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Abstracts

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A NEW LOOK AT THE UPPER WAITAKI CANYON

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There is considerable global interest in the use of modern canyon settings in analogue studies that will help to understand ancient depositional systems in deep-water environments. The Waitaki Canyon, due to its status as the largest member of the Otago Canyon System, its relative accessibility, and the quantity and quality of pre-existing seismic data in its vicinity provides a convenient real-world example where we may study one of these settings in detail. Recent seismic and bathymetric surveys conducted by the University of Otago and the hydrocarbon industry have provided new insights into the sea-floor and near-surface features in the upper reaches of the canyon and surrounding shelf area.

There is a large amount of data available that can be used to investigate the subsurface and seafloor in the vicinity of the Waitaki Canyon, ranging from high-resolution multibeam and boomer seismic surveys (acquired by the University of Otago's *RV Polaris II*) to a commercial 3D seismic volume. These data provide an ideal opportunity for looking at the ancient form of the canyon and its modern seafloor expression. Features indicative of sedimentary processes (e.g., submarine landslides) are visible in the bathymetric data, yet the extent of modern activity in the canyon is uncertain.

The combination of well-defined Pleistocene sequences on the shelf and the density of data around the canyon are used to examine the temporal variation in activity levels within the upper Waitaki Canyon. The integration of bathymetric data and subsurface seismic data in this research provides a novel approach to studying how canyons develop and evolve through time. By analysing the modern form of the seafloor our understanding of the processes that are currently involved in the development of the Waitaki Canyon will be enhanced, and this will assist in our interpretation of the extensive seismic datasets in the region.

RECONSTRUCTING HOLOCENE CLIMATE AND OCEAN VARIABILITY OFF ADELIE COAST, EAST ANTARCTIC MARGIN

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This project aims to produce a detailed Holocene time series (12 ka BP to present) of ocean and climate variability, at sub-centennial time scale, as preserved in an Antarctic margin marine sediment core (U1357) collected by the International Ocean Discovery Program (IODP). Grain size analysis of the terrigenous component will permit changes in sedimentary processes at this site to be investigated. Shifts in the physical sedimentary processes in the region are driven by long-term changes in sea ice extent, polynya activity, wind stress and diatom productivity. These drivers play a key role in identifying potential effects on the production of Antarctic Bottom Water (AABW)-a first order control on global heat, gas, salt and nutrient transport via the Meridional Overturning Circulation (MOC) and an important mechanism for storing CO_2 in the abyssal ocean. These systems will be examined through correlation of the grainsize data with geochemical environmental and paleontological proxies from previous studies of the IODP U1357 core, as well as with the Roosevelt Island Climate Evolution (RICE) ice core records. Little is known about Holocene natural variability in this region from marine records and how it may relate to the pattern of recent warming in Antarctica, despite this being crucial for improved prediction of the impact of future climate change. Spectral analysis of the data will further aid in the assessment of different climatic and orbital forcing factors responsible for centennial to millennial climate variability in the Holocene.

FRICTIONAL CONTROLS ON HIGH-ANGLE REVERSE FAULTING DURING COMPRESSIONAL BASIN INVERSION

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Large normal faults are often reactivated as high-angle reverse faults during compressional basin inversion. Prevailing models to explain steep reverse slip call upon significant fluid overpressure. Though such models are consistent with some seismological data and field observations from incipient (low-displacement) reverse faults, they remain largely untested in the case of basin-scale faults.

We present field and experimental data from the >200 km long Moonlight Fault Zone in west Otago, an Oligocene basin-bounding normal fault that reactivated in the Miocene as a high-angle reverse fault (present dip angle 65°-75°). Excellent exposures of the fault zone exhumed from c. 4-8 km depth are found in creek sections along the entire strike length. Wall rocks are mainly quartz-albite-muscovite-chlorite schists with a strong foliation that is everywhere sub-parallel to the Moonlight Fault (i.e. dip angle 65°-75°). Although the overall structure of the fault zone changes significantly along strike in response to wall rock composition, the <5 metre thick fault core everywhere contains interconnected layers of foliated cataclasite rich in authigenically-grown chlorite and muscovite/illite. Microstructural evidence suggests deformation in the fault core by a combination of cataclasis, frictional slip along phyllosilicate seams and dissolution-precipitation.

Single-direct and double-direct friction experiments were performed with the BRAVA apparatus (INGV, Rome) on saturated wafers (e.g. with intact foliation) of foliated cataclasite at normal stresses up to 75 MPa. The foliated cataclasites have a friction coefficient of <0.25 and negligible frictional healing. In combination with dissolution-precipitation mechanisms, a friction coefficient of <0.25 can account for slip on high-angle reverse faults if accompanied by only moderately high fluid pressures. Our results indicate that friction may be equally as important as fluid pressure during compressional basin inversion.

EARLY TERTIARY CONTOURITES ON THE MARBOROUGH PALEO-PLATFORM: INSIGHTS FROM KAIKOURA WHARF

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During the greenhouse world of the late Cretaceous to Eocene the Marlborough paleo-platform (MPP) sat at high latitudes (~55-60ºS) on the passive eastern margin of Zealandia. During this period a thick sequence of biopelagic sediments (~500 m thick at Mead Stream) belonging in the Muzzle Group were deposited at bathyal depths throughout the region.

There is evidence that the long-lived sedimentary regime that otherwise dominated the MPP during the Early Tertiary was punctuated by some significant short-lived climatic and oceanographic changes in the high-latitude Southwest Pacific conditions. These changes were accompanied by a shift from pelagic sedimentation to periods of unconformity formation, active erosion and sediment transport across the MPP.

One of these periods is well represented throughout southeastern Marlborough by the Teredo Limestone. This is a calcareous, bioturbated greensand unit which overlies a regional unconformity surface. The Kaikoura Wharf section is unique in that it contains two separate greensand units of which, based on this study, only one is correlated with the Teredo Limestone.

Three sedimentary facies have been identified at Kaikoura Wharf, a siliceous micrite facies (F1), a greensand facies (F2) and a micritic limestone facies (F3). Both F1 and F3 are biopelagites and considered to represent 'normal' background sedimentation conditions. However, the presence of perigenic/allogenic glauconite, siliciclastics and phosphatised clasts in F2 is considered to be associated with an energetic bathyal transportation/sedimentation regime.

Based on the presence of crossbedding and the absence of Bouma structures at other locations in southeastern Marlborough, it is argued that both the F2 units at Kaikoura Wharf represent contourite deposits. These are associated with discrete Early Tertiary oceanographic events, possibly driven by short cooling intervals due to ephemeral Antarctic ice sheet growth in the Early Tertiary greenhouse world.

RECONSTRUCTING URBAN FOSSIL FUEL CO_2 EMISSIONS UTILISING THE RADIOCARBON COMPOSITION OF TREE RINGS FROM THE WELLINGTON REGION, NEW ZEALAND

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There is growing global concern over the unabated rise in atmospheric CO_2 directly associated with the growth of world population, industry and technology. Emissions of carbon dioxide (CO_2), a by-product of fossil fuel combustion, are the dominant driver of atmospheric CO_2 increases and current observed global warming. Due to negligible progress of international treaty negotiations, there is increasing pressure for urban cities to take responsibility and lead the way in reducing local greenhouse gas emissions. Reliable emissions reporting is crucial for enabling local political bodies to instigate the best strategies for reducing emissions, however, currently, carbon-equivalent emissions reporting is assessed by "bottom-up" methods that involve reporting of economic data, which tend to aggregate disparate local statistics. As such, an independent and objective "top-down" method of urban emissions quantification is crucial to enable validation of the emissions reported by governments and industries, confirm reduction progress and to facilitate more targeted and financially efficient strategies for reducing emissions.

The radiocarbon method has been successfully applied to the quantification of local fossil fuel CO_2 concentrations and is a promising new development into determining regional CO_2 emissions. This study aims to demonstrate the utility of tree ring radiocarbon analysis as an accurate method of quantifying temporal and spatial patterns of fossil fuel-derived CO_2 emissions in urban areas, as an alternative to large networks of CO_2 monitoring stations and to validate local emissions inventories. With this study we hope to exhibit how this kind of research can used to assist municipalities to ensure accurate emission estimates are quantified to allow appropriate reduction and development strategies to be established.

A NEW GENERATION OF DIGITAL MAPS SHOWING POTENTIAL PETROLEUM HABITATS IN NEW ZEALAND'S OFFSHORE NORTH-WESTERN PROVINCE (REINGA-NORTHLAND-TARANAKI BASINS)

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The distribution of petroleum systems elements such as source, reservoir, and seal rocks, provides key input to understanding basin prospectivity. The NZ Government-funded "Atlas of Petroleum Prospectivity" programme is producing a GIS-based series of updated digital maps and metadata of these key geological components to help understand the potential for petroleum accumulation in New Zealand's northwestern petroleum province (greater Taranaki, Northland and Reinga basins).

Digital maps for the Northwestern Province (NWP) represent a collation of both existing, and new interpretation of regional data based on seismic character of reflection packages, isopach maps, lithologies and depositional settings and biostratigraphic analysis from wells. These digital maps, including new paleogeographic maps, are the main inputs for common risk segment (CRS) maps of source, reservoir and seal rock presence.

The most likely source rocks throughout the NWP are Late Cretaceous coaly rocks, with proven oily source rock potential in the Taranaki Basin. Older Cretaceous units may also have source potential. Jurassic coals may be an important source rock in Reinga-Northland basin. Late Paleocene marine shales may also have source potential.

Potential reservoir units are widespread Late Cretaceous non- to shallow-marine sandstones. In the Taranaki Basin Paleocene–Eocene transgressive sands are proven reservoirs. Older, mid to Late Cretaceous syn-rift deposits in Deepwater Taranaki may also have reservoir potential and Triassic–Early Cretaceous rocks contain potential reservoirs in Reinga-Northland. Submarine fan systems of Late Cretaceous to Miocene age may have reservoir potential, but their distribution and reservoir quality are poorly constrained. One exception are Late Eocene fans, which has some potential in northern Taranaki and Northland basins. Seals are well developed throughout the region, in the form of Late Cretaceous–Eocene marine mudstones as

well as Miocene-Pliocene marine shales. Oligocene–earliest Miocene marls are likely to have particularly good sealing properties.

ESTIMATES OF CRYSTALLIZATION PRESSURE AND MAGMATIC WATER CONTENT FROM TEPHRA LAYERS OF MT. NGAURUHOE, TONGARIRO VOLCANO COMPLEX

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Thermobarometry and plagioclase hygrometry applied to mineral and groundmass glass data from juvenile ash-size grains of three tephra layers from Ngauruhoe eruptions provide estimates of pressure, temperature and water content of the magmas. The tephra layers previously identified to be from Ngauruhoe eruptions were chosen because of good stratigraphic constrain, the layers date from 981 to 295 cal. yrs. BP. Groundmass glass compositions are mostly andesitic and mineral components for all tephra layers are plagioclase, clinopyroxene, orthopyroxene and titanomagnetite. One tephra layer included olivine. Results show a degassing trend (decreasing water with pressure) with a maximum magmatic H_2O content of 1.7 wt. % considering all layers. The maximum value for pressure is 5.9 kbar, equivalent to approximately 20 km depth assuming a crustal density of 2,800 kg/m^3. Minimum crystallization pressure for the microlites is at 0.8 kbar. The estimated water contents are considered low for subduction zone magmas. The low water content may indicate a source that is already degassed at depth or magmatism that is more related to an extensional environment.

SPELEOTHEM RECORDS OF NEW ZEALAND'S PREHISTORIC VOLCANIC ERUPTIONS

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Speleothems are mineral deposits of calcium carbonate formed from drip waters in caves, and are a novel and exciting means to investigate volcanic eruptions and their environmental effects. Speleothem chemistry reflects a number of factors, including overlying geology/vegetation, hydrology, temperature and rainfall. Speleothems can also be robustly dated using uranium-series methods and, as such, have been widely used to reconstruct paleoclimates. However, here we explore their potential to geochemically fingerprint volcanic eruptions, with chemical spikes in speleothem growth layers reflecting leaching of elements from overlying volcanic ash and subsequent changes in soil physico-chemical conditions triggered by the ash and "acidic" precipitation.

We have conducted a reconnaissance LA-ICPMS trace element study of a speleothem from the Disbelief Cave in the Wairoa River catchment (0.7–7.2 ka). Uranium-series ages for the speleothem have uncertainties of ±20 to ±60 yr (2 sd). Within the trace element record, there are numerous large spikes, sometimes 100-10,000 above "normal" values, for elements such as Li, B, and a range of other metals. The ages of these spikes show a marked correlation with known eruptions from Taupo and other central North Island volcanoes including, for example, a spike that correlates within <10 yr with the 232 AD Unit Y eruption. The identified spikes correlate with tephra preserved in Lake Tutira and Kaipo Bog.

Further work is proposed/underway to refine the record in this and other speleothems. If this proves reliable for identifying volcanic eruptions then it will be possible to: (1) Greatly refine the eruption ages of prehistoric eruptions in NZ given that uranium-series dating has some advantages over ^{14}C dating; (2) Identify prehistoric eruptions that are not preserved in the conventional geological record; (3) Quantify the nature, magnitude and longevity of the local and global environmental effects in the aftermath of (super)eruptions.

TREMOR AND LOW-FREQUENCY EARTHQUAKES ASSOCIATED WITH THE LATE-INTERSEISMIC CENTRAL ALPINE FAULT, SOUTHERN ALPS, NEW ZEALAND

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Characterising the seismicity associated with slow deformation in the vicinity of the Alpine Fault is important for understanding how the fault is currently being loaded, late in its typical earthquake cycle. In order to investigate the seismicity in detail, a network of short period seismometers, the Southern Alps Microearthquake Borehole Array (SAMBA) was deployed in 2008 in the central section of the Southern Alps. Using a continuous seismic dataset collected between 2009 and 2012, tectonic tremor was identified along the Alpine Fault. Fourteen families of low-frequency earthquakes (LFEs) were later identified manually within tremor periods and used in an iterative matched-filter routine to detect similar events. Reliable focal mechanisms have not yet been obtained for the LFEs, due to the difficulty of recognising distinct phases. Here, we use phase-weighted stacking in conjunction with a matched-filter routine to get a signal with the highest possible signal to noise ratio. We find this method to be successful in increasing the overall number of detected events by roughly 10% in comparison with linear stacking. Phase-weighted stacking also provides cleaner and more impulsive phase arrivals, potentially allowing signal polarities to be determined and focal mechanisms calculated. Our next step is to manually pick polarities on first arrivals of the phase-weighted stacked signals and compute preliminary locations. We are working to estimate LFE focal mechanism parameters and refine the focal mechanism solutions using an amplitude ratio technique applied to the linear stacks. LFE focal mechanisms should provide new insight into the geometry and rheology of the Alpine Fault and the stress field prevailing in the central Southern Alps.

PROCESSES INFLUENCING THE TIMING AND VOLUME OF ERUPTIONS FROM THE YOUNGEST SUPERVOLCANO ON EARTH

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In their stratigraphic records, caldera volcanoes often display a wide range of eruptive styles and volumes. However, relationships between frequency and magnitude are often chaotic, rather than linear, making the forecasting of future activity inherently problematic. Taupo volcano, New Zealand, provides a unique opportunity to investigate eruptive histories from a hyperactive, modern large silicic magmatic system. Taupo hosted the world's most recent supereruption at 25.4 ka, which discharged >1100 km^3 eruptive material in the Oruanui event. Only 5 kyr later, Taupo resumed erupting, with 3 dacitic eruptions from 21.5-17 ka and a sequence of 25 rhyolite eruptions from 12-1.7 ka. Here we use trends in whole rock, glass and mineral chemistry to show how the magma system re-established following the Oruanui supereruption, and to consider what processes influence the productivity of the modern volcano. The post-Oruanui dacites reflect the first products of the rebuilding silicic magma system, as most of the Oruanui mush was reconfigured or significantly modified in composition following thermal fluxing. Compositional variations within the younger rhyolites at <12 ka reflect fine-scale temporal changes in mineral phase stability, which are closely linked to the development, stabilization and maturation of a new silicic mush system. For the most recent eruptions, the system underwent widespread destabilization. Orthopyroxene Fe-Mg diffusion timescales indicate that the onset of rapid heating and priming of the silicic mush occurred <100 years prior to the <2.15 ka eruptions, with subsequent melt accumulation occurring in only decades. The largest eruption in the post-Oruanui sequence at 232 AD culminated from elevated mafic magma supply, rapid melt accumulation and high differential tectonic stress build up. The latest eruptions of Taupo highlight the multiple controls on the timing of eruptions, and demonstrate how the magmatic system can rapidly change behaviour on timescales of direct relevance to humans and monitoring initiatives.

NEW INSIGHTS INTO THE TECTONIC INVERSION OF NORTH CANTERBURY AND THE STRUCTURAL CONTEXT OF THE 2010-2011 CANTERBURY EARTHQUAKE SEQUENCE, NEW ZEALAND

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The 2010-2011 Canterbury earthquake sequence highlighted the existence of previously unknown active faults beneath the North Canterbury plains and Pegasus Bay, South Island, New Zealand. We provide new insights into the geometry and kinematics of ongoing deformation by analysing marine seismic data to produce new maps of regional faults and cross-sectional reconstructions of deformation history.

Active faulting and folding extend up to 30 km offshore, involving reactivation of Late Cretaceous-Paleogene normal faults under WNW-ESE tectonic compression. These reactivated faults consist predominantly of NE-SW striking, SE-dipping reverse faults, and less commonly E-W to NW-SE faults suitably oriented for strike-slip reactivation. Additionally, newly developing reverse faults obliquely segment and overprint the inherited basement fabric. Although inherited structures strongly control the kinematics of active deformation, the interfering development of new faults imposes geometric complexities revealed by reverse displacement profiles of late Quaternary markers. Tectonic inversion and overprinting, which overall are structurally immature, largely commenced after 1.2 ± 0.4 Ma with no evidence of systematic spatial migration of offshore deformation. Fault growth modelling involving trishear fault-propagation and folding mechanisms successfully restores progressive fault inversion, revealing an evolutionary sequence of reactivation of individual faults. Early stages of folding above a pinned or slowly propagating fault tip, were followed by rapid fault propagation up-section and continued folding. Quaternary reverse slip rates decrease from 0.1-0.3 mm/yr beneath northern Pegasus Bay, to <0.05 mm/yr approaching Banks Peninsula.

Our results, coupled with evidence gathered from the Canterbury earthquake sequence, have implications for ongoing seismic hazard assessment of this and potentially other regions in New Zealand characterised by low-strain inversion tectonics and blind faults buried beneath thick sedimentary sequences. We infer that blind faults beneath Pegasus Bay may generate earthquakes with magnitudes ranging from about M_w 6.2 to 7.1, and with recurrence intervals of the order of 3-20 kyr.

SOUTHERN ALPS GLACIAL HISTORY – SNAKES AND LADDERS

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The evolution of interpretation concerning Quaternary glacial history in the Southern Alps provides some intriguing scientific insights. Ice-age theory developed in the European Alps by Agassiz and colleagues in the 1800s provided a paradigm that assisted in the parallel recognition of ice-age features in New Zealand by Von Haast. Emerging evidence worldwide for multiple episodes of glaciation, from terrestrial deposits and especially from isotopic signatures within marine sediments, provided a means to interpret and subdivide Southern Alps Quaternary stratigraphy. A long-standing inability to obtain ages for poorly fossiliferous Quaternary terrestrial deposits has necessitated recourse to age inference by whatever criteria seem relevant, for the production of chronostratigraphic geological maps.

Analogy can be drawn from the board game of snakes and ladders, with a ladder affording rapid forward progress and a snake offering a rapid slide backwards. Conceptual frameworks of inferred ages represent ladders of understanding, and age hypotheses can be tested as suitable technologies emerge. Some interpretations encounter a snake, for example using cover-bed soil stratigraphy in conjunction with cosmogenic dating, Almond and Barrows found that the type area defined by Suggate in North Westland to represent the Early Otira Glaciation (Marine Isotope Stage 4; ~74-59 ka) is of Late Otiran age (MIS 2). The trip down the snake for Suggate's interpretation was eased by the confirmation, using cosmogenic dating, of extensive Early Otiran glacial moraines at Lake Pukaki in inland Canterbury by Schaefer and colleagues. Another snake/ladder example is the Waiho Loop moraine of South Westland, where a conceptual ladder afforded by an inferred landslide-driven glacier advance for moraine formation (Shulmeister and colleagues) has encountered snakes in the form

of lithological data that challenge the interpretation, and results of computer modelling (Alexander et al.) discounting the physical possibility of the putative landslide-driven glacier advance. Other examples will be discussed.

DUNEDIN URBAN GEOLOGY MAP – PROGRESS REPORT

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Dunedin is one of the initial target cities for GNS Science's urban geological mapping project, which aims to produce detailed geological maps and associated datasets for urban areas of New Zealand. The Dunedin urban area and immediate environs has varied geology, encompassing Mesozoic schist basement, a typical eastern South Island Late Cretaceous – mid-Miocene sedimentary succession, and mid-late Miocene intraplate volcanic strata, along with fluvial, colluvial, aeolian and marginal marine Quaternary sediments. Substantial relief is associated with Late Cenozoic fault blocks, and there are potentially active faults. Geological exposure is sufficient for the construction of a reasonably well-constrained geological map, and the project has generated a 1:25,000-scale geological map, supplementing information from previous 1:25,000 and 1:50,000 scale maps. A geomorphology map, emphasising land surface ages and processes of formation will be an additional component of the dataset. Drillhole data are sparse compared to some urban areas, such as Christchurch, and only a very generalised 3D geological model will be produced, primarily intended to aid visualisation rather acting as a quantitative resource. Recently completed work by GNS Science on liquefaction susceptibility and landslide susceptibility in the Dunedin area, commissioned by Otago Regional Council, will contribute hazard information resources for the published product. The geological and geomorphological maps will be accompanied by an illustrated text describing the geology of Dunedin City. The product will be delivered in digital form via DVD, with map images, text, 3D geological models, and GIS vector data.

EXPLORING METHODS OF ASSESSING LIQUEFACTION HAZARDS

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Liquefaction during the 2010 M_w 7.1 Darfield earthquake and large aftershocks (Canterbury earthquake sequence, CES) caused severe damage to land and infrastructure in Christchurch, New Zealand. Post-insurance pay out losses from the liquefaction-induced damage exceed $NZ 1b, which far exceeds the damages caused by the seismic-shaking alone. Determining liquefaction susceptibility and understanding the factors which affect the distribution of liquefaction is important for reducing losses during future earthquakes. Current practice for assessing liquefaction susceptibility for proposed land developments utilises site-specific geotechnical testing (i.e. CPTu) and given ground motions. MBIE guidelines state a minimum number of tests required per land area, however no constraint is given on the position of the testing. In this study we show that the distribution and severity of liquefaction within Avonside in eastern Christchurch was strongly influenced by geomorphic, geologic, and topographic variability during the CES. Liquefaction features and lateral spreading-induced horizontal displacements were highest proximal to the modern Avon River, and in areas underlain by paleo-channel deposits on the inside meander-bends. Comparably less damage occurred in the higher elevation paleo-dune deposits within the suburb. Paleo-liquefaction investigation also conducted within the suburb revealed paleo-liquefaction dated to post 1660 AD to pre ca. 1905 AD at one site, and post 1435 AD to pre ca. 1910 AD at another site, thus confirming the area had previously liquefied. We argue that geomorphic, geologic, geomorphic, and topographic variability may also be applied to identify areas susceptible to liquefaction, in absence of dense geotechnical testing. Geomorphic mapping should also be applied to better inform placement of any geotechnical testing to ensure that the geologic variability across the site is accurately represented. Paleo-liquefaction investigations may also be employed to assess whether the area has previously liquefied and constrain the approximate timings of historic or pre-historic earthquakes triggering liquefaction.

NEW STRATIGRAPHIC CONSTRAINTS ON THE TECTONIC DEVELOPMENT OF THE AORANGI RANGE, WAIRARAPA

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Late Miocene-early Pliocene stratigraphy varies markedly in the northern Aorangi Range, with changes from mudstone formed at bathyal depths to coarse shell-hash limestone indicative of high energy coastal environments occurring over distances of only a few kilometres. Despite major differences in lithology, the Clay Creek Limestone and Bells Creek Mudstone are shown to be partially laterally equivalent, while the overlying Makara Greensand is shown to be a diachronous unit which ranges from late Miocene (Kapitean) to early Pliocene (Opoitian) in age. This revised stratigraphy provides new insights into regional geological history. The late Miocene-early Pliocene stratigraphy records a history of regional subsidence, punctuated by episodes of deformation which caused significant localised uplift and erosion. Previous seismic imaging studies identified one such episode of accelerated crustal shortening and deformation in the Wairarapa region near the Miocene-Pliocene boundary. The Clay Creek Limestone has proven to be a useful marker horizon for constraining the timing and style of deformation, which is interpreted to have occurred prior to 7.2 Ma. Major differences in stratigraphy between the upthrown and downthrown sides of the Mangaopari Fault indicate that the fault was active during this deformational episode.

UNDERSTANDING THE MAGMATIC EVOLUTION OF AKAROA VOLCANO THROUGH A TEXTURAL AND GEOCHEMICAL ANALYSIS

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Plutonic lithics in lava domes of Banks Peninsula provide rare insight in to the magmatic evolution of Cenozoic volcanism on the Peninsula. Goat Rock, part of the Akaroa Volcanic Phase (9.4-8.0 Ma), is a mafic lava dome that contains lithics (up to 17 cm) of varying textures including prominent schlieren fabrics. Electron backscatter diffraction (EBSD) was used to collect crystallographic preferred orientation (CPO) data on five schlieren samples to examine pre-eruptive magmatic processes.

Plagioclase CPO in four samples have very strong clustering of the {010} with the {001} and <100> distributed in a broad great circle to the {010} cluster in both hemispheres. <100> has a distinct maximum within the great circle. A similar pattern characterizes the fifth sample, except the {010} is spread around a great circle. In all samples, individual plagioclase grains are distorted up to 10 degrees: {001} and <100> lie on segments of great circles that contain the {010} cluster. Augite and olivine have weak, non-random CPOs that share symmetry with the plagioclase CPO.

Bulk-rock geochemistry was conducted on the schlieren samples in addition to a texturally representative population (determined petrographically) of lithics including samples with no obvious fabric. All lithics range in composition from 45.3-54.9 SiO_2 wt% with associated host material from the dome restricted to 48.8-50.6 SiO_2 wt%. Schlieren samples fall between 45.4 and 47.5 SiO_2 wt%.

Our preliminary analysis shows that plutonic lithics with similar textures form distinct geochemical groups suggesting that the eruptive event that produced Goat Rock tapped a stratified magma body or discrete but related crystal mush zones. Such sources may have included cumulate material formed by settling/flow and compaction involving physical grain rotation and internal distortion by dislocation mechanisms. This study improves our understanding of the magmatic processes on Banks Peninsula and the application of EBSD to igneous systems.

IMAGING THE UPPER-CRUSTAL RESISTIVITY STRUCTURE OF THE TAUPO VOLCANIC ZONE WITH MAGNETOTELLURIC DATA

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The Taupo Volcanic Zone (TVZ) is a rifted arc characterised by intense rhyolitic volcanism associated with 8 calderas and supports more than 20 high-temperature liquid-dominated geothermal systems. During the past 6 years, over 400 broadband Magnetotelluric (MT) measurements have been made that form two distinct arrays (2 km site spacing) in the northern and southern TVZ. The largest array (300 sites) includes parts of the Whakamaru, Reporoa and Ohakuri calderas, and encompasses the geothermal fields at Atiamuri, Orakei-Korako, Te Kopia, Ngatamariki, Rotokawa and Ohaaki. The northern array covers the Rotorua and Waimangu geothermal fields, and parts of the Rotorua, Kapenga and Okataina calderas.

3-D inversion models of these MT data image the electrical resistivity structure of the upper crust down to ~10 km depth; including the uppermost brittle or seismogenic part of the crust. These regional-scale resistivity models show good spatial correlation between the locations of some of the geothermal fields and basement low-resistivity zones at the margins of nearby collapse calderas. In particular, the Rotokawa, Rotorua and Waimangu geothermal fields lie above very low-resistivity zones at about 3-5 km below the surface, which we interpret to mark bodies of crystalizing silicic magma and associated regions of near magmatic fluid. Our results suggest that the relationship between the geothermal systems and volcanism in the TVZ is much closer and more direct than envisaged by previous conceptual models of heat transport.

ESTUARINE MOLLUSCAN FAUNA OF THE OLIGOCENE POMAHAKA FORMATION, SOUTH OTAGO

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The unique Duntroonian estuarine molluscan fauna of the Pomahaka River and Waikoikoi Stream, near Tapanui, is revised fully for the first time. Taxa present are **Barbatia* (*Savignyarca*), *Brachidontes*, *Xenostrobus*, *Crassostrea*, *Saccostrea*, Hyriidae (genus?), *Arthritica*, *Maoricardium* fragment, *Spisula* (*Spisulona*), *Tellinota*, *Hinemoana acuminata* (Hutton), *two new genera and species of Veneridae, *Tapes*, **Potamocorbula*, *Periploma*, *Martesia concentrica* Suter, *Sarmaturbo* fragment, *Neritina*(?) *pomahakaensis* (Finlay), *Batillaria pomahakensis* Harris, *Batillona* amara Finlay, **Melanoides*, *Zemelanopsis pomahaka* (Hutton), *Grandicrepidula salebrosa* (Marwick), **Halopyrgus*, **Hydrococcus*, *Onoba*, *Lunatia*, *Pomahakia aberrans* Finlay, *Vesanula*, and **Salinator* (the earliest fossil record of mud-snails, Amphibolidae). Taxa with *asterisks are the first fossil records in New Zealand; five genera (underlined) and most species are recorded only from Pomahaka. Two new genera and 17 new species will be named, along with the earliest species of the estuarine genus *Austrovenus*, from Brydone, Mataura River (Waitakian) to show its lack of relationship to Pomahaka venerids. Several taxa have relatives in tropical present-day estuarine faunas in the Philippines: *Barbatia*, *Brachidontes*, *Potamocorbula*, *Martesia*, *Neritina*, Thiaridae (although distinct genera), and *Salinator*. Other mangrove "mud-creeper" cerithioideans such as *Terebralia*, *Zefallacia* and *Taxonia*, which occur at shallow-water Oligocene localities nearby (Mataura River, Cosy Dell near Waimumu) are absent from Pomahaka, suggesting very low salinity at Pomahaka. Sea temperatures were significantly warmer than in New Zealand today, and although mangroves probably lived nearby, there is no direct evidence of them. Deposition took place in a muddy estuary, varying from channels to high-tidal mud-flats and freshwater streams, similar to mouths of rivers entering Moreton Bay, Queensland today. This large estuary, with five restricted molluscan genera suggesting it was long-lived, provides further evidence that southern New Zealand was not totally inundated during Oligocene time.

