock typing are proposed combined with geochemical and geophysical logging data. Relationship among logging response, physical properties and TOC were well studied, then three methods (empirical formula, multiple regression and support vector regression algorithm) were applied for TOC prediction. After analysing logging responses of source rocks, types of source rock were classified into four types using Fuzzy Spectral Clustering-Fisher Discriminant analyses. The result showed TOC is positive correlated with AC, CNL and RD and negative correlated with DEN. What's more, there are certain positive correlations between TOC and U, TH and GR. Calculation results by multiple regression can basically reflect the overall tendency of TOC but with a low accuracy (mean square error is 30%); results by empirical formula is preciser than multiple regression (mean square error is 18%) and results by support vector regression achieves the highest accuracy (mean square error is 5.4%). The abundance of source rock is high in the area but

the evolutionary stage of hydrocarbon generation is mainly in immature and low mature stage, type I of source rock develops well, then follows the type II1, type II2 and type III of source rock are rare distributed.

THE MIOCENE FLORA OF BEACHLANDS: FRUITS, SEEDS, LEAVES, WOOD AND FUNGI

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A newly discovered fossil flora from outcrops on a wave cut platform near Beachlands, southeast Auckland includes wood, leaves, fruits and seeds, pollen and spores, bracket fungi and amber. Fossiliferous horizons up to 5 m thick occur in fluvial to ?estuarine sediments deposited in a paleovalley cut into Early Miocene Waitemata Group sediments. The age of the deposit is uncertain, but it is probably Late Miocene to possibly early Pliocene. There is one *in situ* rooted tree stump and numerous 30 - 50 cm diameter logs up to 5 m long, many with an east-west orientation. Leaf beds up to 10 cm thick extend over several 100 m^2. Some leaves have cuticle preserved, and preliminary investigation suggests the presence of *Nothofagus* and several species of Lauraceae. Hundreds of three-dimensionally-preserved fruits/seeds represent more than 10 taxa in at least 5 families, including Menispermaceae, Combretaceae and Elaeocarpaceae. Several specimens of rarely-preserved bracket fungi are present. Miospores include at least 15 types of ferns, with well-preserved *Cyathidites* spores dominating. The diverse pollen flora includes several podocarps, and pollen from extinct Asteraceae, but is dominated by *Brassospora*-type beech. The depositional environment was clearly mesic from the abundance of microthyriaceous fungi commonly found growing on leaves under moist humid conditions. The presence of *Bombacacidites and Cupanieidites* suggests a warm temperate to subtropical setting.

BIOGEOCHEMICAL CYCLING OF CADMIUM IN THE SOUTH WEST PACIFIC OCEAN

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The biogeochemical cycling of cadmium (Cd) is likely to be an important component of the ocean's biological pump and thereby global climate. Moreover, the nutrient-like distribution of Cd and its linear relationship with phosphate makes Cd a useful proxy of past nutrient utilisation in the oceans. However, the processes controlling the distribution and uptake of Cd remain poorly understood.

As a diagnostic tracer, stable isotopes of Cd have the potential to offer more insight about the biogeochemical cycling of Cd in the oceans. Additionally, Cd stable isotopes may in itself act as a potential proxy for the past and present nutrient utilisation. The limited data acquired so far shows considerable variability in the Cd isotopic composition between different regions, suggesting the influence of different processes including biological uptake, particle scavenging, atmospheric input and the mixing of different water masses. Further studies are therefore required to understand more about the marine cycling of Cd.

The simultaneous collection of Cd isotopes using Multiple Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS) with double spiking protocols has increased the ability to measure Cd isotopic fractionation with uncertainties at the 0.01% level. Using these methods, we present measurements of Cd isotopic composition and concentration for water samples collected from a comprehensive suite of depth profiles during the GEOTRACES GP13 zonal section. This cruise transect extends for 5,500 km from offshore Australia to the remote interior of the subtropical Pacific Ocean. There is a strong longitudinal gradient, with respect to the supply of trace metal-bearing dust and phytoplankton biomass, along this transect, allowing the biogeochemical cycling of Cd, in relation to other micro- and macro-nutrients, to be systematically

investigated across a gradation of changing oceanographic settings.

RETHINKING PROBABILISTIC SEISMIC HAZARD ANALYSIS

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Since the early 1980s seismic hazard assessment in New Zealand has been based on Probabilistic Seismic Hazard Analysis (PSHA). The most recent version of the New Zealand National Seismic Hazard Model, a PSHA model, was published by Stirling et al, in 2012. This model follows standard PSHA principals and combines a nation-wide model of active faults with a gridded point-source model based on the earthquake catalogue since 1840. These models are coupled with the ground-motion prediction equation of McVerry et al (2006). Additionally, we have developed a time-dependent clustering-based PSHA model for the Canterbury region (Gerstenberger et al, 2014) in response to the Canterbury earthquake sequence.

We are now in the process of revising that national model. In this process we are investigating several of the fundamental assumptions in traditional PSHA and in how we modelled hazard in the past. For this project, we have three main focuses: 1) how do we design an optimal combination of multiple sources of information to produce the best forecast of earthquake rates in the next 50 years: can we improve upon a simple hybrid of fault sources and background sources, and can we better handle the uncertainties in the data and models (e.g., fault segmentation, frequency-magnitude distributions, time-dependence & clustering, low strain-rate areas, and subduction zone modelling)? 2) developing revised and new ground-motion predictions models including better capturing of epistemic uncertainty – a key focus in this work is developing a new strong ground motion catalogue for model development; and 3) how can we best quantify if changes we have made in our modelling are truly improvements? Throughout this process we are working toward incorporating numerical modelling results from physics based synthetic seismicity and ground-motion models.

MODELLING THE SUBSURFACE VELOCITY STRUCTURE OF THE TONGARIRO VOLCANIC CENTRE, NEW ZEALAND, USING AMBIENT NOISE CROSS-CORRELATION

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Volcanic hazard monitoring and successful eruption prediction requires robust measurements of temporally varying data. In the case of Ruapehu and Tongariro Volcanoes, in the central North Island of New Zealand, changes in the subsurface volcanic system may not manifest as surface activity or be accompanied by detectable seismicity in the TgVC; thus eruptions occur with very little or no warning. Recent observation of variation of shear-wave velocities, measured using ambient noise cross-correlation, prior to activity at other volcanoes around the world has the potential to be used as a hazard monitoring tool. Furthermore, ambient noise cross-correlation can be used to produce high resolution, 3D velocity models of subsurface structure. We have used this technique to develop a database of high quality, reference cross-correlation functions, ready to be used for monitoring, using data from the dense temporary seismograph deployments operating in 2001 and 2008 along with data from the permanent GeoNet array at those times. Preliminary results suggest an average 5 s period Rayleigh wave velocity for the study area of 2.4 kms^{-1}. This database will be used to create a high quality 3D shear-wave velocity model of the Tongariro Volcanic Centre.

ANTARCTIC MELTWATER PULSES FROM A POSITIVE ICE-OCEAN FEEDBACK MECHANISM

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Global mean sea level at the last glacial maximum (c. 21 ka) was 130 m lower than at present, with the equivalent ice volume locked up in ice sheets in both hemispheres. Melting of these ice sheets took place episodically [1], with at least two periods of abrupt sea-level rise - `meltwater pulses' - taking place [2,3]. Although the timing and magnitude of these events is increasingly well-constrained [4], the sea-level contribution from Antarctica remains vigorously debated [5]. Here we use a data-constrained ice-sheet model, driven with timeseries-forcings from empirical proxies and from an intermediate complexity Earth system model [6], to reconstruct the pattern and timing of Antarctic ice-sheet recession from 25 ka to present. Our suite of transient simulations indicates that ice-sheet mass loss peaked during two periods broadly coincident with meltwater pulses 1A and 1B [3], contributing to sea-level at rates of up to 1 m per century at ~14 ka. Together with global oceanic proxies, our results offer compelling evidence that Antarctica may have contributed to MWP1A as a consequence of reduced Southern Ocean overturning following Heinrich Event 1, when warmer subsurface water thermally eroded grounded marine-based ice and instigated a positive feedback that further accelerated ice-sheet retreat.

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AUTOMATED STATISTICAL MATCHING OF MULTIPLE TEPHRA RECORDS

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Establishing a detailed record of past volcanic events is important for probabilistic volcanic hazard forecasting, as well as for understanding the dynamics and history of a wide range of other geomorphic, climatic, soil-forming and environmental processes. Compiling detailed tephra records is complicated by: highly variable tephra distribution over time; difficultly in correlating tephras based on physical and chemical properties from site to site; along with uncertainty in age determinations. Multiple sites are needed to build the most accurate composite tephra record, but correctly merging them by recognising events in common and site-specific gaps remains complex.

We present an automated statistical procedure for matching tephra sequences between multiple deposition sites, using stochastic local optimization techniques. This approach eliminates implausible matches through careful reasoning, while heuristically searching over the remaining alternatives. If individual tephra age determinations are not significantly different between sites, they can be pooled to derive a more precise date of each eruption. The known stratigraphic constraints and compositions of the tephras can be used to verify possible matches returned by the procedure.

Our method of identifying plausible matches is demonstrated through the application to five long sediment cores from the Auckland region. These sites include tephras from local Auckland Volcanic Field eruptions as well distal units erupted from Taupo, Okatania, Mayor Island, Taranaki (Egmont), and Tongariro volcanic centres. The new correlated record compiled is statistically more likely than previously published arrangements from this area.

KINEMATICS OF THE GREBE MYLONITE ZONE, EASTERN FIORDLAND

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The Jaquiery Gorge, eastern Fiordland provides an excellent 1000 m wide cross section through the Grebe Mylonite Zone (GMZ). The GMZ comprises three principal lithologies with amphibolite facies metamorphic assemblages: meta-diorite, meta-granodiorite and meta-granite. All lithologies have a steeply west dipping foliation containing a shallow south plunging mineral lineation. GMZ mineralogy is dominated by quartz, oligoclase, orthoclase and two amphiboles, magnesiohornblende and pargasite. Quartz with irregular grain boundaries and undulose extinction indicate recrystallisation by grain boundary migration (GBM). Paleopiezometry of recrystallised quartz estimates differential stresses of ~20 Mpa. Plagioclase core and mantle structures are common and suggest sub grain rotation recrystallisation. Tabular amphibole grains show no evidence of recrystallization. Sigma type porphyroclasts occur throughout the GMZ, however no definitive sense of motion can be inferred as both dextral and sinistral senses are present.

Crystallographic preferred orientation (CPO) data of quartz, plagioclase and amphibole were obtained using electron backscatter diffraction (EBSD). In amphiboles [100] a-axes align preferentially perpendicular to foliation with [001] *c*-axes aligned parallel to lineation; an orthorhombic symmetry that provides no information on shear sense. Plagioclase (001) and (010) planes orient perpendicular to the foliation, [100] and [001] directions align parallel to lineation. These planes and directions are not components of recognised slip systems for oligoclase, although they are recognised in more calcic compositions suggesting a change in composition or previously unrecognised slip systems. Further complexities in plagioclase fabrics may indicate more complex deformation. Quartz CPOs show predominantly Y maxima fabrics, [0001] *c*-axis directions plot within the plane of foliation, however variations in orientation to the lineation indicate the possibility of different kinematics relative to those observed in the field. Interpretation of quartz fabrics indicate a sinistral/west side down sense of motion with the possibility of multiple deformation events that have resulted in <a> prism slip at ~600˚C.

USING EARTHQUAKE-LIKE LABORATORY EXPERIMENTS TO REVEAL ANCIENT SEISMICITY IN CARBONATE-BEARING FAULT ZONES

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Currently, pseudotachylites are the only unequivocal indicator of seismic slip in the rock record, but pseudotachylites do not form in certain lithologies (e.g. carbonates) and are mainly restricted to depths of >5 km. Seismically active carbonate-bearing areas such as central Italy, Greece and the Himalayan belt would benefit from a better understating of how ancient seismicity is preserved in the rock record, to better evaluate the future hazard.

Using a unique dataset of synthetic fault rocks produced in earthquake-like laboratory experiments, this project aims to quantify the microstructures produced in mixed calcite-dolomite gouges. Specifically, the project focuses on the microstructural evolution of samples deformed under identical "seismic" conditions (Slip vel. = 1 m/s, σ_n = 18 MPa) but taken to increasing displacements of 0.03 – 0.4 m (representative of slip during approx. M_w 4-6 earthquakes).

Quantitative analysis of SEM images, combined with chemical and optical analysis, shows that grain size and gouge fabric evolve systematically with increasing displacement. The bulk of the microstructural changes occur within the first c. 0.1 m of slip, during a transient strengthening and dynamic weakening phase during which grain comminution occurs by cataclasis. The weaker calcite phase wraps around relatively rigid dolomite clasts to define coarse foliations formed entirely by brittle processes. After c. 0.1 m of slip, strain has localised within the gouge layers and temperature sensitive processes (e.g. thermal decomposition, grain-scale plasticity and recrystallization) become increasingly important near the localized slip surface. During this phase, cataclastic processes in the bulk gouge layer slow down or cease but the coarse foliations continue

to rotate slowly towards parallelism with the localized slip surface.

Our results indicate that relatively small-displacement, seismic slip events in upper-crustal fault rocks could generate foliated fault rocks. This may leave a lasting microstructural signature of seismic slip in the rock record.

PYROCLASTIC SURGES FROM PELE – RECENT ERUPTIONS AT MASSEY VOLCANO

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Dilute pyroclastic density current (PDCs), or pyroclastic surges, are one of the most frequently occurring and highly dangerous phenomena of explosive volcanic eruptions. They are able to readily spread over complex terrain, to surmount significant topographic barriers, and to develop lethal dynamic pressures near the ground surface. Due to the high complexity of natural turbulent gas-particle mixture flows, there remain large uncertainties and controversies around their detailed transport, flow transformation and sedimentation processes. PELE – the Pyroclastic flow Large-scale Experiment at Massey University - is a new large-scale facility for experimental studies of pyroclastic density currents. It is used to repeatedly generate life-scalable currents involving 500-6,500 m^3 natural volcanic material and air that achieve velocities of 7-30 ms^{-1}, flow thicknesses of 2-4.5 m and runouts of >35 m. The experimental PDCs are synthesized by a controlled 'eruption column collapse' of variably diluted ash-lapilli suspensions dropped from a modified hopper onto a variably inclinable, instrumented channel.

We here present results from a series of hot and cold surge experiments to reveal the first views inside these dangerous phenomena. Along with high-speed video footage, thermal infrared imaging, and data from a variety of geophysical flow sensors we show (a) how the eruption column collapses transform into violent and strongly density stratified currents; (b) how the internal flow structure is altered by both substrate roughness and surge temperature; and (c) how dunes and antidunes (the characteristic type bedforms of dilute pyroclastic density currents) are emplaced. We also demonstrate examples of LUSI surges interacting with model buildings and infrastructure to highlight future research paths on the experimental volcano to investigate PDC destruction dynamics.

INVESTIGATIONS OF PLANT SUBFOSSIL CUTICLES AT A HOLOCENE RAISED BOG COMPLEX, NORTHERN NEW ZEALAND

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Plant macrofossil remains from Moanatuatua Bog (37°55'S 175°22'E) in the northern North Island of New Zealand are being used to test the hypothesis that subfossil plant cuticles of the two principal bog species *Empodisma robustum* and *Sporadanthus ferrugineus* can give robust reconstructions of local bog surface vegetation changes during the Holocene. This hypothesis will be tested by comparing the cuticle records with a pollen record obtained from the same sedimentary sequence, developed independently by Ignacio Jara (VUW).

Subfossil plant cuticles from peat deposits are a neglected source of information in plant macrofossil analysis. *E. robustum* and *S. ferrugineus* cuticles have the advantage of being easier to recognize than their respective pollen remains. Due to their excellent preservation and high identification potential, subfossil plant cuticles should be a significant tool in peat studies and plant macrofossil analysis.

Sampling at two scales of resolution will test the research hypothesis as well as providing information about the vegetation pattern on the bog in the Holocene and about the successive response of the plant assemblage to fire events on the bog surface. Developing a methodology to retrieve, identify and quantify *E. robustum* and *S. ferrugineus* cuticles from the Moanatuatua peat core is the first goal in this study. Sampling at a coarse resolution (~ every 50cm) will offer an insight into the bog development and the successional pathway of the local vegetation. As a next step, the application of this method will sample subfossil cuticles at a finer resolution

around prominent charcoal layers as an abundance of macroscopic charcoal particles indicates a local fire event on the bog surface. This will investigate the response of the local vegetation to fire events and the time of recovery for *S. ferrugineus* and *E. robustum*.

MAGMA PROPAGATION, STRESS AND ERUPTIVES: SPATIAL AND GEOCHEMICAL ANALYSIS OF THE AKAROA VOLCANIC COMPLEX

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Magmatic intrusions and eruptions are dictated by attributes including volume, composition, tectonic environment, and gravitational stress. The balance of tectonic and gravitational stresses is critical in understanding new growth, yet is incompletely characterized. This study investigates the influence of gravity and tectonics on magma propagation (V and L-type) and their related eruptives in the Miocene Akaroa Volcanic Complex, Banks Peninsula.

Analysis of orientations (valleys, ridges, dikes), compositions, and locations of features (lava flow sequences, dikes, domes, and eruptive vents), and relationships between physical and geochemical attributes, reveal a segregation of features both by proximity to eruptive centres and elevation. Lava flow sequences, sourced from main vents, indicate cyclic magmatic processes. Basaltic vents (parasitic) occur at low elevations, while undifferentiated dikes exist from the shore platform to upper ridges. Trachytic features are restricted and evenly distributed in an elevation zone of 400-700m. Segregation of features by elevation indicates a close links between gravitational stress and magma propagation. Zonation of trachytic domes is likely due to a combined critical load stress and buoyancy preventing magma ascension. Low elevation vents display tectonic control in their alignment with co-eruptive faults. Dikes however, when grouped radially and are unaligned with faults, indicating gravitational control.

In light of this apparent segregation, the Akaroa Volcanic Complex magmatic system is modelled with a vertically segregated magma reservoirs stemming from magma at depth. Key processes include: Primitive basalts rising (V-type) via open fractures (highly buoyant magmas, with limited degassing and/or fractional crystallization), magma pooling in dike plexuses (fractional crystallization and degassing), solidification and sealing of vertical conduits driven by increases in gravitational stress (cone growth), lateral L-type intrusions of evolved (trachytic) magma from upper plexuses, and continued magma propagation via new pathways. Over time and with rejuvenation and migration of magma, this process repeated building an aggregate volcanic complex.

TRACE ELEMENTS IN NEW ZEALAND PHOSPHORITE NODULES

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The occurrence of phosphorite nodules on the Chatham Rise has been known since the early 1950's. Shortly after, their economic potential as a source of rock phosphate fertiliser and possibly of metals such as uranium was recognised. It has only been in the last decade, however, with the demise of traditional sources of phosphate for New Zealand (such as Nauru) that the economic demand for phosphate has increased and exploration of this resource has resumed.

Spanning much of the length of the Chatham Rise, apatite- and glauconite-rimmed phosphorite nodules have formed via phosphatisation of Miocene chalk. Early studies have shown these to have on average ~ 20 wt% P_2O_5, but have also flagged high U concentrations (100's of ppm) as well as ppm levels of several other metals [e.g. Cullen, 1978, Marine Geology 28: M67-M76]. The viability of these marine phosphate lag deposits for economic exploitation hinges on the composition of the nodules and their host

sediments: requiring sufficient mineralization combined with acceptably low levels of trace metals that may be eco-toxic (e.g. As, Cd, Cr, V and U).

High precision, inductively coupled plasma mass spectrometry trace element analyses of phosphorite nodules and associated sediments will be presented here together with major element data acquired by x-ray fluorescence spectrometry. These data extend the range of trace metals previously investigated, including potentially eco-toxic elements. The nodule and sediment samples analysed comprise varying grain sizes from multiple sites along the Chatham Rise, as well as from a recently discovered locality on Bollons Seamount. The compositions of the nodules and associated sediments will have implications for mining of the resource, eco-toxicity to the habitat, and their potential as a suitable source of rock phosphate fertiliser.

FORAMINIFERAL RECORD OF HOLOCENE PALEO-EARTHQUAKES ON THE SUBSIDING SOUTH-WESTERN POVERTY BAY COASTLINE, NEW ZEALAND

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Foraminiferal faunas in 29 short cores (max depth 7 m) of estuarine and coastal wetland sediment were used to reconstruct the mid-late Holocene (last 7000 yrs) elevational history on the southern shores of Poverty Bay. This coast is on the southwest side of a rapidly subsiding area beneath western Poverty Bay. Modern analogue technique paleo-elevation estimates based on fossil foraminiferal faunas indicate that our four study areas have gradual mid-late Holocene subsidence rates that increase from the southwest (mean ~0.6 m/kyr) to northeast (mean ~1.0 m/kyr). Several processes could be generating this area of gradual subsidence – such as seamount subduction, back tilting on an upper plate fault, coseismic subsidence related to subduction earthquakes or forearc basin development.

Only two rapid, possibly co-seismic, vertical displacement events are recognised in the core sediments: 1). ~1.2 m of subsidence at 5.6±0.5 ka (cal yrs BP). This correlates in age with a ~5.5 ka subsidence and paleotsunami in sediment cores in northern Hawkes Bay, ~35 km to the south, inferred to be a subduction interface earthquake; 2). ~1 m of uplift (relative sea-level fall) at ~3.8 ka. This correlates in age with uplifted marine terraces at Pakarae and Mahia, 40 km to the north and south, suggesting uplift of the south-western Poverty Bay could be related to rupture on an offshore upper plate fault. Alternatively, it could be related to rupture on the subduction interface beneath Poverty Bay.

The two coseismic events identified do not account for majority of the Holocene vertical deformation in south western Poverty Bay suggesting both coseismic and aseismic processes are at play. This is consistent with contemporary GPS measurements that indicate the subduction interface in this area is currently dominated by steady aseismic creep and slow slip events – i.e., plate motion is accommodated largely aseismically.

SURFACE WAVE STRUCTURE OF CANTERBURY AND SEISMIC VELOCITY CHANGES FOLLOWING THE 2010 DARFIELD EARTHQUAKE.

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The 2010-2011 Canterbury earthquake sequence occurred largely on previously unmapped and buried faults, including the Greendale Fault. Accurate models of the near-surface velocity structure are vital to understand fault characteristics and earthquake resilience.

Cross-correlations between seismic station pairs can approximate their corresponding Green's functions, i.e., the impulse response of the Earth between two stations. These functions can be used for a wide variety of studies, including surface wave dispersion, seismic velocity mapping, noise

source analysis and monitoring temporal seismic velocity changes.

We have determined surface wave dispersion and present preliminary results of temporal velocity changes following the Darfield 2010 earthquake. Knowledge of these will give insights into characteristics of the Greendale Fault and the regional structure. Temporal velocity changes could show changes in noise sources or post-seismic relaxation through crack-healing.

Using data from a temporary deployment to monitor the Darfield 2010 earthquake aftershock sequence, nine-component cross-correlation functions have been obtained. Surface wave dispersion was analysed using the FTAN method. Preliminary results reveal fundamental mode Rayleigh and Love waves and first higher-mode Rayleigh waves. Fundamental mode Rayleigh waves dominate correlations for frequencies of 0.5 Hz to 1 Hz for stations separated by less than 50 km. Higher mode velocities up to 3 $km.s^{-1}$ have been observed and dominate at frequencies less than 0.5 Hz. For inter-station paths along the Greendale Fault we observe a small increase in seismic velocities c. 0.04 % in the four months following the Darfield earthquake.

SEISMIC IMAGING BENEATH THE WELLINGTON REGION, NORTH ISLAND, NEW ZEALAND

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We present 2 and 3D seismic imagines from the Seismic Array HiKurangi Experiment (SAHKE). This joint project involving New Zealand, Japan, and US institutions aims to investigate the subduction zone fault characteristics beneath Wellington. Situated above where the Pacific Plate is subducting beneath the Australian plate at a rate of c. 42 mm/yr, the Wellington region provides a unique opportunity to investigate the frictional properties, geometry, and seismic potential of a shallow, locked megathrust fault. Here the coupled plate interface is 20-30 km deep beneath land and can be sampled with onshore/offshore data from 3 sides. We have published a 2D Vp model (Henrys et al., 2013) incorporating coast-to-coast onshore-offshore transect of 50 stations and utilising first arrivals from 2000 offshore MCS shots on either side. The transect velocity model also combined first arrivals from 800 stations with 100 m spacing recorded from 12 in-line, 500 kg onshore dynamite explosions. Using the 2D Vp model we obtain the scatterer distribution of explosion waveform coda and applied reverse-time migration to image the plate boundary, a broad zone of reflectivity under the Tararua Ranges, and upper-plate faults. In addition, the 1st arrival tomography is extended to include (i) first arrivals from the dense temporary array of 50 seismometers with c. 7 km spacing augmented with 25 regional network instruments to record 49 local and 45 teleseismic earthquakes over a four month period and (ii), 69,000 offshore airgun shots from 17 MCS lines crisscrossing two sides of the array. We combine all shot and earthquake recordings to simultaneously invert c. 750,000 first arrivals for velocity structure and hypocenters in the densely sampled volume. Results from 3D, Vp tomography provide improved resolution over previous studies. Our improved velocity model provides a high-resolution geometry of the subducting plate to support interpretation of other phases identified in SAHKE shot gathers and local earthquakes.

USING SEDIMENT SAMPLES AND SUBSURFACE PROFILES TO GROUND TRUTH SUPERVISED AUTOMATED SEGMENTATION OF MULTIBEAM BACKSCATTER FROM THE CHATHAM RISE

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The use of supervised automated segmentation of multibeam backscatter data to characterise

seafloor substrate type is a relatively novel technique that is not yet fully developed. In particular the use of data acquired using low frequency multibeam systems, such as the 12 kHz EM120, presents difficulties due the ability of the signal to penetrate up to 5 m below the seafloor. This study tests the accuracy of supervised automated segmentation carried out using the SonarScope© software, through comparison of expected versus observed sediment types from substrate classes and physical property data. We use sediment samples, underwater video tows and seismic profiles acquired during Cruise SO226, over the large pockmarks of the Chatham Rise.

Interpretations of seafloor substrate are derived from classes delineated in the supervised automated segmentation according to the Generic Seafloor Acoustic Backscatter (GSAB) model. Key stratigraphic units, such as high-amplitude lithified carbonates, can be identified in subsurface seismic profiles and correlated to layers in sediment cores, facilitating the development of a rudimentary 3D model of sediments. This is then compared to the substrate classes derived from the segmentation.

Correlating physical property data to substrate classes revealed that the amplitude of returned backscatter frequently corresponds to lithologies at depths of up to 4 m below the seafloor. The results of this study also highlight several issues in the process of substrate classification, primarily due to the fact that the GSAB model is based on the grain size and roughness of the seafloor. This does not account for several other parameters which may influence backscatter levels such as the porosity and pore fluid content. Better understanding the limitations of this model, however, allows first order interpretations of substrate type and sediment properties to be derived from the supervised automated segmentation.

DEVELOPING A CHEMOSTRATIGRAPHIC FRAMEWORK FOR THE WHANGAI FORMATION

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The Late Cretaceous to Paleocene Whangai Formation (and its correlatives) is a widespread, thick (>400 m), fine-grained, relatively homogenous siliciclastic sedimentary succession that can be traced from New Caledonia to the Great South Basin, southern New Zealand. Whereas it is lithologically homogeneous, it almost certainly records various sediment sources. Within the East Coast Basin, preliminary results of heavy mineral assemblage studies record varied provenance characteristics. On this basis, we have integrated studies of detrital grain provenance and detrital zircon fission track analysis with major and trace element data from key Whangai Formation outcrops in the East Coast Basin.

Typically, bulk-rock geochemistry requires the application of costly laboratory based methods that require extensive sample preparation. The development of portable X-ray fluorescence (pXRF) technology allows the rapid collection of large datasets with minimal sample preparation. The pXRF data collected from the various lithostratigraphic divisions of the East Coast Basin allows us to develop high-spatial resolution datasets to assess whether it is possible to distinguish provenance characteristics, and provide a chemostratigraphic classification. This method has the potential to be combined with sequence- and bio-stratigraphy data, as well as with heavy mineral provenance information to refine spatial, temporal and depositional relationships for the Late Cretaceous to Paleogene successions of the East Coast Basin.

Key sections throughout the East Coast Basin have been sampled and analysed for detrital zircon fission track ages and heavy mineral assemblages to provide provenance information, whilst the pXRF analysis adds to this data by enabling correlation between sections, and vertical and lateral variation in composition to be resolved. Using this integrated approach, we can gain insights into hinterland tectonics during the Late Cretaceous to Paleocene.

THE THREE R'S OF CARBON BURIAL IN NEW ZEALAND FJORDS: RUNOFF, REDOX, AND RECYCLING

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Continental margins are significant sites for carbon burial, and fjord margins in particular have been shown to accumulate and sequester large amounts of organic matter. The fjords of southwest New Zealand, located in Fiordland National Park, rapidly accumulate carbon-rich sediments (up to 3 mm yr^{-1}) and may bury those sediments long-term as sites of net carbon export. However, the ultimate fate of carbon in these systems depends on the efficacy of processes such as carbon delivery and remineralization.

Using a suite of geochemical proxies (C and N concentrations and isotopes, GDGT distributions, trace element concentrations), we investigated carbon cycling and burial in New Zealand's fjord systems. Bulk organic geochemistry of surface sediments shows a strong terrestrial organic carbon component, driven by high regional precipitation (up to 6 m yr^{-1}). This precipitation is a direct result of the Southern Hemisphere westerly winds: As moisture-laden winds hit the Southern Alps, rain falls on the windward side of the mountains and drains into the fjord basins. This runoff is rich in terrestrial organic matter. Once the carbon settles in the fjords, we show that oxygen content plays a major role in organic matter preservation. In well-oxygenated systems that experience vigorous circulation, organic matter respiration is more likely to occur efficiently.

In addition to surface sediment geochemical data, we will present high-resolution downcore analyses over the last 3,000 years to show how climatic shifts (e.g., shifts in the westerlies) may have influenced carbon delivery and burial in New Zealand's fjords during the late Holocene.

IMAGING THE SUBDUCTING PACIFIC PLATE USING AFTERSHOCKS OF THE SOUTHERN COOK STRAIT EARTHQUAKES

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We present seismic migrations using aftershocks of the Cook Strait (M 6.5) and Lake Grassmere earthquakes (M 6.6). Following these two large earthquakes we began the Seddon Earthquake Aftershock Structural Investigation (SEASI) and deployed a line of 21 seismometers stretching approximately 400 km along the strike of the Hikurangi subduction zone in order to use the ongoing aftershocks to illuminate the structure of the subducted Pacific slab. The SEASI line ties into the SAHKE line, which was an array of up to 900 seismometers that recorded air gun and explosion shots in deployments from 2009-2011. The SAHKE project characterized the structures perpendicular to the strike of the subduction zone. Our results use the SAHKE line as a starting point and look for strike-parallel variations in the depth of the Moho and other structures. Previous studies have suggested potential changes along strike in this region, and the deep slow slip events (> 35 km) beneath Kapiti island also indicate the potential for variation in properties along strike.

We have used 246 M > 3 earthquakes that occurred from September 2013 through January 2014 to create common receiver gathers. Our analysis suggests that earthquake relocation (using the temporary GeoNet array deployed during the sequence) is an important step to produce clean migrations. Multicomponent prestack depth migration of these receiver gathers, with operator antialiasing control and prestack coherency filtering, produces reflectivity sections using a 1-D velocity model derived from the SAHKE project. An initial P-P migration shows a north-dipping reflector at 15-25 km depth under the earthquake sequence, and suggests the Moho at 20-25 km depth. From Wellington, a reflector dips very gently south from 25-35 km depth, which is probably the slab interface. These results are helping to build 3-D image of the plate interface in the Marlborough and Wellington regions.

CORRELATIONS BETWEEN SHAKING CHARACTERISTICS, HYDROLOGICAL RESPONSES AND SHALLOW AQUIFER GEOLOGY DURING THE CANTERBURY 2010-2011 EARTHQUAKES

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Shaking and hydrological responses of groundwater during the Canterbury earthquake sequence have been examined across the hydrogeological transition from unconfined to confined aquifers. Data along a 35 km-wide west-east profile through Christchurch have been analysed to compare observations from the inland zone of unconfined aquifers, where groundwater levels are deepest and have a component of downwards flow, with effects in the coastal zone where aquifers are confined, levels are shallow or pressures above ground (artesian) due to a component of upwards flow. Nearly all sites were in spring recovery prior to the 4 Sept 2010 Mw7.1, and in summer recession prior to the 22 Feb 2011 Mw6.3, but pre-earthquake trends were not accelerated by the earthquakes. Prominent groundwater level increases were recorded during both earthquakes, with response style strongly related to the hydrogeology: unconfined aquifers responded and recovered quickly (closed-system spike responses < 1 day); whereas pressure changes in confined aquifers had longer-lasting effects (>days) and those with artesian pressures appear to have lost water. Shaking recorded by GeoNet seismometers was quantified in terms of PGA, PGV, arias intensity, peak frequency, peak dynamic stress and other spectral characteristics. Provisional analysis suggests the magnitude of hydrological response appears more-strongly related to hydrogeology than variations in shaking. By comparing hydrological response characteristics with nearby thorough range of ground shaking metrics we hope to be able to isolate controlling parameters of the seismic and hydrological responses.