IMPACTS OF AN AUCKLAND VOLCANIC FIELD ERUPTION ON CRITICAL INFRASTRUCTURE: EXTENDING THE MT RUAUMOKO SCENARIO

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Mt Ruaumoko is a hypothetical volcano in the Auckland Volcanic Field (AVF) that first transpired during Exercise Ruaumoko, the largest Civil Defence and Emergency Management (CDEM) exercise held in New Zealand. The exercise focussed on the lead-up to an eruption and was later developed by the University of Canterbury for educational simulation purposes, continuing the evolution of Mt Ruaumoko volcano through its eruptive phase. Here we present new work examining the hypothetical consequences of an eruption in the AVF by evaluating impacts and restoration time during and following the Mt Ruaumoko scenario for a variety of sectors. Our results will be used by the Economics of Resilient Infrastructure (ERI) research programme, a four-year project funded by the New Zealand government to quantify the impacts of natural hazards on infrastructure and to model the economic consequences.

Our study provides snapshots of volcanic hazard extent and severity at relevant timesteps during the Mt Ruaumoko eruption. Based on the hazards, Auckland CDEM contingency planning, new Volcanic Alert Level designations and recent tephra clean-up research, we develop evacuation zones and a clean-up model for the scenario. Comprehensive infrastructure impact and service outage maps, informed by worldwide research and recent discussions with infrastructure providers and emergency management officials in Auckland, form the bulk of our work.

We find that substantial disruption, particularly to transportation, occurs even before the eruption begins, following the implementation of evacuation zones and Civil Aviation Authority guidelines. The majority of physical damage and disruption to infrastructure occurs as a result of the initial pyroclastic surge, with further disruption caused by tephra fall events, which also require extensive clean-up efforts. The eruption is over in a month, but the ramifications for infrastructure continue for years.

Our study is the most comprehensive consideration to date of the societal consequences of an AVF eruption, and highlights the wide-ranging and sometimes surprising impacts such an event could impose on New Zealand's largest city.

ASSESSING NEW ZEALAND'S PETROLEUM ENDOWMENT: THE ATLAS OF PETROLEUM PROSPECTIVITY

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Where, in New Zealand's extensive offshore territory, does the geological evidence indicate that new petroleum fields are likely to be discovered, and which of New Zealand's numerous offshore sedimentary basins will host the next commercial discovery? A recently-initiated 4-year Government-funded (MBIE) research programme at GNS Science aims to address these questions.

The "Atlas of Petroleum Prospectivity" (APP) programme is synthesising the wealth of existing and new data, information, and knowledge within GNS Science and additional open-file sources, to produce a nationally-significant baseline reference dataset. This dataset will, for the first time, summarise in one place the current understanding of our geologically complex offshore petroleum basins, providing a consistent template for evaluating petroleum prospectivity within and between basins across Zealandia. APP will also provide a basis for promulgation and technical administration of exploration permits, and for identifying where new geoscience data and interpretations are required to better demonstrate petroleum potential.

APP is delivering a series of GIS-based digital maps of all key petroleum systems elements in NZ's offshore sedimentary basins. Map layers include total sediment thickness, paleogeography, basement lithology, source and reservoir rock distribution, source rock maturity, heat flow, structure, trap distribution, and other salient information. We are adopting a "common risk segment" approach to delineate exploration play

fairways, evaluate areas of highest prospectivity, and identify areas with poor data control or availability. Petroleum systems in each basin will be evaluated and calibrated with respect to previous exploration drilling successes and failures. The APP will provide a basis for developing new exploration concepts and strategies in the increasingly sophisticated search for new petroleum reserves.

Compilation and assessment of the Taranaki-Northland-Reinga basins is well underway, and compilation and mapping of the Great South-Canterbury and Pegasus-East Coast-Raukumara basins has commenced. Basins of the "far frontiers" will be progressively assessed in coming years.

FRICTIONAL PROPERTIES OF ALPINE FAULT GOUGES AND CATACLASITES

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The Alpine Fault accommodates c. 75% of the total relative Australia-Pacific plate boundary motion and ruptures episodically in large-magnitude earthquakes. Most fault slip has occurred within a gouge-filled principal slip zone (PSZ) bounded by altered cataclasites and ultramylonites. The frictional properties of these fault rocks influence Alpine Fault behaviour throughout the seismic cycle. To understand the potential for fault lithologies to nucleate earthquakes, we conducted hydrothermal ring-shear experiments at temperatures of 25°C, 150°C, 300°C, 450°C, and 600 ºC. We observed that all samples: (1) are frictionally strong (μ>0.6), except when sliding velocity is v<0.3 μm/s and temperature is high (T≥450 ºC), (2) show negative *(a-b)* values coincident with regular stick-slips (i.e. laboratory earthquakes) at T=300°C, and (3) behave frictionally, with shear stress linearly dependent on normal stress at a strain rate of 10^{-5} s^{-1}, even at T=600°C. Our results constrain the temperature range of maximum frictional instability and support observations of rupture propagation into the ductile lower crust. To gain further insight into coseismic slip processes, we conducted room-dry and wet high-velocity (v=1 m/s), low applied normal stress (σ_n=1 MPa) experiments using a rotary-shear apparatus. Experiments conducted on wet smectite-bearing PSZ fault gouges had the lowest peak friction coefficients (μ_p=0.13-0.21) and lowest steady-state friction coefficients (μ_{ss}=0.02-0.10). Thus, smectite-bearing PSZ gouges are strongly velocity weakening at coseismic slip rates. Finally, we used a triaxial deformation apparatus to study post-seismic healing in PSZ gouges. In room-temperature experiments conducted at an effective normal stress of σ_n'= 30 MPa and sliding velocities of v=0.1-10 μms^{-1}, we investigated how diffusion of pore fluid overpressures in low-permeability gouges (k<c. 10^{-21} m^2) may contribute to high values of frictional healing (β≈0.01). In summary, we present new data on the preseismic, coseismic, and interseismic behaviour of Alpine Fault rocks, with a particular focus on PSZ gouges.

SUBSEISMIC-TO-SEISMIC FRICTIONAL PROPERTIES OF AN ANALOGUE FAULT GOUGE

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Collectively, faults exhibit slip modes that span the continuum between slow-slip events and earthquakes. While slip is driven by an applied shear stress, the frictional properties of materials forming the fault plane govern the structure's slip mode. In this study, we describe a ring shear apparatus that simulates slip at subseismic (v=40-100 mm/s) to seismic (v>100 mm/s) velocities; we also document data obtained from analogue fault gouge experiments. The University of Canterbury (UC) Ring Shear comprises a variable speed drive that controls a 3-phase 7.5 kW motor, which rotates a ring shear cell containing granular material loaded by a piston attached to a removable upper platen.

Normal force is applied via a loading arm. A LabJack UE9 Data Acquisition Card records analog signals from the normal load cell, two torque arm load cells, a linear vertical displacement transducer (LVDT), and a rotary encoder. Using the UC Ring Shear, we conducted 12 experiments on an analogue fault gouge composed of 400 σ_n-diameter glass beads at applied normal stresses (σ_n) between σ_n=0.83 MPa and σ_n=3.18 MPa. In 3 large-displacement experiments on room-dry glass beads sheared at v=80 mm/s and v=200 mm/s, we recorded average steady-state friction coefficients (μ_{ss}) of μ_{ss}=0.403±0.06 (n=19), with little correlation between μ_{ss} and normal stress, velocity, and/or displacement. In 9 other large-displacement experiments, 8 to 9 wt.% water was added to the analogue gouge prior to shearing at *v*=40 mm/s, *v*=80 mm/s, *v*=163 mm/s, *v*=200 mm/s, and *v*=400 mm/s. We observed three frictional regimes in the wet experiments: strain-weakening, steady-state sliding, and strain-hardening. Steady-state friction coefficients decreased with increasing sliding velocity from μ_{ss}=0.17-0.18 (n=2) at v=40 mm/s to μ_{ss}=0.10 (n=1) at v=400 mm/s. We suggest that μ_{ss} variations reflect the degree of strain localization and alternation between drained and undrained loading within the shearing gouges.

STRUCTURE OF THE CRUST-MANTLE BOUNDARY ALONG THE CENTRAL ALPINE FAULT FROM RECEIVER FUNCTION ANALYSIS

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We determine the seismic structure of the Moho along the central Alpine Fault (Fox Glacier to Hokitika) to help understand its relationship to the distribution of seismicity and other seismic phenomena, such as tremor and low-frequency earthquakes, identified in this region. We compute P receiver functions from P-to-S conversions to characterise the seismic properties of this boundary. We also use S receiver functions calculated from S-to-P conversions where crustal reverberations mask the primary P-to-S conversions. Our preliminary dataset is composed of waveforms from 700+ candidate teleseisms of magnitude 6 or larger earthquakes recorded by the SAMBA (2008–present), ALFA (2008–2009, 2012), WIZARD (2012) temporary deployments, DFDP stations (2014–present) and GeoNet stations WVZ and FOZ from the New Zealand Seismograph network.

GEOPHYSICAL CHARACTERISATION OF THE HINDON MAAR COMPLEX

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In 2007, airborne geophysical surveys identified four subcircular basins presenting high magnetic intensity near Hindon, 25 km NW of Dunedin, within the Miocene Waipiata Volcanic Field (WVF). Similar magnetic anomalies within the WVF are associated with maar-diatreme structures, e.g. at Foulden Maar or Gladsmuir diatreme. Subsequent excavations produced evidence that at least two of the basins contain extremely fossiliferous laminated diatomite and/or carbonaceous mudstone, likely deposited in former maar-lakes. Surface exposure is very limited, indicating that geophysical surveys including ground-based magnetic, microgravity and seismic surveys are essential for capturing and accurately representing the size, depth and sediment infill of all four maar-like structures.

The higher magnetic susceptibility of the basaltic diatreme allowed for ground-based magnetic surveys to accurately characterise the size and extent of all four structures. It was found that these structures are present over an area of 16 km^2 and are individual anomalies likely related to the same magma source. The relative density of rock within the maar complex then allowed for microgravity surveys to be conducted. Schist has a density of 2.73 g/cm^3, basalt 2.77 g/cm^3 and diatomite 1.53 g/cm^3. The significant decrease in density of diatomite in the subsurface produces a negative anomaly that has been characterised by the Worden Gravimeter. Two maars have yielded negative anomalies relating to a thickness of diatomite in the subsurface. The final geophysical method was a seismic survey conducted in Maar One; processing of this data is still underway.

The seismic plot will reveal the thickness and lithologies of the sediment infill, and this will clarify whether at least one of these deposits is a suitable candidate for full coring and paleoenvironmental

studies, as at Foulden Maar some 25 km to the northwest. New samples of volcanic rock have been selected for radiometric dating to confirm the early Miocene age established by preliminary palynological biostratigraphy.

CHROMITE COMPOSITIONS IN RELATION TO THE TECTONIC SETTING OF THE DUN MOUNTAIN OPHIOLITE BELT, EAST NELSON

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In the Dun Mountain Ophiolite Belt (DMOB) in east Nelson, chromite lenses occur in a lower zone of serpentinised dunite and harzburgite from Wooded Peak (Dun Mountain) south to Little Ben, and also in an upper dunite-rich zone in the Red Hills massif and a southern outlier at Baldy Ridge. Previous analyses of disseminated chromite samples from Red Hills peridotites show a trend from low to medium Cr# (Cr + Al/Cr) and lie mainly in the field of ocean ridge peridotites, although some "upper unit harzburgite and dunite" chromites plot in the part of this field that overlaps with arc-related ophiolitic chromites. Our EPMA analyses of chromite from chromite lenses in the east Nelson DMOB show a compositional range that is typical of ophiolitic chromites, with a wide range in Cr# (0.48-0.84). The TiO_2 contents of chromite in the chromite lenses are low (0.04-0.36%), but less variable than the disseminated chromites from Red Hills (0.02-0.65%). A Cr# vs. TiO_2 diagram discriminates between the effects of partial melting and melt-rock reaction within mantle peridotites, and shows that most of the chromites from the "lower unit harzburgite" at Red Hills represent 15-20% partial melting, whereas most of the chromites in the "upper unit dunite and harzburgite" indicate 18-30% partial melting and reaction with a more Ti-rich melt of mid-ocean ridge basalt (MORB) to island arc tholeiite (IAT) composition. Chromites in the chromite lenses show 25-40% partial melting and reaction with melt of MORB, IAT or boninite composition.

These trends in chromite compositions, both in the Red Hills peridotite and in the chromite lenses, are consistent with initial formation of peridotite, mainly harzburgite, in an ocean ridge setting that evolved into overlying cumulate dunites and gabbros in a forearc or island arc setting, i.e. in a supra-subduction zone.

GEOCHEMISTRY OF CHROMITE, PLATINUM GROUP ELEMENT (PGE) AND NICKEL MINERALISATION IN THE DUN MOUNTAIN OPHIOLITE BELT, EAST NELSON

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In the Dun Mountain Ophiolite Belt (DMOB) in east Nelson, podiform chromite lenses occurs in a lower zone of serpentinised dunite and harzburgite at the top of a peridotite tectonite unit from Wooded Peak (Dun Mountain) south to Little Ben. Chromite lenses also occur in an upper dunite-rich zone at Lowther Creek in the Red Hills massif and in a southern outlier at Baldy Ridge. Chromite samples from the Wooded Peak to Little Ben segment and Lowther Creek have elevated concentrations of iridium (Ir, 12-83 ppb) and ruthenium (Ru, 22-154 ppb), with generally low concentrations of rhodium (Rh), platinum (Pt) and palladium (Pd). These levels are similar to those found in podiform chromite deposits in ophiolites worldwide. Chromite samples from Baldy Ridge have elevated concentrations of Rh (50-58 ppb), Pt (717-1069 ppb) and Pd (287-531 ppb), a similar level to that found in lower crustal cumulate dunite zones in some other ophiolite complexes. EPMA analyses of chromite show a wide range in the Cr/(Cr + Al) ratio (0.48-0.84), which is typical of ophiolitic chromites. Samples from Lowther Creek and Baldy Ridge contain composite grains of pentlandite + magnetite ± pyrrhotite ± pyrite ± chalcopyrite that represent intercumulus blebs of magmatic sulphide. Serpentinite samples from Baldy Ridge, Wooded Peak and Dun Saddle contain minor awaruite (Ni_3Fe) ± magnetite ± heazlewoodite (Ni_3S2) formed from serpentinisation of primary olivine. We suggest that the ultramafic rocks of the DMOB in east Nelson have largely untested exploration potential for: 1) Rh-Pt-Pd-enriched chromites and Ni-Cu sulphides associated with cumulate dunite zones (Baldy Ridge and Red Hills), and 2) disseminated Ni-Cu mineralisation in serpentinites.

HOW PYROCLASTIC FLOWS ATTAIN HIGH VELOCITIES – NEW INSIGHTS FROM LARGE-SCALE EXPERIMENTS

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Explosive volcanic eruptions are most deadly when highly mobile pyroclastic density currents (PDCs) sweep down mountain flanks after eruption columns or lava domes collapse. One of the ultimate goals in volcanic hazard assessment is to predict the velocity of PDCs. However, interrogating PDCs is only practical in the laboratory, but this introduces the problem of scale where it is difficult to minimise the boundary layer effects and replicate the large inertia of the flows. Therefore, we generated large-scale PDCs by gravitational collapse of 1.5 tonnes of a natural pyroclastic mixture and examined velocity fields on various inclined slopes.

We show that PDCs experience expulsion of gas at impact that moves at 200-250% of free fall velocity. The fast-moving gas entrains ash-size particles and yields a fast-moving turbulent and dilute ash-cloud that becomes the flow head. The turbulent cloud moves ahead of a dense basal avalanche created upon impact, the latter propagates downslope with an initial velocity dictated by the potential energy at impact. We show that the velocity-dependent friction coefficient (which represents the rate of energy dissipation) fully explains the kinematics data of the basal avalanche. In cases where the flow front velocity exceeds at all times the basal avalanche velocity, we propose a way to quantify the asymptotic waning of the turbulent flow front velocity with distance. We succeed to theoretically model the deceleration of the flow front and match experimental data, using measurements of the flow head geometry and density. Flow front velocities are dependent on the initial "blast" density, in which high velocities lead to supercritical flow regime. Furthermore, we show that the interplay between the supercritical turbulent flow front and the presence of a basal avalanche leads to the formation of a wedge-shaped head characterized by high entrainment coefficients.

EVALUATION OF ELECTROMAGNETIC CONDUCTIVITY METERS FOR NEAR-SURFACE SOIL INVESTIGATIONS: CMD-EXPLORER AND DUALEM-42

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We evaluated two electromagnetic induction (EMI) systems for near-surface investigations, the GF Instruments CMD-Explorer and the DUALEM-42. EMI techniques are useful in a range of subsurface investigations, such as environmental and engineering geology. In particular, landfill waste properties closely correlate with apparent electrical conductivity (σ_a) signatures. σ_a is a depth-weighted, average conductivity measurement for a column of earth to a specific depth. Electromagnetic induction sensors measure changes in subsurface σ_a, and variations in σ_a are produced by changes in the electrical conductivity of earth materials, increasing with soluble salt, liquids, clay contents, and temperature.

The CMD-Explorer and DUALEM-42 systems were applied to a waste landfill site near Tamworth, New South Wales, to assist in delineating the spatial extent of buried waste ("cell") fill. Both instruments simultaneously obtain quadrature (σ_a) and in-phase (related to magnetic susceptibility, k_a) data from a range of depths. As the maximum depth range is >6 m, analysis of the subsoil conditions within that range is possible. In horizontal coplanar (HCP) mode, the CMD-Explorer simultaneously collects σ_a and k_a data at peaks of 6.7 m, 4.2 m, 2.2 m depth, while the DUALEM-42 simultaneously collects data at 1 m, 2 m, 3.2 m, and 6.4 m depths. A series of test pits were used to 'ground-truth' the EMI data, allowing correlation of with subsurface materials.

Typical values of σ_a for soil and saprolite were 10-50 mS/m, landfill waste and leachate 50-160 mS/m, and metallic structures >160 mS/m. The pattern of σ_a from both tools was remarkably consistent at the 2.2 m/2 m depths. However, at the 6.7 m/6.4 m investigation depths, spatial patterns of σ_a from the

different tools showed marked divergence. In summary, EMI tools can facilitate collection of large volumes of moderate to high resolution data, but results are site-specific, varying due to multiple subsurface properties.

ENGINEERING GEOLOGICAL ASSESSMENT OF FLOOD LEVEE STABILITY USING MULTICHANNEL ANALYSIS OF SURFACE WAVES AND ELECTRICAL RESISTIVITY IMAGING

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Levee embankment stability assessments are critically important because embankments and earth dams are subject to water infiltration and internal erosion, which may lead to mechanical weakness and even breaching. We document the results of a 300 m, 2D longitudinal survey along the crest of a levee using Electrical Resistivity Imaging (ERI) and Multichannel Analysis of Surface Waves (MASW). The surveys were in response to surface cracking and subsidence along the levee surface. In particular, a 100 m section along the levee crest showed continuous cracks (aperture 10 cm, depth 200 cm). Cracking relates to high strain, induced by variable near-surface subsidence, itself due to erosional piping of fine-grained sediments.

Modelled ERI results showed a horizontally-layered structure, with moderate near surface resistivities and low resistivities representing saturated conditions below 5.5 m depth. Relatively high resistivities modelled below 12 m depth represent weathered bedrock. ERI anomalies selected for further investigation were apparent as laterally-constrained areas of high resistivity at surface, underlain by relatively low resistivity at 2 m to 5.5 m depth. These features were interpreted as discrete zones where rainwater percolates more deeply into the levee, with the high resistivity at the surface representing an air-filled crack, an entry point for rainwater.

MASW data follows the pattern of the ERI results, that of a stratified subsurface. Very low Vs in the zone of large surface cracking indicates decreased stiffness/density of the near subsurface, while a low Vs layer at 6 m to 11 m depth represents lower shear moduli at depth due to groundwater infiltration. The corollary is that the integration of geophysical, sedimentary and topographic data, even if only at a few locations, can help locate anomalous zones in sub-levee soil between geotechnical boreholes. Preventive monitoring of flood-protection barriers stands to benefit from integrated geophysical datasets "ground-truthed" with geotechnical data.

MODELLING NEW ZEALAND'S TARANAKI BASIN: RESULTS FROM THE 4D TARANAKI PROJECT

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The southern Taranaki basin has been mapped and modelled as part of the multi-phase, multi-disciplinary 4D Taranaki Project at GNS Science. This flagship mapping project forms a new benchmark reference volume for New Zealand's only hydrocarbon producing basin. It delivers an increase in spatial and temporal resolution over previous regional studies that allows for an improved understanding of the area's geological development and petroleum systems.

A high resolution 3D geological model of the southern Taranaki Basin has been completed, covering an area of ~32,000 km^2, based on interpretation of 15 regionally mapped seismic reflection horizons spanning the Late Cretaceous to the Plio-Pleistocene. The 3D model and maps have a temporal resolution of ~1-4 Myr since 23 Ma and ~5-10 Myr prior to the Miocene. We present the main outputs of the project, including time structure, depth structure and isopach maps, along with a discussion of how the project has identified rapid changes in the basin's evolution and better illustrates the structural complexity. In addition we show how the project results have been applied to related research, including thermal and petroleum systems modelling, seismic facies mapping and paleogeographical analysis.

THE 'AWESOME FORCES' REBUILD

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How, what and why to present earth science to the public at the National Museum of New Zealand Te Papa Tongarewa?

These questions have not really been addressed since the mid-1990s. Now we, the earth science community, have the opportunity to do so again for the first time in 20 years.

Along with EQC, GNS Science is a founding sponsor of Te Papa, and has been since 1997. These three 'partners' bring very different attributes to the table. Respectively they may be thought of as the bank, the brains and the beauty….in that order. Te Papa was opened in February 1998 and at its centre in a prime location on Level 2, was and still is, 'Awesome Forces'. The original concept description for this 'permanent' exhibition was prepared under contract by GNS Science in 1993 and co-authored by Alan Hull and myself.

The current sponsorship relationship is about half way through its fourth five-year cycle, and will be up for reconsideration in 2017. This unusual three-way relationship has been described as strong, successful, and enduring. Based on market research, 'Awesome Forces' can claim to be one of the most successful museum exhibitions in the world. However, it is now 17 years old and although there have been some segmental upgrades over the years it is showing its age.

A completely new 'natural sciences gallery' is planned and it will provide an opportunity for a completely fresh approach to the earth science content.

It is early days yet, so there is plenty of scope for input from the New Zealand earth science community. The planning process has commenced but the intent is to have this rebuild complete by late 2017.

TEMPERATURES AND THERMAL PROPERTIES OF THE ALPINE FAULT'S HANGING WALL

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Here we present in-situ temperature measurements acquired to a depth of 893 m adjacent to the Alpine Fault and laboratory measurements of the thermal properties of hanging wall lithologies.

During the DFDP-2 campaign in late 2014, 16 wireline temperature logs were acquired after circulation had stopped. Temperature profiles acquired at different times after circulation enable us to examine the evolution of temperatures towards equilibrium and thus estimate the thermal diffusivity of the rock environment in the Alpine Fault's hanging wall. For comparison, measurements of the thermal conductivity and diffusivity of major lithologies were measured in September 2015 using the transient heat source ("Hot Disk") method. Specimens of the Alpine Schist and mylonite were taken from the Amethyst Hydro Tunnel drill core and outcrops at Stoney Creek and Tarpot Creek, respectively. We examined the effect of increasing temperature on thermal conductivity and diffusivity under dry and saturated conditions.

A multi-strand fibre-optic cable installed along the full length of the 893m-deep borehole has been used to make repeated temperature measurements on an approximately two-monthly basis since January 2015. Local temperature anomalies correlate with fractures identified in borehole televiewer and laterolog (resistivity) data. Zones where temperature profiles differ from the average geothermal gradient indicate thermal disturbance, caused by advection of heat by fluids. The identification and characterisation of flowing fractures provides insight into the permeability structure in the Whataroa Valley and thus into the thermal and hydraulic state of the central Alpine Fault late in the interseismic cycle.

LOW-FREQUENCY EARTHQUAKES HIGHLIGHT DEEP SLIP OF THE ALPINE FAULT

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Using a brightness-based beamforming approach coupled with a matched-filter correlation method, we have developed an objective and continuous record of low-frequency earthquakes (LFEs) occurring on and near the deep extent of New Zealand's Alpine Fault. Our brightness template detection method, based on that of Frank et al. (2014), scans a pre-determined grid of possible seismic sources to automatically find LFE templates based on the stack of bandpassed squared seismic data. Previous work (Wech et al., 2012, Chamberlain et al., 2014) has shown that the depths of standard seismicity are anti-correlated with those of tremor and LFEs in the central Southern Alps: hence, by careful grid selection, shallow seismic sources can effectively be discriminated against. This beamforming approach produces many (>900) possible events. Initial beamforming detections are grouped by moveout and stacked to produce a subset of higher-quality events for use as templates in a cross-correlation detector. Events detected by cross-correlation are stacked to increase their signal-to-noise characteristics before being located using a 3D velocity model. The catalogue highlights quasi-continuous slow deformation occurring beneath the seismogenic zone near the Alpine Fault, punctuated by periods of increased LFE generation associated with tremor, and following large regional earthquakes. To date we have found no evidence of LFE generation north-east of Mt. Cook, the highest point in the Southern Alps, despite systematic searching throughout the region. We suggest that the along-strike cessation of tremor is due to changes in the fault's dip and the hypothesised presence of partially subducted passive margin material. This remnant passive margin would lie beneath the tremor-generating region and has been linked to along-strike changes in subcrustal earthquake distributions (Boese et al., 2013).

ESTIMATING SHALLOW SUBSURFACE STRUCTURE AT THE NGATAMARIKI GEOTHERMAL FIELD USING REFRACTION MICROTREMOR

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The Refraction Microtremor (ReMi) technique uses both active and passive sources of ambient noise, recorded across a line of geophones, to determine shear velocity structure in the shallow subsurface. ReMi was first devised as a method to efficiently and cheaply constrain shallow shear-velocity structure without the need of intrusive energy sources. The time-series signals are converted to the frequency-slowness domain and used to pick dispersion curves, which are then modelled as physical layers. In February of 2015, we conducted a ReMi analysis at the Ngatamariki geothermal field, located at the southern end of the Taupo Volcanic Zone in the central North Island. The Ngatamariki power station is a 82 MW binary type power station operated by Mighty River Power. The primary purpose of this deployment was as a pilot study on the effectiveness of ReMi for characterization of geothermal areas. We processed the data using SeisOpt® ReMi™ (© Optim, 2015) software. Three types of microseisms were recorded: background noise from geothermal field machinery, vehicles travelling parallel to the array, and hammer shots. The distinct frequency content of each source type allowed us to isolate different segments of the dispersion curve. The experiment questions are: [1] What frequencies seem to propagate across the array for the three noise sources, and what are the corresponding depths we can resolve using those frequencies? [2] How does the determined velocity model for our dispersion curves match the geophysical information from the site? [3] Can we detect any of the faults proposed by prior structural studies across our array? Additionally, we will use the results obtained in this study to discuss the potential benefits and expected outcomes of a hypothetical second ReMi experiment using different geophone instrumentation and array geometry.

A SUBDUCTION EARTHQUAKE RECORD FOR WELLINGTON

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A large earthquake on the southern part of the Hikurangi subduction interface is one of the more significant hazards facing the Wellington region, but it is also one of the least well constrained. To determine the timing and size of past large ruptures of the subduction interface beneath the Wellington region we have radiocarbon dated sedimentary evidence for coseismic vertical deformation at the coastline. A major challenge of this work is isolating evidence of interface earthquakes from earthquakes on the numerous active upper plate faults. We rely on comparison with timing of known paleoearthquakes of upper plate faults and expected patterns of subsidence, uplift, and tsunami impact from modelling of different earthquake sources.

For example, at Big Lagoon in Marlborough we found evidence for sudden vertical deformation that did not coincide with the time of occurrence of known paleoearthquakes and caused a greater amount of subsidence than expected from an upper plate fault. Therefore, we provided the first geological evidence for rupture of the southern part of the Hikurangi subduction interface rupture at 520-470 and 880-800 calibrated years before present. Determining the size of these two paleo subduction earthquakes depends in part on the distribution of vertical deformation at these times so we look to other coastal sites for similar evidence.

We present results from our most recent study at Okupe Lagoon on Kapiti Island where we refine the age of the most obvious earthquake signature in the sedimentary record to 620-564 calibrated years before present. We propose that this signature was caused by rupture of the Rangatira Fault for which we provide lidar-derived evidence of active onshore traces at the lagoon (previously only mapped as active offshore). The potential signatures of interface rupture at Okupe Lagoon are subtle in comparison with those from this very proximal source.

LACUSTRINE UNITS OF THE PAPAROA COAL MEASURES: PRELIMINARY RESULTS INDICATE PROMISING SOURCE ROCK POTENTIAL

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Late Cretaceous syn-rift lacustrine mudstones are potential oil-prone source rocks in the Deepwater Taranaki, Great South, and Solander basins, but have not yet been penetrated in wells. A key uncertainty is whether paleoclimatic conditions were conducive to the development of lake-bottom anoxia and algal-rich rocks. The coeval Paparoa Coal Measures, Greymouth Coalfield, contain three lacustrine units – the Ford, Waiomo, and Goldlight Mudstones – which crop out and have been extensively drilled. The carbonaceous silty mudstones contain leaf and freshwater mollusc fossils and turbidite interbeds. These units provide easily accessible analogues for equivalents that might exist in offshore basins.

Preliminary analysis of the petroleum source rock properties was conducted on 40 lacustrine samples from 17 drill holes using a Source Rock Analyzer. Most of the immature to early mature samples (T_{max} <445°C) have generally good to very good potential for mixed oil and gas with 1.8–3.0% TOC and HI values 132–313 mg HC/g TOC. Waiomo sample 656/461.8 has excellent potential for oil with 4.5% TOC and HI of 552 mg HC/g TOC. Micropetrographic examination of 4 samples revealed variable mixtures of dispersed land-plant organic matter (vitrodetrinite and inertodetrinite) and algal remains (telalginite Botryococcus and lamalginite Pediastrum). Waiomo sample 656/461.8 contains the highest concentrations of algal matter and seeps oil when observed under oil immersion.

In conclusion, the lacustrine Waiomo mudstone has excellent oil potential and is thought to be the best quality Cretaceous lacustrine source rock discovered in any New Zealand basin to date. This has established that anoxic conditions required for formation of high quality lacustrine source rocks existed during deposition of the Paparoa Coal Measures and may therefore also have existed within other Cretaceous syn-rift successions. The kerogen quality, range of maturity, accessibility, and volumes of the Greymouth lacustrine mudstone units make them a potential unconventional shale gas and oil resource in their own right.

CRETACEOUS SANDSTONES AS POTENTIAL PETROLEUM RESERVOIRS: PERSPECTIVES FROM MARLBOROUGH

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Cretaceous sandstones remain unproven petroleum reservoirs in many sedimentary basins of Zealandia. Advances in mapping their seismic character, in well post-mortem analysis, and outcrop studies provide insights to their reservoir character and geometries. Outcropping Cretaceous sandstones may provide an analogue for offshore equivalents. In this study we concentrate on two potential reservoir successions of mid-Cretaceous age in Marlborough. The shallow marine deltaic outcrop at Hapuku River consists of a series of coarsening upward parasequences dominated by more offshore shelfal mudstones at the base of each cycle, which grades up into bedded shoreface sandstones. In contrast, the shelf to deep-water section at the Hodder River is characterised by gravity flow deposits in the form of turbidite sandstones and intervening mudstones deposited in submarine lobe and low net:gross lobe fringe settings. Sandstones in both settings are typically moderately well- to well-sorted, very fine- to fine-grained, massive to planar bedded with variable amounts of carbonaceous debris, intercalated mudstone, conglomerate or scattered shell fragments. Petrographically the sandstones are litharenites and dominated by sedimentary lithic grains (sandstone, siltstone and shale fragments). Provenance was likely from the Torlesse composite terrane. The porosity of the sandstones has often been reduced by carbonate cement and authigenic clay formation. The mineralogy of offshore East Coast-Pegasus basin Cretaceous sandstones (as yet undrilled) is likely to be similar, and these sediments have been buried to depths of >3 sec TWT in the accretionary margin, and to >6 sec TWT in the offshore Pegasus Basin.

IN SITU COSMOGENIC ^{10}BE IN PYROXENES

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Cosmogenic nuclides provide an efficient way to quantify many Earth surface processes. The most widely used nuclide, Beryllium-10 (^{10}Be) is commonly extracted out of the mineral quartz; however many landscapes lack quartz bearing rocks. In order to establish a new chronometer based on ^{10}Be in pyroxene for use in New Zealand and Antarctica, it is necessary to verify cleaning protocols and determine a local production rate.

We have tested and modified an existing decontamination procedure in order to further develop the use of ^{10}Be in pyroxene as a chronometer. This method successfully removes the meteoric component of ^{10}Be in pyroxene, allowing only the concentration of in situ produced ^{10}Be to be measured. Additionally, we determined production rates for ^{10}Be in pyroxene both empirically and theoretically for New Zealand using the Murimotu debris avalanche calibration site in the central North Island. The best estimate for the ^{10}Be pyroxene production rate is 3.4 ± 0.8 atoms g^{-1} yr^{-1} at sea-level high- latitude, which was determined via cross-calibration with the radiocarbon age for the Murimotu deposit. The production rates for ^{10}Be in pyroxene are both empirically and theoretically 8-27% lower than in quartz.

In a case study we determined surface exposure ages for bedrock samples and cobble erratics collected in a vertical transect on Mount Gran, Antarctica, by applying the aforementioned ^{10}Be pyroxene decontamination procedure and new production rates. A chronology for ice surface lowering was obtained for the adjacent Mackay Glacier, indicating the ice surface lowered approximately 60 m during a relatively rapid episode of thinning which occurred between ~13.5 ka and 11 ka.

The development of ^{10}Be in pyroxene allows environments without quartz-bearing rocks to be dated using this widely used nuclide. The pairing of ^{10}Be with ^{3}He in pyroxene would allow complex

exposure histories to be determined, expanding the application.

HOW TO HUG A SNAIL: 3-D MORPHOMETRICS OF GASTROPODS USING ARTIFICIAL INTELLIGENCE

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Mathematical analysis of shape (morphometrics) is a powerful tool in biology and palaeobiology, providing data for taxonomy and biostratigraphy, phylogenetic analysis, evolutionary studies, and palaeoenvironmental reconstruction. Two-dimensional morphometric methods have an established track-record of use; they are relatively quick and cheap to implement, and require little in the way of specialist equipment. However, very few fossils are truly two-dimensional, and reducing dimensionality results in loss of (potentially vital) information. This is particularly true of gastropods (snails), which coil helically. No two-dimensional projection of a gastropod can capture the entirety of its form. Gastropods are some of the most common fossil organisms, with proven utility in palaeoenvironmental and biostratigraphic analyses. They are also the subject of major taxonomic and evolutionary research worldwide. Morphometric data on gastropod fossils could provide significant insights into their phylogeny and increase their usefulness as environmental indicators.

Three-dimensional shape analysis of gastropods presents a number of problems, both methodological and computational. Aligning shapes which coil is complex, and existing morphometric methods, even those that have been extended to three dimensions, do not yet have a satisfactory way of accounting for the problems of differing whorl numbers and geometries between specimens.

In this paper, we present a Java™ spiral-matching artificial intelligence program which overcomes these issues by aligning the spirals described by the centroids of gastropod generating curves through ontogeny. This allows us to represent the three dimensional nature of the gastropod in a mathematical manner which allows rigorous comparisons between specimens and will provide a basis for further development in this area of morphometrics.

ECOPHENOTYPY OF *PAPHIES AUSTRALIS* (BIVALVIA, MESODESMATIDAE) IN THE NUKUMARUAN KAIWAKA FORMATION, HAWKES BAY

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Paphies australis, the pipi, is a common New Zealand mesodesmatid bivalve that is found all around the country both alive and in fossil deposits, such as the Nukumaruan Kaiwaka Formation in the Hawkes Bay. Its shell is generally elongate and equilateral, with a distinctive spoon-shaped chondrophore and a deep pallial sinus. The outline shape of the shell is known to vary in response to environmental factors (a phenomenon known as ecophenotypy).

We have undertaken high resolution sampling of *Paphies australis* shells from closely-spaced beds of the Kaiwaka Formation, and used Fourier analysis to examine shell-shape variation in a highly rigorous and quantitative manner. Fourier analysis decomposes the shell outline to its component harmonics, the wavelength and amplitude of which can then be input to Principal Components Analysis (PCA) and Multivariate Analysis of Variance (MANOVA). These analyses reveal the underlying structure of a multivariate dataset and allow identification of the proportions of variability within that dataset that are attributable to a particular factor.

The aims of this study are: quantifying the extent of morphological variation in pipis; identifying the environmental factor(s) that are the underlying causes of this plasticity; and examining and separating out the patterns of their variation through space (i.e., the ecophenotypic variation) and also through time (i.e. phenotypic changes due to evolution within the population). This poster will

summarise these findings in the form of a map of palaeoenvironment and morphological variation of *Paphies australis* in the Kaiwaka Formation.

INSIGHTS INTO ANDESITE PETROGENESIS: IMPLICATIONS FROM TEMPORALLY DISCRETE MELT INCLUSIONS FROM RUAPEHU VOLCANO, TAUPO VOLCANIC ZONE

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Ruapehu volcano sits at the SW propagating tip of the actively rifting continental volcanic arc system that is the Taupo Volcanic Zone. Although there is evidence, through Hauhungatahi high-Mg andesite volcano, for magmatic activity in this area extending back to ~900 ka, the region has yet to experience a major silicic eruption as witnessed to the NE at Taupo, Mangakino, Okataina, etc. The crustal section beneath this region remains thermally immature.

Here we seek to test the hypothesis that andesites are manufactured in a deep crustal zone adjacent to the crust/mantle boundary. It is in this zone that mafic upper mantle-derived melts are bound by gravity and density to form a plexus of intrusions interlayered with existing lower crust. Repeated injections of mafic melt maintain this zone at supra-solidus temperatures and heat is advected into the overlying crustal section.

The crystalline cargo of TVZ andesites is typically complex, comprising phenocrysts, antecrysts, xenocrysts, and xenolithic material in various stages of decrepitation. All of these contain melt inclusions, which carry a snapshot of the zone in which they were trapped. Melt inclusions from Ruapehu lava flows erupted >150 ka show systematic difference from those erupted <50 ka. Specifically, melt inclusions from the oldest lavas are consistently lower in K2O than those within post-50 ka andesite and dacite lavas. Rare xenolithic samples in ~50–40 ka lavas are partially melted and disaggregated fragments of crust comprising a symplectite intergrowth of plagioclase, orthopyroxene, Fe-Ti oxides and glass. These glasses contain up to 6 wt. % K_2O.

This distinction between low- and high-K_2O glasses in old and young lavas at Ruapehu is matched by the available whole-rock isotopic (Sr, Nd, Pb, Hf) and incompatible trace element characteristics. We argue that these are features acquired during the progressive thermal processing of the lower to middle crust.

GAME OF CONES: A STORY OF LAVA AND ICE TO EXPLAIN THE CAUSE OF HOLOCENE SECTOR COLLAPSES AT RUAPEHU VOLCANO

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The destruction of volcanic edifices and generation of debris avalanches presents a major hazard to populated areas near composite volcanoes. Glaciated cones are particularly prone to sector collapse due to the associated processes of hydrothermal alteration, glacial erosion, and lava-ice interaction, which act to destabilise and over-steepen complexly intercalated volcanic deposits. Defining the links between climatic and volcanic phenomena that affect volcano stability is crucial for monitoring and mitigating these hazards. The timing and triggering of two Holocene sector collapse events at Ruapehu volcano are constrained here by new $^{40}Ar/^{39}Ar$ lava flow eruption ages, radiocarbon ages, whole-rock geochemistry, glacier reconstructions and field evidence for volcano-ice interaction. Prior to 18 ka, effusive eruptions were predominantly sourced from vents beneath a summit ice cap and left no trace of subaerial cone formation. As the ice cap thinned, three distinct, ice-bounded cones were constructed between 18 and 10 ka on the north-western, north-eastern and southern regions of Ruapehu's summit. De-buttressing and destabilisation of these cones followed the ongoing coeval reduction in local ice volume. This, combined with the weakness of the underlying altered deposits, led to major collapse of: (1) the north-eastern and north-western cones to produce the 10.5 ka Murimotu Formation debris avalanche deposit, and (2) the southern cone, which likely produced the 4.6 Mangaio Formation

debris avalanche deposit. Substantial lava flows on the north-northwest flank were erupted <10 ka from a cone rebuilt within the northern sector collapse scar. The cone rebuilt within the southern sector collapse scar includes Pyramid Peak and contains the active vent beneath Crater Lake. In light of predicted trends for future warming and glacier retreat, the recognition of a potentially causative relationship between climatic changes and volcano instability during sector collapses is a valuable contribution to characterising and forecasting volcanic behaviour and consequent hazards.

THE VOLCANOLOGY OF THE CORBETT IGNIMBRITE AND SPATIALLY RELATED HIKURANGI RHYOLITE DOME, WAIHI CALDERA

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Volcanic activity began in the north Coromandel Volcanic Zone (CVZ) at 18 Ma and migrated southward during the Miocene to Pliocene, and continued until the Pleistocene (1.9 Ma). The Waihi caldera was active during the Pliocene and has been infilled with lake sediments (Romanga Formation) and three rhyolitic ignimbrites of the Whitianga Group, the Corbett, Waikino and Owharoa ignimbrites. The Corbett Ignimbrite possibly laps on to the Hikurangi Rhyolite dome on the southeastern rim of the caldera. This study aims to determine the volcanic history and genetic relationships between the Corbett Ignimbrite, Hikurangi Rhyolite dome and the Waihi caldera.

The Corbett Ignimbrite has a maximum exposed thickness of 18m at its type section, and is a pumice-rich, crystal-rich, moderately-welded, creamy-buff ignimbrite. The basal zone of the ignimbrite is pumice-rich (40-50%), crystal-rich (20-30%) and contains two distinct lithic concentration zones. At one locality the ignimbrite consists of a 9 m thick densely welded zone with abundant fiamme. Pumice is creamy-white, typically medium lapilli, subangular with fine spherical vesicles. The matrix is composed of fine ash with shard textures only visible under the scanning electron microscope. Crystals comprise plagioclase, quartz, hornblende, orthopyroxene, augite, titanomagnetite, ilmenite and zircon. Lithics are predominantly andesite with minor rhyolite, dacite and greywacke. The lithic concentration zones suggest that collapse and erosion of the vent occurred several times during the eruption. The type section's facies distribution shows rapid depositional pulsing, defined by lithic concentration zones, which becomes a more steady flow in the upper half of the outcrop. The Hikurangi Rhyolite lava dome is spherulitic and contains quartz, plagioclase, biotite, titanomagnetite and ilmenite phenocrysts. The Hikurangi Rhyolite also contains granitoid lithics with granophyric and myrmekitic intergrowths, providing evidence for a deep granite body below this dome.

HETERODONT CONFUSION: A LATE OLIGOCENE PUTATIVE KEKENODONTID FROM NEW ZEALAND AND *SQUALODON GAMBIERENSIS*

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Many fossil cetaceans are known from isolated triangular teeth with multiple denticles ("cusps"). Such teeth have sometimes been used as type specimens, in spite of uncertainty about diagnostic features. The enigmatic *Squalodon gambierensis* is one example. This Late Oligocene toothed whale (Gambier Limestone, South Australia) is known only from the holotype specimen: a single molariform tooth described by Glaessner in 1955. The denticulate and double-rooted tooth is reminiscent of Eocene basilosaurid archaeocetes, but Glaessner cited its small size, lateral compression, and smooth surface as indicating *Squalodon*. Squalodontids are archaic echolocating heterodont odontocetes with a Late Oligocene to Middle Miocene record; no squalodontid reportedly has a tooth like that of *S. gambierensis*. Rather, *S. gambierensis* seems close to a Late Oligocene kekenodontid, or relict archaeocete (OU 22023, Geology Museum, University of Otago), from New Zealand. This specimen includes a posterior cheek tooth that is nearly identical in crown and root morphology to *S. gambierensis*. Each tooth is double-rooted with a small isthmus below the crown base, and a distal curvature. The crowns are transversely compressed with a triangular profile characteristic of posterior cheek teeth in early heterodont cetaceans. The tooth crowns are similarly denticulate with three accessory denticles on the mesial edge and four accessory denticles on the distal edge. In summary, *S. gambierensis* is recognized as a kekenodontid from both New Zealand and Australia. The

incomplete skull and ear bones of OU 22023 are morphologically similar to other Late Oligocene kekenodontids from New Zealand, linking *S. gambierensis* to the Kekenodontidae. The recognition of similar material from New Zealand and Australia indicates that at least one kekenodontid ranged widely in the southwest Pacific.

THE SIGNIFICANCE OF THE MAGMATIC PLUMBING SYSTEM, DEGASSING, AND MAGMA MINGLING TO THE PYROCLASTIC DENSITY CURRENT HAZARD AT MT RUAPEHU, NEW ZEALAND

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Pyroclastic density currents (PDCs) are a major volcanic hazard. Understanding the types of PDCs that have occurred at a volcano and the processes leading to their generation is essential for hazard assessment. At Mt. Ruapehu, 12 young deposits on the volcano's eastern flanks show that PDCs have frequently occurred over the past ~13.6 ka. We present results from a new MELTS-based method for characterising the pressure-temperature regime of Ruapehu's magma storage system, and combine these with textural studies to investigate the processes leading to PDC generation. Initial results show PDCs have occurred during most of Ruapehu's known eruptive styles, and that magma storage depth and temperature, and the proportion of magma mingling have strongly influenced the PDC characteristics. Our textural observations suggest these factors control the amount of pre-eruptive degassing and hence clast density. Large column collapse PDCs accompanied Ruapehu's largest plinian eruptions from deep (3.7-5.5km) gas-rich magmas (Units 1-5), with PDC generation influenced by both vent widening (Unit 1) and also densification of the erupting mixture through mingling with denser secondary melts (Unit 4). Hazardous PDCs also occurred from smaller column collapse and 'boiling over' style eruptions (Units 8-10) of shallow (<2km) gas-poor magmas similar to Ruapehu's modern-day magma system. A third kind of PDC (Units 6-7) was generated on 2 occasions where hot, slightly degassed material accumulated as spatter on steep slopes and then repeatedly collapsed to form PDCs. Magma mingling occurred during many of Ruapehu's PDC-forming eruptions, and appears to have been a trigger for eruption of otherwise stagnant, degassed magma that consequently may have been more prone to generating PDCs due to the higher density of the pyroclasts. The ubiquity of magma mingling at Ruapehu, as well as the role of shallow magma degassing, are therefore important considerations when assessing the PDC hazard at this volcano.

A TRANSANTARCTIC MOUNTAINS DIGITAL GEOLOGICAL MAP RESOURCE

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There are numerous, hard-copy, regional-scale geological maps of Antarctica that were compiled and published last century. For the most part they reliably but inconsistently define bedrock geology ('deep time'). Glacial geology is generally poorly represented, however, and the maps typically lack information on landscape evolution; thus are not contributing greatly to our understanding of Late Cenozoic climate change in Antarctica. These maps also reflect understanding and paradigms of their eras and over time become increasingly outdated and potentially not locatable or accessible.

To address this, an international effort has been initiated to compile unified geological and geomorphological maps that will result in an authoritative international, internet-accessible GIS dataset to inform studies of glacial dynamics and climate change, as well as deep time geology. As part of the SCAR GeoMAP initiative, a prototype dataset has been built for the Transantarctic Mountains (TAM). Its compilation embodies a philosophical shift away from conventional "bottom-up" construction, whereby information is built up sheet by sheet campaign-style, to a "top down" method starting from a continent-scale, low density, attribute-poor dataset that is added to and

improved through multiple iterations. High-resolution satellite imagery assists characterisation of geological units and landforms, particularly away from the well-mapped, field-verified areas into terra incognita. The quality and reliability of the TAM geological map is expected to improve dramatically as the project progresses through international input and multi-organisational cooperation. An inaugural workshop was held at the recent SCAR conference in Goa, India where participants representing 12 countries identified their roles and responsibilities in the project.

AGRICULTURAL VULNERABILITY TO TEPHRA FALL IMPACTS

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Understanding agricultural impact from tephra hazards and their causal mechanisms is vital when developing mitigation and recovery strategies. It is well documented that tephra can impact agricultural systems. However, forecasting likely impacts has been challenging and focused on creating generalised models where impacts typically increase with tephra thickness or loading. Lack of quantitative data and insufficient sample sizes of impact assessment studies restrict potential analysis. However, previous studies have identified that impacts will be governed by the complex interaction of tephra characteristics (thickness/ loading, grain size, leachates), exposed farm characteristics (farm size/type, pre-existing conditions), climate, time of year and existing risk management.

Post-eruption impact assessments (Post-EIA) have been used to retrospectively investigate tephra impacts to agriculture, including exploring how tephra and vulnerability characteristics of exposed farms interact. In this study, Post-EIA are used to investigate impacts to agricultural land from three silicic eruptions (2011 Cordón Caulle, 2008 Chaitén, and 1991 Hudson) in Patagonia. Analysis of 49 impacted farms suggests that the characteristics of tephra fall are important, but that the vulnerability characteristics of the farms have a stronger influence on impact. Findings show appropriate recovery strategies employed by farmers are crucial for reducing losses.

This analysis is used to: 1) develop an improved understanding of the factors that influence agricultural impacts from tephra fall; 2) design standardised impact assessments guidelines and databases; and 3) develop improved tephra fall risk assessment methodologies fragility functions that include different agricultural vulnerabilities due to farm type, intensity, seasonality, and leachable fluoride. These tools can be directly applied to a New Zealand setting to build predicative capacity and ultimately aid disaster risk reduction strategies in NZ.

EXTINCTION SELECTIVITY THRESHOLDS IN PALEOZOIC PLANKTON: ENVIRONMENTAL, NOT BIOTIC, DRIVERS OF SURVIVORSHIP

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Over long time spans and at large scales, is biodiversity controlled primarily by biotic, species-species interactions (e.g., competition for resources) or by external environmental factors, and do these fundamental drivers vary through time and space? These questions are at the heart of a major, unresolved debate in paleobiology and ecology. Here, we tackle this problem at unprecedented temporal resolution using a unique, global dataset that spans the entire lifespan of the major Paleozoic zooplankton group, the graptolites. As today, Paleozoic plankton comprised the largest biome on the planet, were a major component of the carbon cycle, and were thus a significant element of the planetary biogeochemical system.

We use a new method of survivorship analysis to determine whether extinction probability of graptolite species varied with species age. All else being equal, and according to the (now somewhat abused) 'Red Queen' model of Van Valen, if macroecology is driven by biotic interactions, then extinction probability should be constant ('neutral') through the lifespan of a species. In contrast, we

find that most of the time, short-lived species had relatively high extinction rates, a pattern that is consistent with environmental control of biodiversity. We also find numerous, very short-lived pulses of neutral selectivity, but these nearly all coincide with environmentally-driven extinction events and were therefore apparently driven also by the same environmental factors. Our results suggest that environmental drivers, not biotic, were the ultimate control on Paleozoic zooplankton extinction, and that selective regimes switched rapidly at critical thresholds in the rate of environmental change.

DEFORMATION AND CHEMICAL REACTION IN AN ULTRAMAFIC TERRANE BOUNDARY: THE LIVINGSTONE FAULT, NEW ZEALAND

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The Livingstone Fault is a >1000 km long terrane boundary that defines the eastern margin of the Dun Mountain Ophiolite Belt in New Zealand. The fault is spectacularly exposed where it juxtaposes ultramafic parts of the ophiolite belt (e.g. peridotite, serpentinite) against quartzofeldspathic rocks of the continental Caples Terrane. In such areas, the fault consists of a 50-400 m-wide serpentinite shear zone entraining competent pods of massive serpentinite, Caples Terrane rocks and various volcanic rocks. This shear zone has a steeply dipping, north-south striking S-C fabric. The S-C fabric and steeply plunging slickenlines indicate a Caples Terrane up movement.

The Livingstone Fault provides an excellent example of deformation processes and chemical reactions in a system where peridotite, serpentinite and quartzofeldspathic rocks are juxtaposed, a common situation in many plate tectonic settings (e.g. portions of the San Andreas Fault, central and southern sectors of the Alpine Fault). We will present some initial results of fieldwork carried out in the Olivine Wilderness Area (NE of Milford Sound) focusing on: 1) the transition from intact peridotite to partly serpentinized peridotite to a fully serpentinized shear zone, 2) the distribution of strain within the serpentinite shear zone, 3) the significance of highly localized slip within entrained pods of peridotite and serpentinite, and 4) the nature and possible mechanical effects of talc-forming metasomatic reactions between serpentinite and quartzofeldspathic rocks.

STRUCTURAL AND PETROGRAPHIC FEATURES OF AN ARC-BACKARC DEFORMATION ZONE: THE LANTERMAN-MARINER SUTURE IN NORTHERN VICTORIA LAND, ANTARCTICA

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In this work we deal with the Lanterman-Mariner Suture Zone (LMS) located between the Wilson and the Bowers terranes, in northern Victoria Land (Antarctica). The recent regional interpretations of the northern Victoria Land, suggest that the area could be the result from the accretion of a long-lived and composite backarc-arc-forearc-system to the palaeo-Pacific margin of Gondwana during the Ross Orogen.

The LMS can be considered as a tectonic melange characterised by the amalgamation of discontinuous slices of rocks of varied provenance, reaching distinct metamorphic climax conditions: from medium-P amphibolite facies to highP-UHP conditions, and greenschist /low-greenschist facies, moving from west to the east.

We focus on the structural and petrologic features of metavolcanites and metasediments, that are known as the Black Spider Greenschist, which are considered as derived from the arc-backarc zone. Such rocks, interposed between the medium-P amphibolite facies rocks of the Dessent Unit and the very-low grade rocks of the Molar Formation, were sampled along a SW-NE transect.

From the structural point of view, the Black Spider Greenschist can be considered as a high strain equivalent of the adjacent Sledger Group, with a more complex polyphase deformation history. During regional metamorphism, deformation was non-homogeneously distributed throughout the area: slices of mostly undeformed gabbro and basalt are surrounded by banded mylonitic zones; metasediments show polyphase folding at places characterised by asymmetric shear folds and

pronounced tectonic transposition. Similarly, the metamorphism is inhomogeneously distributed: metavolcanics show both greenschist facies assemblage, and oligoclase-hornblende assemblage, that is typical of the transition between greenschist and amphibolite facies.

The aim of this work is to provide new data and insights for the comprehension of the tectonic evolution of the Paleo-pacific margin of Gondwana which will lead to a better understanding of the tectonics of the intra-arc/back-arc suture zone.

GRANULAR DYNAMICS IN SHALLOW EARTHQUAKE SLIP ZONES: INSIGHTS FROM MICROSTRUCTURAL ANALYSIS OF ROUNDED "FAULT PELLETS"

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An important part of hazard analysis and modelling of ground shaking effects is understanding the dynamics of shallow earthquake rupture and coseismic slip. Although there are some constraints available from rock mechanic experiments and paleoseismological investigations of surface breaks, very little is known about the dynamic processes that occur in narrow fault slipping zones in the near-surface (<3 km) environment.

This project focuses on microstructural analysis of the calcite-dominated, cataclastic principal slipping zone (PSZ) of the Tre Monti Fault, Italy, exhumed from depths of <2 km. This fault was chosen because it is probably hosts large (>M7) earthquakes and previous analysis recognised very peculiar microstructures in the PSZ. The microstructures of interest are rounded aggregate-type grains ("fault pellets" – resembling volcanic accretionary lapilli) that contain a central clast (often angular) of host rock or reworked cataclasite and an outer, often laminated cortex containing much finer grained material. These peculiar grains have only been identified in the high strain PSZ of the Tre Monti fault (i.e. they are restricted to a cataclastic layer <2 cm thick), and thus potentially record the effects of dynamic-slip processes during the seismic cycle.

Through serial sectioning and high resolution imaging of a block sample (~1 cm^3) of the PSZ, a three-dimensional model of the "fault pellets" will be constructed in order to understand their shape. Electron Backscatter Diffraction analysis on the Scanning Electron Microscope at the University of Otago will provide insights into the substructure of the fault pellets, including whether or not the outer cortex contains a calcite crystallographic preferred orientation. Comparisons will be made between the grain size distributions of the outer cortex and surrounding matrix. Understanding the microstructure of the fault pellets is expected to provide insights into the mode of slip and dynamic faulting mechanisms in granular slip zones at shallow depths.

BIOTIC CHANGE ACROSS THE EARLY EOCENE CLIMATIC OPTIMUM IN THE MID-WAIPARA RIVER SECTION, NORTH CANTERBURY

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The early to middle Eocene (56–41.2 Ma) stratigraphic record from mid-Waipara River has provided an important marine temperature history for the SW Pacific during a time of extreme greenhouse climate. In particular, sea surface temperature (SST) is documented for the Early Eocene Climatic Optimum (EECO), an episode of sustained global warmth that persisted for ~2 Myr (~52–50 Ma). These records have helped test and validate Eocene coupled climate models and provide discussion on the reliability of various temperature-proxy calibration methods, such as GDGT-based SST proxies.

While marine temperature history has been relatively well-documented, the absolute SST estimates are debated and, crucially, supporting paleoecological analysis of microfossil records from mid-Waipara River are lacking. The current study examines the timing and response of marine and terrestrial assemblages, in particular dinocysts, miospores, calcareous nannofossils and foraminifera, to changes in SST and climate in the Eocene greenhouse world.

Recent field collections have sampled more of the lower–middle Eocene mid-Waipara section and provide an opportunity for a high-resolution record

encompassing the transition into the EECO and post-EECO cooling. Magnetostratigraphy from part of the new sample-set provides correlation with the geomagnetic polarity timescale in the lower Eocene (~51–47.5 Ma). New GDGT analyses have produced a high-resolution SST record that indicates warmest temperatures are centred around 51 Ma (lower Mangaorapan Stage), and that SSTs remain high throughout the Mangaorapan, with a cooling seen at the Mangaorapan/Heretaungan boundary (~48.9 Ma). Depending on the type of TEX_{86} calibration, warming of 7–12°C occurs from the lower Waipawan to lower Mangaorapan. While preliminary paleoecological analysis of microfossil assemblages indicates an accompanying increase in warm climate indicators, it was not as pronounced as suggested by the TEX_{86} proxy. This apparent mismatch between the biotic and TEX_{86} climate proxies will be further investigated in this presentation.