THE CARBON THE IPCC FORGOT: IMPLICATIONS FOR LOCAL CLIMATE CHANGE IN COMING CENTURIES

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Projections for future climate change released by the Intergovernmental Panel on Climate Change in Assessment Report 5 (IPCC, AR5) in 2013 and 2014 are based on four Representative Concentration Pathways (RCPs) for greenhouse gas emissions. These RCPs range from a very optimistic low emissions scenario, peaking about now (!), to the most pessimistic (and arguably most realistic) scenario with emissions continuing to increase throughout the coming century; the projected increase in average global temperatures by 2100 ranges from 1° to 3.7°C. However, the projections based on these RCPs omit several potential carbon cycle feedbacks that can amplify and accelerate global warming.

The geological record provides several examples of past times when additional earth surface carbon components amplify global warming via positive feedbacks. The best known example, the Paleocene-Eocene thermal maximum (PETM), was an episode of pronounced and rapid global warming 56 million years ago that lasted ~200,000 years. Super-imposed upon a long-term gradual warming trend, the PETM was associated with a rapid release of at least 2000 billion tonnes of carbon. Possible sources of this carbon include methane stored within submarine gas hydrate systems or polar permafrost. Excellent local geological records of the PETM reveal its dramatic impact on the southwest Pacific: mean annual temperatures increased by 3-5°C, significant species turnover occurred within the marine biota, and an accelerated hydrological cycle has been inferred from increased continental erosion.

The widely held view that the carbon cycle feedbacks associated with the PETM and other Eocene “hyperthermals” operated on timescales that are too slow to concern New Zealand’s “farmer at the gate” may need reconsideration given recent accounts of catastrophic releases of permafrost carbon (“compost bombs”) and the accelerated expulsion of methane from submarine reservoirs.

DEVELOPING A NEW ZEALAND TEPHROCHRONOLOGICAL FRAMEWORK FOR THE SHAPE TIMEFRAME

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Tephrochronology has played an integral role in the NZ-INTIMATE project. A framework of 22 marker tephra erupted from Taupo Volcanic Zone (TVZ), Tuhua (Mayor Island) Volcanic Centre (VC), and Egmont volcano from 30 cal. ka to the present underpins the NZ-INTIMATE climate event stratigraphy. It is now timely to review the potential for extending the New Zealand tephrochronological framework to 60 cal. ka as part of the SHAPE project.

An examination of the tephrostratigraphy of long sediment records from terrestrial sites (Auckland maars, Lake Omapere, Lake Poukawa) and offshore (Bay of Plenty, Hawkes Bay, and wider Southwest Pacific Ocean) yields six well-defined tephra deemed as suitably widespread markers, including one from Taupo VC, namely Tahuna tephra, and five from Okataina VC, namely Omataroa (unit K), Mangaone (unit I), Hauparu (unit F), Maketu (unit D), and Rotoehu. Furthermore, several units from Tuhua Volcanic Centre preserved in offshore cores in the Bay of Plenty offer potential if they can be correlated to other sites. The framework may be further expanded through recognition of well-known eruptions in cryptotephra form thus expanding their known distribution, and through further fingerprinting and correlation of widespread andesitic tephra from Egmont and Tongariro Volcanic Centres.

Of the tephra named above, most have relatively poor age control, limited to a relatively few radiocarbon dates or ages interpolated from sedimentation rates. The Rotoehu tephra has received considerable attention, its age most recently being determined as 45 to 50 cal. ka using a combination of $^{238}U/^{230}Th$ disequilibrium and (U–Th)/He ages on zircon, and radiocarbon. Maximising the potential of these markers to help achieve the goals of SHAPE clearly requires better age control. High-precision radiocarbon dating of charcoal, and $^{238}U/^{230}Th$ disequilibrium and (U–Th)/He zircon ages, are viewed as the best methods to obtain new dates.

DIFFERENTIATION OF POLLEN OF NEW ZEALAND SPECIES OF FUSCOSPORA USING AUTOMATED IMAGE CAPTURE AND ANALYSIS

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Accuracy of pollen-based palaeovegetation reconstructions is often hampered by poor taxonomic resolution, whereby different taxa have morphologically indistinguishable pollen. This is particularly problematic in groups where members have very different ecological requirements. There are several such groups in New Zealand. Studies of pollen morphology are the basis for determining taxonomic resolution. Traditionally, these studies are done manually. Analysts observe and measure a typically limited number of pollen grains from a similarly limited number of samples, and this provides the 'reference' for the taxa/taxon. However, technological developments in the fields of automated microscopy and image analysis are realising the capacity for high throughput analysis, which can vastly increase the number of observations and samples which can be analysed in a pollen morphology study. Through increasing sample size, a more accurate picture of the range of morphological variation within and between taxa can be obtained, which in turn can facilitate further differentiation, beyond that achieved by manual methods.

Recent work on *Leptospermum scoparium* and *Kunzea ericoides* pollen has demonstrated how through applying automated image capture and analysis, two pollen types long regarded as indistinguishable are actually quite distinct. This presentation will examine application of the same techniques to another key New Zealand pollen taxon – *Fuscospora*, which is common in Quaternary pollen records. The pollen of the four

members of this genus are also generally accepted as indistinguishable.

Hundreds of pollen grains of each of the four species have been imaged and analysed using the automated palynology system 'Classifynder' (www.classifynder.com). In addition, a sample of *Fuscospora*-type pollen from a late Quaternary lake sediment sequence was analysed and compared with the data from the four species, to demonstrate application in New Zealand palaeovegetation reconstructions.

RAIN INDUCED UNSTABLE SLIDING – TASMAN GLACIER

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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 predictions. Estimating the upper bound of potential accelerations is of particular interest as it allows the limits of realistic scenarios of sea level rise to be determined. Implicit in this approach, however, is the assumption that we have observed, or can predict, the full spectrum of glacier behaviour.

Changes affecting basal slip can cause the flow of glaciers and ice sheets to accelerate rapidly. During times of heavy rainfall, Tasman Glacier in the Southern Alps of New Zealand accelerates to speeds of up to 40 times its normal speed (from 40 to 1600 m a^{-1}). Peak speeds are maintained for periods of less than 12 hours before the glacier velocity returns to close to background levels.

These observations, which were obtained using multi-year continuously recording GPS, greatly expand the observed range of glacier speed ups in response to water inputs, and likely represent a state of unstable sliding. The velocity of Tasman Glacier is shown to be proportional to the 24-hour rainfall magnitude in the surrounding catchment and peak velocities correspond with the peak rate of glacier surface uplift. The sensitivity of glacier speed to water input is increased by glacier down wasting, which lowers the effective pressure at the bed, indicating that rain induced speed-up events will become increasingly common on Tasman Glacier.

AGGRADATION AND AGE OF LATE QUATERNARY GRAVELS BENEATH THE CANTERBURY PLAINS AND IMPLICATIONS FOR GLACIAL ADVANCE AND RETREAT

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The age and depositional history of the near-surface gravels of the Canterbury Plains is important for estimating the activity of faults that underlie the plains. Research into the sedimentation history on the plains has long been hindered by the difficulty of dating the gravel-dominated deposits. Interpretations of the depositional history have relied on limited radiocarbon (14C) and optically stimulated luminescence (OSL) dates at widely scattered locations.

OSL dating from trench and quarry sites near the Greendale Fault provide seven new ages from sand lenses in Burnham Formation gravel deposits at depths of 0.9 to 4.0 m, and one from loess in a surficial channel incised into the gravel (depth of 0.55 m). The intra-gravel sand lenses returned median ages ranging from 20.2±1.9 to 33.0±2.0 ka while the loess yielded an age of 10.0±0.7 ka. This loess age indicates that in this location about 10 kyr may have elapsed between fluvial abandonment of the surface by the Waimakariri River and deposition of Holocene loess, and highlights the importance of sampling from within gravel deposits themselves to constrain the age of the sediment package. Intra-gravel ages are compatible with previously published OSL and 14C dates from elsewhere on the Canterbury Plains (e.g. [1]). The gravel depositional ages are

generally in correct stratigraphic order and cluster in time intervals of ~20 to 24 and ~28 to 33 ka.

We propose a model for multiple periods of fluvial sediment deposition and quiescence on the Waimakariri and other Canterbury Plains glacial outwash fans since at least 33 ka. The data highlight that the penultimate surface rupture on the Greendale Fault occurred at about 20-30 ka, and that a subsequent episode of gravel deposition removed or obscured the surface trace of the fault, until its re-emergence in the 2010 Darfield Earthquake.

[1] Rowan et al., (2012). Quaternary Geochronology 8, 10-22.

THE GEOLOGY OF A SECTION OF THE PAHIATUA BASIN, MANGATAINOKA RIVER VALLEY, NORTH ISLAND, NEW ZEALAND

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Pahiatua Basin, a Late Miocene to Recent basin, is located in the East Coast fold and thrust belt immediately east the major strike-slip fault zone that bounds the axial ranges. The sedimentary succession represents a shallowing marine environment overlain by terrestrial sediments.

The Totaranui Formation, an important unit in this sedimentary succession, is the oldest member of the Mangamaire Group. It is widely distributed, occurring on both ridges of the Mangatainoka Valley, but is not present south of Mangamaire. This study revises the stratigraphy of the Totaranui Formation and subdivides it into five members – Lower Mangamaire Sandstone, Lower Totaranui Coquina Limestone, Upper Totaranui Flaggy Coquina Limestone, Totaranui Limestone Conglomerate and the Upper Mangamaire Sandstone. The formation overlies the Marima Sandstone in the west and the Makuri Group in the east and underlies the Mangahao Formation in the west. The Totaranui Formation varies in thickness, but has a maximum thickness of 110m. Lithofacies show change from a low energy to a high energy environment consistent with the shoaling of the Pahiatua Basin in the past 10 million years. It is considered a potential aquifer in the region.

DISASTER VIEW: CROWD SOURCED DISASTER IMAGERY

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Correct decisions can only be made when there is accurate information available. In a disaster, poor communications and poor physical access limit information acquisition by central authority. However, large numbers of those in the affected area will have cellular telephones with the ability to capture images. The proposal is to provide a digital mapping platform, similar to Google Street View™, where photos taken by members of the public can be uploaded to provide dense visual imagery of damage in near real time of emergency situations.

The majority of cellular telephones can capture images, and these images carry with them metadata. Where the phone is GPS capable, these co-ordinates are part of the metadata. To protect privacy, various social media sites normally strip this information from the image. If, however, images with metadata were sent to a site capable of interpreting this GPS data and assigning the image to a GIS location, a central image source would become available as and where data can be transmitted over data networks.

THE ANCHORITE FAULT SYSTEM - MIOCENE FAULTING IN THE HAURAKI GULF

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A long series of faults crossing the Hauraki Gulf links the Whangarei Harbour Fault with the Waiwhango Fault in the northern Coromandel Peninsula. Hereby named the Anchorite Fault System [AFS], initial activation at ~21.5 Ma is contemporaneous with the end of the emplacement of the Northland Allochthon; we suggest the AFS is structural failure of the anticline / nappe which provided the driving slope for emplacement.

The height of the resultant scarp (~1500m) and the presence of a debris field 40km x 70km – Kawau Subgroup - indicate a large and rapid release of energy, and provide the geological scenario for the sudden plunging to bathyal depths of basal Waitemata Group as described by previous workers. The AFS scarp now forms the eastern boundary of Waitemata Group. Despite the height of the scarp, formations on both sides of the fault were created at bathyal depth. On the upthrown side, Colville Formation demonstrates sudden immersion, bathyal sedimentation and progressive restoration to coastal shallows, indicating rebound from submergence by ~17.5Ma.

The lineation appears to be associated with volcanics at Whangarei (Taurikura Volcanic Complex), Coromandel (Beesons Island Volcanics) and Anchorite Rock, in mid Hauraki Gulf.

Volcanic activity took place at Taurikura from approximately 23Ma to 16Ma. As activity decreased near Whangarei, the Beesons Island Volcanics commenced on the AFS and en echelon faults near Coromandel. Beesons Island Volcanics were active from 16Ma to 13Ma, at which point Anchorite Rock erupted, ending the main sequence of fault related volcanic activity.

THE DEAL WITH THE DEVIL

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Strict measures to limit fossil fuel use are possible but unlikely, for democratic governments will do what is popular with the majority. People in poor countries aspire to the lifestyle which oil, gas and coal allow us. Abrupt cessation of fossil fuel use is implausible and our species will have to live with the climate change consequences.

How resilient is New Zealand? We try to pay for a first world lifestyle through the export of little-processed agricultural commodities such as milk powder but our balance of payments is negative. Expansion of dairy farming to balance the books comes at a significant environmental cost.

Gas generates 20% of our electricity and sustains industry; our reserves peaked in 2002. We still rely on oil and, if we cannot yet give it up, must substitute, import, or produce locally. We import 69% of our oil and pay in US dollars, difficult when the exchange rate is high and even more difficult should it revert to the historic average. Continued use will have environmental consequences but there are no magic alternatives for transport fuels.

Our vast offshore territory includes many sedimentary basins. There have been few offshore wells, except in the area of the Taranaki continental shelf. Are New Zealand's only commercial accumulations of oil and gas in the eastern Taranaki Basin? I don't know the answer and neither do you.

Self-sufficiency in oil and gas would help this country build resilience, to better meet the challenges which this century will bring. A systematic study is warranted. We make some effort, but insufficient effort, and must reconsider how government research money is spent. Will your work improve the social and economic well-being of those who fund it through their taxes? If not, why are you doing it?

PLANT DIVERSITY AND PALEOCLIMATE OF THE MIOCENE LANDSLIP HILL SILCRETE, GORE LIGNITE MEASURES, SOUTHLAND

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The Miocene Landslip Hill silcrete from southern New Zealand is a fluvial deposit consisting of quartz sand cemented by amorphous silica, in which numerous randomly oriented three-dimensional plant fossils are preserved as moulds. Leaf fossils include eight conifer morphotypes, two monocots and about 30 distinct angiosperm leaf morphotypes with dicotyledonous or magnoliid affinities. Additionally, eight different fruit or seed types are recognised. Some morphotypes have affinities with Araucariaceae, Podocarpaceae, Nothofagaceae, Casuarinaceae, Elaeocarpaceae and Lauraceae. Quantitative paleoclimate estimates for temperature and precipitation variables were obtained by cross-correlating

physiognomic variation of dicotyledonous and magnoliid leaf morphotypes with two pre-existing modern leaf assemblage calibration datasets using the Climate Leaf Analysis Multivariate Program (CLAMP). Preliminary results indicates a diverse floral assemblage growing in a much warmer and more humid climate than present day Southland, with moderate to high average precipitation with relatively little seasonal variation and a more or less year-round growing season.

NEW PALYNOLOGICAL INVESTIGATIONS FROM NEW ZEALAND PROVIDE INSIGHTS INTO REGIONAL AND HEMISPHERIC CLIMATE VARIATIONS DURING THE HOLOCENE PERIOD.

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Environmental reconstructions based on vegetation are particularly well suited to New Zealand (34-47°S; NZ) due to its location across sub-tropical and extra-tropical latitudes, an extensive pre-human forest cover and a late settlement history. Previous palynological studies have been focused on the transition out of the last Ice Age. These have revealed important vegetation changes; while the use of numerical techniques have allowed quantitative reconstructions of temperature variations associated with those changes. However, pollen-based climate reconstructions for the Holocene period are comparatively fewer and less well resolved, which prevent more detailed investigations about the climate controls over this period.

Here we present two new postglacial pollen profiles from different vegetation-climate settings in NZ: (1) a 13,000 year-long sequence from Adelaide Tarn (40°56'S; 172°32'W), a small lake near the tree line in the beech (Nothofagus) forest of the northwestern South Island; and (2) an estimated 15,000-17,000 year-long sequence from Moanatuatua (37°58' S; 175°21'E; 60 m.a.s.l), a lowland peat bog in the Broadleaf-conifer forest area of the northern North Island.

A quantitative temperature reconstruction from Adelaide Tarn and a preliminary integration of both records suggest significant early-Holocene warming in the South Island. While a more modest temperature increase is observed in the northern North Island. At the same time, multiple proxies from tropical and extra-tropical latitudes imply that precipitation sourced from the extra-tropics (westerly) may have reduced over most of the country. This reduction could have been compensated in northern and eastern areas by an enhanced subtropical (easterly) precipitation, a circulation pattern in some ways analogous to the present-day positive phase of SAM. Evidence for this scenario will be examined using the pollen records from Adelaide Tarn & Moanantuatua.

TURBIDITES OF THE SOUTHERN HIKURANGI CHANNEL, NEW ZEALAND

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Relatively little is known about depositional flow processes along and across the Hikurangi Channel. This poster presents the results of a sedimentological investigation of three, archived short (<3.5 m) sediment cores, collected by NIWA, from the southern Hikurangi Trough off Wairarapa. The aim of the study is to understand depositional flow processes, from a high resolution analysis of selected beds. The three cores form a lateral transect from the channel thalweg, to the north western levee and distal overbank basin floor environments, allowing comparison of lateral facies changes. Laser particle sizing, magnetic susceptibility and vacuum gasometric techniques are used to investigate, analyse and characterise each core, with focus on key event beds. The beds selected are normally graded sandy-silts that have been interpreted as deposits of low-density turbidity currents. Turbidite caps are muddy and exhibit a spike in the percentage of calcium carbonate ($CaCO_3$), which may indicate the presence of an overlying hemipelagic layer. Comparison of the sedimentary facies in each environment provides an insight into the flow processes and depositional characteristics of the Hikurangi Channel, and more generally, insights

into levee over-spilling and flow stripping processes. A conceptual model of flow evolution from channel to overbank will be presented.

AIRBORNE GRAVITY ACROSS NEW ZEALAND

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Land Information New Zealand has recently completed the first national airborne gravity survey of New Zealand. The aim of the programme was to determine gravity anomalies at a 10 kilometre wavelength and thereby compute a national geoid with at least 3 centimetre accuracy.

The airborne gravity data consist of a uniform set of measurements that cover the whole of New Zealand, including the shallow coastal areas and rough topography that have previously been extremely difficult to survey. Over 50,000 line-kilometres of surveying were completed in two campaigns during August - October 2013 and February – June 2014.

The key steps taken in the data collection and reduction will be outlined along with an analysis of the internal consistency of the data and comparison to the existing global gravity model EGM2008.

DEVELOPMENT OF INTERDISCIPLINARY GEOSCIENCE CURRICULA: APPROACHES AND IMPLICATIONS

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As society increasingly encounters challenges within an interconnected earth system, interdisciplinary research and teaching are becoming more frequent in the geosciences. The broader learning environment that interdisciplinary studies encourages has the potential to develop more comprehensive, transferable skills applicable to the "real world", by helping students identify and leverage disciplinary connections often taken for granted by expert scientists. Despite this, the traditional tertiary education system provides limited opportunities to work outside of disciplinary boundaries and little support to do so.

Interdisciplinary curricula are most effective when knowledge is constructed from the ground up, with links between individual disciplines made during the later stages, at which time foundational knowledge has been solidified. They are also most effective when implemented using active learning (i.e., hands on) techniques. Using these recommendations, interdisciplinary curricula has the potential to be highly impactful in outreach and recruitment, both at the secondary and tertiary level. This is particularly relevant to geoscience, where anecdotal evidence suggests that many majors begin tertiary studies in other subjects and the potential for cross-disciplinary recruitment is high.

This work will situate concepts relating to approaches and implications of interdisciplinary studies in a real curriculum development example. The "Living with Volcanoes" activity is a ninety minute, one-off introductory geoarchaeology activity, developed with the above benefits and framework in mind. Geoarchaeology, the integration of earth science techniques into archaeological investigations, bridges the arts and sciences with applications to past, present, and future human-environment interactions. Learning goals and more holistic aims were used to align the curriculum content with concepts and skills deemed central to geoarchaeological and interdisciplinary thought. The curriculum was piloted with upper year secondary school students in Northern England, followed by an assessment of its effectiveness, proving successful at improving geoarchaeological knowledge and perceptions of interdisciplinarity.

THE ROLE OF SITE AMPLIFICATION, POLARITY AND TOPOGRAPHIC EFFECTS IN THE PORT HILLS DURING THE CANTERBURY EARTHQUAKE SEQUENCE

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Significant building damage and permanent ground displacement occurred in the southern Port Hills suburbs of Christchurch during the Canterbury earthquake sequence. Damage patterns indicate that local amplification of ground motions likely contributed to the most severe effects. The Canterbury earthquake sequence provides an internationally significant case study to understand the influence of topography and local stratigraphy on ground-motion amplification in hillside areas.

We present site-response analyses based on GeoNet national strong motion stations, as well as four small-scale temporary seismic arrays installed in the Port Hills following the 2011 February Christchurch earthquake. These stations are spread across narrow north-south trending volcanic spurs with a variety of topographic shapes. The spurs are also overlain, in part, by thick (up to 10m) loess deposits. Site amplification, polarization and dependence on source back-azimuth are assessed using H/V and site-to-reference spectral ratio methods applied to aftershocks of the Canterbury earthquake sequence. Results are also compared with detailed 2D modelling at key locations.

Consistent amplification peaks at hill-top locations at 1 – 3 Hz appear to be related to slope shape, with the estimated wavelength of amplification comparable to the ridge width at a given location. The strongest amplification at these frequencies generally occurs on top of narrow, steep-sided ridges. Our results imply that relatively low-velocity material comprising the eastern Port Hills has enhanced amplification in this area. At higher frequencies > 3 Hz, significant amplification is associated with local material contrasts or sharp local convex breaks in slope.

Our results show that both local topography and material contrasts strongly influence ground motion in the Port Hills. These observations have implications for slope stability studies and engineering design in hillside areas, given that significant amplification can occur over a broad frequency range at sites generally classed as rock according to the New Zealand design standards.

CHARACTER AND ORIGIN OF LATE NEOGENE SUBSIDENCE AND SEDIMENTATION OF TARANAKI BASIN

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It is possible with a high degree of certainty to map the unfolded position beneath Taranaki and Wanganui basins (on Australia plate) of the leading edge of the subducted Pacific Ocean lithosphere. Our hypothesis is that interactions at the leading edge of this slab and behind it caused a marked change in the stress regime of overriding Australia plate, expressed in basin subsidence, coastal onlap and a change from reverse to normal faulting. We have tested this hypothesis by the mapping of stratigraphic horizons using open-file seismic reflection data sets tied to well logs for age control. This establishes the lag timing of coastal onlap, the end of reverse faulting and start of normal faulting in relation to the transit of the leading edge of the slab beneath the region. In general, coastal onlap lags slab emplacement by 0 – 0.5 m.y. Some reverse faults continue to show displacement for up to 0.5 m.y. amounting to about 20 km after the slab was emplaced beneath them, giving rise to folding of the surface of marine onlap (e.g. Kahurangi Fault). The start of normal fault offset shows variable lag time, with faults farther from the Cape Egmont Fault Zone having longer lag times. A key factor in explaining the lag patterns is due to the scale and location of inherited topography, which relates to prior crustal thickening. The widespread late Neogene subsidence of Taranaki and Wanganui basins is considered to be caused by emplacement of the subducted slab and associated mantle processes rather than being due to interaction across the plate interface.

LEAD IN THE LIVING ENVIRONMENT - THE ANNUAL COST TO THE NEW ZEALAND ECONOMY

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Lead and other heavy metals in house dust are detrimental to human health, especially to the health of young children. Until 2009 the international literature and research focussed on serious lead poisoning leading to dramatic decrease in IQ. More recently the focus has shifted to average nationwide low level lead poisoning, leading to small but far from insignificant lowering of the nation's population IQ level.

The main source of the lead in the living environment is from anthropogenic sources accumulating in the geologic substrate of our living environment: the garden soil. From there it is transported into our homes and from there into our bodies through various mechanisms and pathways.

The costs of this lead exposure are staggering. Several studies in the US found the annual cost to exceed $US 50 billion, while a study in France estimates the annual cost for that country at Euro 20 billion. This means the cost to society due to low level lead poisoning 6 – 10 times that of Asthma.

Phasing out of lead-based paint and leaded fuel in New Zealand occurred much later than it did in the US or EU. Therefore mitigation efforts in our country have to be more intense and are more urgent. However the contrary is current reality. Mitigation only incurs a one-off cost, while it benefits many generations of house dwellers.

In the cost benefit analysis presented the similarities and differences with overseas studies will be highlighted and a case made for shifting our focus from home insulation to dealing with this emerging environmental geohazard.

A RE-APPRAISAL OF THE FRACTURED TIKORANGI LIMESTONE IN THE WAIHAPA-NGAERE-TOKO-TARIKI WELLS

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The producing interval in the Waihapa Oilfield is the Oligocene Tikorangi Fm comprising a mixed siliciclastic-limestone sequence up to 300 m thick. The matrix porosity is very low so oil production comes from steeply dipping fractures. There have been several episodes of fracturing, an early Miocene phase that has largely healed, and a late Pliocene phase that is open. The bulk of the work on the depositional history and complex fluid flow in the Tikorangi Fm stems from the research of Hood [1].

Since 2013 NZEC, and its partner L&M Energy, have reviewed the vast amount of data compiled by the previous operators to identify key elements of the fracture and petroleum system. These data include core (368 m in 5 wells), standard logging suites, image logs, full-wave-form sonic logs, and vertical seismic profiles. These data sets provide information on the rock properties and the fractures at a range of vertical scales from the microscopic to the 30 – 50 m seismic scale. Drilling complications in many wells produced incomplete logging suites, so some novel methods have been used to identify fracture density, including fluid losses and other drilling parameters.

The fracture density is not evenly distributed vertically or laterally. The northeast trending faults that create the fractures step in an en echelon pattern across the Waihapa-Ngaere-Toko Field. The more brittle sparry calcite facies supports a stronger fracture density. The mud-rich zones are more ductile and the fractures have healed. Getting the most information out of the existing well data is key to maximising the efficiency of producing the field, and planning new wells to tap undrained portions of the fracture system.

[1] Hood (2000). PhD Thesis, University of Waikato.

THE EARLY EOCENE FLORA FROM OTAIO RIVER

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Earliest Eocene estuarine to non-marine mudstones and coals within the Broken River Formation in Otaio River, South Canterbury, provide a glimpse of the surrounding vegetation in the form of sparse leaves and abundant palynomorphs. Pollen and spores have been examined from throughout the coal measures and provide a record of vegetation change. Leaves have been recovered from a limited stratigraphic horizon in the lower part of the section and although variable in their preservation quality they provide sufficient information for employment of leaf morphology-based paleoclimate analysis (CLAMP and Leaf Margin Analysis). Temperature estimates derived from leaf morphology suggest a warm temperate to sub-tropical climate.

Palynology, leaf fossils, bulk carbon isotopes, sedimentology, foraminifera and nannofossil analysis have been employed to characterise the exposures and the paleoenvironments they represent. Miospores and dinoflagellate cysts indicate that the coal measures are earliest Eocene (New Zealand PM3b/lower MH1 miospore zones, Waipawan to early Mangaorapan); the leaf flora is Waipawan (PM3b zone). The presence of the dinoflagellate cyst genus *Apectodinium* in combination with an apparent negative shift in the bulk carbon isotope record suggest that the leaves were deposited during the *Apectodinium* acme that occurred during the globally significant high CO_2 and high temperature Paleocene-Eocene Thermal Maximum (PETM).

Macromorphology of the leaves indicates the presence of a moderate diversity of broadleaved angiosperms, at least one fern and rare podocarps and araucarians. Leaf cuticle preservation allows confirmation of taxonomic inferences from macromorphology in some instances. Leaf cuticles of the dicot families Proteaceae, Lauraceae, Araliaceae, as well as the monocot *Ripogonum* and the conifer family Araucariaceae have been recovered.

The palynoflora in the leaf-bearing unit is diverse and contains a number of thermophilic taxa including *Spinizonocolpites prominatus* (*Nypa*: Arecaceae), *Malvacipollis subtilis* (cf. *Austrobuxus*: Picrodendraceae) and *Cupaneidites* species (cf. *Cupaniopsis*: Sapindaceae). Conifer pollen is dominant over angiosperm.

RECENT ERUPTIONS AT WHITE ISLAND: QUANTIFYING THE AMOUNT OF MATERIAL LOST TO THE GEOLOGICAL RECORD

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White Island erupted in two very short bursts on 4th August, 2012 and 11th October, 2013 both after intense periods of unrest. The largest of the two eruptions occurred at ~ 8 pm on October 11. Both events were captured by the camera near the old sulphur factory under low light conditions, which allowed us to determine the rates of plume ascent and surge flow rates crudely.

We focus on the October eruption where we have assessed photographs of the crater floor to determine the number and size of ballistic impacts, coupled with ground-based measurements. We then used the area of altered ground from photographs to determine the deposit extent, again along with ground-based thickness measurements. These data are used to describe the dynamics of the eruption.

A serendipitous sample was collected near the camera site that would otherwise have been lost from the depositional record. We use this sample to determine the amount of material transported out of the crater once effective mixing between the surge and atmosphere took place. This is a rare example where we can calculate the amount of material lost from the geological record. We then discuss the results of a visit one year after the eruption to again assess the effect of erosion of the deposit. These results can then be used to better understand the geological vs. eruption record at an active volcano.

STRATIGRAPHY AND SEDIMENTOLOGY OF A SATELLITE VENT OPERATED BY PHREATOMAGMATIC TO LAVA FOUNTAINING ERUPTIONS: THE OHAKUNE BASALTIC COMPLEX

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The Ohakune basaltic complex is a tuff ring – scoria/spatter cone complex located in the southern ring plain of Ruapehu volcano. This monogenetic volcano was investigated previously by Houghton and Hackett (1983) based on the limited extent of quarry walls. Since the 1980s, intensive quarrying has exposed a 30 m thick, 200 m long lateral sequence of phreatomagmatic deposits from the proximal to distal positions of a tuff ring. The volcanism began along a NW-SE fissure with a phreatomagmatic phase, as demonstrated by the presence of a fine ash-dominated, weakly-bedded ≥3 m thick basal succession abundant in accidental lithic clasts from fluvial/laharic gravel and boulder beds, indicating shallow subsurface magma–water interactions that initiated pyroclastic density currents (PDC). This unit is topped by medium- to thick-bedded spatter and accidental lithic rich units separated by thin PDC-dominated units. These sequences indicate that the rising magma erupted through vents along a 500 m long fissure and formed separate vents and craters. At the NW end of the fissure a scoria/spatter cone formed through relatively steady Strombolian to lava fountaining eruptions, depositing homogeneous, massive-bedded pyroclastic deposits. In contrast, at the SE end of the fissure the eruptions were dominated by phreatomagmatic explosions interspersed with short-lived lava fountaining from multiple vents. This sequence could be interpreted as a reflection of the quick changes in magma discharge rate, degasing and the degrees of interaction with external water. The crater rim of the tuff ring is inferred to have frequently collapsed due to vent shifting, based on the presence of local landslides and chaotic deposit arrays. The volcanic edifice has been eroded by a fluvial network that was re-established in the same drainage system through which the Ohakune volcano originally erupted. Two well-preserved radial gullies in the southern flank of the tuff ring record intense post-volcanic erosion.

CHARACTERISING CHANGE IN POSTGLACIAL CLIMATE BY SEISMIC IMAGING IN LAKE OHAU

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The sediments of Lake Ohau, a glacial lake in the Southern Alps of New Zealand, provide a critical record for evaluating Quaternary paleoclimate models, glacial history and past tectonic activity. New Zealand, extending between latitudes of 34˚-47˚, lies across the prevailing westerly wind belt, which makes it a key Southern Hemisphere location for climate studies and especially Quaternary climatic fluctuations. The Mackenzie Basin contains three large fluvio-glacial lakes: Ohau, Pukaki and Tekapo that occupy glacial valleys within 30-40 km of the Alpine Fault, the major plate boundary in the region. They are thought to contain high-resolution sedimentary records of the last 16-20 ka. ^{10}Be dates from recessional moraines indicate that glacial recession occurred at Ohau at 17,380 ± 510 yr. Moraine belts from the last local glacial maximum (LLGM) from Ohau and the Chilean Lake District (CLD) show a similar dates with respect to glacial advances and retreats, furthermore EPICA Dome C δD signals show that warming occurred ~17,900 ka, both of which are consistent with deglaciation at Lake Ohau and Pukaki.

This project will build on a 2011 dataset of single-channel boomer data that covered the entire lake and extend over 50 km. In a New Zealand first, new multi-channel streamer will be collected in conjunction with a boomer source to characterise these post-glacial sediments and especially to constrain their seismic velocities. Preliminary interpretations of seismic lines show no active tectonics in the lake. Interpretations of the data in the north are hampered by gas accumulations sourced from shallow organic-rich sediments; however, the southern portion of Lake Ohau is remarkably free of such contamination. In this location, in 2015, a Marsden Funded project will drill to extract a core record (approximately 100 m TD) of the sediments that will be tied to the seismic data.

MULTI-DISCIPLINARY TSUNAMI HAZARD STUDY IN THE SOUTHWEST PACIFIC: EXAMPLES FROM WALLIS & FUTUNA AND SAMOA

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Following the September 2009 Southwest Pacific Tsunami, we undertook an assessment of the tsunami hazard in Wallis and Futuna (W&F), and Samoa, respectively ~500, ~650 and ~160km from the earthquake epicentre, using four independent approaches together providing strengthened hazard characterisation: (1) post-tsunami survey. In W&F we investigated the damage generated by the 2009 tsunami during a 10-day survey (undertaken by UNESCO-IOC in Samoa). Maximum inundation of 95m and run-up height of 4.4m were inferred from observations of damage to vegetation and infrastructure; (2) Paleotsunami investigation. Nineteen trenches were logged and sampled in W&F for multi-proxy sediments studies to characterise catastrophic seawater inundation events. This enabled us to infer two paleotsunamis in ~470BP and 1940BP; (3) Numerical modelling. Fourteen scenarios of tsunami were generated using the Gerris flow solver. The sources are local, regional and distant earthquake faults. Results show that Wallis is protected from tsunami by the barrier reef, but inundation depths of 2-3m occur in populated areas. In Futuna, flow depths exceeding 2m are modelled in several populated areas; In South Upolu, one extreme scenario from the Tonga Trench shows inundation of the old village and mangrove of Sa'anapu; and (4) Archaeological, interviews and close engagement with the local population. This approach was further developed in Samoa with the village of Sa'anapu. Excellent support from the council of Matais (chief) was critical in obtaining essential collective memories on past natural disasters. Of particular importance were the potential impacts of tsunamis on reef and mangrove which have significant ecological, economic, and cultural values. Here we were able to develop a plan for the relocation of the old village on the coastal sand dune in a safer area using culturally appropriate and accepted protocols. The hazard associated with landslide-generated tsunami needs to be studied for a full understanding of the hazard.

UNCERTAINTY IN TSUNAMI RUN-UP DUE TO VARIATIONS IN NEAR-SHORE BATHYMETRY

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Accurate modelling of tsunami run-up and inundation is important in determining the tsunami hazard. Knowledge of the undersea bathymetry is an important component of that modelling. Bathymetry guides the waves, causing them to shoal, refract, reflect and focus. Small scale changes bathymetry can also affect the wave run-up by increasing surface roughness. This presentation focusses on the effects of intermediate scale bathymetry variations, between these two end members. These intermediate scale variations may not be well captured by the available bathymetric information – especially in the near shore zone where techniques like multi-beam side-scan sonar are not able to be used. Uncertainty in this nearshore bathymetry can lead to uncertainty in the overall amount of run-up observed. We wish to be able to quantify these uncertainties. Features such as stop banks are critical thresholds where small changes in tsunami height can lead to large changes in inundated area making knowledge of uncertainties important.

Our baseline case is a planar beach with the incoming wave specified at the off-shore edge. We model a series of random perturbations of this case, all with mean zero and with varying standard deviations. Intermediate scale bathymetric changes are unlikely to be random noise, thus we simulate these variations by specifying a radial bathymetric wavelength and randomising the phase. We consider three general cases: even sized bathymetric variation and 'bars' (with wavenumber four times higher is one direction than the other) in both the long shore and the cross shore direction. These perturbations break the long shore symmetry of the tsunami and produce a distribution of run-up heights. We compare these with the baseline case and produce

relationships between bathymetry and run-up height variations. We also consider the ability of contours to capture these bathymetric variations and to provide accurate grid for nearshore tsunami modelling.

ACTIVE FAULTS DATABASE OF NEW ZEALAND VERSION 2.0 AT 1:250,000 SCALE

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The Earthquake Geology team at GNS Science has completed a decadal update of the GNS Active Faults Database in conjunction with the Regional Geology Department. The main output is a new realisation of the database, at 1:250,000 scale. Active faults are defined as faults that have ruptured/caused ground deformation during the last 125,000 years, except in the Taupo Rift where the timeframe of activity is the last c. 25,000 years. The database is presented spatially in a Geographic Information System (GIS), as lines which represent ground surface traces, with corresponding attributes. This talk will describe the philosophy, steps and rules that were used in developing the new database.

An important goal of this project has been to construct a database at a uniform scale that is consistent with other GNS Science databases, particularly the QMAP Geological Map of New Zealand. Linework has been derived primarily from QMAP and the existing, multi-scale GNS Active Faults database (AFDB2003). Within the new 1:250k Active Faults Database fault trace data are merged to form faults (and sometimes fault sections and fault zones). Attribute fields, in numeric or character form, provide information about the fault trace data (e.g., ACCURACY) and fault activity parameters (e.g., SLIP_RATE). The 17 attribute fields are the result of integrating and simplifying existing GIS active fault attribute fields (e.g., from the AFDB2003 Database and QMAP).

The 1:250k Active Faults Database will be viewed online (http://data.gns.cri.nz/af/) and also be easily downloadable in several different formats for uptake by a range of users from scientists to local councils, to the general public. The database comes with a Disclaimer that describes its limitations with respect to scale and accuracy and will be partnered by a citable companion paper (Langridge et al., in review). The 1:250k Active Faults Database and the AFDB2003 will be maintained and updated as new data come to hand. We also hope in future to be able to include more active folds and offshore active faults as data comes to hand.

CARBONATE LITHOLOGIES RECOVERED IN DREDGE SAMPLES FROM THE REINGA BASIN

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The Reinga Basin northwest of New Zealand and is a 75 000 km^2 frontier basin with typical water depths in the range 500-2500 m. The region is contiguous with the Northland and the petroleum-producing Taranaki basins to the east and south, respectively. In November 2013, an 18-day survey on board the RV Tangaroa (survey TAN1312) acquired multibeam and dredge samples from 38 selected sites. Rock samples were collected using a 0.45 x 1.2 m diameter steel rock dredge at locations selected on the basis of seismic and/or multibeam data.

A large proportion of the dredged samples are limestones. Biostratigraphic analysis indicates the samples range predominantly from early Eocene to middle Miocene in age, although a few Paleocene ages were also obtained. Thin section analysis shows limestone rock types range from carbonate mudstones to wackestones (dominantly foraminifera and generally bathyal in origin) to shallow water packstones and grainstones containing common to abundant bivalve, echinoderm and bryozoan debris. Algae, sponge spicules and gastropods have also been found. Non-carbonate detrital grains (quartz, subordinate feldspar), usually comprising <10% of the rock volume, are restricted to shallow water carbonates. Authigenic components comprise various calcite cements filling intra- and/or interparticle porosity, local silicification, and glauconite occurs in many samples. One sample comprised cloudy-centre clear-rim, euhedral dolomite rhombs. Dissolution of bioclasts resulting in mouldic porosity and recrystallization

(neomorphism) of bioclastic material is also observed.

The Reinga Basin bathyal carbonates have characteristics similar to the onshore Amuri Limestone, including local silicification. The shallower water packstones and grainstones resemble facies that occur in Te Kuiti Group limestones. Preliminary analyses suggest that none of the Reinga limestone samples represent potential reservoir lithologies but could be possible seals. Siliciclastic samples recovered from TAN 1312 are described in a separate talk by Greg Browne et al.

FOULDEN AND HINDON MAARS: CONTRASTING MIOCENE *KONSERVAT-LAGERSTÄTTEN* DEPOSITS IN SOUTHERN NEW ZEALAND

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The *Konservat-Lagerstätten* diatomite deposits of Foulden and Hindon Maars in Otago are key sites for reconstructing early Miocene Southern Hemisphere terrestrial ecosystems. Although the maars are similar in size, age, sedimentology and geological setting and both possess exceptionally well-preserved fossils, there are marked contrasts between their respective biotas. Both include numerous leaves, flowers with *in situ* pollen, fruits/seeds, fish and arthropods and the climate at both sites was warm temperate to subtropical. The forest surrounding Foulden Maar was an evergreen, Lauraceae–dominated notophyll vine forest with a diverse understorey, lianes, epiphytes and several canopy layers. None of the ~3000 leaves collected to date are of *Nothofagus*. In contrast, the Hindon Maar forest has abundant and diverse *Nothofagus*, as well as lianes, conifers and cycads. Fish are more abundant at Hindon: they include larval to adult stages of taxa within Galaxiidae, some with preserved soft tissue. Insects are common, and include representatives of Hemiptera ('bugs'), Hymenoptera (wasps and ants), Trichoptera (caddisflies), and Coleoptera (beetles), with weevils particularly diverse. The Foulden fish fauna includes *Galaxias* and eels, while the arthropod fauna comprises ~ 20 families in orders Araneae (spiders), Plecoptera (stoneflies), Odonata (dragonflies), Isoptera (termites), Hemiptera, Coleoptera, Hymenoptera, Trichoptera, and Diptera, which represent faunas typical of soil, leaf litter, forest floor or lacustrine habitats. Many fossil taxa have close relatives in the extant New Zealand biota: others are now locally extinct. Coprolites containing quartz sands sourced from outside the lakes are present at Foulden, but ubiquitous at Hindon. Together with a feather, they indicate the presence of volant birds, presumably waterfowl. Both Foulden and Hindon Maars are crucial in reconstructing Miocene lake and forest ecosystems in New Zealand, in particular the terrestrial arthropod component. This highlights the importance of maar lake sediments as fossil and climate archives in New Zealand and elsewhere.

SEISMIC CHARACTERISATION OF THE UPPER SEDIMENTARY SEQUENCE ASSOCIATED WITH DFDP-2, WHATAROA VALLEY

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The glacio-fluvial sediments of the Whataroa Valley contain a geological record of the changes in climate that occurred as the valley was filled by sediments following the retreat of Pleistocene glaciers, but this record is greatly affected by the significant motion that has occurred on the Alpine Fault over the same period.

A series of hammer seismic reflection lines collected in December 2013 will be combined with sediment samples collected during DFDP-2 drilling to characterise sediments of the Whataroa Valley overlying presumably glacially carved basement. The high-resolution data will be used for three purposes: characterisation of sedimentary strata deposited in the valley, further constraint of the Alpine Fault trace on the coastal plain and contribute to the characterisation of the DFDP-2 drilling site. The Whataroa2013 survey consists of four profiles totalling 3 km in length. Geophone spacing was 5 m with shot points located between every second geophone (spacing of 10 m). Profiles

4 and 5 were collected on the coastal plain running approximately perpendicular to the Alpine Fault. These lines were collected in an attempt to image the Alpine Fault in the near surface sediments. Profiles 1 and 2 lie on a river terrace and are orientated parallel to the Alpine Fault. These profiles characterise the sediments in the lower section of the Whataroa Valley. Additionally, they have been collected as part of a larger data set for site characterisation of the DFDP-2 drill site.

Initial results from lines 1, 2 and 4 show reflections with two-way travel times of approximetly 0.45 s. Using a near surface velocity of 2000–2500 m/s this corresponds to reflective sedimentary units as deep as 250 m in the valley. These units can be interpreted as glacial sediments overlying lacustrine/marine sediments deposited in a deep glacially carved lake or fiord.

DEPOSITIONAL SETTINGS OF EOCENE DELTAIC SUCCESSIONS, WAIAU AND BALLENY BASINS, WESTERN SOUTHLAND

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Diverse macrofloras have recently been collected from Middle-Late Eocene alluvial sediments of the Beaumont and Macnamara Formations in Waiau and Balleny basins. Beaumont Formation extends westward of the NW-trending Ohai Rift around the eastern faulted edges of NNE-aligned Waiau Basin. Drilling data indicates that Beaumont Formation exceeds 250 m in thickness along the eastern margin. Stacked fining-upward arkosic sand–mudstone±coal cycles predominate. Coal beds are generally thin (<3 m) and appear to be concentrated towards the top and base of the formation. Leaf fossils have been collected from sandy siltstone close to the northeast head of Waiau Basin east of Blackmount, and from coaly mudstone underlying a sandstone bed that hosts cemented tree stumps of Pikopiko Fossil Forest on the bank of Waiau River. Beaumont Formation is regionally overlain by lacustrine mudstone and thin turbidite sands of the Orauea Formation. The Macnamara Formation in Balleny Basin was deposited some 200 km southwest of Pikopiko and to the west of the later-active Hauroko-Moonlight Fault Zone. It is exposed, often in small fault-bound blocks, along the Fiordland coast from Chalky Island to Long Reef, 7 km southeast of Puysegur Point. Alluvial granitic boulder fan deposits at the base of the formation are overlain by a >200 m thick meandering channel and floodplain association of upward-fining cycles of inclined-stratified arkosic coarse-medium sand, carbonaceous mudstone, and resinite-rich coal seams ≤2 m thick. Leaves are abundantly preserved in calcite-cemented muddy siltstone exposed along the southern entrance to Preservation Inlet opposite Coal Island. A coastal association of thinly bedded tidal sand and mudstone, delta mouth sand bodies, and thick dark brown bay-fill mudstone conformably overlies the alluvial plain succession at Long Reef and Gates Harbour. It includes biohermal concretionary clusters of heavy-shelled oysters (*Crenostrea* sp.), a few gastropods and smaller bivalves, and sparse benthic foraminifera.

3D RECONSTRUCTION OF GEOTHERMAL CALCITE VEINS USING EBSD, CHEMICAL DATA AND OTHER MACHINES THAT GO PING

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The crystallographic structures of geothermal minerals precipitated in fractures located within active geothermal reservoirs have the potential to record significant information concerning the kinematics of fracture formation and sealing over time. It is important to understand these processes when developing reservoir models, especially when defining the influences of secondary permeability for high temperature geothermal systems. Therefore by reconstructing geothermal calcite filled fracture veins in 3D space, an advanced insight into the complex nature of vein crystal growth evolution and related chemical patterns can be extracted. These can then be used to constrain how precipitated mineral veins control fracture permeability.

This paper presents a detailed pilot study which attempted to recreate and evaluate the complex internal structure of geothermal precipitated calcite veins located in a greywacke basement hosted geothermal reservoir. By integrating sequential slices (spaced ≈100 μm apart) 2D Electron Backscatter Diffraction (EBSD) and Energy

Dispersive X-Ray (EDX) data into modelling software, a 3D view of the vein can be generated. This allows for a better insight into the evolution of crystal growth and subsequent permeability relating to fracture sealing. Initial results highlight the complexities of reconstructing 3D EBSD over the variation of scales, step sizing and slice spacing used in this study. The calcite veins imaged indicate that a fracture fill mechanisms from flowing geothermal fluids may be the main controlling process with crystal orientation controlled by space in 3D as well as the preferential growth axis of calcite.

AGE AND ALTITUDE OF A YOUNG MARINE TERRACE ON THE WAIRARAPA COAST: IMPLICATIONS FOR HIKURANGI MARGIN TECTONICS

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Holocene marine terraces along the Wairarapa coast have been studied at reconnaissance scale, but there have been insufficient radiocarbon ages of *in situ* fossil material to provide the necessary resolution to compare the timing of uplift with events elsewhere along the Hikurangi Margin. In this study we obtained 10 new radiocarbon ages for the youngest Holocene marine terrace along the Honeycomb Rock – Riversdale Beach coast, east of Martinborough. These new ages were combined with existing ages in the Oxcal modelling tool to calculate the timing of uplift and terrace abandonment. Terrace altitudes were also surveyed using Real Time Kinematic Global Navigation Satellite System (RTK GNSS).

The resulting (95th percentile) ages for the time of uplift in each of three areas along the 35 km stretch of coast are: 665-621 cal. yr BP (Glenburn, south), 719-657 cal. yr BP (Flat Point, centre), and 655-557 cal. yr BP (Riversdale Beach, north). If the Flat Point ages are considered to slightly pre-date (i.e., because the shells we sampled were already dead at the time of the earthquake) a single uplift event, then the best estimate for the timing of uplift is 635 ± 20 cal. yr BP. The amount of uplift is approximately 2 ± 0.5 m. Preliminary comparison with the timing of inferred subduction paleoearthquakes, manifest as subsidence events in Hawkes Bay and Marlborough, suggests this uplift event does not correlate. Therefore the uplift is not considered to have occurred at the same time as a Hikurangi Margin subduction paleoearthquake. Instead, the likely mechanism is rupture of an inferred offshore, landward-dipping, upper plate reverse fault, as has been previously interpreted. The close proximity of this fault to the coast means it poses a significant regional seismic and tsunami hazard.

EVIDENCE OF LATE AMAZONIAN VOLCANISM IN THE HYDRAOTES CHAOS BASIN, MARS: A GIS STUDY

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Mars has a substantial history of volcanism, most of which occurred before the Amazonian Period began around 3 ± 0.5 Ga. Late Amazonian (<300 Myr) volcanism is associated with localised areas of thinned, weakened lithosphere. The Hydraotes Chaos region, a fractured, subsided and eroded terrain of mesas and valleys around a smooth basin floor of up to -5000 m elevation, was photographed by the High Resolution Imaging Science Experiment (HiRISE). The images revealed multiple cone and flow features with little erosion. Not all cone and flow features on Mars are true volcanoes, and mud volcanoes have been observed in neighbouring regions including Chryse Planitia and Valles Marineris.

Broad geological units (cone deposits, rough- and smooth-surfaced lavas, basin floor sediments) and geomorphic features (primary impact craters, fluvial troughs, lava ridges and levees) in Hydraotes Chaos were mapped from HiRISE images in ArcMap 10.1. Mineralogical data from the Thermal Emission Spectrometer (TES) on board the Mars Global Surveyor, which detected high abundances of plagioclase, clinopyroxene, and high-Si glass and/or sheet silicates in the area. Impact craters traced during the mapping process were used to obtain age estimates using Hartmann type Martian crater diameter distribution isochrons. Stratigraphic relationships and age estimates were used to construct a possible sequence of events.

The cone and lava flow geomorphology support volcanic origins for the features in Hydraotes Chaos, and may be analogous to that of cinder cones and/or rootless cones on Earth. TES mineralogical data indicates cones without flows are of tholeiitic basaltic composition, while cones with rough-surfaced flows are closer to basalt-andesite, further supporting volcanic origins. Crater counts dated the basin floor surface as Middle Amazonian, indicating a period of fluvial or glacial resurfacing. Cone and flow features are estimated to be Late Amazonian, some possibly as recent as 40 Ma.

DO BURIED ALLOPHANIC SOILS ON HOLOCENE TEPHRAS IN NEW ZEALAND CONTAIN ANCIENT DNA AND CAN WE EXTRACT IT TO RECONSTRUCT PAST ENVIRONMENTS?

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Allophane is a nanocrystalline aluminosilicate clay mineral comprising tiny hollow spherules 3.5–5.0 nm in diameter. It forms rapidly from the precipitation of solutes derived from dissolution of volcanic glass and crystals in well-drained tephras. With its small size, large surface area (up to 1500 $m^2\ g^{-1}$), and variable surface-charge characteristics that arise via $(OH)Al(OH_2)$ groups at wall perforations, allophane has strong affinity for water, metal cations, anions, organic molecules and DNA. Allophane spherules form nanoaggregates up to ~100 nm in diameter, and associated nanopores, poorly accessible to microbes and enzymes, could provide refuges for disseminated DNA. Such a 'protection mechanism' might enable DNA to become stored and hence preserve, potentially, ancient DNA (aDNA) in allophanic paleosols. Any aDNA preserved in such paleosols, once recovered and identified, could provide a genetic signal to help reconstruct past terrestrial environments.

To extract DNA from allophane has been difficult because of the strong chemical bonding between allophane and DNA/RNA (through the phosphate group), and abundant humic substances which bind to DNA and prevent the amplification of DNA via PCR. Current extraction methods for allophane fail, or are very inefficient. We have thus developed a new method using a two-step extraction and gel-purification procedure. We applied our method to three buried soils on Holocene tephras and obtained enhanced DNA yields from 1.5 to 8.3 $\mu g\ g^{-1}$ and fragments mainly 16 kb in length, along with a small portion of fragments in the range 100s to 1000s of base pairs. Plant DNA [*trn*L] of *Araliaceae* (ivy-family) and *Myrtaceae* (myrtle-family) extracted from a buried soil may have originated from early-mid Holocene plants growing on the soil prior to its burial ~5500 years ago, or from downward leaching of DNA from 'modern' plants that grew decades before the current (pasture) vegetation. We are working to separate these hypotheses.

USING PALAEOENVIRONMENTAL DNA (PALENDNA) TO RECONSTRUCT PAST ENVIRONMENTS: PROGRESS AND PROSPECTS

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Palaeoenvironmental DNA (PalEnDNA) is defined as ancient DNA (aDNA) originating from disseminated genetic material within palaeoenvironmental samples. Sources of PalEnDNA include marine and lake sediments, peat, loess, till, ice, permafrost, coprolites, preserved gut contents, dental calculus, tephras, paleosols, and soils as well as deposits in caves or rockshelters and archaeological sites. PalEnDNA analysis provides a relatively new tool for Quaternary and archaeological sciences and its

applications have included palaeoenvironmental and palaeodietary reconstructions, testing hypotheses regarding megafaunal extinctions, human-environment interactions, taxonomic studies, and studies of DNA damage. Because PalEnDNA samples comprise markedly different materials, and represent wide-ranging depositional and taphonomic contexts, various issues must be addressed to achieve robust, reproducible findings. Such issues include climatic and temporal limitations, the biological origin and state (free versus bound) of PalEnDNA, stratigraphic reliability, sterile sampling, ability to distinguish modern from aDNA signals, DNA damage and PCR amplification, DNA extraction methods, and taxonomic resolution.

The combination of PalEnDNA with analysis of plant macrofossils and pollen is providing an enhanced means to reconstruct past environments, and PalEnDNA researchers are also beginning to obtain a greater understanding of the power and limitations of the technique. To utilise the PalEnDNA technique, scientists need to plan field procedures and sample collection techniques carefully. The discipline needs better understanding of DNA damage and degradation rates in PalEnDNA, and procedures to distinguish between true taxonomic diversity and mis-coding lesions. Methods to determine the degree of mixing of ancient and modern DNA in samples are also required. Multiple proxies, replicable stratigraphies, and reliable dating methods can be used to help determine the stratigraphic reliability of PalEnDNA assays and to increase taxonomic resolution in conjunction with the construction of DNA sequence reference databases. Publication of failures in DNA extraction methods is also critical for specific deposits or soils, environments, and time periods.

TEREBRATULIDE BRACHIOPODS FROM THE MIDDLE AND LATE JURASSIC OF NEW ZEALAND

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Terebratulide brachiopods are present throughout the New Zealand Mesozoic, and by the Jurassic are second only to rhynchonellides in abundance and diversity. Only two species have been described from the Late Jurassic, *Kutchithyris hendersoni* Marwick 1953 and *Holcothyris* (?) *kaiwaraensis* Campbell 1965 In this study, about ten species are recognised, with nearly all the material coming from the Murihiku Terrane on the west coast of the North Island.

Two key localities for Temaikan brachiopods are Opuatia Cliff at Port Waikato, and a quarry in the Marokopa Valley. Two species of fairly large terebratulide are tentatively assigned to the cosmopolitan genus *Loboidothyris*. Two species of *Zeilleria* are also present. A new species of *Kutchithyris*, less strongly folded than *hendersoni,* is present at Marokopa.

Captain Kings Shellbed is a metre-thick middle Heterian shellbed that can be traced from Kawhia to the Awakino Valley. It has a rich and diverse fauna in which terebratulides are prominent. *Kutchithyris hendersoni* is probably the most abundant. A species with distinctive wavy concentrics probably represents a new genus. The same two species of *Zeilleria* continue from the Temaikan, and are joined by a species of the related genus *Aulacothyris*. The ribbed terebratulide *Terebratulina* is also present.

Brachiopods are much less common in the later part of the Jurassic (latest Heterian, Ohauan and Puaroan stages). A second species of *Terebratulina* is present. A rare form is the small genus *Disculina*. *Holcothyris* (?) *kaiwaraensis* is known only from the Late Jurassic Pahau Terrane of North Canterbury.

Affinities of the fauna are poorly known, due to the lack of nearby faunas for correlation. *Loboidothyris*, *Aulacothyris* and *Zeilleria* are cosmopolitan. *Kutchithyris* is Tethyan. *Disculina* is described from Southern England and France, but may have a much wider distribution.

TIME LAPSE INVESTIGATIONS ON THE ACOUSTIC AND GEOCHEMICAL EFFECTS OF CO_2 INJECTION IN SANDSTONE CORES

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Carbon geosequestration, or the geological storage of CO_2, is an emerging field of research and technology. One of the biggest challenges of this technology is to ensure that this gas is safely stored in the subsurface. Surface seismic methods are used to monitor the movement of CO_2 in the reservior. However, it is assumed that only fluid replacement and pressure changes are the main control on changes to seismic signitures over time (time-lapse changes). Currently a good understanding is lacking of how rock-fluid geochemical alteration affects these time-lapse changes. In particular, we are investigating how the injection of CO_2 affects the physical and seismic properties of carbonate-cemented sandstone cores. The samples used correspond to the Mangahewa Formation at the Pohokura Field, New Zealand. Petrophysical properties are measured through XRD, NMR and CT scan analysis, while seismic properties are measured using a non-contact ultrasonic source-receiver. The samples range in P-wave velocity from 2100-3500 m/s, carbonate content from 1-22% and porosity from 4.5-12.5%. Previous investigations have found that CO_2 injection causes a decrease in P-wave velocity, with an accompanying increase in porosity and permeability as a result of the dissolution of carbonate minerals. We aim to quantify these changes, and examine how the petrophysical properties of the rock affect the quantitative changes in properties. This study will contribute towards the monitoring of time-lapse changes in CO_2 injected reservoirs, which will have implications world-wide. New Zealand has set targets to significantly reduce its CO_2 emissions and carbon geosequestration is being explored as viable option to meet these goals. Before carbon geosequestration is implemented in New Zealand we believe that further steps must be made to be able to monitor to movement of CO_2 in the subsurface and understand the effects that the injection of CO_2 will have in the subsurface.

PROPOSED MOVEMENT MECHANISMS AND CAUSES FOR THE 'EARTHQUAKES' LANDSLIDE, OTAGO, NZ

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The 'Earthquakes' Landslide is a peculiar pre-historic landslide located near Duntroon, Otago. The landslide owes its name to its defining feature, a large (500 × 100 x 40 m) graben reminiscent of normal-fault (tectonic) grabens. The bedrock is Oligocene gently-dipping weak marl overlain by calcareous greensand grading into cemented bioclastic limestone cap rock. The landslide has developed on the northern edge of a sub-horizontal mesa-like hill bounded by steep slopes produced by fluvial-incision on four sides. A rare lateral spread style of mass movement has previously been described on the southern side of the mesa. To elucidate the mechanical failure mechanism and the preconditioning factors responsible for the geometry and development of the landslide, we undertook geological mapping, RTK GPS surveying, augering, and Ground Penetrating Radar (GPR) surveys of the landslide and surrounding slope. Geological mapping indicated that the graben 'extension' direction is oriented along-strike of the gently dipping bedrock (i.e. not in the dip-direction). Further, there is no evidence of substantial valley bulging or sliding of the downslope graben wall, and the surface expression of the graben 'fault' scarps are everywhere steep (sub-vertical), casting doubt on a purely-extensional mechanism of graben development. The GPR data indicate that the graben owes part of its relief to a paleo-channel, which can be traced along part of the graben. However, the paleo-channel accounts for only a small part of the graben relief; but, it may have influenced the location of graben development by eroding, and thus locally reducing the thickness and strength of the limestone cap rock. We hypothesise that the Earthquakes Landslide is a unique example of a large, incipient lateral spread, facilitated by relief development (fluvial incision) and the presence of a deformable marl underlying a structurally-weakened cap rock than has allowed a combination of brittle and ductile deformation.

TECTONIC EVENTS AND THEIR INFLUENCE ON HUMAN POPULATIONS: THE EVIDENCE OF ARCHAEOLOGY AND HISTORY

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Humans and their hominin forebears have lived with tectonic events for hundreds of thousands of years. Earthquakes have devastated landscapes, towns, and cities, yet communities have been extraordinarily resilient and resistant to moving to safer locations. Paradoxically, this has had positive cultural and economic benefit for human societies.

Recent archaeological research suggests that human physical development is closely related to tectonic plate boundaries, and that civilisation itself is a result of seismic activity. In modern times, earthquakes, along with other calamitous events, have played a Schumpeter-like role of creative destruction, and have stimulated economic development. This talk briefly reviews the effects of tectonic activity on human communities, and outlines some of the implications for how modern communities might respond to future events.

THE MOTUEKA SANDS – RECOGNISING THE SHELF

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When Motueka-1 was drilled in 1990 it encountered stacked high porosity Lillburnian sands which the Operator dubbed the "Motueka Sands Member [of the Manganui Formation]". Nearly twenty years later this section was re-interpreted as Moki basin-floor sands, which form the reservoir in the Maari field to the north. Tuatara-1 targeted the interval 40 km further south but found instead a continental section of interbedded conglomerate, siltstone, shales, sandstone and coals.

Although both Moki and Motueka sands have similar laterally extensive, high seismic amplitudes, the context provided by regional seismic facies interpretation shows that the two are very different depositional environments within a single megasequence. Although genetically related they were separated by perhaps 1000m of water depth at the time of deposition.

The Matemateaonga, Urenui and Mount Messenger Formations, onshore Taranaki, form a single depositional system in the Taranaki Series; similarly the Motueka Sands belong with the Manganui and Moki in an earlier pulse of slope-advance during the Southland Series. Lack of outcrop and sparse drilling in the south Taranaki Basin have contributed to their lack of recognition in stratigraphic syntheses.

The topsets of this megasequence have been traced laterally on the seismic up to 80 km along the eastern margin of the basin. Near the Kupe Field these topsets are cut by several major canyon systems, some of which are feeder canyons to the Moki submarine fans. The late stage of canyon fill on the shelf is likely to be dominated by fine-grained deposits which could form lateral seal to the Motueka sand reservoirs.

Recognition of the Motueka Sands as distinct from the Moki provides a good illustration of the importance of using sequence stratigraphic rather than lithostratigraphic interpretation in Taranaki exploration. The sands represent a substantial, high-quality reservoir target in a sparsely drilled area of the south-eastern Taranaki Basin.

FAULT PROPAGATION AND DAMAGE IN LAYERED ROCKS: THE EFFECT OF TRANSVERSE ANISOTROPY

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This study aims to probe the role of inherent mechanical anisotropy in controlling damage zone localization in both the tip and wall regions of a fault or fracture. Rocks are often mechanically anisotropic due to the presence of bedding planes, penetrative crystallographic or shape fabrics and compositional foliations. Inherent cracks, fractures and faults often act as mechanical flaws to intensify local stresses, leading to mechanical failure at their tips. Earth scientists have used flaw-controlled mechanics to understand a wide variety

of geological and geophysical phenomena including flanking structures, wing fractures, secondary fracture-controlled hydraulic conductivity and growth of crustal-scale tectonic faults. In this study, analogue and numerical models were deformed under compressive stresses either parallel, perpendicular or at an angle to the plane of anisotropy under a constant strain rate. We show from our experiments that the damage localization can dramatically change depending on the orientation of the planar anisotropy (θ). Under layer-normal (θ = 0°) and layer-parallel compression (θ = 90°), pre-existing faults are reactivated. Fault slip leads to mechanical instabilities within the anisotropic layering, causing damage zones in the tip regions. For θ = 0° the planar anisotropy arrests the propagation of tensile fractures across the plane of anisotropy and promotes localised plastic shear instabilities at the crack tips, whereas a combination of layer opening and distributed shear banding occurs when the plane of anisotropy is parallel to the compressive direction. For $\theta = 45^{\circ}$, the faults experience little or no reactivation and instead, bulk (distributed) inter-layer slip occurs. Our results have implications for the deformation style of strongly anisotropic rocks such as schist. They show how the deformation mechanism and degree of localization will be strongly influenced by the orientation of principal stresses and inherited cracks to the plane of the foliation.

METAMORPHISM CONTROLLED DEVELOPMENT OF CU-FE-S VEINS IN THE ONEKAKA SCHIST, NW NELSON

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The Onekaka Schist, a constituent of the east-board Takaka Terrane in northwest Nelson, is a north-trending fault slice of stratigraphically intact Ordovician-Silurian meta-conglomerates, sandstones, mudstones and quartzites deposited from a Continental Island Arc environment. Zircon age populations indicate Ross-Delamerian, Pan-African and Grenville Orogenic provenance consistent with Paleozoic metasediments of the Western Province. Changes in zircon population density from Ordovician to Silurian lithologies indicate- an evolving sediment source. Microtextures in aluminous schists elucidate structural and mineralogical changes, which are divided into four fabrics: S1) primary foliation observed as relict quartz inclusion trails in garnet; S2) development of pervasive lepidoblastic biotite foliation with quartz, muscovite, andesine and late-stage garnet growth; S3) crenulation of the earlier foliation; and S4) a chlorite, epidote and muscovite lineation.