SUBMARINE CANYON INCISION AND GAS HYDRATE FORMATION ON NEW ZEALAND'S SOUTHERN HIKURANGI MARGIN

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Erosion of the seafloor during canyon formation changes the temperature and pressure conditions in sediments beneath the canyon. In regions where gas hydrates are stable, such temperature and pressure changes influence the stability of hydrates bound in the sediments. High seismic velocities directly beneath a canyon on the southern Hikurangi margin were recently interpreted as evidence for the formation of a concentrated gas hydrate deposit. Building on this previous study, we use the same seismic dataset to build a depth-converted geological model of the region. We then use this model to simulate gas hydrate formation with PetroMod® to investigate how canyon incision has influenced gas hydrate stability. Modelling results reproduce the expected depth of the base of the gas hydrate layer, and also predict concentrated deposits beneath the canyon. In our discussion of the seismic data and the modelling results, we present a series of conceptual models that describe potential influences of localised seafloor erosion on the precipitation of gas hydrates. Our favoured model is one where erosion occurs at a similar rate to seafloor uplift. In this case, a situation arises where gas hydrate deposits beneath the canyon are more mature, and therefore more concentrated, than deposits adjacent to the canyon.

EARLY TO MIDDLE EOCENE CHRONOLOGY OF ZEALANDIA: MAGNETOSTRATIGRAPHIC DATA FROM NEW ZEALAND AND NEW CALEDONIA

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The Eocene epoch records the transition from the warmest Earth's climate conditions of the Cenozoic era (i.e., early Eocene Climatic Optimum, 52–50 Ma) to the first emplacement of permanent Antarctic ice cap near the Eocene-Oligocene boundary. To understand the nature and causes of global climatic change during the Eocene, it is critical to have well-dated sedimentary records from key representative sites across the planet. In the last decade great steps forward have been made in understanding the paleoclimate history of the southwest Pacific Ocean. In particular, important magneto-biostratigraphic results have been obtained by early to middle Eocene sections cropping out in the Canterbury (mid-Waipara River section) and Marlborough (Mead Stream section) regions of the South Island of New Zealand. These records have been used to calibrate the age of several dinoflagellate cyst (dinocyst), foraminifera, radiolarians, and calcareous nannofossil bioevents, refining the correlation between the New Zealand and the International time scales, and the age of paleotemperature proxy and carbon stable isotope variations. To fully understand the paleoceanographic evolution of the southwest Pacific Ocean more data are required also from lower paleolatitude. This possibility is given by the Eocene sections cropping out in New Caledonia (northern Zealandia). We present preliminary

magnetostratigraphic data from the middle Eocene Koumac Ridge section (northern New Caledonia). A stable paleomagnetic signal has been isolated in the sediments. The sampled section encompass magnetic polarity Chrons from C20n to C18n.1n, i.e., from ~43Ma to 39.5 Ma. Detailed biostratigraphic and carbon isotope analyses are currently undergoing. Following these encouraging results, further magnetostratigraphic studies are planned in both New Zealand and New Caledonia. The results will help not only to understand the paleoclimate history of the southwest Pacific Ocean, but also on the tectonic evolution of Zealandia.

CLOUD RESOLVING SCALE SIMULATION OF TORNADO OVER BRAHMANBARIA ON 22 MARCH 2013 USING DWR AND WRF MODEL

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A tornado occurred at Brahmanbaria in Bangladesh in the afternoon of 22 March 2013. The tornado event has been studied based on TRMM data, radar observations and model simulations. The maximum reflectivity and the vertical extent of the system has been recorded to be about 54.7 dBZ and 15 km respectively by the DWR at Agartala, India. The event has been simulated by using the WRF model at 3 and 1 km horizontal resolution nested domains based on 6 hourly FNL reanalysis data and boundary conditions of NCEP. Results show that while there are differences of 40 minutes before the observed time of the storm, the distance between observed and simulated locations of the storms is 0.5°. The maximum amount of vorticity transferred by directional shear in the storm updraft (helicity) due to convective motion simulated by the model is found to be 1774 $m^2 s^{-2}$, and the highest value of Bulk Richardson number shear that define the region in which low level mesocyclogenesis is more likely has been 457.3 $m^2 s^{-2}$, which is generally supposed to produce rotating storms according to the prescribed range. The highest vertical velocity simulated by the model is about 28 to 58 m s^{-1}.

INCREASING DISASTER RESILIENCE IN FRANZ JOSEF: MULTI-HAZARD PARTICIPATORY METHODOLOGY

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Franz Josef Glacier township is a rapidly-developing iconic centre for New Zealand tourism. However, the township is seriously threatened by natural hazards including debris-flow, earthquake, landslide, landslide-dambreak flooding, river flooding and rock fall.

Participatory sessions are currently being held in Franz as part of the government-funded research programme “Resilience to Nature’s Challenges”. This is a departure from established practice, because the implementation of resilience strategies is usually considered probabilistically, meaning mitigation for high-frequency, large-magnitude hazards (in highly-populated areas) is prioritised (Saunders *et al*., 2013: *GNS Sci Misc Ser* 67). Therefore, although many natural hazards are not unexpected (Boscher, 2007: *Engng, Construct Architect Manag* 14, 434), substantial pre-disaster resilience is often not implemented, and time and resources are often limited to fundamentally reduce exposure and vulnerability in the aftermath of a disaster (Mileti & Paserini, 1999: *Int J Mass Emerg Disas* 14, 97; Davies *et al*., 2015: *Int J Disas Risk Reduc* 13, 242). Accordingly, the probabilistic methodology is fundamentally flawed because ‘magnitude-frequency information… cannot give any idea of the most important disaster any community will face: the next one’ (Davies, in press, *Environ Syst Decisions*).

Settlements that are vulnerable to hazards still exist because they remain viable for a particular set of factors. Vulnerability assessment needs to take account of all factors (not just hazards) to ensure the sustainability of communities is not compromised (Davies *et al*., 2015).

Pre-emptive (rather than reactive) community planning provides an opportunity to fully consider and implement resilience-enhancing development (Saunders *et al*., 2013). Bowman & Henquinet (2015 *J Appl Volcanol* 4, 14) and Davies *et al*. (2015) advocate the use of participatory methods to integrate all relevant knowledge and viewpoints with the current best scientific understanding. This

methodology allows a community to increase its resilience starting immediately, and produces a well-considered plan (not simply a reaction to the most recent hazard) that can be fast-tracked if a disaster occurs (before the plan is fully executed), with an additional fundamental benefit of the community being highly-informed and invested in the plan (Davies *et al*., 2015).

THE SOUTHERN OFFSHORE LIMIT OF THE SUBDUCTED HIKURANGI PLATEAU – REVISITED

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Not only does the limit of the Cretaceous shallow angle subduction of the buoyant c. 10 My-old Hikurangi Plateau beneath the Chatham Rise Gondwana margin reflect the extent of direct deformation it also marks out a region of subsequent subsidence as the plateau cools. Davy (2014) interpreted the southern offshore limit of the remnant plateau as being marked by a series of horsts that trend NE across the inner Bounty Trough. Further study has revealed however that the horsts have a different tectonic origin and seismic data show that subsidence associated with plateau cooling implies a plateau margin slightly further south.

The pattern of deformation at the leading edge of the plateau is discussed and compared with seismic reflection and potential field data. The nature of the Junction Magnetic Anomaly in the South Island and its offshore continuation is explored as well as fault linkages between this margin and the Bellingshausen/Marie Byrd Land triple junction.

HIDDEN FAULTS IN THE HAMILTON BASIN

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The National Seismic Hazard Model (NSHM) has evaluated a relatively low seismic hazard for the Hamilton Basin, based on an absence of active faults and low levels of historic seismicity. However, it was recognised that Quaternary sediments may obscure the presence of active faults. A range of different lines of evidence indicate the presence of at least four potentially active hidden faults, including geomorphology, offsets in cut exposures, LIDAR topography, geothermal and oil/gas wells, geophysical data, and paleo-liquefaction structures on land and within shallow lakes. Three identified faults occur within Hamilton City, and all four intersect important linear infrastructure including the Waikato Expressway, Main Truck Railway, electricity, gas and communication transmission corridors, and flood defences.

The preliminary data from dated paleoliquefaction features indicates that at least one fault has ruptured within the last 22,000 years, which would qualify as an active fault in the NSHM. An initial field programme is planned to obtain shallow seismic reflection data along the Waikato River bed between Cambridge and Huntly, which will be combined with existing multibeam echosounder and side-scan data to constraint the locations where faults cross the River. These locations will be combined with LIDAR topography to identify sites for Wenner, Schlumberger and Induced Polarization resistivity surveys to establish the locations where the faults can be trenched.

RECENT UPLIFT ALONG THE CENTRAL ALPINE FAULT AND IMPLICATIONS FOR PLATE BOUNDARY BEHAVIOUR

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The plate boundary Alpine Fault is considered to be a major source of seismic hazard on the South Island of New Zealand although there is limited on-fault dating along the Central section to help understand on-fault deformation, and associated hanging wall uplift. Light detection and ranging (lidar)-derived topographic data near the Whataroa River allowed mapping followed by field geological characterization, and optically stimulated luminescence (OSL) dating of hanging wall sediments help constrain Holocene deformation. The subhorizontal attitude of laterally continuous, Whataroa-sourced deposits (sourced from ≥ 20 km distance) suggests that the adjacent bounding faults are steeply dipping dextral faults. New OSL ages for hanging wall sediments of 2.8 ka, and 10.9 ka for Whataroa-derived deposits indicate Holocene aggradation and uplift here, while local-drainage schist and mylonite sediments are found in an 11.1 ka elongate deformational bulge. These ages suggest a 6.0 ± 0.9 mm/yr hanging wall uplift rate here using the OSL dates and suggests that the Southern Alps are in a dynamic steady-state where rock uplift is balanced by exhumation. Finally a multi-channel analysis of surface waves (MASW) geophysical survey shows evidence for faulting up to 2.5 to 3.5 m below the (unfaulted) ground surface in the Whataroa floodplain; continuity of active fault traces beneath young deposits and surfaces is likely along the fault. Importantly, strike-slip traces of the Alpine Fault persist (i.e. are visible in the landscape) over ≥10 ka timescales leaving evidence of repeated surface ruptures. Finally, we present an appraisal of the recently recognised and active South Westland Fault Zone which is also responsible for local tectonic uplift, in this case of the Alpine Fault's footwall.

SEVENTEEN YEARS OF INVESTIGATING SEAFLOOR HYDROTHERMAL SYSTEMS OF INTRAOCEANIC ARCS: WHAT HAVE WE LEARNT?

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Systematic surveying of submarine arc volcanoes for their hydrothermal emissions since 1997 heralded a new chapter in deepsea research related to seafloor hydrothermal systems. Several surveys along the Kermadec arc, with others along the southern Tonga arc, the Tabar-Lihir-Tanga-Feni arc (PNG), the Aeolian arc (Italy), and similar expeditions along the Mariana arc by collaborators, means that ~75% of the world's intraoceanic arcs have now been surveyed for seafloor hydrothermal activity. In concert with these surface ship-based surveys, expeditions with manned submersibles (*Shinkai 6500*, *Pisces V*) and ROVs (*ROPOS*, *Jason II*, *Kiel 6000*) have provided vital rock, mineral, animal and vent fluid samples of these seafloor systems. Also, the recent introduction of AUVs (*ABE*, *Sentry*) has provided information at a scale that is relevant to the study of volcanic and structural processes, ore deposit formation, and vent-related habitats.

A worldwide approach has enabled arc hydrothermal systems to be put into context with respect to global seafloor hydrothermal venting. For example, the ~6,900 km of intraoceanic arcs in the world equates to hydrothermal emissions equal to ~10% of that from the 60,000 km of mid-ocean ridges (MORs) (i.e., a similar incidence of venting). Arc volcanoes and their corresponding hydrothermal systems can occur atop cones, inside calderas and combinations thereof, and range in depth from near surface to ~2000 m below sea level. A compilation of information encompassing more than 50 volcanoes has enabled there associated hydrothermal systems to be categorized into three broad types: volcanic, magmatic-hydrothermal and water/rock interaction. Volcanic systems (~5%) are in various stages of eruption and are dominated by the expulsion of gases; magmatic-hydrothermal are the most common type (~75%) that are also dominated by magmatic gases (CO_2, SO_2 and H_2S) interacting with seawater; water/rock systems (~20%) expel less gas but more metals and are commonly associated with Cu-Au-rich mineralization.

THE ANATOMY OF A BURIED SUBMARINE HYDROTHERMAL SYSTEM, CLARK VOLCANO, KERMADEC ARC, NEW ZEALAND

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Clark volcano of the Kermadec arc is a large stratovolcano comprised of two coalescing volcanic cones; an apparently younger, more coherent, twin-peaked edifice to the NW and a relatively older, more degraded and tectonized cone to the SE. High-resolution water column surveys show an active hydrothermal system at the summit of the NW Cone largely along a ridge spur connecting the two peaks.

Volcano-scale gravity and magnetic surveys over Clark show that it is highly magnetized, and that a strong gravity gradient exists between the two edifices suggestive of a crustal-scale fault. Detailed mapping of magnetics above the NW Cone summit shows a highly magnetized 'ring structure' ~350 m below the summit that is not apparent in the bathymetry, believed to represent the rim of a caldera. A pattern of weakly magnetized 'burn holes' is seen within this caldera; presumably older burn holes occupy the inner margin of the ring structure, which are not related to hydrothermal activity, while younger burn holes are coincident with active venting on the summit.

A combination of mineralogy, geochemistry and seafloor mapping of the NW Cone shows that hydrothermal activity today is largely manifest by widespread diffuse venting with temperatures between 56 and 106 °C. Numerous, small chimneys populate the summit area with one site host to ~7 m tall chimneys with maximum temperatures of 221 °C (pH 4.9). Mineralization is dominated by pyrite-marcasite-barite-anhydrite. Radiometric dating using the $^{228}Ra/^{226}Ra$ and $^{226}Ra/Ba$ methods shows active chimneys to be <20 with most <2 years old; evidence exists for mixing with barite as old as 19,000 years.

A holistic approach to the study of the Clark hydrothermal system has revealed a two-stage process whereby a caldera-forming volcanic event preceded a later cone-building event. This ensured a protracted (~20,000 yr) history of hydrothermal activity and associated mineral deposition.

MODELING THE SPATIOTEMPORAL EVOLUTION OF THE 2010-11 INDUCED EARTHQUAKE SEQUENCE ON THE GUY-GREENBRIER FAULT, ARKANSAS

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In 2010-11, a sequence of earthquakes occurred on an unmapped basement fault between the towns of Guy and Greenbrier in Arkansas. The events are likely to have been triggered by a nine month period of wastewater injection during which 4.5×10^5 m^2 of water was injected at two nearby wells. Magnitude-frequency distributions (MFD) for the induced sequence show two interesting properties: (i) a low Gutenberg-Richter b-value of ~0.8 during injection, increasing to 1.0 post-injection (ii) and convexity of the MFD at high magnitude. Additionally, earthquake activity started at the NE end of the fault, nearest to the injection wells, and propagated to the SW with time. We use a coupled model of injection-triggering and earthquake rupture to show how the spatial and temporal changes in seismicity can be understood in terms of diffusing pressure fronts and fault strength reduction.

Reservoir simulation is used to model injection into a horizontally extensive aquifer that overlies an impermeable basement containing a single permeable fault. Earthquake triggering occurs when the static strength, reduced by the modeled pressure increase, satisfies a Mohr-Coulomb

criterion. Pressure evolution is also incorporated in a model of fault rupture, which is based on an expanding bilateral crack approximation to quasidynamic rupture propagation and static/dynamic friction evolution. An earthquake sequence is constructed as an ensemble of triggered ruptures for many realizations of a heterogeneous fractal stress distribution.

During injection, there is a steady rise in fluid pressure on the fault. In addition to its role in triggering earthquakes, rising pressure affects the rupture process by reducing the dynamic strength relative to fault shear stress; this is equivalent to tectonic stress increase in natural seismicity. As mean stress increases, larger events are more frequent and this is reflected in a lower b-value. The largest events, however, occur late in the loading cycle at very high stress; their absence in the early stages of injection manifests as downward curvature in the MFD at large magnitudes.

THE EFFECT OF VERTICAL LAND MOTION AT NEW ZEALAND'S LONG RECORD TIDE GAUGE SITES

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New Zealand's sea level record, which extends back over 100 years to the late 1800s, is one of the oldest records in the Southern Hemisphere and therefore makes an important contribution to global sea level change studies. Tide gauge measurements record the change between sea level and land and are therefore a measure of Relative Sea Level (RSL). Local and regional vertical land motion (VLM) must also be measured in order to determine true sea level changes. Typically VLM can be due to gas/oil/water extraction, glacial isostatic adjustment or tectonic activity, which is thought to predominate in most locations in New Zealand.

In 2000, a combined Otago University and GNS Science project established continuous GPS (cGPS) at four of New Zealand's long record tide gauges, namely Auckland, Wellington, Lyttelton and Dunedin, with the specific objective of measuring the VLM at each site. The rate of VLM at these four sites, as well as regional trends using nearby cGPS sites, has been determined using up to 20 years of cGPS data. However, the recent earthquake events (Christchurch, Dunedin) and the ongoing East Coast slow slip events (SSE) (Wellington) have had a major impact on the vertical component.

In addition to the analysis of VLM at tide gauge sites, this project provides an updated estimate of the long-term RSL change at four tide gauges in New Zealand using data through to 2013 – an additional 13 years compared to the previous study. Data from a fifth New Zealand tide gauge (New Plymouth) has now been analysed and is also included.

TIMING AND CONDITIONS OF MINERALISATION OF THE BLACKWATER DIKE, WESTLAND, NEW ZEALAND

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There is a known correlation between mineralisation and granitic intrusions throughout the Westland region, with examples such as the Berlins Porphyry in the Paparoa Range and Paleozoic granite at Mt Rangitoto. Gold occurrences in the Reefton Goldfield area, which are undated, are typically attributed to having an orogenic origin but an intriguing recent finding has been an discovery of a mineralised granitoid dike in Blackwater Creek less than 1 km from the historically profitable Blackwater Mine. In preliminary multi-element analysis of grab samples, OceanaGold found that the dike and the alteration zone contained above background levels of Au and Cu. Thin section analysis as part of our work shows that the Greenland Group adjacent to the dike has been hornfelsed and biotite (instead of typical chlorite) is present, in part appearing to replace metamorphic cordierite. An alteration halo extends for up to ~200 m into the Greenland Group, and is mainly manifest as pyrite that is either disseminated or occurring in quartz veins. Although the dike was extensively altered by the mineralising fluids, some features of the igneous mineralogy are still present. For example, U-Pb dating of extracted igneous zircon unequivocally indicates that the emplacement age was Early Cretaceous, which means that the mineralization must be either this age or younger. Future work will test whether the Blackwater Dike style of mineralisation has any similarities to the "orogenic" style described

elsewhere in the area, and hence whether that mineralization could be Cretaceous too.

currently reviewing initial ^{226}Ra/Ba values at other hydrothermal sites to check for reworked barite and if this significantly affects the radiometric dating.

ASSESSING SUBMARINE VOLCANIC ARC-RELATED MINERAL DEPOSITS USING NATURALLY OCCURRING RADIOACTIVE ISOTOPES IN BARITE

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GNS Science has developed radiometric methods for dating massive sulphide samples from submarine volcanoes. This has improved our understanding of seafloor hydrothermal system evolution, the frequency and duration of their activity, and assisted marine mineral exploration companies in assessing the economic potential of these deposits rich in copper, zinc and gold (up to 90 ppm in chimneys).

The radiometric dating methods utilize radium isotopes extracted from rock, without their parent thorium isotopes, by ascending, hot, acidic hydrothermal fluids. When the hydrothermal fluid discharges into cold seawater, chemically similar barium and radium co-precipitate as barite, a common mineral in black smoker chimneys that grow on the seafloor. From the onset of mineralization, the isotopes ^{228}Ra and ^{226}Ra (half-lives 5.75 yrs and 1600 yrs, respectively) are decaying, so the ^{228}Ra/^{226}Ra and ^{226}Ra/Ba values decrease with time. Thus, samples can be dated using these ratios once their initial values have been established, ideally from active chimneys. ^{228}Ra decays to ^{228}Th (half-life 1.91 yrs) and from the ^{228}Th/^{228}Ra values, the growth-rate of individual chimneys can be estimated.

Recently, we studied gold-rich (up to 10 ppm Au) chimneys, and other mineralization dominated by barite, from Clark volcano of the Kermadec arc. The barite is commonly of mixed age due to a component of older barite that has dissolved and re-precipitated. For example, the ^{228}Th/^{228}Ra value for one chimney showed that the recent mineralization was <1.5 years old, whereas the ^{226}Ra/Ba value gave an apparent age of 2000 years. Further investigation found that 3000-year-old barite from a buried caldera is dissolving and mixing with newly extracted Ba and Ra depositing in chimneys on a cone that formed later. We are

WHAT DOES SCIENCE COMMUNICATION MEAN TO YOU? A COMPARISON OF EXPERT AND STUDENT RESPONSES

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Researchers at the University of Canterbury have collaborated to develop evidence-based science communication training modules which specifically target upper-year students' communication skills, confidence and perceptions. We have surveyed professionals (n=51; geologists, emergency managers, and geoscience communicators) and students (n=57; geology, engineering geology and hazards and disaster management majors) to help us define differences between these two populations, and to inform science communication teaching practice in our programme. Students and geoscience experts were asked: "What does science communication mean to you?"

Responses ranged in length and specificity for both experts and students. Four main elements emerged: communication *actions*, communication *mechanisms*, *audiences*, and *outcomes*.

Communicate (as a verb) was the most commonly mentioned action followed closely by the transmission of information. Students focused on performance actions (e.g., portraying, telling a story) and the transmission of information (e.g., transfer and convey), while experts focused more on communication as engagement (e.g., sharing, making a connection) and exchange of information (e.g., listening, discussing). Mechanisms consisted of the strategies and tools (e.g., media or formats) of science communication. Overall, there was more of a focus from both experts and students on communication strategies, rather than tools. Overwhelmingly, both groups stated that communication should be "effective" with common suggestions of: clarity, use of everyday and 'simple' language, and being concise. Expert participants

paid more attention to diversity and cultural aspects and outcomes in their responses. They also described more complex interactions between the information and its use to different stakeholders, whereas students focused more on helping the public "to understand the information".

Our results show that students are focussing on the fundamentals of communication performance, while experts are able to view communication as a dialogic and engagement process. Instructors should be aware that students may be focusing on the basics and encourage them to view science communication as a dialogue within their local and global communities.

ARE LAKE OHAU SEDIMENTS ANNUALLY LAMINATED?

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From a paleo-environmental perspective annually resolvable records that cover thousands of years bridge an important observational gap between short instrumental records and long, but traditionally low temporal resolution geological records. In alpine regions annual coarse-fine sediment couplets resulting from strongly contrasting seasonal controls on sedimentation have been well documented. Sediment cores recovered from southeast Lake Ohau contain mm-scale coarse-fine sediment couplets that represent accumulation over the past ~1400 years. An open question has been whether or not these layers represent 'annual' laminations (i.e. varves). Over the past year we have undertaken detailed (~10 minute resolution) monitoring of sedimentary processes within the lake using moorings containing turbidity and temperature sensors as well as full water column Acoustic Doppler Current Profiling. We have also deployed a rotating carousel sediment trap with a resolution of ~14 days at our core site to measure accumulation. Combining measurements from these instruments with meteorological and river inflow data provides an opportunity to examine the origin of Lake Ohau sediment laminations in great detail. The initial results point to a combination of both seasonally contrasting sediment input with deposits related to flood-stage 'events' superimposed on the sedimentary record.

INTERGLACIAL/GLACIAL CHANGES IN COCCOLITH PRODUCTIVITY OFF EASTERN NEW ZEALAND: A WINDOW INTO THE FUTURE?

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Satellite observations show that modern ocean warming supports increased coccolithophore blooms. However, the causes and long-term outcomes of these events are unclear. Ocean sediment cores are used to assess coccolithophore production north and south of the Subtropical Front over glacial-interglacial cycles. Calcareous pelagites from the subtropics off northern New Zealand (site P71) and from subantarctic waters on Campbell Plateau (Ocean Drilling Program [ODP] site 1120C) record marked depositional changes. Foraminiferal-rich sediments dominate glacials and coccolith-rich sediments characterise specific interglacials. Using sediment grain size to determine relative abundances of coccoliths and foraminifers, results show coccoliths prevailed during Marine Isotope Stages (MIS) 7b/a and MIS 1/2 at P71, and during MIS 6/5e at ODP 1120C. Environmental proxies suggest that coccolithophores at P71 responded to enhanced nutrients associated with intense winter mixing in the subtropical Tasman Sea. An increased inflow of that warm, micronutrient-rich subtropical water, together with surface ocean thermal stratification in late spring/summer, led to peak phytoplankton production. At ODP 1120C during MIS 6/5e, an increased inflow of subtropical water, warm sea surface temperatures and a thermally stratified upper ocean also favoured coccolithophores. These reconstructions aided by model simulations suggest that (i) future subtropical coccolithophore production is unlikely to reach abundances recorded during MIS 7b/a but

(ii) future subantarctic production is likely to dominate sedimentation over Campbell Plateau as modern conditions trend towards those of MIS 5e.

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

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Major climate and environmental changes occurred from the late Oligocene to the late Miocene. Modest increases in atmospheric CO_2 concentrations, ranging between 500 and 300ppm, resulted in warmer Antarctic temperatures that impacted ice sheet growth. This implies the southern high latitudes were highly sensitive to feedbacks associated with changing global ice sheet volumes, sea-ice extent, and the composition and extent of terrestrial and marine ecosystems. This study focuses on two key intervals during the evolution of the Antarctic Ice Sheet. (1) the Late Oligocene to Early Miocene, when the East Antarctic Ice Sheet expanded close to its present day volume following an extended period of inferred warmth and (2) 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. Reconstructions of climate and ice sheet variability, and thus an understanding of the various feedbacks that occurred during these intervals, are hampered by a lack of temperature and hydroclimate proxy data from the southern high latitudes.

We present proxy climate reconstructions using terrestrial and marine biomarkers from Antarctic drill cores and outcrop samples covering a range of depositional settings. Bacterial ether-lipids have been 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 have been used to derive sea surface temperatures using the TEX86 index. Compound specific stable isotopes on n-alkanes sourced from terrestrial plants have been analysed to investigate changes in the hydrological and carbon cycles. These techniques provide new insights into Antarctica's climate evolution during key periods of Antarctic Ice Sheet variability.

OPPOSING STYLES OF POST-ENTRAPMENT RE-EQUILIBRATION IN A SINGLE ERUPTED SAMPLE: FE-LOSS VERSUS FE-GAIN IN OLIVINE-HOSTED MELT INCLUSIONS

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In order to assess the petrologic significance of silicate melt trapped in early crystallising phases such as olivine it is necessary to address the possibility of diffusive re-equilibration of the melt with its host mineral. Studies have shown at least some degree of diffusive re-equilibration is likely to have occurred either as a post-entrapment phenomenon or during experimental reheating of the trapped melt. Re-equilibration associated with the natural cooling path of an ascending magma body results in a quenched or recrystallised melt that has less total FeO (FeO*) than was present in the originally trapped melt. This process is referred to as *Fe-loss*. However, magma bodies often experience more complex interactions with their surroundings particularly in atypical, subduction-related settings that are characterised by young subduction that generates anomalously hot geothermal structures within the mantle wedge. In these settings mixing between magma batches and interactions between the subducting slab and the mantle wedge of contrasting temperatures can act to promote a different type of re-equilibration process. If an olivine that originally crystallised from a fractionated melt is picked up by a hotter, more primitive melt it will start to re-equilibrate to the new conditions of the primitive melt body. Under these conditions any of the original, more fractionated melt trapped within the olivine will also re-equilibrate by becoming enriched in FeO*, relative to the original FeO* content of the melt that the olivine crystallised from. This enrichment

process can be referred to as *Fe-gain*. This paper presents an example of Fe-gain within naturally occurring silicate melt trapped within olivine phenocrysts hosted in two primitive, arc-related basalts from the Hunter Ridge (D2-1) and the Hunter Ridge Rift Zone (D3-1).

THE NATURE OF DISSEMINATED GOLD IN THE EASTERN GOLDFIELDS, WA: ELEMENTAL MAPPING USING THE MAIA DETECTOR ON THE XFM BEAMLINE REVEALS A NEW STYLE OF MINERALISATION WITHIN THE DOLERITE INTRUSION OF THE KALPINI DEPOSIT

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The Kalpini deposit is located within the Eastern Goldfields Province of the Eastern Yilgarn Craton, Western Australia. Locally, the Kalpini deposit is hosted in the Kurnalpi Terrane, 75 km north-east of Kalgoorlie and 1 km east of the Emu Fault that separates the Kurnalpi Terrane from the Gindalbie Terrane. The Kalpini resource contains two separate deposits: Atlas, and Gambia North and South. This area was historically mined for gold-bearing quartz lodes however recent exploration identified a disseminated style of mineralisation at both deposits within the doleritic and andesitic host rocks. The Gambia South altered, granophyric, quartz dolerite sill shows greater potential for hosting a significant resource however, mineralised and non-mineralised dolerites are superficially very similar making it difficult to differentiate between highly prospective and unprospective equivalents within the Gambia South deposit. Micrometre-sized gold inclusions were observed in thin section within arsenopyrite and pyrite, associated with pyrrhotite and chalcopyrite and found within veins and fractures adjacent to sulphides that coincide with high bulk gold grades (>1g/t Au) measured from 1 m composites from diamond drill core. It was suspected that invisible gold could potentially make up a significant portion of the gold budget and likewise would be associated with these sulphide minerals. To investigate this hypothesis a series of 2D elemental distribution maps were generated for 7 polished thin sections from Gambia South diamond drill core intervals on the XFM beamline at the Australian Synchrotron, utilizing the Maia x-ray fluorescence detector. In drill core sample KPDD008-9 (128 m) invisible gold that thought to be solely associated with arsenopyrite and arsinian pyrite was also found in Ti-rich magnetite. This style of mineralisation was not previously recorded in any historical exploration work carried out at the deposit and represents a renewed opportunity for focusing on a more diversified deposit.