Cation-exchange thermometry broadly indicates increasing conditions of peak equilibration southeast across the unit, ranging from approximately 580°C and 5.5 kbar to 640°C and 7.6 kbar. Rare metamorphic overgrowths on detrital zircon potentially record a Devonian event consistent with timing of Terrane Amalgamation in northwest Nelson and localised amphibolite facies metamorphism in juxtaposed fault slices. Several generations of mineralized veins cross-cut the foliation. K-feldspar veins contain Cu-sulphides associated with myrmekite replacement reactions and grain boundary fracturing. Kyanite veins containing an assemblage kyanite + staurolite + garnet + andesine + biotite record 600°C and 5.6 kbar conditions. Chlorite-carbonate veins record a later greenschist-facies event where sulphur enriched fluid has reacted with ankerite nodules, forming pyrrhotite moat structures.

THE BASAL UNCONFORMITY OF THE EOCENE BRUNNER COAL MEASURES: A LOW RELIEF LANDSCAPE WITH MINOR FAULTING

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The unconformity at the base of the West Coast's Eocene (Bortonian) aged Brunner Coal Measures (BCM) has long been recognized as having topographic relief and in places, a substantial weathering profile. However investigations into the contribution of faulting versus relict relief in development of paleotopography along the unconformity have been limited (Flores & Sykes 1996; Titheridge 1993). New research on the unconformity and immediately overlying deposits has provided evidence for a low relief landscape affected by minor faulting. Investigations into the weathering profile show marked lateral variations in degree of weathering and thickness (1m -

>10m), indicating broad areas of low relief with intense soil development. To the south in the Greymouth area, the basal Paleocene Brunner Conglomerate rests conformably on Late Cretaceous - Paleocene Paparoa Coal Measures, representing a final surge of tectonic activity in the Paparoa Basin. This is followed by gradual infilling by low gradient meandering rivers and development of peat mires, overlain by marine Eocene Island Sandstone. To the north and into the Buller Coal Field valley infilling did not commence until the mid-Eocene and often shows no signs of syndepositional faulting. In the southern Buller coal field, BCM lie with angular unconformity on an as yet undated but probable Paleocene conglomerate indicating active faulting and tilting in this location. Finally, direct evidence of minor syndepositional faulting can be found in outcrop in the northern Buller Coal Field on the Stockton Plateau and near Seddonville with offsets of strata ranging from 2-15m. We conclude that the BCM were deposited in a relatively quiescent tectonic setting with minor faulting until the onset of the subsequent Challenger Rift System.

IS A SET OF OVERLAPPING SURTSEYAN VOLCANOES A POLYGENETIC VOLCANO?

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Since the eruption of Surtsey (1963-1965) multiple studies have been made of the resulting island. The pre-emergent base of the volcano, however, remains submarine and unincised resulting in limited studies of this section being conducted.

An alternative to studying the submarine portion of Surtsey is to study volcanic deposits with a similar magma type that were erupted in a submarine environment but are now exposed subaerially. A number of such deposits are exposed along the north eastern coastline of the Otago region, South Island, New Zealand, which hosts numerous intraplate basaltic volcanoes that erupted in Surtseyan style onto a submerged continental shelf at between 35 and 30 Ma.

Currently thought to be part of a monogenetic volcanic field, the stratigraphy of exposed volcanic edifices of north east Otago suggest that they comprise multiple volcanoes built by eruptions at effectively the same sites, but separated by millions of years. Geological mapping, lithofacies analysis and petrology, here represented by the Oamaru volcano, reveal discordant to locally concordant boundaries separating deposits from different construction episodes. Individual volcanoes that overlap in this edifice exhibit complex erosion features formed during a single eruption, such as slumping and other sedimentary structures, which are distinct from the inter-volcano contacts marked by biogenic accumulations or other slow-formed features.

The edifice overall was constructed over millions of years as volcanoes formed and were subsequently partially degraded prior to an adjacent vent opening and adding another volcano to the edifice. Though no central vent or long-active volcano ever formed, this repeated growth of 'monogenetic' volcanoes at a single site could be seen as a novel style of polygenetic volcanism. Absence of a magma chamber based on a significant lack of magma fractionation indicates a mantle-sourced magma. Consequently a mechanism for building a stack of volcanoes at one site is unclear.

LITHO2014: A NEW ZEALAND STRATIGRAPHIC SCHEME FOR EVERYONE

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We formally introduce 14 new high-level stratigraphic names to augment existing names and to hierarchically organise all of New Zealand's onland and offshore Cambrian to Holocene rocks and unconsolidated deposits. The two highest-level units are Austral Superprovince (new) and Zealandia Megasequence (new). These encompass all stratigraphic units of the country's Cambrian to Early Cretaceous basement rocks and Late Cretaceous-Holocene cover rocks and sediments respectively.

Most high-level constituents of the Austral Superprovince are in current and common usage: Eastern and Western Provinces consist of 12 tectonostratigraphic terranes, ten igneous suites, five batholiths and Haast Schist. Ferrar, Tarpaulin and Jaquiery Suites (new) have been added to existing plutonic suites to describe all known compositional variation in the Tuhua Intrusives.

Zealandia Megasequence consists of five predominantly sedimentary, partly unconformity-bounded units and one igneous unit. Momotu and Haerenga Supergroups (new) comprise lowermost rift to passive margin (terrestrial to marine transgressive) rock units. Waka Supergroup (new) includes rocks related to maximum marine flooding linked to passive margin culmination in the east and onset of new tectonic subsidence in the west. Māui and Pākihi Supergroups (new) comprise marine to terrestrial regressive rock and sediment units deposited during early and late Neogene plate convergence.

Rūaumoko Volcanic Region (new) is introduced to describe all igneous rocks of the Zealandia Megasequence and contains the new petro-tectonically different Whakaari (subduction-related), Horomaka (intraplate) and Te Raupua (allochthonous ocean basin) Supersuites. The Litho2014 scheme provides a complete, high-level stratigraphic classification for the continental crust of the New Zealand region.

THERMOTECTONIC STABILISATION OF THE BASEMENT AND BASINS OF SOUTH ZEALANDIA

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We present new apatite and zircon fission track and helium ages, and mineral Ar-Ar ages for drill core, dredges and surface samples from the southern South Island, Great South Basin, Canterbury Basin, Campbell Plateau, and Chatham Rise regions of the Zealandia continent. Looking at the thermochronology of half a continent is instructive and adds to the known tectonic framework. Combined with existing data, our results indicate that much of the exhumed geological basement of the Campbell Plateau and Chatham Rise region had become thermotectonically consolidated (exhumed to near-present day levels) by the end of the Early Cretaceous (100-120 Ma).

There are only very subtle thermochronological signals in the basement that may be attributed to the collision of the Hikurangi Plateau with the Chatham Rise, or to Late Cretaceous and Eocene continent-ocean rift margin development along the Subantarctic and Auckland slopes. In contrast, apatite thermochronometers in basement rocks have been reset to near zero ages in response to (1) extensional sedimentary basin development in the Great South and Canterbury Basins, (2) local Miocene intraplate volcanism and (3) oblique collision in Fiordland and the Southern Alps.

Zircon U-Th-He ages from a dredge sample of Precambrian granite at the southern tip of the Campbell Plateau indicates it probably is not in place but was ice-rafted from East Antarctica.

PROBABILISTIC LANDSLIDE-GENERATED TSUNAMI HAZARD IN COOK STRAIT

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Modelling the hazard associated with landslide-generated tsunami over large regions has received very little attention worldwide, with most studies focused on individual landslide scenarios. Deeply entrenched submarine canyons are one of the principal means by which steep and unstable seafloor slopes can occur near to the coastline, and populated regions. We have developed a probabilistic model workflow to quantify the landslide-generated tsunami hazard to central New Zealand from slope failures occurring within the Cook Strait Canyons.

Landslides are a primary process enlarging the upper Cook Strait canyon system between the North and South Islands of New Zealand. Evidence for previous slope failure within the canyon in the form of landslide scars defines the type of failures occurring, their geometry, and indicates the volume distribution. We have concurrently developed a Monte Carlo modeling approach for earthquake triggered landslide frequency, and a magnitude-frequency relationship for landslide occurrence based on previous landslide

occurrence. We use these to drive a tsunami generation and propagation model to derive probabilistic hazard curves for specific coastal sites.

The project has provided insight into the influence of steep canyon topography on wave generation from landslides. It has demonstrated that Wellington is susceptible to hazards from landslide tsunami and will provide probabilistic hazard curves that can be used to assess tsunami risk to coastal populations in central New Zealand. In the longer term we envisage that the results of this project will be combined with tectonic-source tsunami to assess the overall tsunami hazard. The developed model workflow is intended as a template to be applied to other local and global situations where submarine canyons come within close proximity of populated regions.

A LOCAL AND REGIONAL TSUNAMI EARLY WARNING SYSTEM FOR NEW ZEALAND: A FEASIBILITY STUDY

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Local tsunami mitigation in New Zealand is based on self evacuation following long-duration or intense ground motions. Slow-rupturing 'tsunami earthquakes', as have occurred historically on the Hikurangi margin (1880 and twice in 1947), might not be felt strongly enough to trigger self evacuation. Tsunami propagation and inundation patterns depend strongly on slip kinematics and distribution. To establish an effective early warning system for such events, rapid inversion is needed to resolve these properties.

We will give an update on recent results from on-going efforts at GNS in collaboration with international partners to assess the feasibility of implementing a local tsunami early warning system targeting on 'Tsunami Earthquakes' in New Zealand. We performed simulations of kinematic and static surface displacements for a scenario event similar to the March 1947 tsunami earthquake to create data sets that are used to assess GeoNet's detection capabilities and potential required updates to the network. A suite of detection, classification and inversion algorithms has been tested with the simulated data.

Our findings indicate that an event similar to the 1947 Gisborne Tsunami Earthquake could be classified as potentially tsunamigenic from seismic data alone (Ristau & Kaneko, this session). It also should be detectable and classifiable by the geodetic network in real time (D'Anastasio et al. this session). However, a combination of kinematic and static deformation (seismic and geodetic) data is required to drive a full rapid detection, classification and inversion algorithm chain. For an operational Early Warning system to be implemented a large portion of the geodetic sensor network needs to be upgraded to stream data in real time to GeoNet.

EFFECTS OF RUPTURE COMPLEXITY ON LOCAL TSUNAMI INUNDATION: IMPLICATIONS FOR PROBABILISTIC TSUNAMI HAZARD ASSESSMENT

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We investigate the influence of earthquake source complexity on the extent of inundation caused by a resulting tsunami. We simulated 100 scenarios with sources on the Hikurangi subduction-interface in the vicinity of Hawke's Bay/Napier and Poverty Bay/Gisborne. For both target areas rupture complexity was found to have a first order effect on flow depth and inundation extent for the local tsunami sources considered.

The position of individual asperities in the slip distribution on the rupture interface control to some extent how severe inundation will be. However, predicting inundation extent in detail from investigating the distribution of slip on the rupture interface proves difficult.

The distribution of inundation extent for one earthquake of given magnitude but different realisations of non-uniform slip is skewed. The extent of inundation predicted by a uniform

distribution of slip on the rupture interface is roughly represented by the median of this distribution. Assuming uniform slip on the rupture interface therefore will underestimate the potential impact and extent of inundation. For example, simulation of an M_W 8.7 to M_W 8.8 earthquake with uniform slip reproduced the area potentially affected by inundation of an equivalent non-uniform slip event of M_W 8.4 for Napier.

The extent of inundation does not follow a simple relationship to the magnitude of the earthquake. Therefore de-aggregation, to establish the contribution of different sources with different slip distributions to the probabilistic hazard, cannot be performed based on magnitude considerations alone.

We propose to use parameters of the tsunami wave field measured offshore as predictors for inundation severity to perform de-aggregation based on simulations with the linear wave equations.

INVESTIGATION OF THE EFFECTS OF EARTHQUAKE RUPTURE COMPLEXITY ON TSUNAMI INUNDATION HAZARD IN WELLINGTON HARBOUR

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Recent investigations of the effects of earthquake rupture complexity have shown that not only the distribution of near shore tsunami amplitudes but also the extent of inundation is strongly dependent on the specific instance of earthquake slip distribution.

We have investigated the effects of different examples of potential slip distributions on the tsunami inundation hazard posed by three earthquake sources for the shore areas of the Wellington Harbour and Wellington's south coast: the Hikurangi subduction interface (Mw = 9.0), the Wairarapa Fault (Mw = 8.1) with a potential contribution of the Wharekauhau Thrust, and the Wellington Fault (Mw = 7.4).

We find that the crustal fault sources (Wellington Fault and Wairarapa Fault) pose less of an inundation hazard than the studied events on the Hikurangi subduction interface. The Wairarapa Fault scenarios suggest that an earthquake on this fault will mainly affect the Wellington south coast. A simultaneous rupture of Wharekauhau Thrust would further enhance the generation of tsunami waves. Geodetic studies suggest that slip released in a large Hikurangi earthquake is potentially concentrated at the southern part of the interface and was found to lead to increased inundation in the Hikurangi scenarios. Non-uniform slip distributions that happen to concentrate slip in the Cook Straight region have much the same effect.

This study is the first we know of that attempts to understand the effects of rupture complexity on tsunami generation by earthquakes on upper plate faults, in this case the Wairarapa and Wellington Faults. The results of this study help to understand the role of earthquake complexity on tsunami generation by these faults.

A GEOPHYSICAL STUDY OF THE KELLYVILLE AND ONEWHERO MAAR CRATERS IN THE SOUTH AUCKLAND VOLCANIC FIELD

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The South Auckland Volcanic Field (SAVF) is a Pleistocene basaltic monogenetic field with a close association to the nearby Auckland Volcanic Field (AVF). Phreatomagmatic eruption craters (maars) generally offer detectable contrasts in the subsurface rock density and magnetic signals. Geophysical surveys offer insight into delicate subsurface diatreme features that cannot be identified by surface investigation alone. Interpretation of gravitational and magnetic anomalies can contribute to the development of a syn-eruptive and post-eruptive sedimentary history. Gravity and magnetic surveys will be conducted across multiple transects through two SAVF maar craters: the Kellyville and Onewhero maars. Kellyville maar is of interest because multiple scoria cones occur within the maar crater suggesting a relatively complex subsurface plumbing system. A post-eruptive lacustrine unit, diatomite, is also present, providing a substantial density contrast to underlying scoria/basalt deposits. Onewhero maar is the largest explosion crater in the SAVF. It is not currently known if the symmetrical crater has formed from a larger than

normal eruption with one root zone or if the structure has been created by multiple root zones, with a complex evolutionary history. Shallow country rock geology is exposed at both volcanic centres, the Te Kuiti Group at Onewhero and the Waitemata Group at Kellyville. Both occur as lithics in the surrounding tuff deposits. Preliminary geophysical data and models will enable us to ascertain the depth of the eruption crater before infill as well as outline the subsurface plumbing systems of these "monogenetic" events.

MAJOR EARTHQUAKE ON WELLINGTON (MOHAKA) FAULT CAUSES REGIONAL LANDSLIDING, CIRCA 2,200 YR BP

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One of the difficulties of ascertaining paleoearthquakes, particularly from fault trench excavations, is deciphering whether landsliding or colluvial deposition is from cyclonic rainstorms or from earthquakes (plus rains immediately after earthquakes). Information from Lake Namunamu in the Hunterville district, provides evidence of a major earthquake around 2,220 ± 80 cal. yr B.P.

Of special note is that the landsliding did not result in flowage, which would have been expected with a heavy rain triggering mechanism. Rather the landslide was of a block slide type which dammed a former stream valley, without destroying the forest in the floor of the valley opposite. The former forest trees are now preserved below lake level and the outermost tree rings provided the radiocarbon date (Wk 964).

This date matches the age (NZ100) of drowned standing trees in Lake Waikaremoana (Wellman in Grant-Taylor and Rafter 1963), presumably also created by an earthquake-triggered landslide. It may be that an initial landslide upstream of Lake Colenso was also triggered by this event, prior to a subsequent landslide that formed the Lake, a little time later.

It has previously been hypothesised that there was a major earthquake on the Wellington (Mohaka) Fault between deposition of the Waimahia Tephra at *c*. 3,230 yr B.P. and the Taupo Tephra at *c*. 1,800 yr BP. The best evidence comes from a trench excavated at Trotter 2, west of Dannevirke (Hanson 1998). The widespread occurrence of these lake-forming landslides suggests a major paleoearthquake in the region (here referred to as the Namunamu paleoearthquake) was responsible for their formation, and the trees preserved on the floor of Lake Namunamu provide the best accessible date for this event.

SIMULATING LAHARS IN A ROTATING DRUM

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Lahars are a particularly hazardous type of granular flow [1]. They are a two-phase flow, consisting of a mixture of volcanic rock and other debris (the solid phase) and water (the liquid phase) from one or more sources [2,3].

We attempt to simulate lahars in the laboratory by making use of a rotating drum, a piece of equipment commonly found in industrial research [4,5]. Granular material, when rotated in a drum, creates a flowing body on top of an erodible bed; which, with careful dimensional analysis can be analogous to a lahar.

Results to date include detailed maps of the various regions in a flowing granular material correlated to the speed of rotation and hence momentum of the flows. Also, we have identified two new phenomena; high speed rotations appear to include features similar to Kelvin-Helmholtz instabilities, and enclosed regions of sub-rotation, which we tentatively name Neather cells.

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BUILDING UP A BASELINE ENVIRONMENTAL DATABASE

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New Zealand has a vast complex seascape, and dynamic and biologically diverse marine environment, which poses unique problems for both data acquisition and data discovery. There is rapidly growing interest in New Zealand for offshore hydrocarbon and mineral resources. Under the NZ's Exclusive Economic Zone (Environmental Effects) Act 2012, consent applications must include an Impact Assessment, which requires knowledge of baseline information. Recent surveys in offshore frontier regions provide such information.

Offshore New Zealand has been the focus of numbers of research, industry and publically-funded geophysical surveys and environmental studies. Valuable insight into the deep-sea is gained from bathymetric datasets which contain ~1.5 million km2 of multibeam coverage. Although this represents only 15% of the marine estate mapped in detail, a variety of geomorphological and geological structures relevant to the hydrocarbon sector can be interpreted. Seafloor reflectivity (backscatter) is used as a proxy for benthic habitat. Some ground-truthing of nominal benthic habitats and bottom features have been conducted using underwater imaging and direct seafloor sampling. Distribution of megafauna from predictive habitat suitability modelling and knowledge of other activities in the region, particularly fishing, are also available. These surveys have generated a comprehensive collection of geological, oceanographic, biological and environmental data that together provide the means to develop environmental baselines.

Acquiring encompassing, unambiguous seafloor data at scales relevant to offshore infrastructures or biohabitat is not achievable in the medium term. However, using a combination of datasets allows us to provide a unique view of the topography and composition of the seafloor, its ecological characteristics and biodiversity hotspots. These databases provide significant benefits for all stakeholders of the marine environment, revealing potential for fisheries, environmental management, hazard mitigation, and energy and mineral opportunities, tourism and recreational use, as well as providing key baseline knowledge on which to build well targeted future research.

ARE THE PLEISTOCENE JABAL AKWA MONOGENETIC VOLCANOES IN THE JIZAN REGION (SW SAUDI ARABIA) PARTIALLY BURIED MAAR – SCORIA CONE COMPLEXES?

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The intracontinental Al Birk volcanic field along the Red Sea (Tihamat Asir) in SW Saudi Arabia consists of at least 200 scoria and spatter cones, lava fields and domes/dome coulees, each formed in the past 1 My. In spite of the proximity to the Red Sea coastline, the low-lying setting and abundant dry valley networks indicative of former streams, there has been no report of phreatomagmatic-influenced volcanism. Near the city of Sabya, two large scoria cones stand out from an aeolian sand field: Jabal Akwa Al Shamiah in the north and Jabal Akwa Al Yamaniah in the south. Both volcanic complexes are associated with a suspiciously circular lava field suggestive of some ponding effect caused by obstacles. While Jabal Akwa Al Shamiah is clearly a central cone complex with breached craters, the exposed part of Jabal Akwa Al Yamaniah suggests a different story. Its upper lava field surrounds the westward breached scoria cone and the lava field seems to be ponded and banked against an earlier tuff ring that is partially buried. Tuff deposits are intercalated with a fluvial terrace along the Wadi Sabya and aeolian deposits in the south. The nearly 40 m thick pyroclastic succession shows a general trend of fining upward, from a lithic-dominated lapilli tuff and tuff breccia in the base that gradually transforms to better sorted, finer grained and more juvenile-rich pyroclastic units nearer the top. The estimated volume of accidental lithics in the tuff ring units and the nearly 1 km wide circular lava field indicate substantial excavation of a crater, suggesting that Jabal Akwa Al Yamaniah is a buried maar complex. While no basal tuff ring units are

exposed at Jabal Akwa Al Shamiah, the circular distribution of the ponded lava may be the result of the presence of a maar beneath.

NATIVE METALS IN THE CANTERBURY BASIN

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Examination of cuttings from the Clipper-1 well in the offshore Canterbury Basin has revealed a variety of unusual mineral assemblages. Of particular interest are native metals rarely found in nature, including iron, copper, lead and aluminium. These have been identified through examination of polished sections and use of SEM EDS to determine elemental composition. Two distinct areas of intense mineralisation have been identified: a lower band at 3550m depth that is extremely rich in native iron and associated iron minerals, and an upper band at 2050m depth that contains both aluminium and iron. The upper, Al-rich band is located immediately above limestone deposits indicating that carbonates are an important factor in the formation of native Al. Copper and lead are found together along with graphite in a rare assemblage that occurs in both bands. The metals are closely associated with volcanic glass and mineral-cemented sediments, indicating that they cannot be man-made contaminants.

Producing native metals in a natural setting requires a highly reducing environment and very low oxygen fugacity. The proposed mechanism for producing these conditions in Clipper-1 is a mafic intrusion interacting with carbonaceous sediments, coals and limestone. Assimilation of organic matter lowers oxygen fugacity in the melt and produces gases such as CO that both displace oxygen and act as a reductant. The result may be described as a naturally-occuring blast furnace.

MARINE-TERRESTRIAL COMPARISONS AND OCEAN VENTILATION IN THE EAST TASMAN SEA DURING THE LAST GLACIAL-INTERGLACIAL CYCLE

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We present preliminary results from two projects that are part of our wider investigations into Late Quaternary climate evolution in the East Tasman Sea (ETS) and adjacent Westland. The first uses the occurrence of terrestrial pollen in marine sedimentary sequences from the ETS to enable direct land-sea correlation and to provide a means for transferring Marine Isotope Stage chronologies to terrestrial records that extend beyond the range of radiocarbon. Both applications require an implicit assumption that the time lag between pollen release and final deposition at sea – here referred to as the residence time – is negligible in comparison with the chronological resolution of the marine sedimentary sequence. To assess the extent of the residence time of pollen delivered into the ETS, we have (1) radiocarbon dated pollen-bearing sediments transported in contemporary fluvial settings in Westland, and (2) compared independently dated pollen events common to marine and lake sediment records spanning the last glacial-interglacial cycle.

The second project seeks to radiocarbon date terrestrial pollen, planktic and benthic foraminifera from a transect of cores that span across intermediate and circumpolar depths from the ETS to address changes in the surface, intermediate and deep water marine reservoir age during the last glacial-interglacial cycle. The benthic-planktic age difference varies with time and location, being relatively large (2-3 ka) for upper Circumpolar Deep Water but reducing for Antarctic Intermediate Water. These results are consistent with greater storage of older carbon in deeper water and provide the first numerical values for intermediate and deep water marine reservoir age in the ETS. A progressive reduction in

benthic-planktic age difference commences early in the last deglaciation, consistent with an increase in ventilation of ocean deepwater and exchange of carbon between the deep and surface ocean and between the surface ocean and the atmosphere.

IMPLICATIONS OF HISTORICAL LARGE MAGNITUDE EARTHQUAKES FOR THE INCOMPLETENESS OF NEW ZEALAND'S PREHISTORICAL EARTHQUAKE RECORD

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Moderate to large magnitude earthquakes in the Canterbury (2010-2011) and Cook Strait (2013) sequences caused significant damage, yet ruptured active faults that were not previously known to exist. These earthquakes fuel questions about how many unmapped active faults have the potential to generate future damaging earthquakes and how best to accommodate these in the New Zealand National Seismic Hazard Model (NSHM). Historical moderate to large magnitude earthquakes since 1840 have been analysed to estimate the likelihood of rupture occurring on hidden active faults that are not explicitly accounted for in the NSHM. We consider 105 shallow earthquakes (≤25 km focal depth) with magnitudes Mw 5-8.2 that were located onshore or ruptured faults that extend onshore (e.g., Napier 1931 Mw 7.8 earthquake). Given the relatively short duration of the historical record and the rates of seismicity over this time interval, the number of earthquakes considered is small and only permit first-order conclusions. About half of all historical earthquakes Mw ≥ 7.0 ruptured active faults that based on today's state of knowledge would have been mapped. For the most part, the remaining 50% of historical events on 'unmapped' active faults either did not displace the ground surface or were located in areas where the rates of erosion/burial exceed fault-slip rates. Incompleteness of active faults in the NSHM is greatest for earthquake sources with long recurrence intervals of ≥10 kyr. Historical earthquakes of Mw ≥ 6.5 on faults with recurrence intervals of ≥10 kyr are about 10 times more frequent than predictions based on NSHM fault sources with the same magnitude and recurrence interval ranges. Several hundred additional unmapped active faults capable of generating Mw ≥ 6.5 earthquakes with recurrence intervals of ≥10 kyr are necessary to reconcile the historical earthquake catalogue and NSHM earthquake sources. These inferred unmapped active faults are capable of generating earthquakes up to magnitude Mw ~7.8 and, in many cases, will be located in low strain rate areas where they are expected to make an important contribution to the seismic hazard.

DISCOVERY OF A NEW ACTIVE FAULT IN WELLINGTON HARBOUR AND IMPLICATIONS FOR REGIONAL SEISMIC HAZARD EVALUATIONS

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A newly discovered, active reverse fault (informally named the "Mount Victoria Fault"), with near-surface expression, has been mapped within inner Wellington Harbour, between Lambton Harbour and Kaiwharawhara. The fault is downthrown to the northwest, has a sea-floor scarp up to 1 m-high and extends offshore for approximately 2 km. Mid-Holocene reflectors are dislocated on the southern and middle sections of the fault trace, becoming more gently folded at its northern end, with maximum vertical sub-surface fault offsets ranging from 3–7 m. Deformation at the southernmost extent becomes more distributed, and perhaps transferred to two other associated structures in Lambton Harbour and Oriental Bay. From the available shallow seismic data, the fault does not appear to be connected structurally to the active, strike-slip Wellington Fault off Kaiwharawhara.

Estimated slip rates on the Mount Victoria Fault are ca. 0.6 ± 0.3 mm/y over the last 10,000 years, with at least two surface-rupturing earthquakes (EQ) recognised, dated at ~6,200 ± 900 years (EQ1), with up to ~2 m of co-seismic vertical displacement, and ~8,400 ± 1,300 years (EQ2). The occurrence of other unresolved earthquakes, however, cannot be discounted. Based on the New Zealand National Seismic Hazard Model empirical relationships, the most compelling earthquake-source scenario involves fault rupture lengths along the fault of ca. 30 km, generated by earthquakes of magnitude M_w 6.8–7.1. This suggests that the fault could extend beneath Wellington City and southwards to the south

coast, possibly via Island Bay (or Lyall Bay). Such earthquakes would produce average co-seismic displacements (~1.9–2.3 m) and recurrence intervals (average ~3500 years, range ~2,100–7,700 years) that are compatible with the new offshore data from Wellington Harbour. Further work is required to delineate the possible onland continuation of the Mount Victoria Fault and to better resolve its Holocene earthquake history and potential hazard to Wellington City.

WEATHERING, SOIL PRODUCTION, AND EROSION ACROSS CLIMATIC AND TECTONIC GRADIENTS

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Weathering is one of the fundamental processes that sustain life on our planet. Physical weathering breaks down rock for soil production and chemical weathering is thought to operate as the ultimate long-term negative feedback on atmospheric CO_2 concentrations. There remains, however, uncertainty as to the relationship between chemical and physical weathering at very fast rates. If chemical weathering becomes kinetically limited at rapid erosion rates, as has been shown in a number of locations around the globe, then the fastest erosion rates will be associated with reduced chemical weathering. This has led to a debate as to whether tectonically active mountain ranges or rolling plains are the main source of CO_2 drawdown through silicate weathering.

At the heart of this debate is the dearth of chemical weathering data at fast erosion rates. New cosmogenic nuclide-derived denudation rates from the West Coast of the New Zealand Southern Alps are among the fastest in the world and are linearly correlated with chemical weathering rates. The associated soil production rates reach an order of magnitude faster than previous estimates and far exceed the suggested maximum soil production rate. This suggests that very fast weathering and soil production is possible in such active landscapes and extreme climates. We investigate the controls on these rapid rates with a climate-driven soil production model.

When applied to the Southern Alps, the model predicts very rapid soil production that matches the magnitude of the cosmogenic nuclide-derived rates. High annual precipitation in the Southern Alps supports rapid soil generation through increased chemical weathering rates and extensive vegetation cover. When applied more broadly, the climate-dependent soil production model suggests that actively eroding mountain belts may display a linear relationship between weathering and erosion in strongly orographic settings, such as in New Zealand's Southern Alps.

THE UNSTABLE KAIKOURA CANYON, NORTHEASTERN SOUTH ISLAND: AN ACTIVE CONDUIT FOR TECTONIC AND CLIMATIC EVENT-TRIGGERED SEDIMENT TRANSPORT ON A VERY NARROW SHELF

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Kaikoura Canyon lies at the southern apex of the Hikurangi Trough off the northeastern South Island. Because of its proximity to plate-boundary deformation the region is subject to periodic earthquakes, affecting the episodic riverine delivery of sediment to the coast, along with down-canyon remobilisation and transport into the Hikurangi Channel system. The upper reaches of the canyon are incised into bedrock and truncate overlying Quaternary strata. The partly infilled Kaikoura canyon head incises into the very narrow (<1 km) and shallow (~30 m) shelf, intersecting the northward littoral transport pathway. A potential landslide-tsunami hazard was previously identified here.

Recent seismic data and cores show a shore-attached post-glacial sediment prism over 40 m thick at the shelf break. Radioactive nuclide profiles of excess Pb-210 and Be-7 determined from precision-short cores indicate on-going outer shelf sediment accumulation at rates up to 1.5 cm/y. Excess Pb-210 profiles in the upper canyon axis show little decay over 40 cm, indicating rapid accumulation from mass flows or intense biological mixing. These new data require a re-evaluation of realistic tsunami sources, while indicating that Kaikoura Canyon is very active as a sediment conduit, with delivery events likely at decadal timescales.

FORGOTTEN WORLD

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Today the community of Tangarakau, King Country, is home to fewer than 10, a mere shadow of the former settlement that at its peak in 1926 had a population of around 1200. In 1929 the Egmont Coal Company commenced a small coal mining operation in the Tangarakau Gorge to supply sub-bituminous coal to fire a power station and locomotives during the construction of the railway from Stratford to Taumaranui. A narrow 610mm gauge tramway ran between the underground coal mine in the gorge to the railway settlement at Tangarakau, a distance of about 6km. The mine was closed in 1936 and has been left to crumble away.

There are several small coal measure outcrops in Tangarakau Gorge. These mostly belong to the Mangapapa Coal Measures, upper Mokau Group, and are part of a regressive sequence deposited in the late Early Miocene in response to uplift and shallowing of the Whangamomona Block, southern King Country. The top of the coal measures crops out at road level opposite the mine entrance. Here horizontal burrows in the upper part of the coal are evidence of deposition in a shoreline to shallow marine setting. The coal beds dip in a generally south-easterly direction beneath the road and crop out again on the true left bank of the Tangarakau River. Farther east and south the coal is subsurface. It's presence in the subsurface has been confirmed by 6 exploration wells drilled in the Tangarakau – Whangamomona area by Solid Energy between 2009 and 2011. Confirmation of extensive coal deposits at depth in southern King Country begs the question how does this regressive transitional sequence fit with the Oligocene – early Miocene marine maxima reported elsewhere?

THE NZGD2000 DEFORMATION MODEL, A TOOL FOR MAINTAINING ACCURATE SPATIAL COORDINATES IN NEW ZEALAND DUE TO DEFORMATION ON THE PACIFIC-AUSTRALIA PLATE BOUNDARY

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While John Beavan is best known for his enormous contributions to our knowledge of the tectonics of New Zealand, he also made a significant contribution to the development and maintenance of the NZGD2000 datum and the associated NZGD2000 deformation model (NDM). Over the years John provided versions of the deformation model and transformations between NZGD2000 and various versions of the ITRF. In this paper we discuss key aspects of the NZGD2000 datum including the development of a datum transformation between ITRF2008 and NZGD2000, and a major update to the NZGD2000 deformation model. The NDM contains a submodel representing velocities across the country caused by continuous tectonic deformation, in addition to submodels of representing deformation associated with major earthquakes (including the Dusky Sound earthquake of 15 Jul 2009 and the four earthquakes between September 2010 and December 2011 that make up the Canterbury earthquake sequence). These earthquake submodels may contain separate component to represent coseismic and postseismic deformation. The submodels deal with earthquake displacements in two different ways [1]. In the first, known as a forward patch, the reference coordinates are unchanged, and the deformation model accounts for the deformation associated with the co-seismic and secular parts of the model. In the second, known as a reverse patch, the reference coordinates are changed to reflect the co-seismic portion of the deformation and the deformation model only needs to account for the secular part of the deformation. A consequence of the use of reverse patches is that the epoch 2000 coordinates change to reflect the changes caused by the earthquakes, even though they occurred well after the reference epoch of the datum.

[1] Winefield et al., (2010). FIG Congress 2010 Sydney, Australia, 11-16 April 2010

MAJOR ELEMENT AND STRONTIUM ISOTOPE GEOCHEMISTRY OF GLACIERS, LAKES AND RIVERS WITHIN THE MACKENZIE AND WAITAKI BASINS

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Water and ice samples were taken from an array of locations extending from the Tasman and Hooker Glaciers, Lakes Tekapo, Pukaki and Ohau through to State Highway 1 North of Oamaru. Samples were collected at the beginning of each season from November 2013 (summer) to September 2014 (spring). There is a general lack of time series data for radiogenic isotopes that prevents proper assessment of uncertainties in estimated annual averages. The few rivers for which time series data is available for indicate that Sr concentrations can vary by more than a factor of two, and $^{87}Sr/^{86}Sr$ can vary by several per mil. Here, the current research attempts to add to the field by providing a time series data set across each season for a single year for New Zealand's Waitaki and Mackenzie basins.

The average relative molar abundance of major cations in all waters sampled follows the order Ca^{2+} (66%) > Na^{+} (20%) > Mg^{2+} (8%) > K^{+} (5%). Sample Ca/Sr values range from 0.19 – 0.85 µmol/nmol in the Tasman Glacier terminal lake and Tasman Glacial ice, respectively. Seasonal variation in cation concentrations were observed, with a general decrease throughout the catchments from summer to winter. An exception was the heavily impacted water of the lower Waitaki, which had higher dissolved concentrations in the winter. This could result from the influence of Ca-rich sediments of the lower Waitaki Basin or anthropogenic fertilizers.

$^{87}Sr/^{86}Sr$ ratios in the dissolved load, will be measured in order to further assess the sources of solutes in these catchments from chemical weathering.

U-PB DATING OF SAMS CREEK (NORTHWEST NELSON, NEW ZEALAND)

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Gold mineralisation at Sams Creek occurs within an under-explored region of Northwest Nelson with a rich alluvial gold history dating back to the 1850s. Gold at Sams Creek is hosted by an A-type peralkaline microgranite dike extending 7km along strike up to 60 metres in thickness.

Multiple stages of hydrothermal activity have altered the dike including the precipitation of late arsenopyrite veins, base metal sulphides, and gold. Gold-silver alloy (~80-85% Au) occurs as small growths (up to 40 µm) cementing and in-filling brecciated and fractured arsenopyrite (the most abundant ore-related mineral).

Hydrothermal zircons occur as clusters and stringers of <1-15µm anhedral crystals along arsenopyrite grain boundaries and within the same micro fractures occupied by gold grains. It is suggested that these zircon originated from hydrothermally remobilised Zr derived from original igneous phases of the SCD. Zircons also occur in un-mineralized samples as relatively large ellipsoidal to faceted individual grains associated with primary mafic minerals and are interpreted as late magmatic in origin. These zircons are up to ~25µm in size and many grains exhibit a spongy (?dissolution) texture.

U-Pb analysis by LA-ICP-MS indicates a mid-Cretaceous age for dike emplacement (109 ± 9 Ma) and the main gold bearing hydrothermal event (114 ± 6 Ma). Analysis of a second group of hydrothermal zircons, associated with more advanced replacement of sulphide grains, yields a Late Cretaceous age of 80 ± 4 Ma. This date possibly represents a later remobilizing hydrothermal event, but limited data requires that further investigation be conducted to assess this possibility.

The proposed Cretaceous emplacement age differs significantly from the published Carboniferous age (319 ± 8 Ma) from 40Ar/39Ar analysis of amphibole by Tulloch and Dunlap (2006). The Cretaceous mineralisation age is in agreement

with an estimate constrained by structural mapping which suggests syn-deformational formation.

BASALT 'CRICKET' BALLS AND SHATTERED RHYOLITE; ERUPTION DYNAMICS OF A BASALTIC TUFF SUCCESSION AT KINLOCH, TAUPO VOLCANIC CENTRE

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Basalt is a volumetrically small, but genetically important magma composition of the central Taupo Volcanic Zone. A small field of at least five basaltic monogenetic centres occur at the northern end of the Taupo Volcanic Centre between Kinloch and Acacia Bay, north of Lake Taupo (Punatekahi scoria cone complex, 140 ka, Stipp 1968, Aust. Nat. Univ. PhD thesis; K-trig scoria cone and tuff; Kaiapo tuff; Mine Bay tuff; Acacia Bay tuff, ~100-200 ka, Wilson and Smith 1985, J. R. Soc. NZ, 15, 329-337). We report a previously unpublished phreatomagmatic centre (Kinloch tuff) exposed in a lakeshore cliff near Kinloch and discuss its volcanic process origins. The exposed ~ 7 m-thick Kinloch tuff deposit overlies a succession of interbedded tephras and palaeosols, and is overlain by a ~ 4 m-thick poorly sorted lithic cobble-rich mass flow deposit. Several north-trending normal faults offset the Kinloch tuff and underlying succession by 1-2 m, but have not offset the overlying mass flow deposit. Three facies have been identified within the tuff deposit: (1) alternating weakly-laminated fine ash and thin- to medium-bedded, coarse ash to lapilli pyroclastic surge-dominant facies, with low angle cross bedding and erosional scours; (2) massive, lithic block and spheroidal basalt lapilli-bomb pyroclastic fall facies; and (3) thick-bedded, internally massive, poorly sorted lapilli ash facies. Facies 1 comprises the lower 5.5 m of the section and facies 2 and 3 are intercalated within the upper 1.5 m, suggesting a predominantly phreatomagmatic-driven eruption. Beds of spheroidal basalt lapilli and bombs, often with pumiceous inclusions, and rhyolite lithic blocks (facies 3) indicate brief periods of coarse-scale magmatic and country rock fragmentation.

DEVELOPING ROBUST TSUNAMI FORECASTS FOR PORTS AND HARBOURS

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Tsunami large enough to cause disruption to ports and harbours have occurred several times in the past decade. As New Zealand's economy is heavily dependent on imports and exports it is important that forecasts are accurate, both because tsunami damage to ships and facilities is expensive to repair and can be mitigated given warning, but also because preventable false alarms are costly. Two main approaches to tsunami forecasting are available. The first is to build a database of pre-calculated scenario models which can be referred to during an event; and the second is to use a prepared configuration to model an event in real time. Both of these have pros and cons. This talk will describe the development of a pre-calculated set of tsunami forecasts for key New Zealand ports: Marsden Point, Port of Tauranga, Port Taranaki, and Lyttelton Harbour. A key component of this work is to understand the limitations of the pre-calculated scenario approach, as a prepared scenario is only ever going to be an approximation to a real event; this leads to an analysis of appropriate factors of safety.

CENOZOIC BIOGEOGRAPHY USING POLLEN FROM THE FRED DATABASE

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FRED (online at http://www.fred.org.nz/) is a database recording fossil localities in New Zealand and nearby regions including SE Pacific islands and the Ross Sea region of Antarctica. FRED contains about 98000 locality records registered at regional recording centres since 1946.

In this project, we seek to synthesise the pollen observations from New Zealand Cenozoic sediments that are stored in FRED, and to

document biogeographic variation through time. To do this, we have compiled presence/absence observations of 340 published taxa from >2500 individual sporomorph assemblages of Paleocene-Pliocene age.

Samples were restricted to those collected from outcrop or cores; drill cuttings were excluded. A two-tier hierarchy of age determination was used. Samples with 'non-pollen' age estimates were separated from samples with 'pollen-only' age estimates. Where multiple age estimates were available, a 'best overlap' age was estimated. The paleogeographic coordinates of each sample was inferred using the GPlates model (http://www.gplates.org/). Ecological and environmental observations from modern analogues to the fossil palynospecies were used to interpret pollen associations observed in principal component analyses of time slices defined by New Zealand stages.

IMPACT OF A WARMER WORLD ON SOUTHERN OCEAN CIRCULATION AND BIOPRODUCTIVITY: THE EARLY HOLOCENE

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In the New Zealand region, the sparse data available suggest sea surface temperatures during the early Holocene ranged up to 3°C above present, but timing and magnitude of warming varied across the region. These temperatures are within the range of those expected in the coming century. The early Holocene sedimentary archive has great potential to provide well resolved records of past regional variability in a warmer world.

We report on the first stages of a model-data comparison project for the early Holocene, which has three aims. The first is to generate sub-millennial scale multi-proxy sea surface temperature records for 12-6ka from a suite of marine sediment cores that form a latitudinal transect from New Zealand into the Southern Ocean (36°S-60°S). Methods used to estimate sea surface temperature at each site include Mg/Ca from planktonic foraminifera, alkenones and assemblage-based techniques using foraminifera, radiolaria, dinoflagellates and diatoms. The second aim is to compare the results of these sea surface temperature data with outputs of a climatic model for this interval, the CCSM3 TraCE simulations. Additional proxies (faunal and floral assemblage data, bulk sediment properties, nitrogen isotopes, and measurements of sedimentary iron concentration) will be used to infer semi-quantitative estimates of primary productivity during this interval. Finally, the proxy data will be utilised to infer water mass conditions and the position of frontal systems during the early Holocene.

VOLCANIC DEBRIS AVALANCHES; UNDERSTANDING EMPLACEMENT AND APPROACHES TO MODELLING AND SIMULATION: A CASE STUDY FROM TARANAKI, NZ.

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Fourteen unconfined debris avalanche deposits (DADs) <200ka in age are preserved on the Mt. Taranaki ring plain, providing a record of a high-impact, low-frequency hazard. The youngest of these events, the ~7ka Opua and 26.5ka Pungarehu formations, exhibit the typical chaotic, polymodal, polylithologic and extremely poorly sorted characteristics of DADs. Despite the

apparent invariance of these large-scale properties, the sedimentological characteristics gradually change from proximal to distal areas, with the finer fractions increasing with distance. SEM analyses of clay and silt grains show typical hackly textures and micro-cracks. The lack of variation in the crack distribution or frequency within the deposit suggests cracking occurred at source. Similarly the analysis of macro-scale fracture patterns within domains and/or megaclasts show no alignment or preferred orientation of stress fields.

Deposit surface morphology varies with distance from source. A chaotic surface occurs in proximal regions, which then gives way to ridges of mounds oriented in flow-parallel direction. These eventually transform into clusters of mounds and more widely spaced fields of individual mounds in distal areas.

Both debris avalanches were generated gravitational sector collapses which flowed down individual catchments. Abrupt changes in topography and slope resulted in the transformation of the flows into a more cohesive mobile body, which formed lobes marked by mound/hummocky ridges.

The granular flow model Titan2D has been applied to evaluate possible emplacement conditions and collapse parameters. While useful for defining initial collapse parameters and major flow paths, Titan2D could not adequately simulate the complex rheological transformations of a collapsing/sliding pile through granular flow, into a long-runout, clay-rich, cohesive flow with high fluidity. It is also difficult to adequately define simulation parameters for this rapidly changing flow from the deposits. Hence computer simulations of major flow paths must be used alongside insights from geological mapping to provide future-focused hazard zones for debris avalanches.

PALAEONTOLOGY IN THE PRESS: DINOMANIA, DISCOVERIES AND THE 'GEE WHIZ!' FRAME

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For the general public, the news media play a significant role in providing information on, and shaping discourse around, contemporary research from across all areas of science. Despite growing academic interest in science journalism, media research in this field is typically generalised or, when discipline-specific, focuses on a limited range of largely anthropocentric topics, such as human biology, medical science and climate science. While there are undoubtedly issues that pervade all media/science relations, we contest that the less-studied disciplines - which also generate research of global reach and relevance - exhibit media interactions with unique aspects that merit study.

The purpose of our on-going research is to examine the media/science relationship in one such neglected area of reporting: palaeontology. While limited and often anecdotal, existing literature has proposed a general air of dissatisfaction with these interactions amongst palaeontologists and journalists alike, rooted in a fundamental culture clash between the two professions. In addition to raising recurring themes of Science Journalism Studies (e.g. accessibility, accuracy and sensationalism), many commentators propose the media's alleged 'dinomania' - a singularly overwhelming obsession with dinosaurs - as a problematic and unparalleled quirk of palaeontological reportage. The extent of this trend, however, has not been quantified.

In this presentation we report preliminary results from a content analysis of around 600 palaeontological news stories. Our study is limited to those articles specifically covering palaeontological research that were published in 60 prominent, international, English-language newspapers during the previous calendar year. We identify a number of recurring topics and news frames, discuss these in light of existing literature, and investigate the feasibility of extending our analysis to identify longer-term trends.

THE EXTENT OF WEST COAST IGNEOUS ROCKS REVEALED BY AEROMAGNETIC DATA, NEW ZEALAND

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Aeromagnetic data acquired over the West Coast for the New Zealand Government and industry have revealed a wide range of total magnetic

intensities that generally correlate well with known geological mapping units of differing magnetic susceptibility. Strongly positive anomalies are associated with igneous rocks; notably Mesozoic mafic metavolcanic and ultramafic rocks, Late Cretaceous basalt and some of the Early Cretaceous intrusions. The Pounamu Ultramafic rocks in the Southern Alps have some of the highest intensity anomalies recorded by the surveys and the Dun Mountain Ultramafic Group serpentinised peridotite rocks and dikes also have very strong magnetic expressions. Isolated anomalies along the Alpine Fault are attributed in part to ultramafic rocks incorporated into the mylonite zone. Greenschist bands within the Alpine Schist are well expressed magnetically. Many of the Separation Point and Rahu Suite Early Cretaceous intrusions are strongly magnetic, including the Berlins Porphyry and the Pensini Granodiorite that contribute to the Inangahua Magnetic Anomaly. The strong anomalies associated with the Hohonu Range and many other foothills are caused by magnetic granitoids and dikes. The Hohonu Batholith may persist to the west under Quaternary and older Cenozoic cover and be the cause of the Kumara Magnetic Anomaly. Other Cretaceous and most of the Devonian intrusions have a very weak magnetic intensity and it is difficult to distinguish them magnetically from Greenland Group metasedimentary and gneissic rocks. Many long linear anomalies are attributed to mafic igneous dikes intruding the basement rocks. Late Cretaceous Arnott Basalt in South Westland is highly magnetic and its associated aeromagnetic anomaly indicates a wide distribution including in a newly discovered anticline near Fox Glacier that has been almost completely obscured by glacial outwash and till.

PALEOENVIRONMENT AND SEDIMENTOLOGY OF A WAVE DOMINATED PROGRADING FAN DELTA SEQUENCE, PLIO-PLEISTOCENE KONEWA FORMATION, POHANGINA, NEW ZEALAND

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A 66-m- thick sequence of Plio-Pleistocene Konewa Formation exposed in southern Pohangina Valley, records predominantly coarse terrigenous clastic deposition in a wave dominated fan delta and nearshore to offshore shallow marine environments. The fan delta environment is characterised by sub-aerial to subaqueous, plastic or pseudoplastic, clast-rich debris deposits consistent with flows associated with partial collapse of steeply dipping, unstable, prograding delta foresets resulting in avalanching of sediment from the top of the delta system. The fan delta facies are interpreted to represent a Gilbert-type fan delta with a fluvial signature in the top delta zone, steeply dipping foresets, and more of a marine signature in beds at the front delta zone. Wave sorted conglomerates preserved in this sequence are accumulated on a tectonically active coastline characterised by high-energy wave activity and sporadic intense storms.

The Nukumaruan Konewa Formation was deposited in a shallow marine setting located along the western flanks of the Ruahine Range in the eastern part of the Wanganui Basin. Analysis of conglomerate clasts and paleocurrent data indicate the source of the gravel was an elevated basement located in the vicinity of the present day northern Ruahine Range, some 40 -70 km north of Pohangina. The gravels were transported by a paleo-river system which flowed into the southeastern Wanganui Basin, delivering vast quantities of terrigenous sediment into a shallow marine environment. Correlation in the region supports a fan delta about 1.5 km across. The climate at the time of deposition is interpreted as a glacial period characterised by river aggradation and coastal progradation.

A PRELIMINARY ACCOUNT OF THE FLORAL DIVERSITY AND CLIMATE OF THE MUDDY CREEK LEAFBED, GREY LAKE, CENTRAL OTAGO

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A newly discovered leaf bed in the Early Miocene St. Bathans Member of the Manuherikia Group, Central Otago is described. Previous studies on the St. Bathans Member have focused on dispersed cuticle, but near Muddy Creek a ~20 x 20 m, ~3 m high mud lens is exposed, showing excellent preservation of both leaves and cuticle. The deposit is lensoidal, wedged between cross-bedded sandstones and capped by Quaternary deposits. The mud lens has fine mm-scale laminations. There is no clear evidence of leaf transport, nor is there any alternation of grain-size. The depositional environment was probably an oxbow-lake, or abandoned channel from a braided river system feeding into Lake Manuherikia.

Plant fossils are preserved in oxidized and unoxidized mudstone; the unoxidized mudstone is grey-black and leaf outlines are difficult to distinguish, but have excellent cuticular preservation (~80%). The oxidized mudstone is brown-red and has good preservation of macromorphological characteristics, but no cuticle is preserved. Fruits and possibly seeds are present, but as yet, no floral remains. The leaf assemblage is diverse, with relatively even representation of leaf morphotypes. Podocarps are relatively common and moderately diverse. Some palm-like fronds and other monocots have been recovered, but most of the leaf fossils belong to Magnoliids and/or Eudicots. *Nothofagus*-type leaves are absent from the main mud lens, but present at the bottom of the section in highly oxidized mudstone. The excellent cuticular preservation at Muddy Creek preserves evidence of microscopic fungal colonies together with ~50–100 µm insect puncture marks. *In situ* preservation of fungal hyphae, high abundance of Podocarpaceae, together with results from CLAMP analysis suggests relatively high humidity in a somewhat cool environment.

SEASONAL CLIMATIC GRADIENTS IN THE EARLY MIOCENE OF NEW ZEALAND

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Southern New Zealand has a rich sedimentary record of early Miocene terrestrial paleoenvironment. The broad picture emerging from these records indicates a major transition in the terrestrial climate of southern New Zealand during the period of Drake Passage opening and corresponding amplification of the Antarctic Circumpolar Current. The general trend was from subtropical, warm-temperate humid climate during the early Miocene toward increased Antarctic influence, resulting in cool-temperate conditions in the late Miocene. Additionally, sedimentological and paleobotanical evidence suggests that during certain time intervals in the Miocene, New Zealand's climate was characterized by an increased seasonal gradient.

Today southern New Zealand seasonality is most pronounced in the light regime, with twice as many daylight hours and three times higher solar altitude angle in summer than in winter; in contrast the summer/winter precipitation ratio is much less seasonal at ~0.8–1.0. In modern day monsoon-dominated oceanic climates in the Pacific region, summer precipitation can be 6–8 times higher than winter precipitation, but the light regime is much less seasonal. The restricted seasonal precipitation gradient in New Zealand is mostly the effect of the influence of the westerly wind belt, which brings moisture-laden air year-round, particularly in southern New Zealand. However, with reduced Antarctic influence in the early Miocene, seasonal reduction of the westerly winds could have arrested the main moisture supply.

Using a theoretical model of evapotranspiration, based on quantitative estimates of climatic parameters and paleolatitudinal position, we present paleoenvironmental reconstructions that delineate the seasonal parameters of early Miocene climate in southern New Zealand. These reconstructions suggest that the seasonal shifting of main moisture supply, together with a mid-latitudinal light regime in New Zealand, could account for amplified seasonal precipitation gradients.

CENOZOIC MARINE SEQUENCE OF SWINBURN REGION, MANIOTOTO, CENTRAL OTAGO

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The Maniototo Basin preserves localised Cenozoic marine strata that can be correlated into Waitaki Valley, with formational names as used in the southern Canterbury Basin. The clastic-dominated strata were derived from a schist source on Zealandia during maximum submergence.

Long-recognised marine strata from the Maniototo are the Naseby Greensand and Green Valley Limestone. The basin-wide greensand is now identified as a composite of units including Whaingaroan? and Duntroonian fossils, and Kokonga-Green Valley Limestone is Otekaike equivalent. We now detail a ~200 m section at Swinburn Creek, comprising massive fossiliferous marine rocks with a pervasive micaceous, very fine quartz sand to silt component. The sequence is variably (in places richly) glauconitic, grading up to muddy limestone capped unconformably by basaltic volcanics. Formations include: Wharekuri (truncated by the Marshall unconformity), Kokoamu, and Otekaike. Foraminifera and ostracods date these units as Whaingaroan to Waitakian; low planktic foraminiferal percentages are consistent with limited oceanic influence. Uncommon fossil scallops (Pectinidae) in the *Janupecten-Lentipecten* lineage are consistent with foraminiferal ages. This sequence is thicker, more clastic-dominated, and nearer to sediment source (probably Otago Schist) than in the Waitaki. A nearby stratigraphically lower sequence includes quartzose coal measures, inferred estuarine mudstones with rare molluscs, and shales, consistent with a paralic to estuarine setting. No dates are available. In summary, the Swinburn sequence formed in a shallow, possibly early- to mid-Cenozoic epicontinental sea with a productive source of terrigenous clastics. There is no firm evidence of outer shelf settings.

15 YEARS OF ZOOMING IN AND ZOOMING OUT: DEVELOPING A NEW SINGLE SCALE NATIONAL ACTIVE FAULT DATABASE OF NEW ZEALAND

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We are currently reconciling multiple digital coverages of mapped active faults into a national coverage at a single scale (1:250,000). This seems at first glance to be a relatively simple task. However, methods used to capture data, the scale of capture, and the initial purpose of the fault mapping, has produced datasets that have very different characteristics.

The New Zealand digital active fault database (AFDB) was initially developed as a way of managing active fault locations and fault-related features within a computer-based spatial framework. The data contained within the AFDB comes from a wide range of studies, from plate tectonic (1:500,000) to cadastral (1:2,000) scale. The database was designed to allow capture of field observations and remotely sourced data without a loss in data resolution. This approach has worked well as a method for compiling a centralised database for fault information but not for providing a complete national coverage at a single scale.

During the last 15 years other complementary projects have used and also contributed data to the AFDB, most notably the QMAP project (a national series of geological maps completed over 19 years that include coverage of active and inactive faults at 1:250,000). AFDB linework and attributes was incorporated into this series but simplification of linework and attributes has occurred to maintain map clarity at 1:250,000 scale.

The main goal of the current project has been to provide the best digital spatial representation of a fault trace at 1:250,000 scale and combine this with the most up to date attributes. Where datasets have conflicting line work and/or attributes, data was reviewed through consultation with authors or review of published research to ensure the most to date representation was maintained. The current project aims to provide a coverage that will be consistent between the AFDB and QMAP digital

and provide a free download of these data on the AFDB website (http://data.gns.cri.nz/af/).

THE INFLUENCE OF THE MOKIHINUI METAMORPHIC CORE COMPLEX ON PALEOGENE BASIN EVOLUTION: REACTIVATION OF CRETACEOUS STRUCTURES IN AN EVOLVING STRESS REGIME?

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The influence of mid Cretaceous extensional tectonics and corresponding crustal thinning on New Zealand's modern structural setting is increasingly well understood. However, the influence of inherited Cretaceous structures on the intervening Paleogene and Neogene history remains uncertain. Variation within the Oligocene stratigraphic record overlying the Paparoa Metamorphic Core Complex has been shown to coincide with underlying Cretaceous structures, however, it remains unclear whether this relationship extends temporally or geographically into other parts of the Challenger Rift System. We present sedimentological and stratigraphic data from Eocene (Rapahoe Group) and Oligocene (Nile Group) strata that overlie a newly discovered core complex, herein named the Mokihinui Core Complex, along the South Island's northern West Coast. In particular, the distribution of the Eocene Courtney Limestone (coralline algae limestone), Island Sandstone (calcareous quartz sandstone), and Kaiata Formation (mudstone and muddy sandstone), are shown to coincide with the upper (to the south), lower, and upper (to the north) crustal rocks of the core complex respectively. Oligocene lithologies with relatively deep-water outer platform and slope limestone facies (Whitecliffs and Little Wanganui formations) are absent atop lower crustal basement, occurring on upper crustal basement to the north and south. A pronounced increase in thickness is also recognised from 0-10's of metres to 100's of metres for both the Kaiata Formation and Nile Group across the newly proposed Grenadier detachment fault. These examples highlight the strong correlation between the composition and distribution of overlying Paleogene facies with underlying low angle detachment faults and lower and upper crustal basement lithologies. This result strengthens the growing body of evidence for prolonged and widespread reactivation of Cretaceous structures during younger and orthogonal phases of extension associated with the Challenger Rift System, while raising questions as to what extent these inherited structures were reactivated during Miocene and younger transpressional regimes.

TSUNAMI EARLY WARNING FROM EARTHQUAKE RUPTURE DURATION AND DOMINANT PERIOD

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An effective early warning system for tsunami at local or regional distances requires notification within 5 – 15 minutes. New Zealand is surrounded by a number of potential local and regional tsunami sources making a tsunami early warning system critical for coastal regions. The method for identification of potential tsunamigenic earthquakes presented here uses the first 60 s of data after the *P*-arrival which allows for a rapid assessment (~5 – 10 minutes) of the tsunami potential of an earthquake. This method estimates the apparent rupture duration and dominant period of an earthquake. An earthquake with a long rupture duration and low dominant period is more likely to be tsunamigenic. A number of large magnitude (M > 7) tsunamigenic and non-tsunamigenic earthquakes from around the world were tested using local or regional distance data. Included in the dataset are several slow-rupture tsunami earthquakes which generate large tsunamis but have very little high-frequency energy, are often not felt strongly, and have low initial magnitudes (M < 7). We also tested synthetic data for a slow-rupture tsunami earthquake on the Hikurangi subduction zone, similar to the 1947 Gisborne earthquakes. The method reliably triggers on earthquakes which are known to have generated tsunamis, including slow-rupture tsunami earthquakes, and distinguishes large magnitude earthquakes that did not generate a tsunami. The method is based on the frequency content of the waveforms and is independent of the mechanism, and can be thought of as analogous to a "smoke detector". It provides information on whether the earthquake has frequency content characteristic of a

tsunamigenic earthquake, but not whether it generated a tsunami or how large a tsunami might be. This method provides a rapid warning for more detailed modelling and, for a local source with a tsunami travel time < 30 minutes, may be the only warning available.

MODELLING COSEISMIC LANDSLIDE SUSCEPTIBILITY FROM AN ALPINE FAULT EARTHQUAKE

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Recent mountainous earthquakes such as the 1999 Chi-Chi and 2008 Wenchuan events have vividly demonstrated that earthquake hazard in mountainous environments is not simply the strong ground shaking which results. Consequential landsliding can be as, or more devastating than the initial earthquake. Studies of the effects of previous Alpine fault earthquakes appear to suggest that large earthquakes on this fault result in widespread landsliding within the Southern Alps. Estimating this hazard pre-event is therefore vital for disaster risk reduction and preparedness planning. Yet currently modelling coseismic landslide susceptibility requires either a substantially complete coseismic landslide inventory from an historic event in the region or densely spaced, detailed geotechnical data. As neither of these are available for the Southern Alps, susceptibility modelling has not been possible.

This work therefore utilises complete landslide inventories from the 1994 Northridge, 1999 Chi-Chi, and 2008 Wenchuan earthquakes to statistically model landslide susceptibility from mountainous earthquakes. These events show that on a regional scale, susceptibility is controlled predominantly by ground shaking, slope angle and position, and distance to faults and streams. Applying the observations to an M8 Alpine fault earthquake yields the first coseismic susceptibility map for such an event. This shows that high susceptibility affects an area >50,000 km^2, predominately focussed on the western rangefront and within the southern Marlborough faults system. Observations of landslide densities in the three test events suggest that landslide numbers from an Alpine fault event are likely to exceed 40,000 and could be as high as 170,000. Coseismic landsliding from Alpine fault events therefore clearly presents a substantial hazard and further efforts to understand the effects of this landsliding are required in order to better understand the hazard posed.

VULNERABILITY OF CRITICAL INFRASTRUCTURE NETWORKS TO COSEISMIC LANDSLIDING FROM AN ALPINE FAULT EARTHQUAKE

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Earthquakes account for 30% of all disaster damage costs globally, causing >US$760 billion in damage since 1900. The majority of building damage arises from strong ground shaking, however damage to critical infrastructure, particularly road and utilities networks, is predominantly a function of landslides and liquefaction. The Alpine fault has been shown to present a substantial landslide hazard during ruptures, with >40,000 landslides expected across a >50,000 km^2 area. Assessing the vulnerability of road and utilities networks to such landsliding is therefore vital to understand the earthquake hazard as a whole. Using a landslide susceptibility map developed from observations of similar earthquakes in mountainous terrains we assess the vulnerability of the State Highway and high voltage electrical transmission networks to Alpine fault generated landsliding. The most vulnerable sections of highway are SH6 between Hokitika and Haast, SH7 (Lewis Pass) between Hanmer Springs and Reefton, and SH73 (Arthurs Pass) east of the Waimakariri River. In total >230 km of highway has a high vulnerability to landslides, resulting in >20,000 people in West Coast region being vulnerable to isolation. SH69 and SH7 between Reefton and Greymouth is identified as the most critical section of the network, with only limited vulnerability to landslides. If this route remains functional post-earthquake, access to ~20,000 people in Greymouth, Hokitika, and the Grey Valley will be possible. The electrical transmission network is shown to be more robust with only 32 steel pylons in Arthurs Pass demonstrating high

vulnerability; the Inter-Island link has only low vulnerability. Nevertheless, loss of wooden-pole supported sections south of Hokitika could render >20,000 people without power until repairs can be completed. Mitigation methods to reduce the vulnerability to both networks are therefore likely to substantially reduce the impacts of a future Alpine fault earthquake.

TRACING ANOXIC CONDITIONS IN THE OCEANS USING FRACTIONATION OF $^{238}U/^{235}U$

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Tracking the history of free oxygen in Earth's atmosphere is of vital importance to understanding the evolution of life on Earth. Transitions from reducing to oxygenated conditions in the ancient ocean-atmosphere system can be inferred from elemental abundances of redox-sensitive metals (e.g. Fe, Mo, Cr, U, V) in reducing organic-rich marine sediments. However, local depositional processes, such as variable mass accumulation rates, can significantly impact the observed relative enrichments of redox-sensitive metals, thereby hindering an accurate interpretation of the sedimentary record of the redox state of ancient oceans. The isotopic compositions of redox-sensitive metals, including uranium (U), in marine sediments have recently emerged as powerful diagnostic tracers of the redox state of the ancient ocean-atmosphere system. Interpretation of sedimentary isotopic information requires a thorough understating of the environmental controls on isotopic fractionation in modern anoxic environments before being applied to the paleo-record. In this study, the relationship between ocean anoxia and the isotopic fractionation of U was investigated in the water column and sediments of the Black Sea. The Black Sea is the world's largest anoxic basin and significant removal of U from the water column and high U accumulation rates in modern underlying sediments has been documented. Removal of U from the water column occurs during the redox transition of soluble U^{6+} to relatively insoluble U^{4+}. The primary results of this study are two-fold. First, significant $^{238}U/^{235}U$ fractionation was observed in the water column of the Black Sea, suggesting the reduction of U induces $^{238}U/^{235}U$ fractionation. Second, the $^{238}U/^{235}U$ of underlying sediments is related to the water column through the isotope fractionation factor of the reduction reaction but is influenced by mass transport processes. These results provide important constraints on the use of $^{238}U/^{235}U$ as a proxy of the redox state of ancient oceans.

MAFIC-FELSIC INTERACTIONS IN THE ORUANUI SUPERERUPTION: INSIGHTS INTO PRE- AND SYN-ERUPTIVE PROCESSES AND MAGMA CHAMBER DYNAMICS

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In silicic volcanic systems, mafic magmas are parental to rhyolites, and provide heat and volatiles that can drive magma chamber processes and trigger eruptions. Owing to their higher density, these magmas rarely reach the surface in rhyolite-dominated volcanic centres, although occasionally may be erupted as a minor component. The chemistry, mineral assemblages and textures of any mafic material evacuated during large silicic eruptions hold valuable information on processes and interactions occurring within the magma body during and immediately prior to such an eruption. These processes are investigated in this MSc thesis work by examining and documenting textural relationships and mineral and glass chemistry in juvenile mafic clasts (52-63% SiO_2) from the 25.4 ka Oruanui supereruption (*c*. 530 km^3 magma) of Taupo volcano.