THE LAST GLACIAL COLD PERIOD IN CENTRAL NORTH ISLAND: PALAEOCLIMATE INFERENCES FROM 2D GLACIER MODELLING

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Quantitative palaeoclimate reconstructions provide important data for evaluating the drivers and mechanisms of past, natural climate variability. Geometries of former mountain glaciers constrained by moraine mapping afford the opportunity to reconstruct palaeoclimate, due to the close relationship between ice extent and local climate. In this study, we present results from a series of experiments using a 2D coupled energy-balance/ice-flow model that investigate the palaeoclimatic significance of moraine records that pertain to the Last Glacial Cold Period (c. 28 – 18 ka) in nine catchments on Tongariro and Ruapehu volcanoes in central North Island. We find that the mapped former ice limits can be simulated when present day temperatures are reduced by between 4 °C and 7 °C, when precipitation remains unchanged from present. The spread in the results between the 9 catchments is likely to represent a combination of chronological and model uncertainties. The majority of catchments yield results that fall in the range of 5.1 °C and 6.3 °C, which represents our best estimate of the peak temperature anomaly in central North Island, New Zealand during the Last Glacial Cold Period. A decrease in precipitation, as suggested by proxy evidence and climate models, of up to 25 % from

present, increases the magnitude of the required temperature changes by up to 0.8 °C. Model experiments using reconstructed topographies that exclude the volume of post-glacial (<15 ka) effusive volcanic deposits, generally increase the magnitude of cooling required to simulate the former ice limits by up to 0.5 °C. Our palaeotemperature estimates expand the spatial coverage of proxy-based quantitative palaeoclimate reconstructions in New Zealand, and are consistent with independent, proximal temperature reconstructions from fossil pollen assemblages, as well as similar glacier modelling reconstructions from central Southern Alps.

GLACIAL GEOMORPHOLOGY OF THE SPENSER MOUNTAINS, SOUTH ISLAND, NEW ZEALAND

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Temperature mountain glaciers erode, transport and deposit geological material, producing distinctive landform assemblages. Identification of glacial landform assemblages preserved outside present day ice limits enables reconstruction of past glacier geometries. In turn, such reconstructions allow inference of past climatic conditions due to the close relationship between ice extent and local climate. Here we present preliminary results from geomorphological mapping and glacier-climate reconstructions in Spenser Mountains, South Island. The Spenser Mountains represent the northern margin of the Southern Alps and are largely ice-free today, except for small perennial snow patches / niche glaciers. The range is bound by the Matakitaki and Waiau River valleys, which exhibit truncated spurs and classic parabolic cross sections indicative of erosion by former valley glaciers. Previous work has suggested these glaciers existed at the peak of the last glacial cycle. Overlooking these larger glacial troughs, hanging valleys and cirques punctuate the upper slopes of the Spenser Mountains and contain suites of moraines. Geometric reconstructions of these former cirque glaciers indicate local snowline depressions of c. 300 – 500 m, relative to present. We suggest these features may record the northernmost expression of glacial advance in South Island during the last glacial termination and possibly the Holocene. Cosmogenic ^{10}Be exposure dating of these features is underway, which will test this inference.

CHARACTERISING THE ALPINE FAULT DAMAGE ZONE USING FAULT ZONE GUIDED WAVES, SOUTH WESTLAND

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Fault Zone Guided Waves (FZGWs) are observed within the Alpine Fault, which is late in its typical seismic cycle. Distinctive dispersive seismic coda waves (~7-35 Hz), trapped within the low-velocity fault damage zone, have been recorded on three component 2 Hz borehole seismometers installed within 20 m of the principal slip zone in the shallow (< 150 m deep) DFDP-1 boreholes. Near the central Alpine Fault, known for low background seismicity, FZGW-generating microseismic events are located beyond the catchment-scale strike-slip and thrust segment partitioning of the fault indicating lateral connectivity of the low-velocity zone immediately below the near-surface segmentation. Double-difference earthquake relocation of events using the dense SAMBA and WIZARD seismometer arrays allows spatio-temporal patterns of 2013 events to be analysed and the segmentation and low velocity zone depth extent further explored. Three layer, dispersion modeling of the low-velocity zone indicates a waveguide width of 60-200 m with a 10-40% reduction in S-wave velocity, similar to that inferred for the fault core of other mature plate boundary faults such as the San Andreas and North Anatolian Faults.

THE NEW ZEALAND STRATIGRAPHIC COLUMN FILE

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New Zealand's nationally significant database of geological measured sections (MS), the New Zealand Stratigraphic Column File, contains important information from historic handwritten documents that were predominantly compiled under the Cretaceous-Cenozoic Programme of the 1970s-1990s. These records embody tens of millions of dollars of time, and substantial logistical and scientific investment. In many cases, these records are irreplaceable, and represent significant knowledge from over 50 years of research, geological mapping, and paleoenvironmental interpretation.

The digitisation process of the measured section data into an Access database was begun as a Victoria University of Wellington Summer Research Scholarship project with GNS Science (2014-2015) and has been on-going. Though initially the focus was on the East Coast region, the intention is to capture data from all regions. The purpose of this database is to enable digital searches and retrieval of the data.

As of September 2015, around 900 MS documents have had relevant header data captured, and approximately 250 MS have been captured digitally (at least in part), with an additional key aspect of this project being the completion of scanning paper records to PDF format. Changes to map sheet cut-up systems (NZMS1 to NZMS 260, and more recently to Topo50) has guided the decision to avoid future confusion in the identification of MS records through map sheet identifiers. The records (both captured data and PDF files, along with paper copies) are now each identified through discrete numbers with no geographic significance. The PDF files can be accessed online through GNS Science's Petroleum Basin Explorer (PBE) web portal.

MECHANICS OF THE OFFSHORE HIKURANGI ACCRETIONARY PRISM: IMPLICATIONS FOR FLUID PRESSURE ALONG THE DÉCOLLEMENT

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GPS data show that the northern portion of the Hikurangi subduction thrust fault is creeping steadily, while the southern segment is locked and appears capable of producing great earthquakes. Wedge morphology and deformation also change along-strike, with a wide accretionary imbricate wedge in southern and central Hikurangi transitioning to a non-accreting, steep wedge in the north that experiences periodic subduction erosion from seamount subduction.

We use depth-converted seismic sections along the margin to constrain numerical models investigating these along-strike changes. Firstly, we compute fluid release from porosity loss as sediment enters the margin to calculate steady-state fluid pressure and its influence on effective stresses and permeabilities. Predictions for wedge morphology, fault development, and fluid-flow rates are tested against interpreted wedge structure and fluid chemistry. Sediment subducted around the seamounts provides a fluid source that can drive fluid overpressure on and around the subduction interface. Whether this significantly weakens the décollement depends on the development of fracture permeability and its interactions with upper plate faults. To produce high rates of fluid flow consistent with fluid chemistry in the central and northern margin, significant permeable pathways must develop, locally limiting décollement overpressure.

Secondly, we use wedge structure restored to 2 Ma as an initial condition for forward modelling. We test the range in décollement friction and fluid overpressure compatible with wedge deformation over the last 2 M.y. We show the influence of enhanced sedimentation rates, the buildup of the outer wedge and the sequence of thrust fault propagation and protothrust zone development with increasing shortening. The central and southern Hikurangi accretionary wedges

approximate growth of a critical wedge geometry, while northern Hikurangi margin morphology episodically cycles as seamounts enter the margin. Both northern and southern Hikurangi wedge evolution requires a low-strength décollement consistent with weak clay minerals and/or moderately high fluid overpressure.

AMBIENT SEISMIC NOISE TOMOGRAPHY OF THE AUCKLAND VOLCANIC FIELD

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Auckland, New Zealand's most populous region (1.4 million), is situated on top of a monogenetic volcanic field with at least 53 volcanoes. The Auckland Volcanic Field (AVF) is considered active, but the risk and hazard of a volcanic eruption are difficult to assess. A high-resolution model of the subsurface structure of Auckland is lacking, partially due to its low seismicity. However, New Zealand's long coastlines experience high energy ocean waves, generating seismic noise. This study is the first to exploit seismic recordings of ocean noise to infer the structure of Auckland's subsurface.

We took the instrument-response corrected vertical components of 200 days of noisy wavefields from 66 possible station pairs and cross-correlated to obtain an estimate impulse response; this resulting time series is as if one of the stations is a seismic source, and the other a receiver. We estimate Rayleigh wave group and phase velocity dispersion relations by multiple filter analysis of the impulse responses.

Frequency-dependent surface wave speeds with periods between 3 and 10 seconds provided robust information about the subsurface. We inverted group and phase velocity dispersion curves from 16 impulse responses, obtaining shear velocity models that extend from the surface to approximately 25 km depth. The average of our models largely agrees with a shear velocity model obtained by joint teleseismic receiver functions and seismic surface wave inversion techniques by Horspool et al (2006). We found that the shear velocity variations of individual station pairs correlates well with the crust type and surface geology. The appearance of low-velocity zones shows good spatial correlation with the semi-continental crusts of the Murihiku and Waipapa Terranes. Models with monotonically increasing shear wave velocity of typical oceanic crust are mainly associated with the Dun Mountain Ophiolite Belt, of the Maitai Terrane.

THE POTENTIAL OF DYNAMIC TIME WARPING FOR CORRELATION OF MULTIPROXY DATA SETS BETWEEN MULTIPLE LAKE CORES THAT EXHIBIT VARIABLE SEDIMENTATION RATES

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Sediment core correlation is usually undertaken by "eyeballing" patterns observed in the stratigraphic data sets. This process is often effective, but not statistically robust. Dynamic time warping (DTW) is a time series analysis algorithm for comparing similarity between two linear data sets that vary in time. From a stratigraphic perspective, this allows the comparison of linear data sets representing multiple proxies with variable sedimentation rates.

Carbon, Nitrogen, and magnetic susceptibility were measured and compared from two lake sediment cores extracted from Lake Kawaupaka, New Zealand, in order to test the viability of applying the DTW method to aid in proxy pattern matching and resolving stratigraphic complexities. Each of these data sets were compared with the DTW add-on for the R platform (Ihaka and Gentleman 1996, Tormene et al. 2009). Both Kawaupaka cores have high resolution-optical and X-ray density images that show the same stratigraphy on a millimeter scale with variable sedimentation rates. Accuracy of the mathematical DTW correlation will be checked against the visual stratigraphic correlation.

The results of these comparisons suggest that a statistical best-fit scenario does not necessarily equal a correct stratigraphic correlation. One issue is that the algorithm compares absolute peak values, and not the peak locations as with the "eyeball" method, leading the DTW algorithm to ignore "known" stratigraphic markers. Another source of error in the DTW-inferred core correlations is when extreme differences in sedimentation rate are present, causing the DTW calculation to exceed acceptable alignment ranges. Best results were obtained from data sets that had comparable peak values, which were pinned with stratigraphically known start and end points. Consequently, although the DTW approach shows

potential uses in stratigraphy, the algorithm needs more refinement in order to be applied to stratigraphic sequences such as the multiproxy lake sediment cores examined here.

STRESS DISTRIBUTION IN THE WELLINGTON REGION

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It is important to understand the dynamics associated with faulting, as they relate to structure and potential hazards. The Wellington region of New Zealand is situated on the boundary of the Pacific and Australian plates on the southern portion of the Southern Hikurangi margin. The tectonics of the region are dominated by a subduction zone at depth, where the west verging Pacific plate is subducting under the east verging Australian plate, and at the near surface by dextral strike-slip faulting. The GeoNet network of 18 stations (within the Wellington region) were supplemented by 50 SAHKE stations during a 4-month period from 2009-2010, allowing for increased stress mapping resolution. The dense spatial distribution of the 50 additional seismic sites will allow for the inclusion of smaller seismic events, which otherwise would be undetected by the regional GeoNet network. Relocated hypocenters of microseismic events were determined using NonLinLoc, a non-linear location method, and a 2D velocity model developed from the SAHKE transect. For events located within the region (174.5W to 176.5W and -40.75N to -41.75N), which are shallower than 40 km, focal mechanisms and stress parameters will be calculated using a Bayesian method. Preliminary results have shown there to be at least 326 microseismic events located within the designated area.

COUPLING TEMPORAL AFTERSLIP WITH VISCOELASTIC REBOUND USING HYBRID NUMERICAL GREEN'S FUNCTIONS

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Postseismic deformation following large earthquakes is often described in terms of either time-varying afterslip on the coseismically ruptured surface or its extension or viscoelastic relaxation. Here, we describe an inversion framework with which to estimate afterslip while taking account of viscoelastic effects. Estimating time-dependent afterslip is an ill-posed problem unless steps are taken to avoid high-frequency components of deformation affecting the calculated slip, and this requires regularization in both space and time. Conventionally, the problem of computing the slip distribution in space is regularized using Laplacian smoothing of the fault slip. In order to regularise the ill-posed problem in time, we adapt the method of Kositsky and Avouac (2010) to accommodate viscoelastic media. Ground deformation in response to a dislocation source is a linear function of slip for an elastic medium, meaning that Singular Value Decomposition (SVD) of the observed deformation time series yields the temporal evolution of slip (Kositsky and Avouac, 2010). The problem remains linear for a viscoelastic medium but in this case the Green's functions are time-dependent. We estimate hybrid Green's functions expressing the response to both afterslip and viscoelastic rebound using the finite element code PyLith (Aagaard et al., 2009). In this approach, we decompose the time-dependent Green's functions and the ground deformation into space and time functions and use these to represent the evolution of slip. We apply this method to the postseismic ground deformation observed following the Mw 7.8 Dusky Sound (New Zealand) earthquake of 15 July 2009.

GEODYNAMIC EVOLUTION AND CRUSTAL ARCHITECTURE OF NORTHERN VICTORIA LAND: CLUES FROM NEW AEROMAGNETIC AND GRAVITY SURVEYS

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Northern Victoria Land (NVL) contains several key geological records of the Ross Orogen in the framework of the paleo-Pacific active margin of Gondwana. The past literature models depicts NVL as a collage of three terranes, the Wilson, Bowers and Robertson Bay terranes (WT, BT, RBT), but whether these are exotic terranes or merely different components of an evolving backarc-arc-trench system is now debated.

Here we interpret new aeromagnetic, aerogravity and land-gravity compilations, derived from over 2 decades of geophysical exploration: our aims are to trace the subglacial extent of major terrane-bounding and intra-terrane faults in NVL, investigate crustal architecture, and propose an evolutionary model for the active margin of the craton.

Prominent aeromagnetic anomalies characterize the eastern edge of the Wilkes Subglacial Basin. Further south, in the Prince Albert Mountains, small outcrops of gabbro-diorites suggest that these anomalies may be delineating the buried extent of an early-Ross magmatic arc. Magnetic signatures of this arc are also identified within the Wilson Terrane, at present disrupted by arc boudinage, possibly triggered by extension/transtension, linked to the overall retreating Early Cambrian subduction setting. Prominent magnetic lows in the central WT are interpreted as thick mid-Cambrian(?) sedimentary basins, linked to the same extension/ transtension setting.

High amplitude magnetic and gravity anomalies suggest that oceanic basement floors the northern BT. Previous geophysical interpretations suggested that a renewed Cambrian subduction caused the obduction of such basement onto the margin. Here we suggest that the docking a microcontinent, inferred to underlie part of the RBT, facilitated obduction; intriguingly, this scenario has similarities with recently proposed geodynamic models for the Tasmanian sector of the Gondwana active margin.

Overall, this new geophysical interpretation of NVL supports a long-lived and composite backarc-arc-forearc-system, which migrated and evolved in response to changing geometry and dynamics of the subduction system and also involved microcontinents.

THE MUNGAROA FORMATION (WAIRARAPA) AS A HYDROCARBON RESERVOIR ANALOGUE

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Outcrop analogues provide a useful means of assessing reservoir potential of as yet undrilled rocks in the offshore parts of the Pegasus and East Coast basins. The Early Eocene Mungaroa Formation crops out in coastal Wairarapa at Te Kaukau Point, where it comprises both greensands and fine-grained limestone, and these outcrops indicate what might be in the subsurface nearby offshore, such as submarine fans of similar but more distal lithologies.

Greensand units within the Mungaroa Formation comprise thick (dm-m) units consisting mainly of centimetre-amplitude cross-beds. Porosities are around 20% and air permeabilities range from <1 mD to ~50 mD at confining pressures of 5–30 MPa (equivalent to depths of up to ~1 km). Fractures in the greensands strike NE and E and are mostly less than 1 mm wide (filled with dark, fine material) though may have apertures of up to 2 mm; one was observed to be partially open. Fracture apertures and spacings in the limestone appear to be scalable (set 020/85°E). Petrographic studies of three Mungaroa Formation sandstone samples show them to comprise very fine-grained, moderately well to well sorted, glauconitic subfeldsarenites. Authigenic phases are dominated by clays (grain-coating and grain-replacing), with generally minor quartz overgrowths (<2%), associated with reasonable macroporosity (~4%). However, locally pervasive pore-filling carbonate cement has been observed in places (19% in a highly glauconitic sample) and this corresponds with no visible macroporosity.

These data show that the Mungaroa Formation is likely to contain intervals with reasonable reservoir potential at shallow to moderate burial depths. Matrix porosity/permeability may be improved by additional permeability from fractures, and it is therefore suggested that, depending on burial and

diagenetic histories, the formation might form a viable close-to-source play target in the Pegasus Basin.

LESSONS LEARNT FROM THE AUGUST 2012 TE MAARI, TONGARIRO AND THE 2014 MT ONTAKE, JAPAN ERUPTIONS: FINDINGS FROM A POST-ERUPTION BALLISTIC IMPACT ASSESSMENT TRIP

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Two eruptions in the past three years have highlighted the hazard that volcanic ballistics pose to both life and infrastructure. The August 2012 eruption of Te Maari, Tongariro ejected thousands of ballistics up to 2.3 km from vent, impacting the popular Tongariro Alpine Crossing. Fortunately this eruption occurred at night and in off-peak season when no one was on the track or staying in the impacted Ketetahi Hut. The September 2014 eruption of Mt Ontake, Japan also ejected ballistics but occurred in peak season in the middle of the day and resulted in 58 fatalities and over 70 injuries (almost all from ballistics). Both eruptions were phreatic, had little precursory activity and were on volcanoes visited by thousands of tourists each year. A post-eruption ballistic impact assessment trip to Japan was undertaken in July 2015 by UC and GNS to learn lessons from the Mt Ontake eruption to apply back at New Zealand volcanoes. This presentation will report on preliminary findings from this trip, addressing similarities in the eruptions, the extent of the ballistic hazard zone, the locations and causes of fatalities, ballistic size, the successful actions taken by survivors, risk mitigation measures applied by authorities and the methods of communication utilised.

DEVELOPING A HOLOCENE STORM RECORD FROM LAKE MAVORA, WESTERN SOUTHLAND

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Modelling the likely impacts of climate change on the hydrological cycle has led numerous researchers to suggest that change is likely to be characterised by significant modification of the magnitude and frequency of extreme events. However, understanding the characteristics of extreme hydrological events requires records of the magnitude and frequency of events on centennial and millennial timescales, which are not available from instrumental records of climate and river flow. Recent research has shown that abyssal lake sediments have the potential to yield continuous records of floods in the form of turbidites that record the delivery of coarse-grained sediments into lakes during energetic river flows. In this paper we describe the development of a flood stratigraphy for South Lake Mavora, a small (1.23 km^2) moraine and outwash sediment-dammed lake in western Southland. The sediments of the lake were sampled using a Mackereth corer capable of retrieving continuous cores 50mm in diameter and up to 6m long. Two 6m-long cores were retrieved from the deepest part of basins and seven 1m-long cores adjacent to the longer cores and in a transect from the deepest part of the basin to a fan-delta on the western side of the lake. The age model for the sediments is based on 28 ^{14}C dates from a single core. The lake sediments are predominantly planar-bedded hemipelagic fine and medium silts with individual layers between <1mm and 300mm thick. The hemipelagic sediments are interrupted by three types of rapidly-deposited layers (RDL's). Type 1 RDL's are beds of deformed lacustrine sediment which we interpret as the products of subaqueous mass movements. Type 2 RDL's are 2-200mm-thick beds of normally graded coarse to medium silt capped by thin fine silt layers. They overlie type 1 RDL's and are interpreted as turbidity currently generated by the underlying subaqueous mass movements. Type 3 RDL's consist 1mm to 30mm-thick beds of very fine sandy silt that grade into fine silt which are interpreted as turbidites that represent floods from the Mararoa catchment. The record of fluvially-derived turbidity currents provides a Holocene record of storminess in the southern South Island.

ZEALANDIA – A ROSETTA STONE FOR WHALE AND DOLPHIN HISTORY IN THE SOUTHERN HEMISPHERE

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Zealandia's fossils are important in understanding the history of whales and dolphins. Most specimens are from the Canterbury Basin, but fossils occur New Zealand-wide. The history of finds started with Mantell in 1848; most later discoveries were serendipitous, but for targeted work by McKay (1880s) and Marples (1940s). Research has expanded since the 1980s, with many recent advances summarised here.

Our oldest cetaceans, upper Bortonian archaeocetes, mark major range expansion from ancestral tropical-subtropical regions. Archaeocetes persisted into the late Oligocene, when *Kekenodon* and relatives were coeval with "modern" Cetacea in Zealandia. The earliest Mysticeti (baleen whale group) were toothed forms, cf. *Llanocetus* and cf. Aetiocetidae (Whaingaroan, Duntroonian?). True baleen whales appeared by the Duntroonian, and Duntroonian-Waitakian assemblages are diverse in species and structure. Of these, the eomysticetids (e.g. *Tohoraata*, *Tokarahia*) are basal mysticetes with narrow long jaws, probably used in skim-filter feeding. *Horopeta* (Duntroonian) is a bowed-jawed presumed gulp or lunge-feeder, of uncertain relationships; the Waitakian *Mauicetus* is a basal balaenopteroid, related to living minke whale. Unnamed putative right whales (Balaenidae) suggest the advent of arched-skull skim feeding.

Odontocetes – toothed echolocators – are Duntroonian and younger. Phylogenetic studies reveal a high diversity of Platanistoidea (especially in Otekaike Limestone), a group now represented by the endangered Ganges River dolphin. *Waipatia*, *Otekaikea* and relatives are platanistoids, but squalodontids are less clearly so, while *Papahu* lies with the sperm whale-delphinida radiation. True dolphins – Delphinida – are rare. Phylogenetic analyses give widely varying results, suggesting that only a little of odontocete diversity has been sampled. For mysticetes, a morphological-molecular cladistic analysis uses fossils, including from Zealandia, to date major diversification. Diversity and disparity in the Oligocene were high, consistent with major early radiation. The earliest Miocene (Aquitanian) record globally is poor, but New Zealand fossils should help to address this.

EARLY MIOCENE DEGLACIATION PRECEDED BY SHORT-LIVED INCREASE IN ATMOSPHERIC CARBON DIOXIDE

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The Oligocene/Miocene (O/M) boundary bore witness to a transient glaciation of Antarctica known as the Mi-1 event. This event lasted approximately 400 kyr, peaking at the O/M boundary (23.03 Ma). Due to the low resolution of marine sediment records, the details and drivers of this short-lived event are still poorly understood. A lacustrine sediment deposit from Otago preserves a unique annually laminated record of the peak and rapid deglaciation phase of Mi-1. Persistent anoxia in the deeper parts of the lake has led to excellent preservation of fossils, including original soft tissues of flowers, leaves and insects. Leaf cuticle architecture is preserved in most cases, allowing the use of the stomatal index technique to reconstruct levels of atmospheric carbon dioxide. We show that a short-lived (20–40 kyr) increase in atmospheric CO2 occurred around 23.00 Ma, ~20 kyr before the initiation of rapid deglaciation of Antarctica at the end of the Mi-1 event.

BRITTLE DEFORMATION AND FAULTING IN FOLIATED BASEMENT ROCKS OF COASTAL OTAGO

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Foliated schists belonging to TZIIa are well exposed across extensive, clean coastal outcrops in Otago, where they are cut by various sets of late-stage joints, brittle faults and fault-related vein networks. This provides an opportunity to study the nature of brittle deformation and fluid flow in the outboard portion of the Otago reverse-fault province.

Brittle deformation features were mapped at a range of scales between Taieri Mouth and Chrystalls Beach. From high-resolution aerial photography, lineaments (n=6625) with lengths ≥3m show preferred orientations trending NW-SE, correlating to regional-scale faults in Otago, and ENE-WSW. Structural fieldwork indicates the NW-SE lineaments correspond to first-order faults ≤2m wide hosting breccias, as well as smaller (generally sinistral) faults that nucleated on continuous, planar, steeply-dipping joints. The latter are associated with paired quartz-calcite veins and small breccia pods developed in dilational jogs between overlapping joints. ENE-WSW lineaments correspond to a second (often dextral) fault set hosting thin, continuous breccia layers formed within intact schist. Both fault sets host shallowly plunging lineations and form a conjugate set.

Stress inversion indicates the paleostress field during faulting was similar to the modern-day stress field in Canterbury and Otago, characterized by horizontal σ_1 trending c. 115° and vertical σ_2, i.e. a strike-slip regime. Preliminary stable isotope analysis of fault-related calcite veins indicates the host fluid was a mixture of deep-seated basinal waters and shallow water from the limestone overburden. Fluid inclusions will be used to further constrain the P-T conditions of faulting. The orientations of the widespread basement faults that we have documented in coastal Otago mimics aspects of the faulting pattern from the 2010-2011 Canterbury Earthquake sequence. Thus, there may be a common basement fault fabric developed throughout Otago and Canterbury that plays an important role in controlling earthquake sequences developed within the contemporary stress field.

ECOTOXIC TRACE ELEMENTS IN NEW ZEALAND PHOSPHORITE NODULES

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Seafloor mineral resources are increasingly being considered as economically viable sources of many elements as reserves on land become depleted. In New Zealand, offshore phosphorite deposits have been identified as a resource of interest since the 1970s due to being a key ingredient in agricultural fertilizers. The environmental effect of mining these reserves, however, remains uncertain, with the Environmental Protection Agency in February this year refusing permission for mining of nodules from the Chatham Rise. This was in part due to uncertainty regarding potential mobilization of heavy metals, and their associated ecotoxicity.

This study aims to clarify the uncertainty regarding the ecotoxicity resulting from the potential mobilization of heavy metals during the mining process (e.g. As, Cd, Cr, V and U). Phosphorite and sediment samples were collected from the Chatham Rise during four voyages in the 1960s and 1970s, and from the Bounty Plateau and Bollons Seamount in 2003. Two box core samples containing nodules, sediment and organisms, as well as surface and deep seawater samples, were also collected during a voyage earlier this year. Trace metal and nutrient analyses of the sediments and seawater samples, as well as on ship elutriate experiments, and preliminary ecotoxicity experiments from the samples collected this year will be presented. Preliminary results on 26 nodules of comparable size suggest wide chemical variability in phosphorite nodules across the Chatham Plateau (e.g. 2.5 – 11.1 wt.% SiO_2, 0 – 1.7 wt.% Al_2O_3, 4.8 – 10.7 % Fe_2O_3, 0.54 – 1.3 wt.% MgO, 45.2 – 61.2 wt.% CaO, 15.7 – 35.6 wt.% P_2O_5 and 2400 – 11340 ppm S. In general, nodules from the west have higher SiO_2, Al_2O_3 and MgO, and lower S and Cl than nodules from the east. Notably CaO and P_2O_5 show no systematic change with geographical distribution. Key ecotoxic element concentrations vary by a factor of 10 or more.

AMBIENT NOISE MONITORING OF SSE WITH THE HOBITSS OCEAN-BOTTOM ARRAY

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The recent discovery of the shallowest, well-documented slow-slip events (SSE) on earth prompted an offshore deployment of 15 ocean-bottom seismometers (OBS) near the northern Hikurangi subduction margin, offshore of the North Island. This OBS array was extracted in April 2015 after capturing the second largest SSE ever observed in the area. The SSE potentially extends to the trench and represents one of the best seismic datasets of an SSE ever recorded. We exploit the relative proximity of the recorders to the SSE by examining the azimuthal dependence of the ambient noise surface wave field. We will present results of inverting ambient noise cross correlations for anisotropic structure with critical examination of time-dependence in the data. Shallow surface wave anisotropy is particularly sensitive to small-scale perturbations in stresses and represents a promising tool to monitor changes in stress, including possible changes resulting in pore fluid pressurization, driven by the SSE.

PETROGENESIS OF PLUTONIC ROCK AT ORAKA POINT, SOUTHLAND

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Plutonic igneous rocks of the Southland coast provide important information on the nature and timing of accretion of the Permian Brook Street intraoceanic arc to the Gondwana continental margin. Coastal exposures east of Oraka Point (Riverton, Bluff Peninsula) are volcanic, volcaniclastic and related plutonic rocks of the Brook Street Terrane whilst exposure to the west (Wakaputa Point, Ruahine Hill, Pahia Point) are of Triassic Median Batholith with Gondwana-margin affinity. The aim of this research is to examine gabbro, diorite and granite exposed at Oraka Point in order to better understand which of these two basement terranes they are most closely associated as well as explore petrogenetic models for their formation.

Five new U-Pb zircon ages have been obtained for the Oraka Diorite and Colac Granite by LA-ICP-MS. These are in agreement with each other and two published dates at 244 ± 3 Ma, and further support the progressive decreasing age trend from east to west along the Southland coast. Major and trace element data for fifteen whole-rock samples highlighted fractionation as a driving force of magma evolution which is especially evident in the SiO_2 vs Zr relations. Trace element patterns are similar to those previously obtained for the Median Batholith to the west. Analyses of plagioclase by LA-ICP-MS indicate that Oraka Point rocks have initial Sr isotope ratios between those of the Brook Street Terrane and the main mass of the Median Batholith. Taken together, the data indicates that Oraka Point magmas were derived from a source transitional between the primitive Brook Street Terrane and evolved Median Batholith.

A REVIEW OF THE STRATIGRAPHY AND PALEONTOLOGY OF THE LATE OLIGOCENE TO EARLY MIOCENE CHATTON FORMATION

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The Chatton Formation is described as a sequence of marine sandstones, greensands and grits containing a generally shallow water fauna, intercalated conformably, in some places, with carbonaceous muds, lignites and sands. It crops out sporadically in Southland and south Otago at Waikaia, Balfour, Waikaka, Chatton and Pomahaka districts in the north and at Brydone, Copland's Pit and Cosy Dell in the south. The patchy outcrops and lack of many localities with extensive exposures has resulted in limited, mostly unpublished, information on specific areas that includes core logs, coal reports, paleontological lists, maps and a bulletin. The current study integrates unpublished and published material with new field observations and fossil collections to review the paleontology, sedimentology and thickness variation of the formation.