The groundmass of the Oruanui juvenile mafic clasts consists of framework of acicular plagioclase and amphibole microlites, with interstitial rhyolitic glass. The disequilibrium groundmass textures, including hopper and swallowtail plagioclase, and stellate clusters of amphibole, are characteristic of rapid diffusion-controlled crystallization at high undercooling. This indicates the mafic magma was chilled upon injection into the host rhyolite. Thermal modelling of cooling rates will be used in conjunction with BSE imagery, x-ray tomography and electron microprobe analyses of microlites in order to quantify how the quench crystallization

process is manifest in the textures and mineral chemistry of the mafic clasts. Textures will be compared and contrasted with pre-existing experimental work, in order to aid quantitative interpretation of the conditions under which they formed.

Preliminary results highlight a spectrum of textural types, ranging from fine-grained and glassy to relatively coarse with abundant stellate clusters of acicular amphibole. This diversity indicates crystallization occurred over a range of conditions and timescales. Further work will focus on constraining the conditions under which these different textural groups crystallised, and the processes responsible for this diversity.

VOLCANO-TECTONIC EVOLUTION OF THE WAIRAKEI-TAUHARA GEOTHERMAL SYSTEM: INSIGHTS FROM U-PB DATING OF ZIRCONS

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The combined fields of Wairakei and Tauhara (WK-TH) make up one of the largest geothermal systems in the Taupo Volcanic Zone (TVZ). In a volcanic-structural context, the WK-TH system is located in the Taupo-Reporoa Basin (TRB) across a region of narrow horst-graben structures defined by predominantly NE-striking faults of the active Taupo Rift. The system also lies within the Whakamaru caldera near its south-eastern margin.

New U-Pb ages and volcanic and sedimentary stratigraphy refined from >200 geothermal wells up to 3 km deep, are combined to reveal focussed episodes of volcanism from ~ 310 ka to ~120 ka. The ages conform to stratigraphic order and the extrusions (each ~0.1 km^3 to ~7 km^3) occur in a spatial cluster in the uppermost ~1.5 km of strata beneath the Wairakei (north-western) area.

U-Pb dating (by SHRIMP-RG ion microprobe) of magmatic zircons from hydrothermally altered lavas and ignimbrites has revealed that rhyolitic volcanism occurred at WK-TH just prior to ~ 0.9 Ma, and was dominant in the same area after ~0.35 Ma. However, stratigraphy and dating reveal an apparent >500 ka lapse in volcanic activity or local deposition between those episodes.

The ages of pyroclastic strata from the Tauhara (south-eastern) area make it clear that a substantial volume of Whakamaru group ignimbrite was emplaced into and then eroded from the southern TRB between ~0.35 and 0.31 Ma, and then after ~0.31 Ma, replaced with as much as 2.5 km thickness of tuffs and sediments.

These ages help constrain the timing of broader scale developments of the TRB, including fault formation/reactivation, which were also likely to have been major influences on hydrological evolution of the system. These ages provide an important contribution to understanding the structure and subsidence of the Whakamaru caldera, and evolution of the Taupo-Reporoa Basin and the eastern side of central TVZ.

INSIGHTS INTO GLACIATIONS AT THE AUCKLAND ISLANDS

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The Southern Ocean south of New Zealand hosts small and isolated groups of volcanic islands that protrude above New Zealand's continental shelf. The largest of these are the Auckland Islands, which have an area of approximately 500 km^2 (above sea level). The larger size of the Auckland Islands has implications for the environmental conditions on the land and in the neighbouring seas. In particular, the prevailing westerly winds are much less harsh on the eastern side of the island, making this relatively sheltered position ideal for harbouring glaciers during Quaternary glaciations. Evidence of this glaciation is observed in the U-shaped valleys and fjords that dominate the topography of the islands. The regular volcanic geology and limited sediment sources of the Auckland Islands facilitates the preservation of a sub-Antarctic climatic history in the sediments of present-day fjords and their ancient offshore equivalents. What makes the Auckland Islands special is their larger landmass, which serves to

maintain not only a climatic history in the sedimentary record but also preserve the powerful and dramatic effects of erosion; be that erosion sub-aerial, sub-marine or glacial.

402 km of 2D seismic data collected on the leeward (eastern) shelf of Auckland Island in early 2014 reveal numerous deep in-filled valleys beneath a relatively flat seabed. The deepest of these valleys has a maximum depth of 130 m below modern sea level. 3D interpretations of these valleys have been undertaken and sediment thicknesses have been mapped.

Preliminary data shows that the southern portion of the island has deeper, steeper and longer fjords, whereas the northern portion has flatter and less dramatic paleo-valley topography. The data provide new information on the extent of the glaciations that occurred at the Auckland Islands and enable the assessment of interactions between glaciers, the climate and ocean conditions.

DEVELOPMENT OF A NATIONAL LANDSLIDE DATABASE FOR NEW ZEALAND

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A national landslide database is being developed as a repository for all New Zealand landslide data. The spatial database is being developed using open-source software (PostGIS). The database is being used for landslide hazard and risk assessment and as a tool to develop a probabilistic landslide hazard model for New Zealand.

A unified landslide data model has been developed to enable the New Zealand landslide database to be a repository for potentially all New Zealand landslide data. The new database incorporates data from existing databases that were developed and populated for different purposes. Therefore, the national database presented here contains landslide data with a variety of scales, accuracy and attributes. The national database is also designed for future data collection on an on-going basis.

Along with the locations of landslides, the Landslide Database contains information on the timing of landslide events, the type of landslide movement, the triggering event, volume and area data, and damage consequences for each landslide where this information is available. Landslide data has been collected and summarised from a variety of sources including aerial photograph interpretation, field reconnaissance and media accounts. There are currently over 28,000 landslide records in the database. Future work will involve the development of automated data upload routines and mobile applications to allow the public to report a landslide.

USING X-RAY DIFFRACTION TO DETERMINE VOLCANIC ERUPTION STYLES ON EARTH AND MARS

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Explosive basaltic volcanism is common to both Earth and Mars. Phreatomagmatic eruptions and “magmatic” explosive eruptions, such as strombolian or plinian eruptions, have distinctive eruptive processes resulting in varied groundmass textures. Here we demonstrate that groundmass crystallinity determined by X-ray diffraction can distinguish broadly defined eruption styles. Crystallinity, determined from X-ray diffraction is advantageous because it 1) is a true measure of crystalline and amorphous components, 2) can be determined remotely, and 3) is measured rapidly on small volumes of material. Terrestrial results on end-member eruption styles suggest rapid quenching of phreatomagmatic volcanic products by ground/surface water results in lower groundmass crystallinity compared to air-cooled volcanic ejecta characteristic of strombolian or plinian eruptions. Based on numerical modelling of Martial plinian eruptions, the distinction between eruptive styles on Mars are reduced compared to Earth with only 20-30% syn-eruptive

crystallization. Applying the technique developed on terrestrial volcanics, the crystallinity of Martian sediments analysed from Gale Crater by the CheMin tool on the Mars Science Laboratory rover are consistent with a strombolian or plinian eruptive origin and may imply widespread dispersal of volcanic ejecta across the surface of Mars.

Preliminary results from the Auckland Volcanic Field, which demonstrate a "drying out" of volcanism, or a transition from phreatomagmatism to strombolian style eruptions, have minimal distinction in crystallinity between eruption styles. Juvenile magmatic clasts from early phreatomagmatic events have anomalously high groundmass crystallinities and may imply distinctive eruption dynamics prior to cooling or quenching of volcanic groundmass. Deep degassing may promote early groundmass nucleation and crystallization prior to rapid quenching, or ground/surface water may be insufficient to fully quench volcanic clasts, allowing further crystallization during slower air-cooling in volcanic systems experiencing "drying out".

EXTRAPOLATING SPATIO-TEMPORAL MODELS THROUGH TIME

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The field of probabilistic volcanic hazard analysis is rapidly expanding via the development of a range of statistical methods, many that include novel approaches to incorporate geological information. There is now a large number of potential methods available to the hazard modeller and thus, a large number of potential 'answers'. Model selection is dependent on the information required (model outputs), data availability (model inputs), any assumptions about the physics or chemistry of the volcanic behaviour, and the goodness of fit to the observed data. For volcanic fields, information as to the likely location(s) and timing(s) of future eruption(s) are frequently required for hazard and risk assessments. To obtain this information, a spatio-temporal model can be fitted to the locations and timings of previous eruptive activity and then extrapolated through time to the present or near future.

For model selection, a predictive density can be used to assess how well a model forecasts subsequent eruptions as it evolves through time, allowing some of the parameters of each model under consideration to vary as an eruption occurs, whilst keeping the baseline model constant. Here, we develop this idea and extrapolate three well-established spatio-temporal models far into the future via numerous simulations to assess whether the cumulative future behaviour of a volcanic system based on each model is geologically plausible or consistent with observations elsewhere.

GROSS DEPOSITIONAL ENVIRONMENT MAPS AND RISK ANALYSIS FROM THE MID CRETACEOUS TO PALEOCENE SECTION IN THE GREAT SOUTH BASIN

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The distribution of petroleum system elements, such as source, reservoir and seal rocks, provides key inputs to understand basin prospectivity. Gross Depositional Environment (GDE) maps typically include these elements. The main aim of this study is to develop a series of updated GDE and common risk segment (CRS) maps in the offshore Great South Basin for the mid Cretaceous to Paleocene section.

GDE maps are prepared based on the seismic character of reflection packages, isochron maps, lithology observed in wells, wireline logs, paleoenvironments, and biostratigraphic analysis. Source rocks identified in offshore wells in the basin are mainly marginal marine coals and coaly mudstones within the Cretaceous interval. In the syn-rift sequences these source rocks are distributed throughout the basin whereas in the post-rift sequences they are restricted to the western margin of the basin. Within the Paleocene section, Waipawa (Tartan) Formation shows high organic carbon contents with very good potential for petroleum generation (Schiøler et al., 2009). Waipawa Formation displays a high amplitude and highly continuous seismic reflector character and is widely distributed in the basin. Potential reservoir rocks occur in a wide range of depositional environments. Cretaceous reservoirs

are mainly fluvial, coastal, shoreface, and shelfal sandstones. In addition to the above reservoir play types, the Paleocene submarine fan complexes that are recognised from the seismic character can act as potential reservoirs. Seal rocks are mainly shelfal and deepwater mudstones. Shelfal mudstones are developed in the Late Cretaceous and Paleocene section whereas deepwater mudstones are typically developed in the Paleocene section.

These GDE maps provide the main inputs for preparing common risk segment (CRS) maps of source, reservoir, and seal rocks presence. These maps show areas of high, medium and low risk for each element, and are requisite in evaluating basin prospectivity and play fairway analysis.

A BRAVE NEW WORLD? THE USE OF COMPUTED TOMOGRAPHY IN VERTEBRATE PALEONTOLOGY

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Over the past 30 years, Computed tomography (CT) technology has progressed to reduce the scanning speed, to improve the imaging resolution, to simplify the overall operation, and to increase scanning resolution. Since the first fossil hominids were scanned in 1984 this technology has become increasingly common but only in the last 2-3 years, with increases in computing power and the availability of comparatively cheap imaging software, have palaeontologists taken control of the imaging themselves. Because of the destructive processes that occur during fossilization, vertebrate fossils are usually fragmented, distorted, and filled with heavily calcified matrix when they are unearthed from sediments. Traditional preparation involves physically separating the fossil from the surrounding matrix and then repairing the missing parts with plaster or silica. Mechanical preparation and reconstruction is a highly invasive and potentially destructive process that is often irreversible; it is also highly subjective and dependent upon the skills of the preparator. Virtual CT preparation is reversible, repeatable and can create files that allow 3D models to be produced for any future researcher anywhere else in the world. Here I will talk about the use of CT to undertake virtual fossil reconstruction, 3D modelling, preparation of virtual endocasts for comparative neuroanatomy, biomechanical analyses of bones and Finite Element Analysis (FEA), and skeletal and dental microanatomical research.

THE LITHOSPHERIC MANTLE BENEATH ZEALANDIA AND ITS ROLE IN HIMU-LIKE INTRAPLATE MAGMATISM

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There has been long debate on the asthenospheric versus lithospheric source for numerous intraplate basalts with ocean island basalt (OIB) and high time-integrated U/Pb (HIMU)-like source signatures that have erupted through the Zealandia continental crust for the last 90 Ma. Analysis of over 200 spinel facies peridotitic mantle xenoliths from localities across southern Zealandia permits the first comprehensive regional description of the sub-continental lithospheric mantle (SCLM) and insights into whether it could be a source to the intraplate basalts. Intraplate basalts have sampled refractory craton-like domains (West Otago, Westland, Chatham Islands) and moderately fertile domains (East Otago, North Otago, Auckland Islands). Most domains have an early history decoupled from the overlying continental crust, and each domain has undergone varying degrees of depletion followed by re-enrichment. Clinopyroxene grains reveal trace element characteristics (low Ti/Eu, high Th/U, high LREE) consistent with enrichment through reaction with carbonatite. This metasomatic overprint has a composition that closely matches the HIMU mantle reservoir in terms of Sr, Pb and Nd isotopes [1,2]. Clinopyroxene Hf isotopes in most samples are more radiogenic than the intraplate basalts. However, new Hf isotope analyses of the most highly depleted and strongly metasomatised samples overlap with those of the intraplate basalts. Batch melting models of highly depleted spinel facies peridotite enriched by carbonatite

can generate LREE-enriched melts with trace element profiles very similar to ocean island basalt. The melting models do not require residual garnet to generate the high LREE to low HREE patterns observed in the Zealandia and other worldwide intraplate basalts. This would challenge the current paradigm that attributes the intraplate magmatism to an asthenospheric source.

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[2] Scott et al. (2014b) Geochem. Geophys. Geosyst 15.

POLYGONAL FAULT SYSTEMS AND THEIR POTENTIAL IMPACT ON SEAL INTEGRITY

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Polygonal fault systems (PFSs) are networks of non-tectonic normal faults that form in hemipelagic sediments. They have been identified in many sedimentary basins worldwide [1], including Tertiary strata of the Taranaki, Northland, Great South and Canterbury basins in New Zealand. In seismic section polygonal faults form layer-bound arrays that extend vertically for 100s of metres and accommodate small (< 100 m) normal displacements. Many PFSs are tiered in cross section and comprise segmented fault arrays that increase in degree of linkage, length and displacement with depth. Fault maps constructed using 3D seismic reflection data reveal polygonal cells with maximum dimensions of several kilometres, which are defined by faults with no preferred strike or dip direction and many high-angle fault intersections or triple junctions. These fault geometries are generally considered to develop in association with the dewatering and compaction of mudstones. On individual stratigraphic horizons fault displacement patterns and cross-cutting field relations indicate that faults forming high-angle intersections slip simultaneously with no dominant extension direction. Systematic up-dip displacement variations in PFSs are similar to those of tectonic faults and suggest that fault segments in different tiers develop synchronously as kinematically coherent arrays. Polygonal faults form slowly over timescales of millions to tens of millions of years and have the potential to act as fluid conduits that impact seal integrity in New Zealand petroleum systems. Bulk permeability of PFSs is believed to increase with depth and to be highest at fault triple junctions, where the tendency for dilation is greatest and, in some systems, there is evidence for enhanced vertical fluid flow.

[1] Cartwright (2011). Marine and Petroleum Geology 28, 1593-1610.

MILANKOVITCH IN MUD: TESTING THE INFLUENCE OF ORBITAL FORCING ON GLOBAL SEA-LEVEL CHANGE USING A LATE PLIOCENE MARINE SEDIMENTARY RECORD FROM THE WANGANUI BASIN, NEW ZEALAND

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Milankovitch Theory directly links the waxing and waning of ice sheets to orbitally-forced insolation changes and suggests that variance in precession (23 kyr) and obliquity (41 kyr) cycles should drive ice volume changes. However, the globally-integrated record of marine oxygen isotopes ($\delta^{18}O$) during the Late Pliocene (3-2.6 Ma) consists of obliquity dominated signals, with an absence of precession. Continuous, high resolution records can help assess whether ice sheets in the Late Pliocene responded to precession, obliquity or both.

Shallow-marine sediment records are independent of the $\delta^{18}O$ record, and enable us to reconstruct the frequency of Late Pliocene glacial-interglacial variability via its effect on global sea-level recorded as cyclical water depth changes. The Wanganui Basin, New Zealand, contains a high-resolution and well-dated Neogene shallow-marine sedimentary succession. Consequently, this basin is the perfect location to examine sea-level/ice-volume change. We aim to evaluate the frequency and magnitude of Late Pliocene sea-level changes in the Mangaweka Mudstone (~3-2.5 Ma), where it is exposed between the Turakina

and Rangitikei Rivers. This will be achieved through an integrated analysis of sediment grain size, a quantitative census of benthic foraminifera (both proxies for paleo-water depth) and oxygen isotopes (a proxy for ice volume).

Preliminary results show zircon fission track ages of tephra at 2.9±0.3 Ma, and the Gauss-Matuyama paleomagnetic reversal at 2.58 Ma, which form the basis of an age model. Correlation of tephra geochemistry and paleomagnetic data within a regionally-established chronostratigraphic framework will place this record within the context of other records such as ODP 1123. It is anticipated that water-depth changes corresponding to 23 kyr, 41 kyr and/or 100 kyr orbital drivers of global ice volume will be resolved in the Late Pliocene record and will provide insights into whether northern and southern hemisphere ice sheet responses to Milankovitch cycles are anti-phased, synchronous or both.

TSUNAMI RESEARCH AT THE UNIVERSITY OF AUCKLAND

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The University of Auckland (UoA) is actively involved in research associated with tsunami impacts on inland-structures. The research effort is directed towards improving knowledge about design of tsunami resilient structures. The hydraulic laboratory at the UoA is fully equipped to conduct experimental studies on the impact of a tsunami bore on structures, accompanying scouring around the structures, and impact of tsunami-borne debris. The experiments are carried out in a 14m long, 1.2m wide and 0.8m deep large wave flume; the flume is connected to an 11m long, 7.3m wide and 0.6m deep reservoir with an automatic gate across the full flume width. The gate consists of a sliding gate and a shutter gate, allowing rapid release of water into the flume to generate the tsunami bore.

Experiments have been successfully conducted to investigate the fully-developed bore impact on a square prism structure (SPS) and a cylindrical structure (CS). The objectives were to investigate (a) the vertical pressure distribution and the forces on the SPS for different orientations to the flow and (b) the vertical and angular pressure distributions and the forces on the CS. The Influence of structure flexibility was investigated using four different types of the SPSs. Scouring around the SPS and the CS was observed for different bore heights and velocities, using two high-definition video cameras positioned inside the structures. Also, the impact of the tsunami bore on elevated structures was observed using the SPS, at elevations of 50mm, 70mm and 90mm above the flume floor. In addition to the bore impact on structures, the collision forces associated with tsunami-borne debris impact were investigated using a new measurement technique, utilising a smart debris device. The smart debris device is an object with an attached impact accelerometer, allowing direct measurement of the impact acceleration and subsequently impact force.

3D INVERSION OF SHEAR WAVE SPLITTING FOR MODELLING ANISOTROPY IN CANTERBURY

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In order to understand the distribution and possible cause of elastic anisotropy (expressed as a directional seismic velocity dependence) in the crust, we have developed an inversion method that produces 3D anisotropic models using shear wave splitting data. The method iteratively employs a linearised least squares inversion technique, solving for the magnitude and orientation of anisotropy for each element of a three-dimensional model grid (where data is available). Love parameters and available velocity models are used to define an anisotropic elastic regime for each model elements, however any appropriate formulation of the elastic tensor can be applied. We apply this method to a shear-wave splitting dataset of events from the aftershock sequence of the 2011 M_w 7.1 Darfield Earthquake. The dataset covers a broad volume of the Canterbury region encompassing the Greendale fault group. We compare results from a number of different starting models including an average starting model that takes into account ray propagation direction, a uniform starting model that represents regional maximum compressive stress, and a model that uses previous calculated 2D delay time tomography results as an input. Our

results show a broad lateral heterogeneity in anisotropy for the region with areas of anisotropy that are orientated sub-parallel to the regional stress direction, indicating that the anisotropy is generally stress controlled. Other areas show anisotropy orientations that are rotated E-W which may be attributed to fault controlled anisotropy.

THE IMPACT OF GLOBAL WARMING ON CALCAREOUS NANNOFOSSILS: AN EOCENE CASE STUDY FROM CANTERBURY BASIN, NEW ZEALAND

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The impact of global warming on the oceans is an important issue for a maritime nation like New Zealand. Changes in ocean temperature and circulation will affect nutrient availability, food changes and the composition of the marine biota. Coccolithophores (calcareous nannoplankton) are important primary producers in the ocean that play a fundamental role in the global carbon cycle. Recent modelling studies predict that under warmer climates, ocean waters will become more stratified, leading to a reduction in nutrients in the eutrophic zone. Under this scenario coccolithophores become more abundant than diatoms, resulting in a reduced efficiency of the biological pump and possible positive feedbacks in the carbon cycle [1, 2]. It is therefore important to verify these modelling studies by examining how climate change affects the productivity and assemblage composition of coccolithophores.

One of the ways that this can be achieved is to study global warming events that occurred during the geological past. Our study examines calcareous nannofossil assemblages from two Canterbury Basin sections spanning early to middle Eocene. Of particular interest during this interval is the Early Eocene Climatic Optimum (EECO, ~50 Ma), a warming event where global temperatures increased by almost 5°C above background. Geochemical proxies for sea surface temperature (SST) have been used to identify the EECO in the mid-Waipara and Hampden sections [3]. We examine how calcareous nannofossil assemblages change across the EECO, both in comparison with SST and with dinoflagellate cyst assemblages, and we discuss how this event affected composition of marine plankton communities and marine productivity in Canterbury Basin.

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[3] Hollis et al., (2012) Earth and Planetary Science Letters 349-350, 53-66.

SEISMIC DATA ANALYSIS ON WAYS TO MONITOR ROCK-CO_2 REACTIONS AND FLUID SUBSTITUTION IN SANDSTONES, POHOKURA FIELD, NEW ZEALAND

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In recent years, geosequestration of anthropogenic carbon dioxide (CO_2) into a depleting oil reservoir, has become an increasingly popular process to store CO_2 waste without leakage for at least 1000 years. Geophysical seismic methods are used to monitor subsurface variations in fluid pressure and saturation when CO_2 is injected in a reservoir, as seismic wave velocities are highly sensitive to these changes. However, in the presence of CO_2-water mixtures (carbonic acid), besides saturations and pressures change, the rock microstructure also alters due to rock-fluid reactions such as the dissolution of carbonate minerals caused by carbonic acid. In this study, we first look at the effect of fluid substitution of water for CO_2 alone has on wave speed. Secondly, we study how the sandstone's carbonate cement dissolution changes the seismic velocities. As both fluid substitution and dissolution of carbonate cement decrease wave velocities, due to fluid compressibility and rock microstructure differences respectively, our goal is to quantify these geophysical changes independently and combined. Up to now, how rock-fluid reactions affect wave velocities and the feasibility to monitor these with time-lapse seismic interpretations is still unknown.

The Pohokura Gas-Condensate Field in New Zealand is selected because the Mangahewa formation sandstones have a variable range of carbonate cement from less than 1% to up to 30%. Porosities range from 2 % to 12 % (with an average of 9%). We plan to use the suite of sonic logs, XRD data and petrophysical analysis available at Pohokura Field for detailed characterization of the reservoir rocks, where resulting rock physics models can be used to generate 1D synthetic seismogram and reflection coefficient models (AVO), in order to help better understand the effects on the seismic signatures in the Pohokura Field when it is subjected to a CO_2 sequestration scenario.

GLACIAL RAINFALL RECONSTRUCTION USING TROPICAL SOUTH PACIFIC SPELEOTHEMS

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The South Pacific Convergence Zone (SPCZ) is the largest component of the Intertropical Convergence Zone (ITCZ), and its impact on global climate rivals that of the deep convection at the heart of the Western Pacific Warm Pool. Rapid glacial climate fluctuations, such as Dansgaard-Oeschger (D-O) Events, would have triggered a reorganization of tropical systems such as the SPCZ, manifesting as significantly altered rainfall across the tropical south Pacific. However, a critical lack of high-resolution glacial records from this region means the dynamics of the SPCZ are largely unknown.

Recently, speleothems have proven to be effective recorders of tropical hydroclimate over the last several hundred thousand years. Stable oxygen isotopes ($\delta^{18}O$) and trace elements (Mg, Sr) respond to changing rainfall, while modern high-precision mass spectrometers allow U/Th dating of speleothem calcite to an unprecedented precision. Speleothems are therefore ideal archives for studying glacial changes to atmospheric circulation systems such as the SPCZ.

In this poster, I present details of, and preliminary results from, an ongoing NSF/VUW funded research programme aimed at studying the glacial dynamics of the SPCZ using speleothems collected from the islands of Niue and Tonga.

USING PALEOECOLOGICAL PROXIES TO DETERMINE HOLOCENE ENVIRONMENTAL CHANGES: A CASE STUDY AT ONAERO BEACH, NORTH TARANAKI

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A multi-proxy paleoecological and sedimentological record for the Holocene is extracted from a 2.5m coastal seacliff located at Onaero Beach, North Taranaki and used to infer changes in shoreline and coastal conditions. The tectonic, and especially postglacial, history of the North Taranaki coast is reviewed followed by analysis of diatom and pollen populations, particle size, and loss on ignition. Paleoecological and sedimentological data will be tied to a chronology determined through radiocarbon ages and tephrochronology. A number of key tephras have already been identified, tying the Onaero Beach seacliff to the Holocene. Key objectives of this study are: (1) To characterize changes in the relative position of the shoreline at Onaero Beach during the Holocene and, (2) Analyse results in the context of eustatic sea level change and the tectonic history of North Taranaki. Carbonaceous sediments abundant in pollen record early Holocene vegetation changes after which a transition into estuarine muds, abundant in diatoms, around the mid-Holocene shows small changes between predominantly fresh and brackish water environments.

GEOCHEMICAL VARIATIONS IN GLAUCONITIC MINERALS: APPLICATIONS AS A POTASSIUM FERTILISER RESOURCE

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Glauconitic clays display significant variation in geochemical signatures, both structurally and in terms of their elemental proportions. The maturity of the green marine minerals is

influenced primarily by seafloor residence time, the parent materials' physical properties and local chemical conditions on the seafloor. Here we use spatially resolved geochemical techniques including LA-ICP-MS and SEM with EDS to assess the geochemical variation of glauconite in three field areas: the Oamaru Basin; the Mid-Waipara section, North Canterbury; and the Oparara Quarry, Karamea. Potassium contents are consistently high, representing evolved to highly evolved glauconite. Significant variations in trace elements exist between deposits and this appears to be related to the genetics of the proximal continental rocks. Concentrations of chromium, a known carcinogen, are consistently high in all deposits (average 270 ppm). We also measured the dissolution kinetics of glauconite in water using ICP-MS. Potassium is released from glauconite, however the low concentrations in solution and the potential to contaminate soil through the addition of toxic trace elements raises questions regarding the application of glauconite as a standalone fertiliser resource.

THE LITHOSPHERE-ASTHENOSPHERE BOUNDARY (THE LAB): WHY IT'S IMPORTANT, AND IMAGING IT BENEATH NZ WITH SEISMIC METHODS

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The LAB is the most pervasive, and arguably the most important, boundary within the Earth. It separates the elastic crust and the cooled upper mantle lid (together called the lithosphere) from the more viscous and weaker asthenosphere below. Typically the LAB is at a depth of ~ 100 km in the old oceans but can be as deep as 300 km beneath continental cratons. The LAB is important because mechanical changes that occur across the boundary dictate how mountains become elevated, how the earth rebounds after melting of ice caps and how and when sea levels change through time. But perhaps the most important role of the LAB is to facilitate plate tectonics by forming a low stress base to the tectonic plates.

A serendipitous outcome from the SAHKE active-source seismic experiment across the lower North Island was the recording of very deep reflections from the LAB. Here we deployed 887 seismographs along a 85 km-long line from coast to coast. 12 x 500 kg dynamite shots were used as seismic sources. Although the main aim was imaging the subduction zone interface at about 7-10 seconds (25 km-deep), reflections between 25–35s (95-120 km-deep) were also recorded. These deeper reflections define a ~ 10 km-thick channel that dips parallel to the top of the plate (i.e. ~ 12-15 degrees to west) and at a depth of 95-105 km. We interpret this channel as a low-viscosity, low-seismic-velocity channel created by the ponding, then strain localisation, of melt and/ or volatiles.

CONSTRUCTION OF SURTSEYAN VOLCANOES AT CAPE YOUNG AND MAUNGANUI BLUFF, NORTHERN CHATHAM ISLAND

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Chatham Island is a rare subaerial part of Zealandia 700 km to the east of New Zealand and has been the locus of basaltic intraplate volcanism. Three major episodes of volcanism identified are a late Cretaceous (81-70 Ma) shield volcano, late Eocene (41-36 Ma) Southern Volcanics, Red Bluff Tuff and Northern Volcanics, and Miocene – Pliocene (4 - 5 Ma) Rangitihi Volcanics and Rangiauria Breccia. We have recently completed a radiometric dating field campaign in the northern part of Chatham Island which included two volcanic "centres", Cape Young and Maunganui Bluff. The objective was to examine the age relationships and preservation of these volcanic edifices.

Cape Young comprises proximal to distal, pumiceous, eruption-fed stratified pyroclastic density current deposits, suspension-deposited pyroclastic falls and minor syn-eruptive remobilised pyroclastic sediments deposited in a

relatively shallow marine environment. K-Ar dates from basaltic clasts in the Cape Young pyroclastics are c. 40 Ma, placing them within the Northern Volcanics. Some dykes cutting the pyroclastics of similar age probably represent feeders to the source volcanoes while others are much younger at c. 4Ma. Cape Young is preserved as a result of the presence of numerous dykes rather than edifice structure and this appears to be true for a number of other volcanic-derived topographic features as well.

Maunganui Bluff comprises c. 4 Ma basal pillow lavas on shallow marine carbonates, succeeded by palagonitised kaesutite-bearing volcaniclastics and capped by air-fall lapilli tuffs, suggesting that Maunganui Bluff was emergent in its latter stages.

The facies architecture at both localities indicates shallow subaqueous explosive and effusive eruptions, confirming that the region was mostly submarine in Miocene – Pliocene time. The 4 Ma eruptives, however, indicate that low tuff cones emerged above the sea level to form archipelagos of ephemeral volcanic islands a few tens of metres high in a shallow marine environment.

GLOBAL OCEAN ANOXIA DURING ANCIENT 'GREENHOUSE' CLIMATES: CONSTRAINTS FROM METAL STABLE ISOTOPES

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Ocean oxygenation is crucial to marine life and, via a link with the carbon cycle, is a key regulator of climate. During the warm "super-greenhouse" world of the Mesozoic, between ~250 and ~65 million years ago, the oceans underwent repeated episodes of expanded anoxia, in which vast regions were devoid of oxygen. These so-called 'oceanic anoxic events' (OAEs) were closely linked to the rapid influx of CO_2 into the atmosphere, which in turn drove abrupt global warming, increased weathering and supply of oceanic nutrients, enhanced plankton productivity, and stagnation in restricted ocean basins. One or more of these factors led to anoxia and ultimately euxinia, the build-up of toxic H_2S in the oceans. OAEs, recorded by seafloor sediments, strongly perturbed Earth's climate and ecosystems. However, the exact mechanisms driving OAEs remain uncertain because the evolution of the oceans during these events from oxic to anoxic and ultimately euxinic is poorly constrained.

Our research uses a suite of new palaeo-redox tracers, based on the uranium (U), molybdenum (Mo), chromium (Cr) and iron (Fe) isotope signatures of seafloor sediments, to reconstruct the timing, duration and extent of anoxia across known anoxic events of the Mesozoic Ocean. Our research will also quantify the degree to which oxygen depletion extended from the deep ocean into the shallow photic zone, which currently remains uncertain. Using high-resolution records from palaeogeographically widely separated regions, we will aim to constrain the mechanisms leading to extreme oxygen deprivation in the oceans. This, in turn, will provide information that will have a direct bearing on assessing future climate-change impacts, particularly given the rapid expansion of anoxic 'dead zones' in the modern oceans that has occurred in recent decades.