Key fossil localities include the Chatton Formation type locality at Shell Gully, which has >100 species of molluscs, Cosy Dell with >350 species of molluscs (most undescribed), Brydone with >55 species of

molluscs (most undescribed) and others at sites mentioned above. Paleoecological investigations have revealed that each locality has a different suite of molluscs, corresponding with a wide range of paleoenvironments. Faunas of some localities have previously unreported groups which include vertebrates (stingrays, teleost fish and indeterminate penguin and whale bones) ostracods, corals, brachiopods and echinoderms. Sandy siltstones exposed in the Mataura River near Brydone include many intertidal molluscan species which indicate that the setting was probably a sheltered embayment with rocky shores or nearby submerged rocky platforms. Foraminifera from Brydone give a Waitakian age. In contrast, the fauna in greensands at Wendon Valley, near Waikaka has a slightly deeper water molluscan assemblage and, like Shell Gully, is Duntroonian in age. Paleontological case studies such as these, when coupled with sedimentological data, will enhance the reconstruction of paleogeography of southern New Zealand for both the Duntroonian and Waitakian stages.

CALDERA MARGINS AND HYDROTHERMAL FLUID FLOW: A CASE STUDY FROM LAKE CITY CALDERA, COLORADO, U.S.A.

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Silicic volcanoes produce some of the most catastrophic eruptions in geologic history, yet are also often associated with hydrothermal systems that can be economically important for electricity generation and the creation of ore deposits. The caldera margins that form during the largest of these eruptions have been identified as potentially favourable structures for high fluid up flow; however, the poor exposure that is typical in such settings has limited the number of detailed studies of the relationship between caldera structures and fluid flow.

The Lake City caldera formed ~22.9 Ma in the San Juan Mountains of Colorado and hosted an active hydrothermal system that developed soon after the eruption. The good exposure of this fossil system enables the caldera margin to be mapped in detail and observed at the outcrop scale. Hydrothermal alteration and quartz-rich veins are concentrated near faults in the resurgent intrusion and near the ring fault.

Field mapping, outcrop scale line transects, and petrographic analyses were used to characterize the caldera margin, its associated fault rocks, hydrothermal alteration and veining. The margin consists of relatively straight segments linked by more structurally complex corners. Fault rocks are rare due to the gravitational collapse (land sliding) along the over steepened structural margin of the caldera. However, where preserved, fault rocks consist of gouge and ultra-cataclasite grading outwards into undeformed rock. The juxtaposition of rocks with contrasting rock properties across the ring fault resulted in contrasting styles of fracture versus matrix controlled fluid flow on each side of the fault, as evidenced by contrasting vein densities and alteration haloes.

Whether modern caldera margins, such as those in the Taupo Volcanic Zone of NZ, have the same permeability characteristics will depend on the style of caldera collapse and how much the physical properties of intracaldera rocks and country rocks differ.

THE LAST 2 M.Y. OF WEDGE CONSTRUCTION IN THE HIKURANGI MARGIN: INSIGHTS FROM STRUCTURAL MODELLING

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Reprocessed, depth-converted and geologically interpreted seismic lines across the central Hikurangi margin (latitudes 40°-41°.5 S) provide a clear image of the offshore accretionary prism above the subducting Pacific plate. Turbidite units deposited in the last 2 M.Y. over older clastic and pelagic sequences of the Hikurangi plateau have been rapidly accreted to the margin by imbrication along E-verging thrust faults that propagated up-section from the low-angle interplate thrust. Growth stratigraphy of piggy-back basins and thrusting of progressively younger horizons trace the eastward advancement of the outermost thrust

front for a distance of c. 60 km over 2 M.Y. Moderate shortening within fault-bounded panels reflects fast creation and abandonment of thrust faults; however, early formed faults have also undergone out-of-sequence reactivation, attributable to maintenance of the critical wedge taper.

Structural reconstructions show progression of shortening involving: (1) initial development of c. 10 km wide "proto-thrust" zones, comprising conjugate sets of moderately to steeply dipping low-displacement reverse faults; (2) localisation of dominant thrust faults that exploit the early proto-thrust fabric and propagate up-section by progressive break-through of folds localized above the fault tips, with the youngest, unbreached folds deforming the present-day seabed. Progressive retro-deformation of sedimentary packages bounded by marker horizons interpreted as 0.01, 0.6, 1 and 2 M.Y. in age shows a scenario with deformation rates higher than sedimentation rates, resulting in a continuous re-adjustment of the "seabed" morphology imposed by folding and thrusting, isolation of satellite basins perched above surface-breaching faults, and strong control on thickness and bathymetric depth of syntectonic units.

This structural evolution provides the basis for forward numerical modelling of the accretionary wedge, aimed at constraining the mechanical parameters that control the wedge taper and interplate slip, progression of wedge shortening in relation to interplate convergence, and along-margin changes in the observed geometry of the accreted units.

EXPERIMENTAL STUDY OF THE AGGREGATION AND SEDIMENTATION OF VOLCANIC ASH

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An experimental study of the aggregation and sedimentation of volcanic ash has been carried out with detailed analyses from high-speed cameras, using programs such as Matlab, Image J and M-Track J. Samples of phonolitic and andesitic ash (< 90 μm), from the volcanic district of Phlegrean Fields (*Italy*) and from Sakurajima volcano (*Japan*), have been separated into three main size classes (> 60 μm, 32 – 59 μm and < 32 μm). Particles in each size class were held in turbulent suspension and filmed with the high-speed camera as they collided, aggregated, and disaggregated to form a growing layer of electrostatically bound particles along a vertical plate. At standard temperature and pressure conditions and regardless of particle composition, 60-80% of the colliding particles < 32 μm remained aggregated. In contrast, aggregation of particles > 63 μm was less efficient; when a layer formed, it was disaggregated by collisions or drag twice as frequently as were smaller ones. The rate of aggregation for bigger particles was found to be lower by orders of magnitude than that of smaller particles and there was a negative relationship between the number of aggregated particles and their average speed. We conclude, firstly, that smaller particles were more involved in the aggregation because of their larger specific surface area. Secondly, if particles collided on the slide too fast, during impact, too much kinetic energy was released, causing destruction or collapse of the material previously aggregated.

Videos have been also analyzed with these software packages, allowing us to study the sedimentation of natural volcanic aggregates, as filmed during a recent eruption of Sakurajima volcano. We were able to measure the equivalent diameters of aggregates and their average speed of sedimentation. This speed increased linearly (up to 5m/s) with increasing diameter of the aggregates.

HIGH-RESOLUTION FJORD SEDIMENTARY RECORDS OF HOLOCENE AND LATE GLACIAL CLIMATE CHANGE FROM THE SUBANTARCTIC AUCKLAND ISLANDS

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An important component of global oceanic and atmospheric circulation is the strong zonally symmetric wind belt located at approximately 50°S known as the Southern Hemisphere westerly winds (SHWW). The SHWW affect climate and CO_2 flux in the mid to high southern latitudes. Despite their importance, there are few highly resolved Holocene and Late Glacial records of past climate change from the New Zealand subantarctic Auckland Islands (50.5°S) that can reconstruct past westerly change. The subantarctic Auckland Islands are in a unique location at the core of the modern SHWW belt. Changes in hydrology, temperature, and vegetation on the islands are driven by SHWW changes, which should be preserved in the fjord sediments.

A series of marine sediment cores were collected in February 2015 from Norman Inlet, Auckland Islands, and are being used to reconstruct a high-resolution record of climate change spanning the last ~15,000 years. Physical property data indicates the cores capture several phases of sedimentation. From this data and visual core descriptions, we identify 4 primary sedimentary facies: 1) a deglacial facies exhibiting mm-scale laminae defined by magnetic susceptibility and density contrasts and 2 to 50 mm clasts interpreted as dropstones; 2) a lacustrine facies defined by low density and high organic carbon concentrations; 3) a marine transgression facies with moderate density and moderate bioturbation, and 4) a marine facies that contains biogenic carbonate. A radiocarbon chronology, ITRAX XRF major element profiles, and carbon and nitrogen stable isotope measurements will be used to create a robust record of climate change since the Late Glacial at the Auckland Islands that can be compared to existing records from Tasmania, Southern South America and Antarctica build a broader picture of SHWW change across the Southern Hemisphere.

DETAILED PATTERN ANALYSIS OF LIQUEFACTION SURFACE EJECTION IN AN ALLUVIAL SETTING: LESSONS FROM THE CANTERBURY EARTHQUAKE SEQUENCE

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The 2010-2011 Canterbury earthquake sequence has provided an opportunity to study how liquefaction correlates with different sedimentary environments. Our results demonstrate that liquefaction surface manifestation at two sites in a floodplain setting was mainly located on higher topographic areas such as crevasse splays or scroll bars ridges. However, in the crevasse splay the potential liquefiable layer we identified was part of a channel fill sequence within an abandoned meander partially buried by the crevasse splay. In an inner meander setting, the source layers of the liquefied sands is associated with sediments that form the scroll bar itself.

Our study focuses on liquefaction in the alluvial environment along the Halswell River (Greenpark, 5 km South-West from Lincoln). We aim to establish a correlation between landforms affected from liquefaction and their sediment architecture. The first site (Hardwick) is an old river channel overlaid by a crevasse splay deposit, and the second site (Marchand) is an inner meander belt; both were severely affected by liquefaction during the Darfield and Christchurch earthquakes. At each site we: (1) mapped the distribution of liquefaction and alluvial geomorphic features with DEMs derived from LIDAR; (2) undertook Ground Penetrating Radar surveys; (3) dug several trenches to expose the surficial stratigraphy and liquefaction features; and (4) retrieved 18 m of core sediments to look for the liquefiable layers. We also collected samples for radiocarbon, microscopic sediment fabric and grain size analysis. Nine seismic cone penetration tests were also carried out to at least 12 m to reveal the geotechnical properties and explore the sediment architecture of the deeper sediments

The lessons learned about the influence of sediment architecture on the patterns of liquefaction during the Canterbury sequence will be

applied in future paleoliquefaction studies , helping to improve assessments of liquefaction potential and seismic hazard across the country.

MICROMORPHOLOGICAL ANALYSIS OF LIQUEFACTION FEATURES IN ALLUVIAL AND COASTAL ENVIRONMENTS OF CHRISTCHURCH, NEW ZEALAND

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We conducted micromorphological analysis of liquefaction features (dikes, sills, sand blows) associated with the 2010-2011 Canterbury Earthquakes Sequence and dikes of an earlier generation of liquefaction (paleoliquefaction). Our aim was to determine if diagnostic features existed that would allow robust discrimination of the two generations of liquefaction features to support paleoliquefaction studies and earthquake hazard assessment. We found that there were similarities in sedimentary fabric between all forms and ages of liquefaction but that paleoliquefaction could be distinguished on the basis of pedogenic features.

We studied liquefaction and paleoliquefaction at two sites of distinctive sedimentary setting: the first the floodplain of the Halswell River at Greenpark in the Lincoln-Taitapu area, and the second, coastal sand dunes in Wainoni and QEII Park in Christchurch. Analysis was carried out on thin sections prepared from resin-impregnated blocks of soil hosting the liquefaction features. The modern liquefaction fabric in the alluvial system is characterised by a single grain micro-structure, from moderate to well sorted with many simple packing voids and planar voids. Similarly, modern liquefaction fabric in the coastal dune system is characterised by a very well sorted single grain micro-structure. In both environments it was possible to see evidence of *porewater-induced structures* such as water escape structures, cutans and silt caps. The paleoliquefaction fabric is characterised by similar microstructure type but differs from modern liquefaction by the presence of pedogenic features in the form of infilling of planar voids, silt coating, hypocoating of voids and excrement features.

Our results demonstrate how the thin section analysis can be a valuable post field-campaign tool to support and better define evidence of sequences of liquefaction events. In the future, more quantitative applications of this technique could be focussed, for example, on determining the resolution of the technique for discriminating multiple generations of paleoliquefaction.

LOVE WAVES SLOWER THAN RAYLEIGH WAVES AND THE ROLE OF ANISOTROPY IN SURFACE WAVE PROPAGATION AT RUAPEHU AND TONGARIRO VOLCANOES, NEW ZEALAND

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Surface wave dispersion can be measured in stacked cross-correlations of ambient noise at two seismic stations, which are approximate Green's functions. Most studies deriving the shallow subsurface shear-wave velocity structure from cross-correlations use vertical components to retrieve the Rayleigh waves, but it is becoming increasingly common, to use the horizontal seismogram components in addition to the vertical. We have made 2641 high quality dispersion measurements using cross-correlation stacks from 66 stations operating in the Tongariro Volcanic Centre in 2001 and 2008. Average isotropic velocities of 0.8-1.8 km/s, above a layer of 2.0-2.6 km/s are interpreted as low velocity volcanic and sedimentary deposits above basement greywacke. A persistent observation is that group velocities of fundamental mode Love waves, measured from TT correlations, are slower than measurements of fundamental mode Rayleigh waves, on the RR and ZZ components, in the frequency range of 0.25-1 Hz. Furthermore, the differences between the Love and Rayleigh dispersion curves vary with the azimuth of the interstation path across Ruapehu and Tongariro Volcanoes. At Tongariro, Love dispersion is on average 0.4 km/s (28%) slower than Rayleigh for E-W oriented paths, and 0.1 km/s (9%) slower for NNE-SSW paths at 0.3-0.9 Hz. At Ruapehu, E-W Love paths are 0.1 km/s (8%) slower than Rayleigh, however, for NNW-SSE paths, Love is faster by 0.2 km/s (22%). At both volcanoes, the E-W paths are perpendicular to previous estimations of the fast direction modelled by

anisotropy with horizontal symmetry axes using shear-wave splitting and dispersion inversion techniques, suggesting that anisotropy in the top few kilometres of the crust has measurable affects in surface wave propagation.

THE WAHIANOA, RANGIPO AND UPPER WAIKATO STREAM FAULTS AT THE SOUTHEASTERN TERMINATION OF THE TAUPO RIFT, NEW ZEALAND

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At the southeastern termination of the Taupo Rift in New Zealand, two of the major regional normal faults intersect in a very oblique way suggesting radial extension, the NE-trending rift bounding Rangipo Fault and the EWE-trending Wahianoa Fault. This intersection in the Upper Waikato Stream has not been yet studied and is not well understood, therefore we analysed the earthquake history of these two faults. To better understand whether these faults belong to the Rangipo or the Wahianoa faults, we characterized the geometry and kinematics of the main faults exposed in the stream, together in pursuance of the earthquake history. We demonstrate the occurrence of at least 12 recurrent surface-rupturing earthquakes in the last 45.1 ka in the Upper Waikato Stream Fault, with a mean slip-rate of 0.3-0.63±0.06 mm/yr; and at least 9 surface-rupture earthquakes in the last 133.6 ka for the Wahianoa Fault, with a mean slip-rate of 0.15±0.31-0.33±1.12 mm/yr. If we consider a c. 23 km length rupture of the Wahianoa Fault together with the Upper Waikato Stream Fault, the expected earthquake would be M_w 6.7; and for a c. 35 km length rupture, involving either the Rangipo Fault, the Ohakune Fault or the Kaimanawa Fault together with the Upper Waikato Stream Fault, we would expect a M_w 6.95 earthquake.

MEANDER MIGRATION AND LIQUEFACTION SUSCEPTIBILITY ALONG THE HEATHCOTE RIVER IN SOUTHERN CHRISTCHURCH

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Spatial variations in river facies exerted a strong influence on the distribution of liquefaction features observed in Christchurch during the 2010-11 Canterbury Earthquake Sequence (CES). Liquefaction and lateral spreading were less severe along the Heathcote River in southern Christchurch than along the Avon River in eastern Christchurch. Our study of two adjacent meander bends along the Heathcote River compares the distributions of surface ejecta and liquefaction-induced ground deformation with sedimentologic, topographic, and geomorphic variability to seek relationships between near-surface properties and observed ground damage. Aerial imagery, geospatial data, geotechnical reports and eye-witness evidence reveal that recurrent liquefaction and subsidence (>0.5 m) occurred primarily within a topographic low in the suburb of St Martins, a freely migrating meander loop. Trenching investigations showed the majority of surface ejecta was sourced from well-sorted fine to medium sand deposits at <5 m depth, corresponding with a paleochannel location. Holocene channel abandonment preserved shallow sandy units prone to liquefaction promoting manifestation of severe liquefaction within the spatial extent of the paleochannel. In the adjacent suburb of Beckenham, where migration of the Heathcote River has been laterally confined by Banks Peninsula, severe CES liquefaction and subsidence were absent. Auger sampling across Beckenham revealed thick (>1 m) clay-rich overbank and back swamp sediments; these produced a strata which confined susceptible units and prevented the manifestation of severe liquefaction and subsidence. The scale and variability in the spatial distribution of CES liquefaction in the two adjacent suburbs is predominately related to geomorphic features controlled by meander evolution, where freedom of the channel to migrate produces fluvial facies more vulnerable to liquefaction. Incorporating geomorphic studies alongside conventional geotechnical approaches can assist liquefaction susceptibility assessments.

THE GOOD, THE BAD AND THE UNKNOWN – SHORT-TERM IMPACTS AND LONG-TERM BENEFITS OF VOLCANIC ASH AND AEROSOLS ON AGRICULTURAL PRODUCTIVITY

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Volcanic eruptions are a global issue. They distribute trace elements to extensive areas of land. These trace elements can have either a detrimental or beneficial effect on agricultural production. We here introduce the objectives and initial outcomes of a new Masters Research project aimed at defining new land-management strategies to mitigate risks to agricultural production in the aftermath of a volcanic eruption. This research will also determine the maximum fertiliser effect of trace elements added to soil through solid volcanic ash particles and microscopic aerosols.

Experimental work will define the short-term impacts of fluorine on soil microorganisms and investigate strategies that can protect essential soil biological function. This experimental work will also evaluate the potential long-term benefits of essential trace element components of the ash and aerosols, and define management strategies that can unlock the future potential of these components to increase both production and the value of agricultural products. Our experimental approach will inform field measurements that record the variable effects of volcanic solids, liquids and gasses on soil chemistry, biology and physics as a function of time since eruption. One target outcome will be to delineating the risks and benefits of volcanic products to the agricultural sector so that appropriate management strategies can be exploited by farmers.

Our research methodology will focus on the assessment of trace element bioavailability and the correlation of this with microbial activity and function. Controlled pot trials where productive soil is exposed to simulated eruption events will define initial parameters that can be further investigated at field locations where historic eruptions have introduced variable trace element loads to soil. Crucial to our methodology is the hypothesis that the release of bioavailable trace elements into soil will depend on the interactions of volcanic ash with soil, plants and soil microorganisms.

PALAEOMAGNETIC SECULAR VARIATION AND NEW AGE CONSTRAINTS ON HOLOCENE LAVA FLOWS FROM THE TONGARIRO VOLCANIC CENTRE

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Detailed records of palaeomagnetic direction and absolute intensity are not only required to improve global data coverage and to enhance our understanding of the temporal behaviour and spatial characteristics or Earth's magnetic field but in comparison to existing records also provide a powerful tool to date or refine existing age estimates on young volcanic material.

Here we present the palaeomagnetic results from 33 sites sampled on 12 individual lava flows from the Tongariro Volcanic Centre. All flows sampled are of Holocene age and eruption ages are constrained by new $^{40}Ar/^{39}Ar$ geochronology data and existing tephra stratigraphic controls. The swings in our new directional record (Declination from 5°W to 18°E, Inclination from -80° to -49°) compare well with a recently published palaeosecular variation master curve from Lake Mavora (Fiordland, NZ) and also the most recent global field model 'pfm9k', but suggest more easterly directions between 8 and 10 ka BP. Seven successful palaeointensity results indicate a steady increase in the palaeointensity through most of the Holocene, from an intensity of 37 µT obtained from a pre-8 ka lava to 70 µT from the youngest (< 1.7 ka) flow sampled.

Existing eruption age constraints on the sampled flows have accompanying uncertainties of 2-3 kyrs due to the limitations of tephrochronology and the $^{40}Ar/^{39}Ar$ dating method. Comparison of our new data with the Lake Mavora record allows us to refine the eruption ages of five of the flows sampled and reduce the uncertainties to as little as 500 years. This provides important information for the eruptive histories of Tongariro and Ruapehu volcanoes.

IMAGE LOG-BASED FRACTURE ANALYSIS AND STRUCTURAL INTERPRETATION OF A PROSPECTIVE UNCONVENTIONAL PETROLEUM PLAY, ONSHORE SOUTHERN EAST COAST BASIN

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Petroleum exploration in the greater East Coast region has experienced an increase in recent years as companies target both conventional and unconventional resources. In 2011 New Zealand Energy Corp drilled the Orui-1A and Te Mai-2 stratigraphic holes to provide multi-disciplinary insights into the suitability of the Waipawa and Whangai formations as unconventional shale oil/gas plays in the onshore part of the southern East Coast Basin. As part of this assessment, drillcores and acoustic borehole image logs were acquired. Orui-1A successfully cored the Waipawa–Wanstead Formation transition, reaching a total depth of 130 m. Image logs were acquired over most of the well. Te Mai-2 reached 193.10 m total depth and cored the Whangai–Waipawa Formation transition. Image logs were run over the interval 35–147.50 m.

These datasets provide a unique opportunity in the East Coast Basin to directly calibrate image logs to observations of core, allowing us to enhance our understanding of the fracture reservoir potential of the Whangai-Waipawa Formation play.

Preliminary structural data analysis from the image logs show orientation trends of fractures and bedding varies between the two wells. Orui-1A has a dominant NNE–SSW to ENE–WSW fracture strike orientation, and a northwesterly-dipping bed trend, while Te Mai-2 displays a dominant NNW–SSE to N–S fracture strike orientation, and a westerly-dipping bed.

While the fracture strike trend in Orui-1A is in agreement with the regional modern day tectonic trend, and the initial values of SH_{max} identified from borehole image logs matches the stress regime, the trends in Te Mai-2 do not. Further work is planned to identify the origin and geological source of this NW-SE strike orientation.

GEOCHEMICAL TRACING OF THE SOURCE OF DISSOLVED INORGANIC CARBON AND CHLORIDE IN BANKS PENINSULA WARM SPRINGS, NEW ZEALAND

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Warm springs are a natural phenomenon that exist at temperatures <90°C and are at least 4°C warmer than the localised groundwater. The warm springs of Rapaki Bay occur within the Lyttelton Volcanic Group of the extinct Banks Peninsula Volcanic province, New Zealand. As a result of the Christchurch Earthquake Sequence; multiple springs have appeared in areas formally occupied by individual springs. Geochemical tracing of the water in conjunction with soil-gas flux surveying has been applied to these warm springs at Rapaki Bay in order to discern the relationship between the individual springs and their water source. Here we show five different temporally variable intertidal warm springs with detectible methane at Rapaki Bay, whose geochemical signature is comparable, as well as consistent with previous studies. Notable changes in the warm springs post the Christchurch Earthquake sequence; are the increase in temperature, as well as chemical shifts in the K and HCO_3^- values. These results show an expansion of the pre-existing geothermal system of Banks Peninsula, and provide an updated and more in-depth geochemical analysis of the Rapaki Bay warm springs.

QUANTIFYING POSSIBLE DAMAGE ZONE STRUCTURE OF THE ALPINE FAULT THROUGH BAYESIAN INVERSION OF FAULT ZONE GUIDED WAVES

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A Fault Zone Guided Wave (FZGW) is a high amplitude dispersive body wave that can be observed on or near a low velocity fault zone. These phases have been observed on the three component 2 Hz seismometers that were installed

within 20 m of the Alpine Fault's principal slip zone during DFDP-1. We analyse several FZGW generating events using dispersion modelling from a three-layer model and a Bayesian inversion methodology. These inversion results show that the values of the effective low-velocity zone width and S-wave velocity contrast are depend heavily on the earthquake location as well as the country rock velocities and densities. Therefore, uncertainty in these parameters is propagated to uncertainty in the estimated fault zone width and velocity contrast values which can be used to understand strain localisation. To allow for the uncertainty in fault zone velocity contrast and fault zone width we can include the additional parameters in the inversion. This, however, can make the inversion more difficult, especially when using physically more realistic models, e.g. considering gradational velocities that have greater computational complexity. To account for this issue, we employ the Bayesian approximation error method in order to treat the effect of these additional properties as error terms in the inversion. This allows us to invert only for the critical parameters whilst giving more realistic uncertainty bounds. This methodology is employed for a joint inversion of several FZGWs that are contained within a region bounded by the DFDP-1 borehole and 20 km south of the DFDP-1 borehole. We present the resulting estimates for the effective width, effective depth and S-wave velocity contrast of the Alpine Faults Damage Zone.

LORD HOWE RISE DEEP STRATIGRAPHIC DRILLING: TECTONICS, CLIMATE AND ANCIENT LIFE

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The Lord Howe Rise (LHR) region is one of the last remaining geoscientific frontiers on Earth. The LHR, part of northern Zealandia, comprises submerged and extended continental crust that separated from Australia in the Late Cretaceous. Present knowledge of the LHR is based on widely-distributed marine and satellite geophysical data, limited dredge samples and sparse shallow (<600 mbsf) ocean drilling. This information has provided a general understanding of crustal structure, sedimentary basin architecture and resource potential. Constraining the Cretaceous and older tectonic and climatic history of the southwest Pacific in more detail requires drilling into sediments and older basement rocks that are buried beneath ~500 m of Cenozoic pelagic sediments. Geoscience Australia and the Japan Agency for Marine Earth Science and Technology are leading an international effort to drill a deep stratigraphic well into a LHR rift basin. A full proposal for drilling up to 3500 mbsf using the JAMSTEC riser drilling vessel Chikyu was submitted to the International Ocean Discovery Program in October 2015 (IODP 871). The objectives of the deep drilling are to: define the role and importance of continental crustal ribbons like the LHR in plate tectonic cycles and continental evolution; recover new high-latitude data in the southwest Pacific to better constrain Cretaceous paleoclimate and linked changes in ocean biogeochemistry; and test fundamental evolutionary concepts of sub-seafloor microbial life over a 100-million-year timeframe. These objectives are complementary to the goals of the New Zealand-led IODP proposal 832 focussed on Paleogene subduction initiation and climate in the southwest Pacific. Together these IODP proposals will contribute to a unified understanding of the Mesozoic and Cenozoic tectonic and climatic history of northern Zealandia.

REACTIVATED AFTERSLIP IN GEORGE SOUND, NEW ZEALAND, FOLLOWING THE 2009 Mw 7.8 DUSKY SOUND EARTHQUAKE

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Identifying the distribution of seismic and aseismic slip along major faults is critical for assessing seismic hazard with the magnitude, location and recurrence interval all dependent on what portion of the total accumulated moment is released aseismically. However, changes to the local stress field may cause the distribution of slip to vary over time periods much shorter than the seismic cycle making it difficult to assess. It is now well established that the redistribution of stresses induced by an earthquake may promote, or inhibit, slip along faults in nearby regions. Triggering may be caused by the static stress changes from a local

earthquake or the dynamic stresses due to passing seismic waves. Here we present Satellite Radar Interferometry (InSAR) and GPS data of the co and post-seismic deformation associated with the 2007 Mw~6.8 George Sound (Fiordland, New Zealand) earthquake. Time series analysis reveals a period of increased displacement rate two years after the main shock coincident with the Mw 7.8 Dusky Sound earthquake which occurred 150~km away. We show that the coseismic stress changes from the Mw 7.8 earthquake triggered a pulse of aseismic slip along the George Sound fault plane with a comparable magnitude to the mainshock.

E-TECH ELEMENTS IN NEW ZEALAND SUBMARINE POLYMETALLIC NODULES

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Iron-manganese (Fe-Mn) hydroxyoxides precipitate from seawater forming slow growing polymetallic crusts and nodules. Their highly reactive surfaces effectively scavenge and concentrate a wide range of metals and metalloids from the surrounding waters. Not only do these slow growing (typically < 10mm/Ma) deposits record changes in water masses and water chemistry over time, but they are becoming an increasingly attractive prospect for mining of rare metals and rare earth elements vital for green and E-tech industries. The vast Campbell Nodule field in the deep waters south and east of New Zealand has long been recognised as a potentially economic source of metals, but little data exist on their compositional range and diversity, or on the effect of their extraction on the ecosystems they host. We will present major and trace element compositions of nodules from the Campbell Nodule field and more widely dispersed Fe-Mn deposits from New Zealand surrounds, including other deep water (~4000 m) nodules from the Tasman Ocean as well as shallower water (< 2500 m) nodules from the Bounty Plateau, Campbell Plateau and Shipley Seamount.

Preliminary data from 25 of these nodules show them to average 18 wt.% Fe_2O_3 (range of 11-26 wt. %) and 19 wt.% MnO (range 9-26 %). They are highly enriched in most of the > 30 trace elements analysed compared to average continental crust, with only Sc, Cr and Rb occurring in lower concentrations. For example, Mo, Mn, Ni, and Cd are all > 100 times enriched and rare earth elements are typically 5-10 times enriched. Notably, potentially ecotoxic metals are also concentrated in New Zealand polymetallic nodules, including Pb (725 ppm), V (502 ppm) and As (130 ppm). However, U and Th are present in concentrations only twice that of average continental crust.

A PRELIMINARY STUDY OF MIOCENE FRESHWATER DIATOMS FROM THE FRIIS HILLS, ANTARCTICA

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Lacustrine deposits in the Friis Hills formed in shallow lakes among tundra during the Early to Mid-Miocene. There is good preservation of diatom remains in these deposits. We have identified over 30 taxa; there are species which grow in open water, on sediment and attached to waterweeds and rocks. Most of the taxa no longer live in Antarctica as open water is rare and waterweeds have disappeared. Conditions for their growth can be deduced from where they occur in New Zealand and elsewhere. We are also interested in the affinities of the floras and whether any taxa are now likely to be extinct.