DEVELOPMENT OF MAGNITUDE-FREQUENCY DISTRIBUTIONS FOR ACTIVE FAULTS IN NEW ZEALAND

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Development of the next generation of national probabilistic seismic hazard model for New Zealand is taking place within the "Rethinking PSHA" MBIE-funded project. Initial efforts are being focused on developing new seismic source models, evaluating ground motion prediction equations for application in New Zealand, and updating the software platform for the national seismic hazard model. An important consideration in the development of fault source models is the assumed shape of the magnitude-frequency distribution for the fault sources. A long standing debate in the seismological community surrounds

the question of whether the Gutenberg-Richter relationship or Characteristic Earthquake model best describes the shape of the magnitude-frequency distribution for the faults. The Gutenberg-Richter relationship assumes a log-linear distribution of magnitude and frequency, whereas the Characteristic Earthquake model assumes a very narrow range of magnitudes and frequencies near a maximum magnitude that is estimated from the physical dimensions of the fault. A hybrid Gutenberg-Richter/Characteristic magnitude-frequency distribution has also been proposed (the "Youngs & Coppersmith" distribution). Our initial work on resolving this issue within the "'Rethinking PSHA" project is to develop seismic moment-balanced magnitude-frequency distributions for these three models, and then evaluate them on the basis of: (1) assessing how many earthquakes should have been observed in the historical period if the magnitude-frequency distribution was correct, and; (2) comparison of the predicted frequency of the largest events to the available paleoseismic data. Issues such as non-stationarity of earthquakes, and uncertainties in event completeness and magnitude are being carefully considered in the evaluation process.

RIFT TO DRIFT ON THE EDGE OF GONDWANA: CRETACEOUS–EOCENE PALEOGEOGRAPHIC EVOLUTION OF THE TARANAKI BASIN, NEW ZEALAND

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The Taranaki Basin, located predominantly offshore of western North Island, has had a complex geological history. A regional reassessment of the evolution of the Taranaki Basin and surrounding areas, with a focus on the regional geodynamic implications, is presented in the form of 14 paleogeographic maps spanning the mid-Cretaceous to Late Eocene that synthesise paleobathymetric and paleofacies data. Three main phases of basin evolution are recognised through the Cretaceous–Eocene:

(1) An early rift phase, of 'mid' to early Late Cretaceous age (c. 100–85 Ma), affecting mainly Deepwater Taranaki, and possibly northern parts of the proximal Taranaki Basin. This phase, with approximately NE–SW-orientated extension, was related to Tasman Sea rifting, and ceased roughly coincident with the onset of seafloor spreading, which focused extension in the Tasman Sea. The orientation and timing of this extensional event is comparable to that observed in the West Coast and Great South-Canterbury basins, consistent with suggestions that this was a New Zealand-wide tectonic event associated with Gondwana breakup.

(2) A later, Late Cretaceous–Paleocene rift phase (c. 80–55 Ma), with E–W to NW–SE-oriented extension, affected only proximal, especially southern, parts of the Taranaki Basin. This rift phase, also observed in the basins of the West Coast and Western Southland, was mainly confined to western New Zealand and did not affect more distal areas, such as Deepwater Taranaki. This second phase of minor extension (<10%) led to the formation of a failed rift arm associated with seafloor spreading in the area between the Ross Sea and Zealandia.

(3) The second rift phase was followed by passive thermal subsidence through much of the Eocene (c. 55–40 Ma), which formed part of a New Zealand-wide marine transgression. Subsidence and transgression ceased in the Early Miocene with the onset of rapid plate convergence.

A NATIONAL TEPHRA GEOCHEMISTRY ONLINE DATA SET FOR NEW ZEALAND

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PETLAB is New Zealand's national rock and geoanalytical database, and contains the locations and descriptions of over 191,000 rock and mineral samples collected from on- and off-shore New Zealand and worldwide. More than 50,000 of these samples have geochemical, geophysical and/or other analytical data. The PETLAB database provides a number of powerful tools, including the ability to customize search queries to specific research problems, and as such, is a valuable research tool across all avenues of earth science.

Tephrochronology plays an important role in many earth science disciplines, where volcanic ash layers are used to provide correlation and age control between sites. In 2012 the PETLAB team augmented the PETLAB database with the addition of a national tephra geoanalytical data set, compiled primarily from old and new published journal articles and unpublished university theses. Stage one of the tephra data entry is in progress and consists of entering geochemical analyses (modal analyses and mean major and trace element analyses of tephra glass and silicate minerals), and allows users to search tephra which match particular geochemical criteria. Furthermore, the name of the tephra horizon/eruptive episode is also listed where it is known (i.e. the regionally extensive Kaharoa Ash). Stage two will involve entering chronological data (i.e. the published accepted age for the tephra horizon or radiometric ages).

The reasons for adding the tephra data set are many and varied, and include a) complementing the soon-to-be completed geology map of Tongariro National Park; b) recovering value from old analyses by entering decades of unpublished university thesis data into one online database; and c) providing a source of readily accessible, pre-compiled data for studies using tephra marker horizons. Potential applications of the tephra geochemistry data set housed within PETLAB include quaternary geology, climate change, paleolimnology, archaeology, and paleoseismology studies.

ARSENATE AND SILICATE INTERACTIONS ON IRON OXIDE SURFACES: A DANSE MACABRE

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Iron oxides are important solid phases influencing the distribution of trace elements in aquatic systems. In particular sorption onto the surfaces of iron oxide particles is the principal process controlling arsenic in drinking water. Other sorbing ligands, in particular phosphate and silicate, can compete for these surfaces causing elevated solution arsenic concentrations. In this study we probe these interesting and important competitive surface reactions using *in situ* infrared spectroscopy to provide valuable insights into factors impacting public health. A significant feature of these systems is that silicate adsorbed on oxide surfaces can be disposed towards condensation reactions if adjacent sorbed monomers are orientated to allow insertion of a solution H_4SiO_4 to bridge the sorbed monomers and to form a linear trimeric silicate. This study has determined how the presence of non-polymerizing ligands, such as arsenate, on the iron oxide surface influences the propensity of the system towards silicate polymerization. From simple stochastic arguments we had anticipated that sorbed arsenate would inhibit silicate polymerization by blocking polymerization options for monomeric sorbed silicate. Unfortunately *in situ* infrared spectroscopy indicated that the stochastic processes were not simple and the presence of sorbed arsenate promoted silicate polymerization. This implies a much more dynamic approach to equilibrium which includes a spectrum of silicate polymerization probabilities with arsenate "pushing" silicate towards sites with higher polymerization probabilities.

THE DISTANT INLAND NAGANO EARTHQUAKE (M6.7) FOLLOWING THE 2011 TOHOKU-OKI EARTHQUAKE

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On 12 March 2011, an inland earthquake (M6.7) occurred 13 hours after the 2011 Tohoku-Oki earthquake (Mw9.0). The hypocentre was about 400 km far from the Tohoku-Oki one, and located in a high-strain-rate and high-seismicity area, called the HIZUMI zone. Reverse faulting was expected to be suppressed due to extensive tension following the Tohoku-Oki earthquake; however the focal mechanism showed a reverse fault type. Therefore the relationship between the inland earthquake and the Tohoku-Oki megathrust event is not well known.

We used data of the dense seismograph network that had been temporarily deployed in the Nagano region before the Tohoku-Oki earthquake as part

of the HIZUMI project sponsored by a Japanese ministry, MEXT, and finally obtained the detailed hypocentral distribution and the velocity structure in and around the source area. The obtained velocity model shows different velocities in the NE and SW areas, and also reveals the existence of a high Vp/Vs ratio structure below the inland hypocentre.

Based on the above results, we propose a schematic source fault model. This model contains two crustal blocks of the NE and the SW parts. The NE block includes the SE dipping mainshock fault, while the SW block has another fault. The high Vp/Vs ratio structure below the mainshock hypocentre involves fluid existence. Therefore the inland earthquake may have been triggered by a pore pressure increase due to high-amplitude surface waves generated by the Tohoku-Oki earthquake. Analysis of inland seismicity that occurred in the Nagano region just after the Tohoku-Oki earthquake, suggests the inland earthquake might have been delay-triggered by fluid migration from the deep source.

NEW ZEALAND OLIGOCENE DOLPHINS REVEAL THE EARLY HISTORY OF THE GANGES RIVER DOLPHIN GROUP (PLATANISTOIDEA)

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New Zealand's record of Oligocene marine dolphins, especially from the Waitaki region, is outstanding for temperate regions of the Southern Hemisphere. Important early finds involved Walter Mantell in 1848, who recovered *Phocaenopsis mantelli*, named by Huxley, and Alexander McKay in 1881, who collected a skull from the Otekaike Limestone, described as *Microcetus hectori* by Benham. More-recently named key species based on skulls include *"Notocetus"* [now *Otekaikea*] *marplesi*, *Waipatia maerewhenua*, and *Papahu taitapu*. Tanaka's PhD project has reviewed *M hectori*, *O marplesi*, *W maerewhenua*, and new species based on OU 22306 (*Otekaikea*), OU 22125 (cf. *Waipatia*) and others from the Waitaki region. Morphological cladistic analyses are used to establish phylogeny. Most of the Waitaki fossil dolphins represent basal species of the once-diverse and now nearly extinct clade Platanistoidea, which includes the endangered living Ganges River dolphin. Cladistic studies confirm that *Notocetus* and the Squalodelphinidae are not present in New Zealand. Other undescribed and unnamed dolphins from the Otekaike Limestone include at least 4 species, some with exceptional skeletal preservation, plus 1 species from the Kokoamu Greensand. These animals lived in the extensive shelf seas of later Oligocene Zealandia, along with baleen whales (including *Mauicetus* and eomysticetids), penguins, billfish, and a diverse assemblage of invertebrates.

A NEW SPECIES OF PLIOCENE SHEARWATER (AVES: PROCELLARIIDAE) FROM TARANAKI

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A Pliocene (Waipipian) bird fossil from Taranaki, New Zealand, represents a new species of seabird. It is a well-preserved partial skeleton representing the main wing elements and some legs elements. In structure these bones most closely resemble those of a shearwater (Procellariiformes: Procellariidae) but it is distinguished from all known living and extinct taxa by a combination of unique features. It was a gliding species as large as the largest species of living shearwater. It represents the first pre-Pleistocene record of a new shearwater taxon from the Western Pacific and helps reveal the history of shearwater evolution worldwide. Today New Zealand has the greatest diversity of breeding shearwater species in the world and the new fossil adds weight to other evidence that shearwaters have a long history in this region.

THE GLEN MURRAY PENGUIN, AN OLIGOCENE GIANT FROM THE NORTH ISLAND

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Paleogene tetrapods are rare discoveries in the North Island of New Zealand. A particularly

significant addition to our knowledge of the ancient biota was made in 1971, when hindlimb bones from a large Oligocene penguin were collected from a Waikato farm near Glen Murray. The ancient marine bird was described by J.A. Grant-Mackie and G.G. Simpson in 1973, but with comparatively few fossil penguins known, the Glen Murray specimen was considered 'unidentifiable as to genus or species'. Subsequent fossil penguin discoveries from across the Gondwanic fragments have generated renewed interest in the taxonomy of the Glen Murray penguin. From a more complete understanding of New Zealand stem penguin taxonomy we may gain insight into giant penguin biogeography. Several broadly contemporaneous Paleogene penguins are now known from both the North and South Islands of New Zealand, presenting an interesting biogeographic question for the Glen Murray penguin: was this rare Paleogene tetrapod a member of a Zealandian radiation? Alternatively, was the Glen Murray penguin instead recruited into the Paleogene avifauna from elsewhere? Here we present phylogenetic data from the Glen Murray penguin and discuss the specimen in a Zealandian context.

EFFECTS OF HIKURANGI PLATEAU SUBDUCTION ON KERMADEC ARC VOLCANISM AND ELEMENT TRANSFER

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The impact of large igneous province subduction on arc volcanism has rarely been studied. Subduction of the Cretaceous oceanic Hikurangi Plateau beneath the southern Kermadec arc and the North Island of New Zealand provides a modern example of this phenomenon. The southern Kermadec arc has the highest magma flux and the highest volcano density of the entire Kermadec arc. Furthermore, Kermadec arc lavas south of *c.* 32˚S have high Pb and Sr and low Nd isotope ratios. Combined with changes in seafloor morphology and a positive Bouguer gravity anomaly (consistent with crustal thinning), this suggests initial Hikurangi Plateau – Kermadec arc collision *c.* 250 km north of the Hikurangi Plateau's present position. Oblique plate convergence caused southward migration of the thick and buoyant large igneous province crust, which is likely to create an H_2O-rich, buoyant 'Hikurangi' mélange by tectonic erosion underplated beneath the arc crust (near the Moho) that interacts with ascending arc melts. The combined dataset further indicates that a much larger portion of the Hikurangi Plateau (the missing Ontong Java-Nui piece) than previously believed has already been subducted.

Located above the subducting Hikurangi Plateau, the two submarine volcanic centres Rumble II East and Rumble II West form a *c.* 22 km arc - backarc transect across the southern Kermadec arc. Although just *c.* 13 km apart, volcanic rocks from these two volcanic centres show fundamentally different geochemical compositions, posing the question whether these differences may be related to Plateau subduction. Whereas low $^{206}Pb/^{204}Pb$ (< 18.75) and high $^{143}Nd/^{144}Nd$ isotope values (> 0.51302) in Rumble II West lavas do not require input from a geochemically enriched source, some Rumble II East lavas show high $^{206}Pb/^{204}Pb$ (> 18.8) and low $^{143}Nd/^{144}Nd$ (< 0.51298), consistent with input from a geochemically enriched source, such as the Hikurangi Plateau and its associated seamounts.

RECONSTRUCTION OF THE LARGEST ERUPTIONS OF MT. TARANAKI FROM PROXIMAL RECORDS: LITHOFACIES AND ERUPTIVE SCENARIOS

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The ca.150 ka Mt. Taranaki is an excellent example of an andesitic stratovolcano producing lava flows, domes, and explosive eruptions. In order to reconstruct the largest eruptions through to the Plinian range, spanning the last 5,000 yrs BP, a lithofacies stratigraphy of proximal pyroclastic deposits within multiphase eruption periods was developed. Proximal deposits comprise the most complete eruptive sequences at Mt. Taranaki, including onset-phases and the intervening low-level activity between the deadliest explosive bursts.

Our detailed proximal stratigraphy suggests three plinian to sub-plinian eruptive scenarios at Mt. Taranaki: 1) pumice-rich, steady sustained convective columns, preceded by thin ash fallouts and/or pyroclastic density currents (PDCs), and ending with a gradual energy decrease (massive to normal graded fallouts); 2) pumice- or lithic-rich, unsteady sustained columns (strongly stratified fallout deposits), in some cases interrupted by PDC-forming partial collapses, and preceded and followed by thin ash fallouts and debris flows; and 3) pumice-rich, steady sustained columns (massive fallouts), following violent blast-type PDCs and explosively decompressing lava domes. The largest eruptions of Mt. Taranaki are similar to some of the most explosive phases of the eruptions of Kelut in 2014 and 1990, Merapi in 2010, Mt. St. Helens in 1980, and Vesuvius in 79 AD and 1631 AD.

NEW ERUPTIVE EPISODES AND HAZARD FINDINGS REVEALED FROM DISTAL MASS-FLOW DEPOSITS AT RUAPEHU VOLCANO, NEW ZEALAND

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Flank failures of stratovolcanoes generate debris avalanches that pose a great risk to inhabited areas, and may permanently reshape the landscape. We examined the distal sedimentology, geochemistry, and petrology of six individual large debris-avalanche deposits and a debris-flow deposit that are exposed along seven major rivers catchments currently or previously sourced from Mount Ruapehu. The debris avalanches inundated an area of > 1200 km^2, and have volumes between 1.35 km^3 and 3 km^3. Andesitic lavas within the deposits were geochemically correlated with dated lavas exposed on the cone, and indicate that the landslides occurred between 90 to 250 ka. Trace element compositions of the debris-flow deposit hint that the volcanic edifice is ≥ 340 ka old and is underlain by a hornblende-bearing gabbroic layer at *c.* 40 km depth. Another hitherto unknown eruptive episode related to an initial intrusion event, which triggered a large flank collapse, occurred at c. 90 ka. Channelization of all mass flows within the steep river catchments resulted in extremely long run-outs up to 90 km from source. The corresponding deposits reveal "dry" debris-avalanche features, e.g., jig-saw jointing and hummock formation, alongside "fluid-like" properties, e.g., dish structures and strongly sheared rip-up clasts. Incorporation of saturated river gravel and volcaniclastics en route potentially added vast amounts of interstitial fluids, which formed a highly mobile basal zone, and increased the mobility of the flows by up to 2.5 times compared to unconfined avalanches.

ORIGIN OF THE PETER PAN WHALE, *CAPEREA MARGINATA* (CETACEA: MYSTICETI)

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'Descent with modification' has been the essence of evolution since Darwin. Ideally, an understanding of biological evolution would be based on ancestor-descendant relationships (ADR) revealed by the fossil record. ADR is difficult to recognise for groups with a sparse fossil record, but may be addressed using phylogenetic methods. An example here involves fossil and modern pygmy right whales.

We assessed the relationship between the relatively complete fossil pygmy right whale, *Miocaperea pulchra* (7-8 Ma, Miocene, Peru) and its sole living relative, the modern pygmy right whale, *Caperea marginata* (Southern Ocean). Two published matrices were used to include juvenile and adult *Caperea marginata* as separate OTUs (in

total 25 and 46 taxa), involving 166 and 246 morphological characters respectively, analysed using TNT (Tree analysis using New Technology). Results show *Miocaperea* as phylogenetically bracketed between juvenile and adult *Caperea*. No autapomorphy (unique derived character) occurred solely in *Miocaperea* to preclude *Miocaperea* as the direct ancestor to *Caperea*. We thus interpret the *Miocaperea-Caperea* relationship as an ancestor-descendant relationship – the first so far identified within baleen whales (Cetacea: Mysticeti).

Caperea marginata differs from other baleen whales in having similar skull shape throughout ontogeny, consistent with the idea of 'Peter Pan' - not growing up in terms of morphology. The similar skull morphology throughout ontogeny in *Caperea*, with *Miocaperea* phylogenetically bracketed between juvenile and adult *Caperea*, suggests that the *Miocaperea-Caperea* relationship shows long-term morphological stasis (7-8 Ma to Present). Given that punctuated equilibrium involves geologically rapid origination followed by a long interval of morphological stasis, the *Miocaperea-Caperea* may be the first possible example of punctuated equilibrium in baleen whale evolution. Phylogenetic and ontogenetic studies can therefore indicate ancestor-descendant relationships in the absence of a dense fossil record.

A POSSIBLE MID-CRETACEOUS METAMORPHIC CORE COMPLEX UNDER TARANAKI BASIN

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Basement granodiorite core in Taranaki Basin well Taranga-1 exhibits shallow dipping ductile shear deformation of quartz that is overprinted by steeply dipping brittle deformation and associated hydrothermal alteration.

These features are characteristic of the lower plates of cordilleran metamorphic core complexes that represent rapid extensional tectonic exhumation of the middle crust. The defining feature of metamorphic core complexes, a low angle normal detachment fault juxtaposing brittle (cold upper plate) over ductile mid-crust (hot lower plate), has not been identified in the vicinity of Taranga-1. However, support for a metamorphic core complex interpretation includes the location of Taranga-1 along strike from the Aotea Basin, and a $^{40}Ar/^{39}Ar$ K-feldspar age of c.99 Ma that indicates rapid cooling during tectonic denudation following granodiorite emplacement and crystallisation at c.110 Ma.

In the Paparoa (Buller District) and Sisters (Stewart Island) core complexes, steeply dipping transfer faults cut detachment faults at a high angle, striking sub-parallel to the extension direction. Application of this orthogonal relationship to Taranaki Basin suggests a) that many of the north-easterly trending faults can be regarded as Cretaceous transfer faults, and b) an original north-westerly trend for postulated detachment faulting. This orientation matches north-westerly strikes for detachment faults in the Paparoa core complex and rift margins in the Aotea-New Caledonia Basin.

If correct, these interpretations indicate and/or predict a) that initial opening of the Aotea-New Caledonia Basin was underway by c.99 Ma, some 6 Ma before equivalent Paparoa exhumation, b) an original north-westerly structural trend in basement and deepest sedimentary rocks may be more common than currently recognised in Taranaki Basin, and may have guided Late Cretaceous fluvial pathways, and c) that north-westerly trending culminations of lower plate rocks will likely define zones of relatively high Late Cretaceous heat flow and diagenesis.

THE SOUTHERN SOUTH ISLAND GEOCHEMICAL BASELINE SURVEY

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Regional, national and trans-national geochemical baseline surveys are recognised worldwide as important datasets for understanding normal ranges of chemical element concentrations in the earth, and monitoring and assessing any variation with time. A pilot programme of soil collection

over an 8km-spaced grid across south Otago and Southland, has so far collected 335 sites of the 400 planned. The area of the pilot study was chosen for the diversity of the underlying geology (e.g. volcanic, sedimentary, crystalline igneous and metamorphic rock, mineralised schist) and the variety of land uses (e.g. urban, agricultural, historic mining, pristine conservation estate). Approximately five kilograms of soil was collected at each site from both the A soil horizon and a deeper sample (50-70 cm) typically equal to the B soil horizon using hand augers, with the sieved <2mm fraction retained for chemical and isotopic analysis. The survey sampling methodology is based on best-practice, international geochemical baseline surveys.

This collection will form the basis for a detailed chemical and isotopic study where a snapshot of the distribution and abundance of specific chemical components in the soil at the time of sampling will be established. The entire sample collection will be analysed for a suite of >60 trace elements by aqua-regia ICPMS. A sub-set of samples will also be analysed for major and some trace elements using laboratory XRF, and isotopes (S, Sr, Pb). Data from this regional survey will be freely available from the national rock and geoanalytical database (pet.gns.cri.nz), and will have applications in fields as varied as environmental, agricultural, public health and natural resources.

TO SEE THE WORLD IN A GRAIN OF SAND – A SINGLE GRAIN PROXY FOR SOURCE ROCK CHEMISTRY

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We have successfully calibrated a new micro-geochemical method that is capable of determining the provenance of individual detrital feldspar grains from sedimentary basins on the basis of trace element characteristics. Zealandia's plutonic suites are largely compositionally and chronologically distinct, and represent major first cycle detrital components of Cretaceous-Cenezoic sedimentary basins. As the dominant mineral group their varied trace element compositions make them an ideal target for use in provenance studies where onshore plutonic sources have been well classified and mapped.

Plagioclase and alkali feldspar from 38 samples of plutonic igneous rocks representing the principal igneous suites of Zealandia were analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) for a suite of 10 major elements and 34 trace elements. Results show that feldspar grains from plutonic suites are mostly readily distinguished on the basis of trace element concentrations such as Sr, CaO, and Rb. A strong correlation between the elemental composition of feldspar and whole-rock compositions of Zealandia plutonic suites indicates that distinctive chemical signatures of the whole-rock samples mirrored by individual feldspar grains from that sample.

Trace element fingerprinting of detrital feldspar grains is a novel, world-first, utilisation of the major framework mineral component of sandstones as a provenance tool (sources suite proxy). As a complement to accessory zircon U-Pb ages (source rock age proxy), it has the potential to be a rapid and effective provenance tool than can be readily applied to Zealandia basins. This method should prove a valuable new tool for unravelling sediment source to sink pathways, allowing quantitative modelling of depositional paleogeography, petroleum reservoir distribution, and crustal evolution. The technique has also shown potential as a tool for determining the provenance of mm-sized seafloor dredge samples that comprise too few grains to represent a whole-rock sample.

THE FUTURE OF PETROLEUM EXPLORATION IN NEW ZEALAND – A PERSONAL VIEW

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Taranaki is New Zealand's only producing petroleum province. Discovery rates and size continue to decline. Ten years ago, one well in seven was a commercial success, while today, that figure is one in ten. A new prolific Taranaki play is a receding possibility.

New Zealand is a by-product of collision between the Pacific and Australian plates. Associated tectonism created numerous potential petroleum

traps and then breached them. Testing the hypothesis that the best place to find large volumes of petroleum is where Neogene tectonism is minor means taking the plunge into deep water.

Our first deep-water exploration wells were drilled in the Great South Basin, where a sub-commercial gas-condensate field, Kawau, was discovered in 1977. In 1999 Waka Nui-1 in the Northland Basin was followed recently by Romney-1 in Deep-water Taranaki and Caravel in the Canterbury Basin. Anadarko operates in Deep-water Taranaki, Pegasus and Canterbury basins. Shell, OMV and Mitsui are exploring the Great South Basin. Statoil has a permit in the Northland Basin and Woodside, with New Zealand Oil and Gas, operate permits across the slopes of Taranaki and the Great South Basin. The recent licensing round offers further acreage in all of these basins.

Current exploration resulted largely from Government reconnaissance 2D seismic surveys that allowed companies to assess the potential of New Zealand's frontier basins. New speculative surveys have been acquired in the Pegasus and East Coast basins, others are about to start, and Shell, Anadarko and CNOOC are investigating the vast New Caledonia Basin. The large volume of new data available and to be acquired will re-draw the petroleum prospectivity map of New Zealand. The future for petroleum exploration in New Zealand is already happening.

THE ROLE OF PALAEOCLIMATE IN PREDICTING THE FUTURE

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The study of past climates is frequently motivated by efforts to improve our understanding of future climate change. However, it is often difficult to demonstrate that such knowledge of the past has truly helped improve the predictions of future climates. In part, this is because there are no direct palaeo-analogues for the coming century. Instead knowledge of past climates have to be used to test and improve the climate models used for future climate change predictions. The talk will review the role that palaeoclimate has played in improving our understanding of future climate change. We will show that there have been many examples in which palaeoclimate studies have helped evaluate our confidence in climate change models. These examples can be drawn from many different time periods including the Quaternary, Pliocene, and earlier times. But there are also weaknesses with palaeoclimate studies and it has been rare that climate models have been changed and improved because of palaeoclimate research. This is often because of uncertainties in the quantitative interpretation of the climate proxies. Therefore the talk will finish by showing some new methodologies of model-data comparisons which can fully embrace these uncertainties and open up considerable further opportunities for palaeoclimate research to contribute towards improving our confidence in future climate change predictions.

SEDIMENT FINGERPRINTING IN THE MANAWATU RIVER CATCHMENT

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Suspended sediment contributes to the chemical and ecological character of fluvial channels and is a product of the contributing catchment. It is therefore important to understand rates of suspended sediment delivery, transport and deposition in the fluvial system. In the Manawatu River Catchment, extensive landuse conversion from indigenous forest to pastoral agriculture has occurred following European settlement of New Zealand. This has influenced slope stability and caused widespread mass movements, soil erosion and an increased sediment supply to the river. Catchment scale identification of erosion processes and geomorphically active areas contributing sediment have often been poorly understood and quantified. Sediment fingerprinting provides an approach capable of directly quantifying sediment delivery through differentiating between sediment sources based on their inherent geochemical signature. In this research step-wise discrimination function analysis and principal component analysis of bulk geochemical concentrations (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr,Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf,

Ta, Pb, Th & U) has been employed to differentiate between and understand key sediment sources in the Manawatu River Catchment.

ENVIRONMENTAL RESEARCH, ENVIRONMENTALLY CONCIOUS?

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The world is slowly waking up to the concept of preserving natural resources and monitoring the effects of our actions. We are torn between our immediate need for food and fuel vs the future welfare of the world as we know it. Billions of Dollars a year are invested in environmental research but are we conscious of the effects of this research on the very resources that are so precious to us. As an example, every day I supply kilometres of sample tubing to environmental consultants. The situational irony is not lost on me that this tubing is used once to determine contamination and then disposed of as a consumable item. Is there a better way? YES! From equipment installation to sample acquisition there is progress in the industry to design and manufacture equipment that is more sensitive to our environmental needs. The following presentation will highlight some of the traditional methods of using a sledge hammer to crack a nut vs recent developments that can offer better results with less impact on the immediate environment.

RU: THE NEW ZEALAND NETWORK FOR SEISMOLOGY IN SCHOOLS

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Earthquakes are 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 different versions of "seismometer in schools" projects thrive around the world. Our New Zealand network is named "Ru" after the Maori God of Earthquakes and Volcanoes.

Ru uses a cheap, robust and easy-to-build seismometer –called the TC1— to measure seismic displacements in the vertical direction. Assembling and running the system naturally introduces students to a number of concepts in physics and engineering, while we hope that upon completion seismic recordings trigger discussions about the dynamics and internal structure of the Earth.

This presentation will be an update of our experiences with the roughly 10 schools in the network.

PALEOTEMPERATURE CONSENSUS RECONSTRUCTIONS FROM LIPID BIOMARKERS, POLLEN AND CHIRONOMIDS: IS THIS A DUMB IDEA?

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New Zealand temperature reconstruction models, based on biological indicators preserved in lake sediments, are essential for defining the temporal and spatial magnitudes of paleoclimate variability in the Southern Hemisphere and for providing quantitative temperature reconstructions for constraining and testing paleoclimate model simulations. Common proxies include pollen, insect remains and lipid biomarkers from bacteria (branched isoalkyl Glycerol Dialkyl Glycerol Tetraethers: GDGTs). The interpretation of temperature estimates derived from a proxy is highly dependent on that organism's biology, and extrapolating these individual reconstructions to regional temperature signals, rather than non-

climatic local environmental controls, remains an important consideration.

We present a consensus reconstruction of lipid, chironomid and pollen-based temperature estimates, covering the glacial-interglacial cycle, from two climatically sensitive sites in southern New Zealand. The consensus reconstruction approach is designed to smooth local, *site*-specific signals by combining several lake sediment cores, and by the same logic, we hope to smooth local, *proxy*-specific signals by amalgamating the three proxies and two sites into a single temperature reconstruction. This consensus is developed by normalising and smoothing each record and then combining all of the data into a single temperature profile. We both discuss the validity of this approach as a means to provide robust interpretations of multi-proxy data and ask the question, "Is it a dumb idea?"

SEISMIC IMAGING OF THE WAIHEMO FAULT SYSTEM IN THE SOUTHERN CANTERBURY BASIN OFF COASTAL OTAGO

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The Waihemo Fault System is a major crustal-scale structure that forms the northern boundary of the active north-east striking ranges of Otago. The fault system on the east coast of the South Island is orthogonal to the coast but its offshore geometry is still poorly understood. The Waihemo Fault System originated in the Cretaceous as a set of crustal-scale northeast trending normal faults that reactivated as reverse faults in the Late Cenozoic. This study aims to investigate the offshore extent of the Waihemo Fault System, how it changes further away from the coast, and how this compares to the known nature of the onshore fault system.

Three multichannel seismic data sets were used in a comparison study to comprehensively characterise the offshore section of the Waihemo Fault System. Petroleum industry exploration data from the 1980s were compared to recent seismic data from 2012 (*RV Kaharoa* 48-channel data with a generator-injector airgun source) and 2014 (*RV Polaris II* 24-channel data with a boomer source), with notably different depth penetration scales and seismic resolutions.

The Waihemo Fault System can be seen to extend from the basement through the overlying Tertiary sedimentary units, with the Shag Point Anticline visible on the northern side. The new high-resolution data, as well as the older exploration data, appear to confirm previously created offshore segment models, and potentially extend the fault system further offshore. Strands of the Waihemo Fault System are shown to continue from onshore to offshore away from the coast with an approximate northwest-southeast strike. At least one of these main strands is confirmed, while the two others are not seen in the new high-resolution data. A previously inferred extension of the Titri Fault System in the area, running parallel to the coastline and extending from south of Dunedin, has not been proven and remains a possibility.

THE ROOTS OF A MONOGENETIC VOLCANO: HYALOCLASTITES, DYKES AND DIATREMES REVEAL A COMPLEX HISTORY OF PLIOCENE VOLCANISM ALONG THE WAIKATO COAST, NEW ZEALAND

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Monogenetic volcanic fields have been drawing growing research interest - Auckland City is but one example of a major settlement on or near a dormant volcanic field. Many questions remain about the catastrophic nature of hazards associated with this type of volcanism. Recent literature has demonstrated the need for a thorough understanding of subsurface geology as to comprehend the triggers, scales and impacts of eruptions in monogenetic volcanic fields. As such, a section at Ngatutura Bay along the Waikato coast offers a rare opportunity to observe the roots of a monogenetic volcano that are thoroughly exposed and extraordinarily well preserved. The volcanic features observed include hyaloclastite piles and lava domes with pillows and peperitic margins, as well as at least one diatreme structure. Diatremes are subsurface structures, often associated with maar volcanoes. They are filled with fragmented magma and country rock that originated from numerous phreatomagmatic explosions. The

presence of a diatreme indicates subaerial explosive activity. In contrast, pillow lavas and dykes represent non-explosive volcanism in a subaqueous environment. Local stratigraphy is well defined and helps to explicate the eruption history of the region. The base of the section comprises Oligocene-Miocene marine sediments of the Te Kuiti Group that is overlain by the Pliocene Kaawa Formation and Late Quaternary Awhitu sandstone, the latter being of terrestrial provenance. Non-explosive features are found within the Kaawa Formation, indicating a shallow marine environment. A rapid shift to subaerial conditions is envisaged with the diatreme forming in close association with the terrestrial Awhitu sands. Furthermore, the facies architecture of the diatreme is complex; highly varied volcaniclastic domains pertain to the vibrant nature of diatreme formation. The significance of such dynamic volcanism, and applicability to the Auckland Volcanic Field are elucidated by unravelling the processes behind the spatially and temporally confined volcanism at Ngatutura Bay.

EFFECTS OF ORGANIC MATTER SULPHURISATION ON THE PETROLEUM GENERATION CHARACTERISTICS OF THE LATE PALEOCENE WAIPAWA FORMATION OF THE EAST COAST BASIN, NEW ZEALAND

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In this study we examine whether sulphurisation of organic matter (OM) has enhanced the petroleum generation characteristics of the Late Paleocene Waipawa Formation of the East Coast Basin, New Zealand. Kerogen, the non-extractable OM in sedimentary rocks, typically forms by the decomposition and condensation of biogenic polymers. Within Fe-limiting, sulphidic environments the sulphurisation of OM plays an important role in kerogen formation. Under these conditions even highly labile compounds, such as carbohydrates, can be reduced and bound to sulphur radicals to form organosulphur compounds that are in turn joined together by relatively weak intermolecular carbon-sulphur and sulphur-sulphur cross-linkages. Cleavage of these weaker bonds and the ensuing release of sulphur radicals can enable petroleum generation and expulsion to occur at shallower burial depths than would otherwise be required.

The Waipawa Formation is an organic-rich, marine source rock that occurs in many New Zealand sedimentary basins. Weathered exposures frequently display sulphur oxide coatings suggest the presence of reduced sulphur species (e.g. HS^-, polysulphides) in the rock matrix. Preliminary analyses of twelve outcrop samples from the Raukumara Peninsula, Hawke's Bay, and Wairarapa suggests sulphurisation of OM may have been an active preservation pathway that impacted the quantity, quality and maturity of OM within the Waipawa Formation. To verify these observations the freshly exposed Upper Angora Road (Taylor–White) section in southern Hawke's Bay is currently being analysed. The ~70 m thick Waipawa Formation in this section has transitional boundaries with the underlying Whangai Formation and the overlying Wanstead Formation. The section consequently offers a rare opportunity to evaluate the bottom water geochemistry during sediment deposition and the potential impacts sulphurisation of OM may have played on the petroleum potential and generation history of this formation.

INTERSEISMIC, COSEISMIC, AND SLOW SLIP EVENT DEFORMATION ABOVE A SHALLOW SUBDUCTION THRUST IN THE WESTERN SOLOMON ISLANDS

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The western Solomon Islands are a remarkable natural laboratory to investigate processes occurring on a shallow subduction interface. Islands within the New Georgia Group are located <15 km from the San Cristobal Trench, with the subduction thrust located only a few km beneath the southwest coast of islands like Rannonga and Rendova. This offers a globally unique opportunity to use GPS to monitor deformation processes very close to the trench at a subduction zone. We present results from a campaign GPS network in the western Solomons that was operated from

1996-2007. The data from 1996-2002 indicate interseismic coupling on the shallow portion of the interface, at a rate of nearly 100% of the relative plate motion. Coupling does not appear to extend deeper than ~20 km depth, and the relatively shallow down-dip limit of coupling is consistent with subduction of young (<6 Ma) oceanic crust of the Woodlark Basin. We also show evidence for a slow slip event in late 2000, observed at a GPS site near Gizo that was running continuously from 1999-2002. In April 2007, an Mw 8.1 earthquake occurred on the subduction thrust beneath the network, resulting in large coseismic displacements at nearby campaign GPS sites. The earthquake caused widespread coastal uplift and subsidence in the region, as revealed by studies of coral microatolls following the earthquake (Taylor et al., 2008). We invert displacements of the cGPS sites jointly with vertical displacements of coral microatolls to evaluate the coseismic slip during the earthquake. The area of the interface that underwent slip in the earthquake matches well with the region that was interseismically coupled just prior to the 2007 earthquake. The data also require large coseismic slip on the shallow interface near the trench, which likely contributed to the generation of a large, damaging tsunami following the earthquake.

INVESTIGATING SPATIAL AND TEMPORAL VARIABILITY OF SLIP BEHAVIOUR ON THE HIKURANGI SUBDUCTION THRUST

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Over the last decade, campaign and continuous GPS measurements in the North Island have revealed marked along-strike variations in slip behaviour of the Hikurangi subduction thrust. The southern Hikurangi interface undergoes deep interseismic coupling (down to 30 km depth) and deep (>30 km), long-term (>1 year) episodic slow slip events (SSEs), while much of the interface at the northern and central Hikurangi margin is dominated by aseismic creep and SSEs. The character of SSEs at Hikurangi also undergoes strong along-strike variations. At central Hikurangi, the majority of the megathrust between <10-50 km depth undergoes SSE slip of varying durations (weeks to > 1 year), indicating that the physical conditions conducive to SSE slip may be inherently broad. SSEs also appear to dramatically impact seismicity rates in the North Island: the large (Mw > 7.0) 2013/2014 Kapiti SSE and many of the east coast, shallow SSEs are excellent examples of this. We will also discuss interactions between the 2013 Kapiti SSE and the January 2014 Eketahuna Mw 6.3 intraslab earthquake. The Eketahuna earthquake was consistent with being triggered by the Kapiti SSE, while stress changes on the interface induced by the Eketahuna earthquake may have abruptly halted the Kapiti SSE. This is the first-ever example of a local earthquake halting an SSE.

The marked along-strike changes in subduction interface slip behaviour at Hikurangi have sparked much international interest in the Hikurangi margin as a natural laboratory to understand subduction megathrust slip behaviour. SSEs offshore Gisborne are the shallowest well-documented SSEs on Earth, making them an excellent locale to undertake investigations of the SSE source area. Offshore Gisborne is the target of a variety of marine geophysical studies including seismological and seafloor geodetic investigations, as well as proposals to use scientific drilling to understand the origin of SSE behaviour.

USING SEISMICITY TO DETECT THE OCTOBER 13TH 2012 TE MAARI LAHAR

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Volcanic mass flows are a major concern for populated areas on and around volcanic mountains. Being able to detect these flows is of most importance for the safety of lives, communities, and industry. Many instruments and techniques have been used to detect, measure, and record mass flows, but none have been more promising then seismic techniques. The benefits seismic techniques have over other techniques include the fact that seismic instruments can

collect data at a safe distance from the event and most importantly seismic methods can work in any weather and during the day and night. Here we present the seismic recordings for the October 13th-14th 2012 Te Maari lahar as a possible stepping-stone to seismic lahar detection. Seismic recordings of the October 2012 event are particularly important because the lahar occurred overnight with no eyewitnesses. The seismic data from the October 2012 event were collected from three broadband 3-component seismometers located on and around Mt. Tongariro. The seismic data were processed, and spectra were created. From the spectra, spectrograms were generated to determine where in the seismic records the lahar occurred. From the spectrograms it was determined that the lahar occurred at approximately 11:30 UTC on October 13th and lasted for about 40.0 minutes, with a frequency range between 3-15Hz. The use of spectrograms is especially important when there is a lot of background noise. Noise can cause the seismic signal of the lahar to get lost in the overall seismic recording and the lahar can be almost impossible to detect just from the record. Furthermore, lahars are more likely to be found in spectrograms because lahars occur in a distinctive frequency range. Detecting the frequency outputs produced by lahars has much potential for identifying future events, and may lead to a real time lahar warning system.

TRACKING POLLUTANT AND DEBRIS DISPERSAL DURING TSUNAMI EVENTS

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Dispersals of debris and hazardous material are recognized among others as major environmental aftermaths of the 2004 Indian Ocean Tsunami and the 2011 Tohoku event, in addition to direct losses of property and human lives. In these events, dislocated and contaminated waste and debris posed immediate threats to tsunami evacuation and became one of major obstacles in reconnaissance actions and recovery process following the tsunami disasters.

In order to investigate the dispersal of debris and pollutants during tsunami events, we develop a coupled simulation model in which Random Walk Particle Tracking (RWPT) schemes are integrated into a depth-integrated tsunami run-up and inundation simulation. In this model, the tsunami simulation provides information on temporal and spatial evolution of tsunami currents and the dispersals of waterborne debris and pollutants are simulated as passive agents with RWPT. Scenario studies show that the coupled model can provide indicative and quantitative information with respect to this type of environmental influences of tsunami impact, including dispersal pathways, and the distribution and extent of hazardous material in tsunami events. This information will benefit land-use planning and evacuation mapping for improved tsunami hazard mitigation.

THE WAIHAPA OILFIELD – WHAT 25 YEARS OF EXPLORATION AND PRODUCTION DATA TELLS US ABOUT THE INTERNAL PLUMBING OF NEW ZEALAND'S ONLY FRACTURED CARBONATE OIL RESERVOIR

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The Waihapa Oilfield is one of a number of hydrocarbon accumulations along the Tarata Thrust foldbelt located in eastern Taranaki. The field has produced 24 million barrels of oil and 28 BCF of gas since 1998, mostly from 8 wells. Reservoir comprises fracture porosity in the Oligocene Tikorangi Limestone which developed as a result of Pliocene extensional faulting. Successful wells are characterised by extensive fluid losses and hydrocarbon shows while drilling, though total produced oil volumes are strongly controlled by the timing of water influx. Artificial lift has been used to maintain oil production, with economic limits being controlled by water cut and oil price. Unusually, many wells exhibit apparent recharge over weeks to months when shut in, indicating that mobile oil is still present in the fracture system. Pressure measurements indicate water has replaced oil up to the level of the highest producing well in the main Waihapa structure.

Hydrocarbon column pressure measurements indicate that there was an initial oil column in the Tikorangi Limestone covering 900+ vertical metres and extending along strike through the Waihapa, Ahuroa and Tariki structures. Despite this, only 1 additional well in the far north has produced

modest volumes of oil from the Tikorangi Limestone. Many wells have failed to intersect sufficient connected fracture systems to sustain commercial production.

In late 2013, New Zealand Energy Corp and its partner L&M Energy acquired the Waihapa Production Station and the Waihapa, Ngaere and Tariki Mining Licences. NZEC has reactivated 6 Tikorangi production wells, using gas lift and a high volume downhole electric pump to extract reservoir fluids and increase pressure drawdown, in order to mobilise oil trapped in tighter fractures. Total NZEC production to date is over 51,000 barrels. NZEC also continues to evaluate further drilling opportunities within the wider Tikorangi Limestone oil column.

RE-INTERPRETATION OF THE EXHUMATION PROFILE OF THE SOUTHERN LAKES REGION, NEW ZEALAND, FROM APATITE AND ZIRCON FISSION-TRACK AGES

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Apatite and zircon fission-track (AFT and ZFT) ages from New Zealand's South Island show that displacement on the Alpine Fault largely controls Cenozoic vertical kinematics of the Pacific [1]. In the Central Alps, AFT ages within ~25 km of the Alpine Fault are fully reset as a result of late Neogene exhumation of the hanging wall. These young AFT ages (<5 Ma) define a high exhumation zone (HEZ) which transitions through partially reset ages to background Cretaceous AFT ages with increasing distance from the Alpine Fault.

However, in the Southern Lakes this HEZ appears to widen, with very young (0 Ma) AFT ages found up to 60 km from the Alpine Fault. These ages are inconsistent with geological observations, and we believe are artificially young as a result of a low uranium concentration in the apatite used for age calculation.

Here we present new AFT and ZFT ages for 29 samples from the Haast Schist around the Southern Lakes to examine this apparent along-strike change in exhumation pattern. Our results show the width of the apatite HEZ in the Southern Lakes has been previously over-estimated. Instead, fully reset AFT ages are limited to within ~30 km of the Alpine Fault (comparable to the Central Alps), whilst the transition to Cretaceous ages though partially reset AFT ages occurs over a wider area than further north.

Combining this new exhumation profile with inverse modelling techniques we are able to impose constraints on the sub-surface geometry of the Alpine Fault underneath the Southern Lakes.

[1]J. Tippett Kamp (1993). J.G.R. 98, 16119-16148.

GRAIN SIZE ANALYSIS OF CATACLASITES WITHIN THE OTAGO SCHIST

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We discuss the deformation mechanisms and microstructure which form during earthquake rupture. Three main processes are identified as being important in forming cataclasites: mineralogic alteration, constrained comminution, and selective fragmentation of particles. Together these result in increasing irregulatity of particles and mean size reduction. Such microstructures and evidence that result from these processes can be identified and used to estimate the conditions under which the cataclasis occurred. The degree of particle size reduction may be directly related to the energy 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 to the processes observed during cataclasis. Samples have been examined from three brittle fault zones at Loch Laird Reserve, Otematata. The displacement along the fault planes ranges from 0.6 – 6.8m. High-resolution backscatter images were taken using a scanning electron microscope from which particle maps were produced distinguishing grains according to their size and shape. Mineral phases can be separated by manipulating the contrast and brightness to investigate the size and shape of each phase

separately. Comparison of this data allows us to determine the conditions at the time of cataclasis. Future work is intended to compare the particle distribution with the mechanisms of deformation to assess the energy released during fault rupture.

CHEMISTRY OF CARBONATE VEINS, THE ORIGIN OF THEIR COMPONENTS AND THE ALTERATION HALOES AROUND THEM - A CASE STUDY FROM WESTERN OTAGO

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In Otago's Southern Alps, Miocene tectonics have caused the formation of faults and joints. In places, these structures served as pathways for fluids that produced the Shotover gold deposits and for the alkaline intrusives of the Alpine Dike Swarm. Additionally, Fe-carbonate veins and alteration zones are found connected to these structures. The goal of this study is to trace back the origin of the different components of the carbonate and whether there could have been a connection between the CO_2 bearing fluids in the mesothermal gold system of the Shotover and the carbonatites of the Alpine Dike Swarm.

Radiogenic isotopes (Sr, Nd) reveal that the isotopic signature of fluids and precipitating carbonates are highly influenced by the immediately surrounding host rock. Trace element concentrations seem to be mostly dependent on their structural position of the carbonate, eg. whether it is in a silicified breccia, veins or disseminated in the wall rock. However, carbonates at the southern end of the Alpine Dike Swarm do show mixed signals regarding their chemical and isotopic compositions, which can be explained as the result of the interaction of magmatic and crustal sourced fluids.

The CO_2-rich fluids not only form carbonate in veins, but also infiltrate the wall rock. This causes the breakdown of metamorphic epidote, chlorite, actinolite and titanite and the formation of carbonates. During this alteration the LILEs (Sr, Rb, Ba, K, Cs) show the highest mobilities, but also in some changes in the concentration of major elements (e.g. Ca, Si) and the volatile components (e.g. CO_2, S). Mobility of elements is traceable on microscopic scale, too. For example, during the replacement of calcite by ankerite, Mg and Fe, the light and medium REE are added and Ca removed.

GLACIER MONITORING IN 3D USING STRUCTURE FROM MOTION (SfM)

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The end of summer snowline (EOSS) dataset, comprising oblique aerial photographs of glaciers in the New Zealand Southern Alps dating back to 1978, has proved a valuable resource for glacier monitoring. Here we outline a method for extracting additional quantitative information from these data using newly developed photogrammetric techniques.

The technique of 'structure from motion' (SfM) enables the creation of 3D digital models without laser scanning or conventional stereoscopic photogrammetry. Digital models made with SfM from oblique photos have a higher resolution than conventional DEMs, and can be created more frequently resulting in a more accurate representation of the landform. This makes SfM ideally suited for extracting metrics from changing glaciers, such as snowline, terminus position, and volume, from existing and future photo datasets.

As a proof of concept, we present the photo sets of Brewster Glacier covering the years from 1985 to 2012. Photoscan software was used to generate models, which enabled orthophoto construction for most years within that period. Coregistration of the orthophotos allowed visual and quantitative analysis of the snowline and terminus positions.

Adequate photo coverage also enables the generation of accurate 3D point clouds. Brewster Glacier elevation models were directly compared at the point-cloud level using CloudCompare

software. Future goals include determining a method for quantifying volume changes and the establishment of ground control points (GCP's) to increase the accuracy of terminus and snowline positions, and volume change estimates.

A REVIEW OF NEW ZEALAND PALAEOCLIMATE FROM THE LAST INTERGLACIAL TO THE GLOBAL LAST GLACIAL MAXIMUM

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Results from terrestrial and marine palaeoclimate proxies are integrated to reconstruct palaeoclimate variations in New Zealand from the Last Interglacial to the global Last Glacial Maximum (gLGM). The MIS 5e thermal maximum in New Zealand was around 128-122 ka BP. Temperatures in parts of the North Island may have been 2°-3°C warmer than present and sea level 3-5 m above modern. In MIS 5d and 5b cool conditions with glacial advances occurred in the South Island, but from about 87-73 ka in MIS 5a warmth within 2°C of present characterised most of the Otamangakau Interstadial. Conditions then cooled rapidly and culminated in a MIS 4 glacial advance that was the greatest of the Last Glacial Cycle (nzLGM). Conditions that followed during MIS 3 were very variable. The climate in Hawke Bay and the Bay of Plenty at the start of MIS 3 was similar to the Holocene, and the period 61-43 ka was relatively mild overall and is termed the Aurora Interstadial, although it contained a short interval of mountain glacier expansion around 49-47 ka. After 43 ka conditions cooled again with a glacial advance from 42-38 ka, before a return to milder, but still cool conditions during the Moerangi Interstadial from 37 - 31 ka. The maximum glacial advance occurred in late MIS 3 around 31 ka. The glacial onset was abrupt, with the Te Anau Glacier in Fiordland taking only about 2000 years to achieve its maximum gLGM height, probably because conditions were wet as well as cold. The climate then became drier, while remaining cold, and the glacier progressively ablated such that its surface had lowered 390 m by the start of MIS 2 and by >600 m by ca. 18 ka. The culmination of the gLGM in NZ occurred in MIS 3 about 12 000 years before global ice volume reached its peak. By the time global ice was at a maximum (19 ka) glaciers had almost disappeared from major Fiordland valleys in New Zealand.

TSUNAMI AND CYCLONE DEPOSITS: THE SAMOAN CASE

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We report on geochemical and sedimentary proxies used to identify and distinguish tsunami from cyclone deposits on Savai'i, Upolu, and Ta'u islands in the Samoan archipelago. Subtle differences in the elemental ratios, loss on ignition, and grain size characteristics between the preserved 2009 South Pacific Tsunami deposits, and the identified 1990—1991 Cyclones Ofa and Val deposits, provide analogues for distinguishing probable tsunami from cyclone deposits deeper in the stratigraphic record. ^{210}Pb and ^{14}C geochronological indicators help to corroborate the identified historical events, and constrain the timing of identified palaeo-events, respectively. An approximately 3,000-year-long baseline tsunami and cyclone chronology is developed for this region, and directions for future research are proposed.

NUMERICAL MODELS OF THE HIKURANGI MARGIN - THE ROLE OF DIFFERENT LITHOSPHERIC BLOCKS IN THE SUBDUCTION DYNAMICS

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The role of different lithospheric blocks along the Hikurangi margin has been investigated using Underworld models setup to mimic northern New Zealand's lithospheric setting. Using free-slip boundary conditions, the models rely on the buoyancy contrast of the subducting lithosphere to create a slab pull force that drives deformation in visco-elastic models. By including and excluding equivalents of the Chatham Rise, Hikurangi Plateau and South Fiji Basin, as well as altering their relative strengths, we have explored dynamic role each of the lithospheric blocks plays in the complex tectonic setting. The models have shown it is possible that the Alpine Fault and Hikurangi Trough once formed a continuous, linear plate boundary and that slab pull is driving the Chatham Rise further into the overriding plate. Velocity outputs from passive tracers in the near surface of the models have been compared with GPS and schematic displacement diagrams of New Zealand. The velocities show that rotation of the North Island only requires the presence of the Chatham Rise driving into the overriding plate and an area opening up above a subduction zone in roll back. The rotation seen in the Pacific Plate is only matched when a buoyant plateau enters the subduction zone, creating differential velocities of subduction and trench roll back along the subduction zone. Once introduced, the thin weak lithosphere of the oceanic South Fiji Basin allows quicker back-arc extension in the over-riding plate, this velocity increase results in a quickening of subduction roll back to the north of New Zealand and increasingly asymmetric subduction rollback.

CRUSTAL SEISMIC ANISOTROPY AT THE HIKURANGI SUBDUCTION MARGIN, LOWER NORTH ISLAND, NEW ZEALAND

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The Seismic Array Hikurangi Experiment (SAHKE) was a large seismic acquisition project undertaken from late 2009 until mid 2011, across the southern North Island of New Zealand. The SAHKE data set provides high spatial resolution of the Pacific Plate subducting beneath the Indo-Australian plate. SAHKE consisted of two phases: A series of active source seismic lines, and a five month passive seismometer deployment consisting of 57 short-period & 10 broad band seismometers. The passive data collected during the SAHKE deployment provides an excellent opportunity to measure seismic anisotropy at the Hikurangi margin from shear wave splitting analysis. We plan to build a model of azimuthal shear wave anisotropy and from this infer the orientation of compressional stresses across the southern North Island. Preliminary results from a subset of seven seismometers recording earthquakes of magnitude greater than 3 returned fast directions parallel to the NE/SW regional maximum horizontal stress direction determined by focal mechanism studies. From a larger set of anisotropy measurements we will model the upper crustal stress field, and if time permits calculate focal mechanisms for local earthquakes collected by the passive array and compare them to the stress model.

NEW ZEALAND'S IMPROVED VERTICAL DATUM

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The most timely and cost effective means of determining heights is to use technologies such as GNSS. However, GNSS heights are related to an ellipsoid: a mathematical figure used to approximate the shape of the Earth. As they are not related to the Earth's gravity field, they may not accurately predict the direction which water will flow.

An ellipsoidal height can be converted to a normal-orthometric height or "height above sea-level" through the application of a geoid model: a hypothetical surface that describes the irregular shape of the Earth's gravity field. Normal-orthometric heights can then be used in surveying, hydrology, agricultural and other land management applications.

Land Information New Zealand is halfway through a four-year project to improve the New Zealand Vertical Datum 2009 (NZVD200), the national reference surface for elevations. Much of this improvement will be realised through the integration of data from a national airborne gravity survey with existing terrestrial gravity

observations. The final result will be a more accurate geoid and national vertical datum.

This presentation investigates the role of gravity observations in height system definition and the benefits of easier access to more accurate and comparable heights in New Zealand.

NEW INSIGHTS INTO WELLINGTON HARBOURS' TECTONIC SETTING FROM MARINE GEOPHYSICAL & SEDIMENTOLOGICAL DATA

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After the experience of several damaging coastal earthquakes in New Zealand in the last three years, the importance of locating and characterising the earthquake potential of active faults close to urban areas has become more obvious, especially when cities lie in complex tectonic settings as it is the case for Wellington. To assess the earthquake and tsunami potential and the associated hazard posed by such faults, it is necessary to characterise fault geometry, slip rate, earthquake history and earthquake potential. In the marine environment, we have the advantage that faults can be assessed cross-sectionally through the application of high-resolution geophysical data without having to excavate trenches across the active fault trace.

We present new marine data from Wellington Harbour that helps to characterise three faults; the Wellington Fault at Kaiwharawhara, the Evans Bay Fault, and a newly discovered fault off Oriental Bay, informally referred to as the Mount Victoria Fault (see paper by *Nodder et al.* this conference). New marine geophysical data has better delineated the location and characteristics of these faults. High-resolution multi-beam bathymetric data (50 cm grid-cell size), covering the entire Wellington Harbour, were also used to determine the occurrence of seafloor scarps associated with surface ruptures on the faults. Sediment cores from either side of the Wellington Fault off Kaiwharawhara Stream, in about 17.5 m water depth, provide insight into the late Quaternary-Holocene stratigraphy and age of sediments that have been deformed by activity on the faults delineated in Wellington Harbour. The stratigraphy reveals details of the post-glacial marine flooding of the harbour that occurred about 10,000 years ago.

HAVRE 2012: THE LARGEST HISTORIC SUBMARINE ERUPTION THE WORLD HAS NEVER SEEN

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The July 2012 eruption of Havre caldera volcano was likely to have been the largest submarine eruption documented. The eruption, reported to be a one in a century event, produced an atmospheric plume that penetrated at least 900 m of seawater, and a pumice raft reported to have had an aerial extent similar to Canterbury. Pumice from this raft has since dispersed and is still washing up on beaches across the Pacific. The estimated volume of the eruption is at least 1.5 km^3.

Multibeam echosounder data was collected over the volcano during the R/V *Tangaroa* Nirvana expedition (TAN1213) 3 months after the eruption. Comparison with previously collected data in 2002 allowed changes in the seafloor resulting from the eruption to be established. These show (i) the growth of a new *c.* 250 m high cone on the southeast flank of the caldera rim thought to be the main eruption conduit; (ii) a field of 8 small cones on the southern rim; and (iii) a bulged area on the western wall of the caldera. The 5 km wide caldera floor itself was in places 50 m higher in relief than before the event, but it was not the source of the eruption itself.

Samples collected from the caldera range include dark dense rhyodacite, light to dark grey pumice, and white pumice clasts. Pumice dispersed from the raft is all white pumice. The 2012 eruption products show a range of chemical compositions with little change in chemistry by pumice colour. Despite the large range, the sample suite shows a well-defined fractionation trend and geochemical composition that differs from other caldera volcanoes of the Kermadec arc, which generally show fractionation trends unique to themselves. These distinct compositions can be used to fingerprint the source volcano of pumice rafted from the Kermadec arc.

A STRUCTURALLY-CONTROLLED HYDROTHERMAL SYSTEM IN THE MANUHERIKIA FAULT ZONE, ALEXANDRA, CENTRAL OTAGO

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A zone of brittle faults, hosted within quartzofeldspathic Otago Schist, occurs along the NE-trending margin of the Manuherikia valley in Central Otago. The faults were initiated in the Cretaceous with predominantly normal sense of motion. Some faults have been reactivated as reverse structures since the Miocene, offsetting Cenozoic sediments. There is also evidence for strike-slip motion on some fault strands. Quaternary reactivation has resulted in stepped topography adjacent to the Manuherikia River. Cretaceous fault activity was accompanied by hydrothermal fluid flow and minor alteration of fault rocks and adjacent wall rocks. There are three different styles of hydrothermal alteration: narrow silicified zones, wide silicified cataclasite zones, and carbonitic shear zones. The narrow silicified zones have 5-10 cm wide silicified cataclasites along the fault plane, and these dominate the southern end of the area. Some of these zones host veins with euhedral crystals of calcite and quartz. The narrow zones have a wide range of orientations, and are traceable for only short distances (<100 m) along strike. Some are north-striking, whereas many of the smaller faults are predominately orientated east-west. Farther north in the area, wide resistant, silicified slabs of cataclasite, up to 5 metres across, form resistant ridges across topography. These zones are well-exposed, with prominent fault planes containing slickenlines which predominately show a dip-slip sense of motion. These large resistant faults range from moderately to steeply dipping and are largely orientated NE-SW. Carbonitic shear zones are prominently orange-stained where ferroan calcite has been altered to limonite, and form easily-eroded lower topographic features within the area such as gullies or saddles between ridges. Some carbonitic shear zones occur along the same strike as the wide silicified cataclasite zones. Scattered pyrite occurs in some silicified rocks, and there are low but anomalous levels of arsenic and gold in some fault rocks.

RAPID ASCENT OF APHYRIC MANTLE MELTS THROUGH THE OVERRIDING CRUST IN SUBDUCTION ZONES: EVIDENCE FROM VARIABLE U-SERIES DISEQUILIBRIA, AMORPHOUS HYDROUS ALTERATION MICROTEXTURES IN CRYSTAL RIMS, AND TWO-PYROXENE PSEUDO-DECOMPRESSION PATHS

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Volcanic hazard mitigation at subduction zones critically depends on knowledge of magma generation and ascent processes and timescales. Two diametrically opposite scenarios are presently debated: One paradigm is the generation of low-silica (basaltic) melts in the mantle wedge, followed by protracted sub-liquidus magma ascent and evolution through crystal growth and fractionation in crustal reservoirs, which are tapped during volcanic eruptions. The contrasting model favours the generation of higher silica melts in the mantle or in a lower crustal hot zone, followed by rapid decompression to the surface under super-liquidus conditions. In the latter case, crystals are picked up during magma ascent and are in the process of dissolving. We present multiple lines of evidence that point to crystal uptake as the principal processes by which mafic to intermediate arc melts acquire their crystal cargo: (i) variable ^{234}U-^{238}U disequilibria in mineral separates; (ii) hydrous mineral rims with amorphous alteration textures; and (iii) two-pyroxene pseudo-decompression paths; cf. Zellmer et al. (2014a,b,c), doi: 10.1144/SP385.3 and 10.1144/SP385.9 and 10.1144/SP410.1. These observations point to a scarcity of true phenocrysts in many arc magmas, and thus to

decompression of aphyric melts that take up their crystal cargo during ascent. The data imply that many hydrous wedge melts are more silica-rich than basalts and achieve super-liquidus conditions during rapid ascent from great depth.

ANALYSIS OF NEWLY ACQUIRED HIGH-RESOLUTION LIDAR DIGITAL TOPOGRAPHIC DATA ALONG THE MARLBOROUGH FAULT SYSTEM, SOUTH ISLAND, NEW ZEALAND

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We analyze newly acquired lidar high-resolution digital topographic data to measure offset geomorphic markers along the Wairau, Awatere, Clarence, and Hope faults in the Marlborough Fault System, northern South Island, New Zealand. With an average shot density of ≥ 12 shots/m^2, these lidar data, which were acquired for us by the US National Center for Airborne Laser Mapping (NCALM) and New Zealand Aerial Mapping, offer a uniquely detailed view of the topography along ~250 km of fault parallel imagery. We identify and measure offset geologic features ranging in size from ~1 m to 100s of meters to constrain the style and distribution of surface slip along each of these four faults, and present examples of the lidar data at several key study sites including the well-known Branch River and Saxton River sites on the Wairau and Awatere faults, respectively. The precise fault offsets we measure at these sites, combined with post-IR IRSL (225˚C) single-grain K-feldspar dating of fluvial terrace sediments, will provide the basis for determining incremental slip rates on these faults at a range of latest Pleistocene to late Holocene timescales. This project is part of a broader effort to generate incremental slip rates, and paleoearthquake ages and displacements from the four main faults that comprise the Marlborough Fault System with the goal of further understanding how mechanically complementary faults work together to accommodate relative plate motions.

THE HOLOCENE TEPHRA RECORD OF MARINE CORE MD06-3017, BAY OF PLENTY

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The volcanic record preserved in terrestrial deposits in the Bay of Plenty is reasonably well established, especially for larger eruptions where thick deposits allow the eruptive events to be well characterised. Smaller eruptions, or smaller phases of larger eruptive events, however, may not be as well preserved as a consequence of the small amount of erupted material, differential erosion, burial by subsequent events or lack of exposure. By contrast, these events may be better preserved in the marine record, particularly where sedimentation rates are sufficient to create an expanded, high resolution record to be preserved.

Marine core MD06-3017 was collected during the R/V *Marion Dufresne* MD152 (MATACORE) voyage in early 2006. It was recovered in 150 m water depth just 20 km from the coast in the Whakatane Trough. This near-shore setting has a high sedimentation rate (1000 yrs/m of core), with the 10 m recovered core spanning the Holocene epoch. This high sedimentation rate has allowed a number of tephras to be preserved, ranging from small eruptions that deposited < 5mm of ash, to the large well-known eruptives of the Taupo, Mamaku and Rotoma events.

We will present 6 carbon ages, and major (EPMA) and trace (ICP-MS) element data for 35 tephra units, both primary and reworked, from MD06-3017. These data will add to the terrestrial record of the Holocene volcanic depositional history of the offshore Bay of Plenty. We will also examine the temporal evolution of larger volcanic events found in the core, as well as processes that rework and redeposit the tephras in the marine record through the comparison of glass shards in reworked units with primary pristine tephras.

Unravelling these deposits could yield a more contiguous eruption history for the region.

IMPROVING CAPABILITIES OF SURFACE EXPOSURE AGE DATING WITHIN NEW ZEALAND

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For the most commonly used terrestrial cosmogenic nuclides, ^{10}Be and ^{26}Al, quartz is the target mineral of choice [1]. Alongside improvements of in situ production rate calibrations and of AMS measurement techniques, many labs continue to refine the technique to extract pure quartz from various rock types. New Zealand contains extensive areas of quartz-bearing rocks. In particular, the greywacke and schist lithologies of the Southern Alps have proved to be well-suited to surface exposure dating [e.g. 2], despite low abundance of sand-sized quartz grains. Victoria University of Wellington and GNS Science have started a collaboration to refine the analytical capabilities within New Zealand. At present, the focus is on establishing practical limits of key parameters for ^{10}Be, such as minimum sample size and AMS detection limit, for different lithologies with low quartz concentration and/or small quartz grain size. We will present preliminary results from a replication study in which we sampled and analysed greywacke boulders from Last Glaciation moraines in the Southern Alps. These boulders have previously been surface exposure dated by the LDEO Cosmogenic Nuclide Group [2]. Part of our study aims to achieve a more efficient and safe implementation of the hot phosphoric acid (HPA) technique to separate quartz from other minerals [3,4]. We compare degrees of purity and recovery against those of the more widely employed etching method using hydrofluoric acid. Initial results show that the HPA method has a factor two higher quartz yields, while visual inspection suggests that quartz purities are similar to those obtained via HF etching.

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