ANTHROPOGENIC INFLUENCE ON THE SEDIMENTARY EVOLUTION OF THE COROMANDEL HARBOUR

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Coromandel Harbour is one of the largest estuaries on the Coromandel Peninsula and is of significant economic importance in the region. However, its sedimentary structure remains relatively underexplored compared to its smaller regional estuarine counterparts. A previous study based on limited data found that recent sedimentation rates

are much greater than those observed before human habitation. Anthropogenic activity such as Polynesian vegetation burning, European Kauri deforestation and gold mining throughout the catchment are likely to have heavily influenced the harbour's post-habitation sedimentation rates. With high sedimentation rates infilling boating channels and threatening mussel farm operation, further research into sedimentation in the harbour is required to assess the future sustainability of these operations.

The focus of this research is to investigate the sedimentary history and sedimentation rates of the harbour and provide insight into the future through quantitative analysis and predictive modelling. We have retrieved a number of sediment cores from the intertidal region as the first phase of this study. Here we present preliminary sedimentological and X-ray fluorescence (XRF) results. We compare these results with XRF data from an ongoing study into anthropogenic impact on sediments in the Hauraki Gulf, offshore from Coromandel Harbour.

INCREMENTAL HOLOCENE SLIP RATES FROM THE HOPE FAULT AT HOSSACK STATION, MARLBOROUGH FAULT ZONE, SOUTH ISLAND, NEW ZEALAND

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The Marlborough Fault System, which links the Alpine Fault with the Hikurangi subduction zone within the complex Australian-Pacific plate boundary zone, partitions strain between the Wairau, Awatere, Clarence and Hope faults. Previous best estimates of dextral strike-slip along the Hope fault are ≤ ~23 mm/yr ± 4 mm/year. Those rates, however, are poorly constrained and could be improved using better age determinations in conjunction with measurements of fault offsets using high-resolution imagery. In this study, we use airborne lidar- and field-based mapping together with the subsurface geometry of offset channels at the Hossack Station site 12 km ESE of Hanmer Springs to more precisely determine stream offsets that were previously identified by McMorran (1991). Specifically, we measured fault offsets of ~10 m, ~75 m, and ~195 m. Together with 65 radiocarbon ages on charcoal, peat, and wood and 25 pending post-IR50-IRSL225 luminescence ages from the channel deposits, these offsets yield three different fault slip rates for the early Holocene, the late Holocene, and the past ca. 500-1,000 years. Using the large number of age determinations, we document in detail the timing of initiation and abandonment of each channel, enhancing the geomorphic interpretation at the site as channels are offset over many earthquake cycles. Our preliminary incremental slip rate results from the Hossack Station site may indicate temporally variable strain release along the Hope Fault. This study is part of a broader effort aimed at determining incremental slip rates and paleo-earthquake ages and displacements from all four main Marlborough faults. Collectively, these data will allow us to determine how these four faults have worked together during the late Pleistocene to Holocene to accommodate plate-boundary deformation in time and space.

RECENT STRATIGRAPHIC AND TECTONIC EVOLUTION OF THE REINGA BASIN USING 2D SEISMIC REFLECTION DATA

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The Reinga Basin is a mid-Late Cretaceous basin whose formation is associated with the southwest Pacific region-wide extension and rifting of the Cretaceous period. It is contiguous with the Northland Basin to the south, bound by the parallel ridges Wanganella Ridge and West Norfolk Ridge to the west and the Reinga Ridge to the northeast. The basin extends to the edge of the New Zealand Extended Continental Shelf (ECS). Past studies have focused in detail on the Cretaceous to Miocene evolution of the Reinga basin and its place in the regional evolution or its hydrocarbon potential. The aim of this presentation is to focus on the post-Miocene in the Reinga Basin and provide a detailed tectono-stratigraphic model of its recent evolution to fill this information gap. Seismic reflection data

and the seismic stratigraphic interpretation method provide a useful tool for interpreting the geology below the seafloor, allowing paleoenvironmental reconstruction and hydrocarbon potential to be investigated. High resolution, industry standard, 2D seismic reflection data acquired in 2009 and 2014 are used in conjunction with the closest offshore exploration well Waka-Nui-1 in the Northland Basin to perform a detailed seismic stratigraphic interpretation. Key horizons (current seafloor, mid-Pliocene and top Miocene) have been mapped using the loop-tie method over the basin. Horizons were picked using a combination of previously published age constraints and the seismic interpretation method. Seismic facies are defined and regional maps including isochron and mean amplitude of the horizons were generated. Elements found so far include: channels and channel-like features, numerous small-scale faults, and high amplitude deposits associated with volcanic edifices and other sloped features.

THE VALUE OF A TEPHRA CLEAN-UP MODEL FOR PRE-ERUPTION RESPONSE AND RECOVERY PLANNING

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Tephra in urban environments can lead to a reduction of infrastructure service or functionality, public health concerns and impacts, and asset damages. Removing the tephra from the urban area is often a key component to reducing the impacts and restoring urban functionality. However, clean-up operations are often carried out in an ad hoc manner due to a lack of appropriate pre-event planning and/or little to no experience of carrying out such operations. This can led to directly increasing the cost of clean-up operations and indirectly increase economic losses and social impacts experienced due to tephra fall.

Tephra clean-up operations are a critical component of volcanic response and recovery. Important information for pre-event response and recovery planning for clean-up operations includes:

- expected volume of tephra to be removed
- priority clean-up zones
- resource requirements
- methods of collection
- potential disposal locations
- likely duration of clean-up operation
- likely cost of clean-up operation

Here we detail the information garnered from using a simple and adaptable geospatial model which assesses potential tephra clean-up operations for urban areas. The model is informed by tephra clean-up operations from around the world with a variety of different localised contextual influences (e.g. eruption size, climate, socioeconomics, clean-up experience). The model requires volcanological information such as tephra isopachs (for thickness or loading) in conjunction with basic geospatial data about the physical urban environment (e.g. roads, buildings, vegetated areas, paved surfaces).

SALT-MARSH FORAMINIFERAL RECORD OF TEN LARGE HOLOCENE EARTHQUAKES ON A SUBDUCTING PLATE MARGIN, AHURIRI INLET, HAWKES BAY

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Sudden changes in microfossils and lithologies in Holocene sediments of a former tidal inlet (Ahuriri, Napier) on the Hikurangi Subduction Margin provide evidence of ten large earthquakes. Studies focussed on three former embayments on the western side where intertidal shelly sediment inter-fingers with freshwater and salt-marsh peat. Paleoelevation histories were reconstructed using the modern analogue technique with foraminiferal assemblages. Land Elevation Record analysis indicates 8–9 m of mid-late Holocene tectonic subsidence occurred prior to 1.5 m of uplift during the AD 1931 Hawkes Bay Earthquake. Chronologies of displacement events were constrained using 50 radiocarbon dates and three widespread air-fall tephra. We infer the following earthquakes: Eq.1: 7.3–7.0 ka (-1.1±0.3 m), Eq.2: 5.6–5.1 ka (+0.4±0.4 m), Eq.3: 5.2–4.9 ka (-0.5±0.5 m), Eq.4: 4.4–3.8 ka (-

0.6±0.5 m), Eq.5: 2.8–2.4 ka (-0.9±0.5 m), Eq.6: 1.73–1.70 ka (-1.0±0.3 m), Eq.7: 1.5–1.3 ka (-0.7±0.5 m), Eq.8: 1.04–0.89 ka (-1.2±0.4 m), Eq.9: 0.60–0.44 ka (-0.8±0.6 m), Eq.10: AD 1931 (+1.5±0.3 m). The additional 1.6–2.6 m of recorded subsidence could have occurred by gradual aseismic slip or in smaller undetected earthquake displacements. The age ranges of four of the recognised earthquakes (Eqs 1, 6, 8, 9) overlap with other documented displacement events onshore along 250–600 km of the Hikurangi Subduction Margin, and with turbidites offshore 100–300 km to the north. These four are considered strong candidates for large subduction-interface earthquakes. The other five inferred earthquakes are less strongly correlated with along-margin displacement events and offshore turbidites. These could have been caused by upper plate fault ruptures (like historic Eq.10), but subduction-interface sources cannot be ruled out.

CRACK-HEALING OBSERVED FOLLOWING THE 2010 Mw 7.1 DARFIELD EARTHQUAKE FROM AMBIENT SEISMIC NOISE

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Quantifying seismic velocity changes following large earthquakes can provide insights into the crustal response of the earth. The use of ambient seismic noise to monitor these changes is becoming increasingly widespread. Cross-correlations of long-duration ambient noise records can be used to give stable impulse response functions without the need for repeated seismic events. Temporal velocity changes were detected in the four months following the September 2010 M_w 7.1 Darfield event near Christchurch, using temporary seismic networks originally deployed to record aftershocks in the region. The arrays consisted of stations lying on and surrounding the fault, with a maximum inter-station distance of 156km. The 2010-2011 Canterbury earthquake sequence occurred largely on previously unknown and buried faults. The Darfield earthquake was the first and largest in a sequence of events that hit the region, rupturing the Greendale Fault. A surface rupture of nearly 30km was observed. The sequence also included the M_w 6.3 February 2011 Christchurch event, which caused widespread damage throughout the city and resulted in almost 200 deaths. Nine-component, day-long Green's functions were computed for frequencies between 0.1 – 1.0 Hz for full waveform seismic data from immediately after the 4th September 2010 earthquake until mid-January 2011. Using the moving window cross-spectral method, stacks of daily functions covering the study period (reference functions), were compared to consecutive 10 day stacks of cross-correlations to measure time delays between them. These were then inverted for seismic velocity changes with respect to the reference functions. Over the study period an increase in seismic velocity of 0.25% ± 0.02% was determined proximal to the Greendale fault. These results are similar to studies in other regions, and we attribute the changes to post-seismic relaxation through crack-healing of the Greendale Fault and throughout the region.

RESISTIVITY STRUCTURE OF THE PLATE INTERFACE OF THE NORTHERN HIKURANGI SUBDUCTION MARGIN, NEW ZEALAND

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Inter-plate coupling on the northern part of the Hikurangi subduction margin along the east coast of New Zealand's North Island is weak. This part of the margin is characterized by shallow (10-15 km depth) slow slip events that occur at roughly 2 year intervals. The conditions needed for slow slip are poorly understood but the presence of fluid and/or clay rich sediments may play an important role in controlling the frictional strength of the interface and thus inter-seismic plate coupling. Magnetotelluric (MT) measurements from the northern part of the Hikurangi margin show that a dipping electrically conductive zone is present above the subduction-interface, the increased conductivity marking fluid and/or clay-rich sediments within the subduction-interface shear-zone. Results from 3-D inverse modeling of new MT data from a 90 km along-strike segment of the margin show that the conductivity within this zone varies significantly. If our interpretation of the cause of the high conductivity is correct, more resistive regions may correspond to regions of increased frictional-strength.

DRYING OUT OF PHREATOMAGMATISM: INTERPRETATIONS FROM GROUNDMASS CRYSTALLINITY

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The Auckland Volcanic Field (AVF) is characterized by a significant proportion of volcanic eruptions which transition from phreatomagmatic to magmatic as the amount of external water decreases as the eruptions progress. The direct response to this drying out process is a change in eruption mechanisms resulting in varying distribution, size, and explosivity of eruptive products. Recent research as suggested that groundmass crystallinity of eruptive products can be directly linked to the eruption style, broadly defined as either phreatomagmatic or magmatic. In these end-member scenarios, rapid quenching of magmatic glass from interaction with water during phreatomagmatism results in less groundmass crystallization compared to air cooled magmatic volcanic materials. Groundmass crystallinity is determined from X-ray diffraction techniques, similar to those utilized in previous studies of phreatomagmatic eruptions and supported by back-scatter electron images of representative clast groundmass textures.

In the case of the AVF, where there is a significant "drying out" of volcanism, or a transition from phreatomagmatism to strombolian style eruptions, we observe minimal distinction in crystallinity of volcanic clasts from different eruption styles. Juvenile magmatic clasts from early phreatomagmatic events have anomalously high groundmass crystallinities (up to 60%) and may imply distinctive eruption dynamics prior to cooling or quenching of volcanic groundmass. Relatively 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". Variations in groundmass crystallinity with clast size and FTIR mapping of water distribution are used to help distinguish between these potential models.

THE INTERNATIONAL OCEAN DISCOVERY PROGRAM: SCIENTIFIC DRILLING OPPORTUNITIES IN THE NEW ZEALAND EEZ AND ANTARCTICA

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The International Ocean Discovery Program (IODP) is the latest iteration of 45 years of scientific ocean drilling, and is the world's largest international scientific geoscience program, with an operational budget of $US180 million p.a. and 27 participating nations, including New Zealand. IODP is a wide-ranging international program that provides access to marine science infrastructure well beyond what is generally available at a national level. IODP deploys two large drilling vessels and other special-purpose drilling platforms (e.g., operation in shallow waters, heavy sea-ice cover) on expeditions that recover continuous deep sea cores to address global scientific problems in the fields of climate and oceanographic change, the evolution of biota, planetary dynamics and natural hazards, among others.

The Earth Science community has also benefitted from the forerunner programs Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP), with access to deep stratigraphic cores from the Tasman Sea, Canterbury Basin, as New Zealand examples.

In the next 5 years there is likely to be unprecedented IODP activity in the New Zealand's EEZ and Antarctica, with New Zealand scientists lead or co-proponents on five active riserless and 1 riser IODP proposals.

1. Unlocking the secrets of slow slip plate boundary behaviour by drilling at the northern Hikurangi subduction margin, New Zealand: **Riserless and Riser drilling** to sample and monitor the forearc and subducting plate; and to intersect the plate interface, respectively,

2. Creeping Gas Hydrate Slides: Slow Deformation of Submarine Landslides on the Hikurangi Margin,
3. Subduction initiation and Paleogene climate – Lord Howe Rise and New Caledonia Trough,
4. Gateway to the Sub-Arc Mantle: Volatile Flux, Metal Transport, and Conditions for Early Life - drilling of Brothers volcano,
5. Ocean-ice sheet interactions and West Antarctic Ice Sheet vulnerability: clues from the Neogene and Quaternary record of the outer Ross Sea continental margin.

ACOUSTIC INVESTIGATIONS OF GAS FLUX FROM A FIELD OF SHALLOW SUBMARINE SEEPS ON THE NORTHERN HIKURANGI MARGIN OF NEW ZEALAND

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Numerous recently discovered hydrocarbon gas flares along New Zealand's Hikurangi margin are situated at uncharacteristically shallow water depths (~250m below sea level). Previously studied cold seeps along the accretionary wedge of the subduction zone occur in much greater water depths. In these cases, the overlying water column is almost certainly sufficiently thick to absorb the flux of injected gas, such that there are no emissions reaching the atmosphere that can be directly attributed to the flares themselves. The discovery of shallow cold seeps along the upper plate margin represents the possibility that gaseous hydrocarbons may be capable of breaching the water's surface and dissipating into the atmosphere. EM302 Multibeam data were collected over the Margin on their discovery in April 2014. Subsequent voyages have resurveyed the flares, collecting ship-borne EM302 Multibeam and EK60 Single beam acoustic data as well as deep-towed underwater video footage.

Multibeam backscatter data have been used as a means of locating and analyse depth dependent features of the submarine gas flares. Tools from multiple software packages are used to vertically integrate the reflection values of points that have been acoustically imaged. By colouring the bathymetry by the summed scalar values, the precise position of activing flare sites have been identified. By extrapolating these results based on geomorphic evidence for fluid venting, it is estimated that up to 700 flares may be present over the 50km^2 survey area.

The flux of methane produced at the vent sites is calculated by correlating bubble size distributions to the acoustic profiles of the flares. To measure the dimensions of the bubbles, photogrammetric methods have been applied to still frames of the underwater footage. Bubble radii distributions have been resolved to peak in the range of 4-6mm, which translates to flux values in the range of 100-200mL/min for a single flare.

PHOTOGRAMMETRIC TECHNIQUES FOR MEASURING SUBMARINE-SEEP BUBBLE RADII

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Calculating the flux rate of bubbles that are being released from submarine vents requires an accurate size distribution and rise rate of the gas bubbles that are being released. Deep-towed camera footage of active vent sites is commonly used as a method of approximating bubble radii, although true dimensions can't typically be acquired because of the depth-of-field issues that arise. Measurements of a three-dimensional scene become distorted when viewed on a two-dimensional image as captured by a camera. When trying to reference bubbles to a scale, they will appear larger or smaller than their true size as they move respectively closer of further from the reference. These perspective distortions have been corrected with the use of Canadian Grids combined

with additional geometry that spatially relates the camera to the each rising bubble.

The process of constructing the geometric framework for making these distance measurements has been fully automated for still frames of a video. This implements a laser location program that has been designed for cameras equipped with parallel lasers of a known separation. The pixel distance is used to relate the real-world dimensions to those displayed in the image. Bubble measurements can then be made by 'picking' the axis lengths of the circular or ellipsoidal bubbles in a GUI interface. The true radius and distance from the sea floor are then computed and transformed into normalised size distributions and rise-rates.

In this investigation, the photogrammetric techniques have been applied to flares from a recently discovered field of densely populated methane seeps along the Hikurangi Margin. These are situated at uncharacteristically-shallow depths and have the potential to release greenhouse gasses directly into the atmosphere. Quantifying the flux of ensuing undissolved gas will be imperative in assessing any atmospheric emissions for individual flares as well as for their entire regional extent.

CENOZOIC SEA TEMPERATURE VARIABILITY RECORDED BY CRASSATELLID MOLLUSCS

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Paleoclimate studies of the mid- to high-latitude southwest Pacific during the early Cenozoic have demonstrated that it is difficult to reconcile sea surface temperature proxies with modelled values. Conventional, widely applied proxies for deep-time paleotemperature estimates (e.g. foraminiferal $\delta^{18}O$ and Mg/Ca; alkenones and TEX_{86}) have been argued to display a seasonal (typically summer) bias in Paleogene temperature reconstructions. Preliminary results suggest that the aragonitic shells of crassatellid bivalves record both seasonal and annual variability. We assess the relationship between conventional foraminiferal and lipid-based temperature proxies with the seasonal temperature variations recorded in mollusc growth bands.

Nine representative crassatellid specimens have been sampled from localities around Central Otago and Southland, from strata of Late Eocene to Middle Miocene age. Crassatellid bivalves demonstrate a shallow marine affinity, particularly associated with low energy facies, making these molluscs ideally suited for application as a sea surface paleothermometer. Macroscopic shell bands visible in the specimens of *Triplicitella*, *Spissatella* and *Eucrassatella* studied here have been demonstrated as annual, enabling a seasonal sea temperature record to be reconstructed. The relationship between $\delta^{13}C$ and $\delta^{18}O$ has been examined to assess the state of primary aragonite preservation, in conjunction with X-ray diffraction analysis (XRD) of shell fragments to confirm the absence of diagenetic alteration products in the dataset that we present. This allows us to use the seasonal temperature variability captured in the shells of these thick-walled bivalves to assess the relationship with more widely applied temperature proxies through several key points in the Cenozoic paleotemperature evolution of the southwest Pacific.

CROSSING THE STRAIT: RECONCILING PALEOGENE STRATIGRAPHIC LINKAGES BETWEEN WAIRARAPA AND MARLBOROUGH

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Late Oligocene – Early Miocene inception of the Hikurangi Subduction Margin has resulted in extensive deformation of the East Coast Basin (ECB), which has greatly complicated models of this basin's evolution. Linkages between the southeastern Wairarapa and northern Marlborough are still unresolved. For example, the controls on the Late Cretaceous – Paleogene transitional succession between the largely siliciclastic facies of the Hawke's Bay – Wairarapa and the dominantly pelagic-hemipelagic sediments of Marlborough are largely unconstrained. To address this problem a

chemostratigraphic framework is being implemented to extend the correlation between stratigraphic sequences across the Cook Strait and to enable the identification of additional provenance characteristics.

We used high-resolution portable X-ray fluorescence (pXRF) to measure elemental concentrations in over 1100 samples collected from numerous outcrop sections across the Southern Hawke's Bay, Wairarapa and Marlborough. Measurement of bulk modal mineralogy determined by X-ray diffraction and source rock analyses of selected stratigraphic intervals have also been compiled. These data collected from various lithostratigraphic divisions have allowed for the development of high-resolution datasets for assessing provenance characteristics and chemostratigraphic classification. These measurements provide a preliminary framework for producing chemostratigraphic correlations across the ECB that supplement traditional stratigraphic studies. By the detection of vertical and lateral variations in common redox sensitive trace metals and bio-limiting or provenance dependent elements, large-scale patterns relating to basin fill histories and paleoenvironmental variations can be elucidated.

Elemental relationships, in conjunction with XRD analysis, petrographic and heavy mineral assemblage studies, suggest a largely granitic sediment source supplied the basin throughout the Cretaceous to Eocene. Principal component analysis identifies similar geochemical affinities between both the Whangai Formation, and Paleocene limestones sampled in the Wairarapa and Marlborough. These methods can be combined with sequence- and bio-stratigraphic data to refine spatial, temporal and depositional relationships for the Late Cretaceous to Paleogene successions of the ECB.

CALCULATION OF THE GRAVITATIONAL STRESS FIELD IN NEW ZEALAND

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While the deformation in New Zealand is well quantified, the stresses that drive that deformation are not well quantified. The three sources of stress in a tectonic environment are boundary stresses, gravitational stresses and basal tractions. We present our calculation of the gravitational stress field in New Zealand. The force balance equations were vertically averaged, allowing the vertically averaged gravitational stress to be calculated from a density structure model based on topography and crustal structure. A finite difference method was used to numerically solve the force balance equations. The method was tested on synthetic examples of a cone and ridge, which have predictable stress regimes. The New Zealand gravitational stress field was calculated for density structures of the crust and of the lithosphere at 40 km spacing. The gravitational stress field was compared to the orientation of the total stress as determined from focal mechanisms. The orientations of the gravitational and total stress fields were generally similar in the North Island. There is a greater difference between the orientations of the two fields in the South Island. This may indicate that the gravitational stress field is a greater contribution to the total stress field in the North Island than in the South Island.

BROADBAND GROUND MOTION MODELLING OF A MAJOR ALPINE FAULT EARTHQUAKE (NEW ZEALAND)

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The large September 2010 and the tragic February 2011 Canterbury earthquakes caused widespread damage by ground shaking and sand liquefaction in the Canterbury region. Both earthquakes were less than 50 km from the Christchurch central business area and had a magnitude that is much smaller than that expected from the Alpine Fault (M_w=8.2). Recent advances in earthquake mechanics allow us to compute seismograms for realistic earthquake scenarios, at specific locations, and with specific site conditions. Such simulations can provide very useful alternative estimates of possible ground motions from large faults for major population centres in the South Island (NZ).

Synthetic broadband strong-motion records are produced for a possible large Alpine Fault earthquake (M_w8.2) at selected population centres that may be strongly affected. We compute seismograms using a hybrid approach combining a simple discrete wavenumber approach and a stochastic method. To define the earthquake sources, we apply the validated recipe based on a

characterised source model for large crustal earthquakes developed by Irikura and Miyake (2011). We also test source models from past earthquakes as well as a synthetic heterogeneous source model. The synthetic rock site motions are then used as the input motion for a frequency-dependant site amplification function.

The synthetic records show that near-source ground motion accelerations in main West-Coast towns of the South Island are expected to exceed 20%g during an Alpine fault earthquake, while ground motions in Christchurch are expected to be moderate, with peak ground accelerations (PGAs) of 8%g. This high near-source PGA will need further modelling as it is likely due not only to non-linear soil response not accounted for in this study but also to the presence of a modelled asperity nearby and to strong directivity effects.

HANGING WALL AND NONLINEAR SITE RESPONSE TERM OF RECENT GROUND MOTION PREDICTION EQUATION. WHICH OUTCOMES FOR NEW ZEALAND?

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In an objective of improving ground motion prediction in New Zealand, we have been interested in integrating recently studied near-fault ground motion parameters. We have investigated the hanging wall (HW) and nonlinear site amplification terms implemented in recent Ground Motion Prediction Equations (GMPEs) as these effects are currently not well accounted for in New Zealand seismic hazard estimates. A special concern has been given to the Next Generation Attenuation (NGA) project from the Pacific Earthquake Engineering Research centre (PEER).

Hanging Wall effect is described using several 3-D localisation parameters including Depth to top of rupture Z_{TOR} , horizontal distance to top of edge rupture R_X, horizontal distance off the end of rupture plan measured parallel to strike R_Y and horizontal distance to the surface projection of rupture plan (a.k.a. Joyner Boore Distance) R_{JB}. Those parameters and will be presented through the talk, as well as modelisation of Hanging Wall term in a range from Magnitude 3.0 to 8.5. This study will show the effect of these parameters on engineering ground-motion parameters, including peak ground acceleration (PGA) and pseudo spectral acceleration (PSA).

Also will be presented non-linear site amplifications factor used in the various implementation of GMPE, from fully simulation-based non-linear characterization (Kamai et al., 2014) to derivation of semi-empirical nonlinear site response.

Ground Motion Prediction Equation from Abrahmson et al., 2014, Boore et al., 2014, Campbell and Bozorgnia, 2014, Chiou and Youngs, 2014, Idriss, 2014 as well as a simulation-based hanging wall effect from Donahue and Abrahamson, 2014 are used to compare the parameters of interest.

THE EARLY EOCENE CLIMATIC OPTIMUM IN THE SOUTHWEST PACIFIC

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The Early Eocene Climatic Optimum (EECO) is a climate event in which global temperatures reached their Cenozoic maximum for a sustained period of time (~3 million years). It was preceded by a series of short-lived (<250,000 years) climate events in which similar temperatures occurred, the most well-known being the Paleocene-Eocene Thermal Maximum (PETM). The EECO and PETM are inferred to represent Earth's climate state under extreme greenhouse conditions (>2000 ppm CO_2[eq]). Over the last five years, a team of international researchers and students have published a series of articles that help to constrain the age and duration of the EECO in the SW Pacific, to determine the magnitude and nature of associated regional climate impacts, and to reconcile the climate signal with General Circulation Model simulations.

The EECO is correlated with Mangaorapan local stage (52−48.9 Ma) and is associated with a trebling in sedimentation rate in hemipelagic settings offshore eastern Zealandia (Dallanave et al. 2014, 2015), implying a dramatic increase in onshore precipitation and erosion (Slotnick et al. in press). Local temperatures increased by 7°C on land and by 4°C in marine surface waters, respectively reaching maxima of 23° and 32°C (Hollis et al. 2009, 2012; Pancost et al. 2013). These absolute temperatures are subject to large calibration errors and marine surface temperatures may represent seasonal

maxima. Analysis of marine microfossil distributions indicate that fully tropical conditions (>25°C) were not achieved in the mid-latitude (~50°S) SW Pacific Ocean during the EECO (Hollis et al. 2014).

ONSHORE AND OFFSHORE SEISMIC CHARACTERIZATION OF GEOLOGIC HAZARDS IN THE DUNEDIN COASTAL REGION

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The extents of onshore faults can be easy to define where someone is able to walk along a rock outcrop and observe a fault line and offset fault blocks. This is not the case where the outcrop has been obscured by sediments, vegetation, or human development. Offshore faults have the added complication of being covered with seafloor sediments and water. In both cases, the faults will only be visible where there is surface deformation after an earthquake event. The Titri, Akatore, and Green Island fault systems south of Dunedin fall under these criteria and are of particular interest due to their Quaternary activity. In addition, the shallow coastal water table, changes in sedimentary patterns between glacial and interglacial periods, and recent human modifications to the landscape may make the region more vulnerable to earthquake induced ground deformation.

A number of offshore and onshore scientific studies have been conducted in the Dunedin coastal region with many research aims. Land seismic data in the region is notably sparse. Most of the marine studies have incorporated single-channel high-resolution marine seismic data. More recent datasets have made use of multi-beam echo sounder (MBES) along with multi-channel acquisition and processing for improved depth penetration and resolution. More than 1000 km of these seismic data have been jointly interpreted with a focus on identifying geological hazards and structures.

The seismic data show two faults, characterised by offset sedimentary units on either side, running parallel to the coast. Synclinal/anticlinal structures, dipping sedimentary strata overlain with Quaternary sediment, and presumed metamorphic units are also visible in the data. MBES data show varied seafloor relief, and backscatter data show variations in the seafloor sediments. These data may enable a correlation between the positions of faults and particular seafloor environments.

PRINTING POLLEN: AN EXAMPLE OF THE POTENTIAL OF 3D PRINTING FOR ENHANCING TEACHING

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Palynology is a ubiquitous palaeoecological proxy, and therefore features prominently in undergraduate and postgraduate palaeoecology programmes at Universities in New Zealand and worldwide. Students are typically required to become familiar with the morphology of a variety of pollen types. Pollen grains are three-dimensional objects, and may feature intricate surface patterning and complex aperture arrangement. Pollen atlases provide a valuable resource for students learning to identify pollen, and scanning electron microscopy can provide stunning images of pollen grains at sub-micron resolution. However, in the first author's experience, students often struggle to appreciate pollen grain morphology when viewing them in 2D, as seen under a basic transmitted light microscope in the teaching lab environment, and this can make pollen identification quite challenging initially.

One way to enhance students' appreciation of pollen morphology, in particular, the arrangement of apertures and other structures in 3D, is through complementing reference material and atlases with scale models of pollen grains. The field of thermoplastic 3D printing, now readily accessible, offers an exciting new opportunity to create such models. This is essentially taking the concept of 3D-rendered digital pollen models to the next level, to create physical models which can be easily used and handled in the classroom setting.

This presentation documents how we created scale models of some different pollen types. The morphological data were obtained from scanning confocal microscopy. Datasets were then enhanced and rendered, to create CAD files which could then be imported into the program SolidWorks™ from which they were then printed. The same process is

of course, not limited to pollen, and could be applied to other microfossils used in palaeoecology (phytoliths, diatoms, foraminifera, etc.). Once created, CAD files could be easily shared between teaching programmes/departments through online libraries, (as is currently done for other 3D-printable objects).

LATE GLACIAL-HOLOCENE POLLEN RECORDS FROM THE WAIPAOA CATCHMENT: A SYNTHESIS OF NEW TERRESTRIAL AND MARINE RECORDS

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The MARGINS Source-to-Sink program was directed at developing a thorough understanding of sediment dispersal systems at focus sites, including the Waipaoa Sedimentary System (WSS). Vegetation cover is a critical component in these systems, with shifts in vegetation in response to late Quaternary climate variation influencing rates of erosion, aggradation and downcutting on land, and subsequent delivery of large quantities of sediment to the continental margins offshore.

Terrestrial records of vegetation spanning the late glacial to post-glacial period from the WSS region have been challenging to obtain. Arid conditions combined with the unstable landscape characteristic of the WSS precluded development and persistence of sites suitable for the preservation of continuous pollen records spanning long periods.

Lacustrine sediments preserved in abandoned meander channels on relict fluvial terraces provide a hitherto untapped source of pollen records for the WSS. Three such sites have been cored to yield discontinuous pollen records, the oldest of which dates to ~18ka BP following incision of Last Glacial Maximum (LGM) aggradation surfaces. These data are further supported by a ~21-7 ka pollen record from rapidly accumulating sediments (1.1m/kyr) captured in marine core MD06-3002, lower Poverty Bay continental slope. The stratigraphic framework for these systems is provided through tephrochronology and ^{14}C radiochronology.

For the LGM, both the onshore and offshore data imply cool climate conditions, with open vegetation represented by Poaceae, Cyperaceae, Asteraceae, *Coprosma*, and other cool climate species, and stands of beech (*Fuscospora*), or mixed beech/podocarp forest. By 14ka BP much of the catchment was under forest, roughly corresponding with the first major degradation step below the LGM aggradational surface. The terrestrial sites record *Podocarpus*/*Prumnopitys* forest, while MD06-3002 records mixed beech-*Podocarpus*/*Prumnopitys*-*Dacrydium* forest. This discrepancy reflects local variation in vegetation cover onshore, with the terrestrial sites capturing a localised signal and MD06-3002 capturing the pollen from the wider catchment.

VEGETATION CHANGE AND FIRE IN A HOLOCENE PEAT BOG, OTAKAIRANGI, NORTHLAND, NEW ZEALAND

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Plant cuticles and other identifiable remains offer a useful method for determining vegetation change in peat bogs because the signal is more representative of the plants growing at the site. A 3 m long core from a bog at Otakairangi, Northland, New Zealand affords an insight into the development of the bog over the past 3000-plus years. Although the upper 1 - 1.5 m shows evidence of disturbance due to human activities, the lower part of the core suggests that the bog has switched from ground-water fed swamp to rain-fed bog and back on a number of occasions and has experienced a number of fires in the period before human settlement in the area. The presence of probable *Sporadanthus* cuticles provides evidence that the range of *Sporadanthus ferrugineus*, now confined to three sites in the Waikato region was greater in the past.

MACROFOSSIL EVIDENCE FOR LAST INTERGLACIAL VEGETATION CHANGE IN NORTH TARANAKI

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Plant cuticles have a similar composition and preservation potential to pollen and spores. They have distinctive morphologies that allow identification, often down to specific level and their potential for long-distance dispersal is less than for pollen. Disseminated plant cuticles and other macro remains therefore offer a useful complement to palynology and sedimentology in a variety of paleoenvironmental and paleoclimate studies.

A last interglacial fossil forest exposed at Airedale Reef near Waitara on the North Taranaki coast offers a good opportunity to assess the potential of macrofossil analysis, since detailed stratigraphic and palynological surveys of the site have already been made (Newnham and Alloway 2004). Results so far indicate a succession from stabilised sand dunes through mature podocarp/broadleaf forest to more open bog/forest communities, before all vegetation was destroyed by the Okawa Debris Avalanche. Overall, the successional pattern matches the pollen record well, but there are differences in detail. The presence of several prominent coarse tephras and increasing levels of charcoal in the upper part of the organic sequence suggest that forest disturbance due to increased volcanicity, rather than climate change, was the primary cause of the changes in vegetation.

This study is ongoing and future work is discussed. It offers scope for better understanding of environmental change during MIS 5 and nearby sites on the Taranaki coast have the potential to extend the work to earlier periods.

CORRELATING BASALTIC TEPHRAS TO SOURCE VOLCANOES; METHOD DEVELOPMENT AND IMPLICATIONS

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Linking distal tephra deposits to their source is a relatively simple exercise, if potential sources are limited, eruptive episodes (and deposits) are well dated, and/or the geochemical signatures of proximal deposits are distinctive. Where these criteria are not met, accurate correlations are difficult to make, and at present there are no established methods to resolve the ambiguities. Here we present a new method that has been developed to correlate distal basaltic tephra deposits from the Auckland Volcanic Field (AVF) to a corresponding source volcano. In order to achieve these correlations, previously published tephra-derived glass geochemical data and cross-core horizon correlations are compared with existing and new whole rock geochemical data for the field. These data are analysed to determine which geochemical signatures can be used to correlate between dispersed tephra and source whole rock compositional data. Our results suggest that incompatible trace element ratios are the most variable over the entire field, and yet also the most limited for an individual centre. These ratios are also the least affected by fractional crystallisation, and crystal removal, therefore are considered to be the most useful tools for correlation. However, each centre (in the field as a whole) does not have a unique geochemical signature, and therefore the tephra horizons cannot be unambiguously correlated based purely on their geochemistry. Thus, a number of criteria are combined, including age and location of both the tephra and whole rock deposits, to further constrain the sources of the distal tephra deposits. These criteria are assessed for each potential source, and correlations are given a confidence rating based on the number of criteria that are satisfied. This new method overcomes previous shortcomings in tephra-centre correlation and provides improved constraint on the AVF eruptive sequence.

TOOLS AND TECHNIQUES FOR IDENTIFYING AND CROSS CORRELATING BASALTIC TEPHRA IN LACUSTRINE CORES

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Probabilistic hazard forecasting for a volcanic region relies on understanding and reconstructing the eruptive record (derived potentially from distal as well as proximal volcanoes). Tephrostratigraphy is commonly used as a reconstructive tool by cross-correlating tephra deposits to create a stratigraphic framework that can be used to assess magnitude-frequency relationships for eruptive histories. When applied to widespread rhyolitic deposits, tephra identifications and correlations have been successful; however, the identification and correlation of basaltic tephras are more problematic. Here, using tephras in drill cores from six maars in the Auckland Volcanic Field (AVF), New Zealand, we show how X-ray density scanning coupled with magnetic susceptibility analysis can be used to accurately and reliably identify basaltic glass shard-bearing horizons in lacustrine sediments. This information, when combined with the major and trace element signatures of the tephras, can be used to distinguish primary from reworked layers. After reliably identifying primary vs. reworked basaltic horizons within the cores, we detail an improved method for cross-core correlation based on stratigraphy and geochemical fingerprinting. Our results suggest that in cases where major element compositions (SiO_2, CaO, Al_2O_3, FeO, MgO) do not provide unambiguous correlations, trace elements (e.g. La, Gd, Yb, Zr, Nb, Nd) and trace element ratios (e.g. $[La/Yb]_N$, $[Gd/Yb]_N$, $[Zr/Yb]_N$) are successful in improving the compositional distinction between the AVF basaltic tephra horizons. These correlations allow an improved eruptive history of the AVF to be reconstructed.

VERTICAL TECTONICS AT AN ACTIVE CONTINENTAL MARGIN: INITIAL RESULTS FROM 12 YEARS OF CGPS IN NEW ZEALAND

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Vertical movement of the earth's surface within New Zealand has been mapped from continuous GPS (cGPS) data for epoch 2002-14. Using 152 stations across the country key regions of both uplift and subsidence are mapped. Formal uncertainties are ± 1 mm/y for the vertical velocity of stations that have been installed for more than 6 years. A large area of subsidence ~ 3 mm/y is seen along southeastern North Island that is ascribed to the locked subduction zone. Uplift of 1-3 mm/y further north along the margin of the eastern North Island is interpreted as being due to the plate interface being unlocked and underplating of sediment on the subduction thrust. In the central North Island there is a broad area of uplift of 1-2 mm/y that we argue is due to basaltic melts being injected at a (vertical)rate of ~ 6 mm/y in the active mantle-wedge that underlies the central North Island. In the Taupo Volcanic Zone of the North Island there is a 50 x 50 km region that shows an elliptical subsidence of up to -18 mm/y, which developed in the relatively short epoch of 2005-2012. We interpret this event as being due to rapid degassing and possibly some dike intrusion, similar to that seen elsewhere in the TVZ, and in other rift and volcanic zones of the world. In central South Island uplift rates of ~ 6 mm/y are linked to uplift of the Southern Alps. For the whole country the distribution of vertical velocities is normally distributed with the mean rate being about 1 mm/y, which is the same order as mean sea level rise. However, in another 5-10 years this data set will have errors reduced to ~ ± 0.5 mm/y and the associated conclusions we can make will be more robust.

QUATERNARY GEOLOGY OF THE DFDP-2 DRILL HOLES, ALPINE FAULT, NEW ZEALAND

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Drilling in the Whataroa Valley as part of DFDP-2 revealed a 240 m-thick Quaternary sediment sequence that was much thicker than predicted before drilling. Bore-holes DFDP-2A and DFDP-2B were predominantly drilled by the dual-rotary method using air or water circulation, returning cuttings bagged at 1 or 2 m sample intervals. Intact sediment core was retrieved in DFDP-2A from 125-160 m, with highly variable recovery (0-100%) and mixed preservation/quality. Interpretation of the sedimentology indicates that the sequence contains: fluvial-glacial gravels (0-58m); grading downward into sandy lake delta sediments (59-77 m); overlying a monotonous sequence of lake mud and silts, with rare pebble-cobble diamictite (77-206 m); with a basal unit (206-240 m) containing coarse cobbles and boulders that may represent a distinct till/diamictite. To date there is no evidence for any marine influence in the lowermost sediments, despite deposition of muds and silts at least 120 m below present day sea level, and potentially 200 m bsl if uplift has occurred on the Alpine Fault. Radiocarbon dating of plant fragments indicate 70 m of upper lacustrine and deltaic sediments (129-59 m) were deposited rapidly between 16350-15800 Cal BP. Overlying alluvial gravels are much younger (<1 ka), but potentially also involved pulses of rapid aggradation. The sequence provides a record of sedimentation on the Alpine Fault hanging wall following late-glacial ice retreat up Whataroa Valley, with uplift and erosion followed by Holocene alluvial gravel deposition. Future work will address: (1) the nature and history of sedimentation, including the micro-fossil assemblages, lithology, and origin of sediments; (2) what, if any, geological record of tectonics (movement) the sediments contain (3) rates of landscape evolution in Westland.

LACUSTRINE PALEOSEISMOMETERS REVEAL SPATIAL AND TEMPORAL PATTERNS OF RUPTURE DURING GREAT EARTHQUAKES ON THE ALPINE FAULT, NEW ZEALAND

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The rarity of long, well-dated paleoseismic records from sites along plate boundary transform faults is a major constraint on the development and evaluation of conceptual models of fault rupture behaviour. In this paper we use a new lacustrine paleoseismology approach to determine the rupture behaviour of the high slip rate (27±5 mm.yr^{-1}), dextral strike-slip Alpine Fault at the boundary between the Pacific and Australian plates in southern New Zealand. The approach uses the sedimentary records from seven lakes that act as natural seismometers recording high intensity shaking events as turbidites formed by subaqueous mass-wasting. These turbidites are overlain by terrigenous sediment from co- and post-seismic landsliding on hillslopes in the lakes' mountainous catchments. Chronologies derived from Bayesian modelling of hundreds of AMS ^{14}C dates on terrestrial leaf macrofossils precisely constrain the timing of earthquakes at the lake sites, facilitating along-strike correlation of high intensity shaking events. The record of synchronous shaking at the lake sites provides first order constraint on the rupture lengths of Alpine Fault earthquakes that ruptured the Central and North Westland geometric segments. The lacustrine paleoseismic observation are combined with paleoseismic records from the South Westland geometric segment to produce rupture scenarios for the last 19 earthquakes along ~400 km of the Alpine Fault spanning the last 3500 years. The rupture scenarios suggest the Alpine Fault is capable of a range of rupture behaviour governed primarily by the geometric segmentation of the fault.

CRUSTAL DEFORMATION IN THE TAUPO VOLCANIC ZONE

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The oblique convergence of the Australian and Pacific plates at the rate of 40 to 50 mm/yr in the North Island of New Zealand is partitioned into a trench parallel translation, accommodated by large strike slip faults in the upper crust, and subduction of the Pacific plate along the Hikurangi margin. Geodetic and geophysical studies suggest that the subducting slab interface is creeping steadily under the northern part of the North Island while it remains largely locked and accumulating stress along its southern segment. The subduction and rotation of the fore arc result in back arc rifting, with extension and volcanism in the Taupo Volcanic Zone. The Taupo Volcanic Zone has been active for 2 Myr and is one of the world's most productive rhyolitic systems. It has numerous high temperature geothermal fields and a very high heat flow. GPS studies have suggested increasing rate of extension from south to north along the Taupo Volcanic Zone with over 15 mm/yr extension at the Bay of Plenty. Fault slip data have suggested that the current active extension is taken up over 20 km wide zone, however GPS measurements suggest that the deformation zone is wider. In 2005 over 100 GPS sites were measured in the Taupo Volcanic Zone. The network was re measured and further densified in 2007, 2011 and 2015. In addition GeoNet has installed a number of continuous GPS stations in the region since 2002 with focus on the volcanic centers. Crustal deformation within the Taupo Volcanic Zone is complex and varies both in space and time. InSAR and GPS measurements show widespread subsidence with of rates up to 20 mm/yr, possibly related to the cooling and contraction of magma. We present an updated velocity field for the Taupo Volcanic Zone.

COMMUNICATING MODEL UNCERTAINTY: A REVIEW OF INTERNATIONAL BEST PRACTICE

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Recent events, including the tsunami warnings of 2009/2010, the Christchurch earthquake and aftershock sequence starting 2010, and the Te Maari volcanic eruptions of 2012, have highlighted that uncertain science advice presents a challenging communication environment. In the psychology literature, there is much discourse as to whether revealing the uncertainties will strengthen or decrease trust in a risk assessor and their message. We will present preliminary findings of a structured literature review of the evidence base for effective communication of model uncertainty, with a view to developing best practice guidelines for hazard and risk models. A structured approach has been adopted to reduce bias that can arise during a classical approach, and this review includes fields beyond natural hazards, for example medical science, climate change, and psychology. Key questions that will be addressed include: What approaches are used to classify model uncertainties? How do communication approaches vary across short, medium and long term hazards? How do the different approaches vary depending on the different audiences and advice pathways? How is model performance communicated, and how is this addressed in low data situations? Through this, we will explore the main recommendations for communicating model uncertainty, and identify areas that require further research.

INTERPRETATION OF SRTM DEM WITH IMPLICATIONS FOR THE SPATIAL RELATIONSHIP BETWEEN GEOLOGICAL STRUCTURES AND VOLCANISM IN WEST JAVA, INDONESIA

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West Java is situated in the transition zone between oblique convergence at the Sumatra Segment and orthogonal convergence at the Java to Banda Segment of the Sunda Banda Volcanic Arc. The subduction related volcanic arc is distributed along the active continental margin of the Eurasia plate that overrides the Indian-Australian oceanic plate. Unlike the Sumatra Segment where the volcanic arc is highly associated with the major Sumatra Fault Zone, the volcanic arc in Java segment has never been associated with major regional faults. Anomalously, only in West Java, the volcanic arc occurs in double chains where the other sub-segment in East Java has a single chain only.

The high resolution digital elevation model (DEM) prepared from Shuttle Radar Topographic Mission dataset (SRTM 30 m) is interpreted manually and automatically, to enhance structural patterns in West Java and circular volcanic features. Both parameters are analysed qualitatively to find out whether any relationship exists between regional structures and unusual volcanic distribution in West Java.

Based on the interpretation of these datasets the volcanism in West Java is likely localised by intersection of faults where the arc-parallel faulting, trending at WNW-ESE, is crossed by NW-SE and NE-SW faults. An anomalous volcanic pattern is identified in Bandung-Garut Zone where some volcanoes are distributed almost in a circular pattern. The distribution pattern might follow a bigger circular structure, bounded by several faults, trending at NW-SE and NE-SW. Based on the pattern, the volcanic arc distribution in West Java is divided into two types, which are parallel to the arc and associated with the circular structure. The analysis shows that volcanism in West Java is highly associated with regional structures.

FAR AND WIDE: STRAINS INDUCED IN THE TAUPO VOLCANIC ZONE BY SLOW SLIP EVENTS IN THE FAR-FIELD

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Volcanic and geothermal areas have been shown to be more susceptible to dynamic triggering from large earthquakes than normal tectonic regions. In this study we examine whether the Taupo Volcanic zone, especially around Taupo volcano, may be susceptible to strains induced by slow slip events (SSEs). This relationship has yet to be examined for a number of reasons, including the limited local seismic response to SSEs, and the large distance between the volcanic zone and most East Coast SSEs (~150km). Deep SSEs (>20 km) discovered further down-dip provide the possibility that previously undetected SSEs are influencing the timing of volcanic unrest. There is evidence that seismicity and gas changes at Taupo volcano accompanied a deep SSE in 2008. We use cGPS from GeoNet network to analyse strain changes around Taupo volcano for two deep SSEs in 2006 and 2008, the Manawatu 2010 SSE, and a typical East Coast SSE in 2013. Because the absolute strain changes are small we also examine strain rates. These strains are compared to finite element models of strain predicted from the slip distribution of the individual SSEs. The strain and strain rate changes are also compared to long-term seismicity rates in the TVZ to determine their influence, if any on the timing of volcanic unrest.

SITE EFFECTS IN THE AREA OF THE OWHIRO BAY QUARRY – OBSERVATIONS AND MODELLING

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As part of a larger study focussing on an investigation of seismic site effects and their impact on stability of the slopes around Wellington, several sites have been instrumented with small seismic arrays and subsequently modelled using the finite difference numerical modelling code FLAC. Here we present the results of such modelling and observations from one of the sites, the Owhiro Bay Quarry, located on the south coast of Wellington. Continuous recording on 3 seismic stations provided large amount of earthquake signals, out of which over 230 were assessed as being of reasonable quality and further analysed. The data confirm some of the generally accepted phenomena, such as increased amplification on the top of a ridge, while other observations yield surprising results. These include increased amplification for the seismic sources whose back-azimuth lies in the direction of the dip of the slope, and a fair agreement between the Standard Spectral Ratios and Horizontal to Vertical Spectral Ratios for the station at the top level of the quarry, even for high frequencies. The numerical modelling results then provided a tool for the analysis of the contribution of various factors to the total site effects. The results of the model clearly show that the Standard Spectral Ratios on the site are strongly affected by the site effects (mainly de-amplification) on the reference site not only in terms of the amplitude, but also in terms of shape and location of the peaks of the resulting spectral ratios. This emphasizes the importance of calculating virtual spectral ratios using the signal from a point corresponding to the reference station in the field rather than input signal as the reference, when comparing the data from numerical models with the field observations.

THE COMPOSITION AND ORIGIN OF TURBIDITES IN THE SOLANDER TROUGH

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Solander Trough is a marine depression, south of the South Island of New Zealand sitting between the Macquarie Ridge to the west and the Campbell Plateau to the east. During the last glacial maximum the Solander Trough was regularly influenced by turbidity and gravity flows funnelling sediment down into the trough. Visual logs, grainsize, magnetic susceptibility, carbonate content, X-ray diffraction and benthic foraminiferal analyses have been conducted on 6 cores down the length of the Solander Trough. The cores display both terrigenous and calci-turbidites originating from multiple sources. A model outlining the potential origin(s) of sediment found composing the turbidites of the Solander Trough will be presented. The results suggest a highly dynamic submarine environment.

STUDENT ENGAGEMENT WITH SINGLE AND MULTIPLE SITE FIELD TRIPS: LOCATION, LOCATION, LOCATIONS?

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Field trips are a mainstay of geology curricula, offering unique and often transformative experiences. Students get the opportunity to ground content in the “real world”, learn about the scientific method, and develop their own identities as geologists. In this study, we compare the same

group of students on two week long field trips: one situated and mapping-based, the other roadside and skills-based. Students were surveyed on their motivation for learning, environmental attitudes, and landscape perceptions, before and after each field trip. A subset of students were interviewed to understand these topics in more detail. Lecturers were surveyed and interviewed on their environmental attitudes and landscape perceptions. All participants were observed in the field to uncover the nature of the trip and their engagement with the field environment.

Students developed a strong attachment to the situated mapping environment, but did not develop any attachment to the collection of sites visited in the roadside environment. Most students felt they accomplished more in the situated environment and were more engaged throughout the trip, as they were able to work at their own pace and had to make crucial navigational and observational decisions. A small number of students felt they were more engaged in the roadside field trip, as piecemeal tasks were more manageable. Students that were more intrinsically motivated tended to develop stronger attachments in the situated environment, whereas those that were more test anxious tended to develop stronger attachments to the roadside environment. These results suggest that it is beneficial to understand the different types of students we have as participants on our trips. A balance of autonomy, clear task rationale, and spatio-temporal awareness may aid in evening out differences in engagement between situated and roadside environments and therefore, making both types of field trips effective for a variety of students.

DOES IT MATTER WHERE YOU HOLD YOUR FIELD TRIPS?

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Although the way we choose our field sites is largely driven by practical reasons, students have an interaction with the landscape that is much more complex in nature. As they navigate in the field, they learn about geological and other landscape meanings, through interactions with instructors, demonstrators, and peers. Students create a unique picture of the field sites in their mind, even developing attachments with the places they have visited. These affective interactions (relating to emotions, attitudes, and values) are crucial drivers of the learning process, as well as personal and identity development.

But what specific aspects of the field trip and landscape are important for engagement, and how do we capitalise on these in attracting and retaining keen geology students? Does it matter which instructors teach certain field trips? Is it more important to have local knowledge of the area, or to be an expert in the relevant geologic specialty? What about factors that are completely out of our control, such as the weather? Preliminary questionnaire and interview results suggest that despite what we might be inclined to believe, student attachment to a place does not significantly differ with instructor background or weather encountered. However, the novelty factor, particularly for students from overseas, was highly beneficial in engaging students with the field environment and created lasting attachment that may be leveraged in the future.

Questions regarding the influence of other site characteristics remain. For example, should the field environments be physically demanding, or require little walking? Does the type of environment need to connect to future careers, or is the value of being in the field enough regardless? Do students engage more on field trips to regions they are already familiar with, through reputations

passed down by their peers, or their own personal experience?

RAPID HOLOCENE THINNING OF AN EAST ANTARCTIC OUTLET GLACIER DRIVEN BY MARINE ICE SHEET INSTABILITY

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Outlet glaciers grounded on a bed that deepens inland and extends below sea level are potentially vulnerable to 'marine ice sheet instability'. This instability, which may lead to runaway ice loss, has been simulated in models, but its consequences have not been directly observed in geological records. New surface-exposure ages from an outlet of the East Antarctic Ice Sheet reveal that rapid glacier thinning occurred seven thousand years ago, in the absence of large environmental changes. Glacier thinning persisted for more than two and a half centuries, resulting in hundreds of metres of ice loss. Numerical simulations indicate that ice surface drawdown accelerated when the otherwise steadily retreating glacier encountered a bedrock trough. Together, the geological reconstruction and numerical simulations suggest that centennial-scale glacier thinning arose from unstable grounding line retreat. Capturing these instability processes in ice sheet models is important for predicting Antarctica's future contribution to sea level change.

PHYSICAL VOLCANOLOGY OF THE OWHAROA AND WAIKINO IGNIMBRITES, WAIHI BASIN, COROMANDEL VOLCANIC ZONE

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The Waihi caldera is defined by a 15 km diameter gravity anomaly in the Coromandel Volcanic Zone (CVZ). It is a trapdoor caldera that was active during the Pliocene and infilled by 1.5 km of rhyolitic to dacitic ignimbrites, rhyolite lava domes and lake sediments forming the Waihi Basin. The aim of this study is to characterise the Pliocene Owharoa and Waikino ignimbrites, two of the ignimbrites which infill the Waihi Basin, and to compare their eruption and emplacement processes.

The Owharoa Ignimbrite reaches up to 80 m thick and shows wide variations in pumice/fiamme and lithic abundance, and wide degrees of welding over short (~2 m) stratigraphic intervals. Pumice/fiamme abundance varies from 10 - 25%, lithics 1 - 10%, and crystals 1 - 6%. Juvenile clasts include creamy rounded woody-textured pumice in the east, and dark to black glassy fiamme with lensoidal shape in the west. Free crystals include plagioclase, quartz, biotite, titanomagnetite, ilmenite, hornblende and zircon. Lithics are rhyolite, andesite, ignimbrite, sandstone and siltstone. The vitriclastic matrix is comprised of a variety of glass shards and very fine ash-sized material unresolvable even under the SEM.

The Waikino Ignimbrite, also approximately 80 m thick, is a finer grained, massive, glass shard matrix-rich (~93%) ignimbrite that is separated into two facies – a non-welded, coarse ash basal unit and a strongly welded, fine ash, massive upper unit. Free crystals (1 - 6.5%) within the matrix include quartz, plagioclase, biotite, opaques and zircon. The pumice within the Waikino Ignimbrite (1%) was only seen in hand specimens as coarse ash-sized, white fragments. Lithics (2%) include greywacke, glassy rhyolite and ignimbrite.

The Owharoa Ignimbrite indicates an intra-caldera, pulsating depositional flow that shows subtle increases and decreases in pumice and lithic abundance. The massive nature of the Waikino Ignimbrite indicates a consistent, steady depositional flow that was intensely fragmented to a glass shard-rich deposit.

IMPLICATION OF COAL SOURCE ROCK DISTRIBUTION FOR THE HYDROCARBON SYSTEM IN THE GREAT SOUTH BASIN

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A source rock contains a significant volume of organic matter that over time and with sufficient temperatures and pressures can be converted to oil and gas. Oil and gas have been found in sub commercial quantities in Great South Basin (GSB) exploration wells. For example gas found in Kawau-1A in two test zones that produced 4.7 and 6.7 billion cubic feet per day from the Kawau and upper Hoiho sandstone units, respectively. In another example, a "yellow cut" oil show was reported in well Toroa-1 from a depth of 4530 m (bellow Kelly bushing) from a side wall core sample. Source rock lithologies vary a cross the basin from totally organic sediments like the coal found in the Tara-1 and Toroa-1 wells through to shale with gas peaks that approach 20 units with components C1=2000 ppm,C2=200 ppm and C3=200 ppm in Pakaha-1. Data analysed from seven exploration wells in the GSB show the highest TOC at Tara-1, approaching 50 (% weight). The coal was found in a 2000-m-thick interval in this well that can be subdivided based on relative age into Palaeocene, Maastrichtian and Santonian units.

Source rock characteristics have a range of impacts on seismic reflectivity. Palaeocene, Maastrichtian and Santonian coal bodies and shales have been mapped using the IHS Kingdom data analysis package. In particular, the extensive set of seismic data has been tied to geological interpretation of well logs from the existing exploration wells. The ultimate purpose of this study is to identify the source rocks in the well data Tie these units to their equivalent seismic facies, and map their geographical distribution in the basin to better understanding the elements of hydrocarbon system in the GSB.

AN EXPERIMENTAL STUDY TO CHARACTERIZE PHYSICAL ROCK PROPERTY CHANGES DURING CO2 REACTIONS WITH AUCKLAND VOLCANIC FIELD BASALTS

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CO_2, water and basalts are known to react in volcanic environments. Mineral sequestration of anthropogenic CO_2 is one of the proposed solutions to capture and decrease CO_2 emissions. This involves reacting naturally occurring minerals that contain high amounts of magnesium and calcium with supercritical CO_2 and water to form carbonate minerals. Basalts are thought to be one of the promising rock types for mineral sequestration of CO_2 by creating such hydrothermal mineral alterations. Rock-fluid interactions occurring during the sequestration process, change the physical properties of the rock in terms of porosity, permeability and rock microstructure. In order to characterize these changes, CO_2-water-rock alteration in young basalts (less than 0.3 Ma) of the Auckland Volcanic Field will be studied over a 30 week period. Eight core samples from Lake Pupuke, Mount Eden and Three Kings volcanoes will be reacted with CO_2 and basalt equilibrated water at 100 °C and 8 MPa fluid pressure and analysed in three stages: before reaction, post 15 and 30 weeks reaction to monitor the alterations in the rock frame and type of carbonate mineral precipitation. Changes in rock microstructure will be detected using computed tomography scanning, helium porosity-permeability measurements and velocity measurements at ultrasonic frequencies. The samples have similar chemical compositions being silica-undersaturated with high FeO, Al_2O_3, MgO and CaO, on average. Porosity analysis from CT scan data are in agreement with the helium porosity and permeability results. In addition carbonate precipitation will be monitored with XRD, XRF and petrographic analysis. Water chemistry will be regularly monitored by ICPMS analysis. This project will provide useful insights for volcanic research, and mineral and oil and gas industry by understanding the evolution of hydrothermal mineral alteration and rock microstructure in basalts.

GROUND MOTION SIMULATIONS OF 'SCENARIO' SUBDUCTION EARTHQUAKES IN THE NORTH ISLAND OF NEW ZEALAND

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In the North Island of New Zealand where the Hikurangi subduction interface appears to be fully locked at 23 km beneath Wellington (e.g., Wallace et al., 2012), the absence of recorded mega-thrust earthquakes necessitates the use of simulation-based approaches for ground motion prediction. In this study, we simulate long-period (>2 seconds) ground motions of plausible magnitude-8 mega-thrust earthquakes in the North Island of New Zealand using a spectral element method. Our approach accounts for (i) the 3D velocity model of New Zealand derived from body-wave tomography (Eberhart-Phillips and Reyners, 2012), (ii) the 3D plate interface geometry derived from seismicity and seismic-reflection data (Williams et al., 2013), and (iii) local tomography and bathymetry. We consider a range of kinematic source parameters, including slip distributions, stress drops and rupture propagation directions. For each source scenario, we calculate site-specific ground motion parameters, such as long-period response spectra and peak ground displacements and velocities. Our result suggests that rupture nucleating from the up-dip end of the locked zone and propagating into the down-dip direction causes the largest ground motion in the Wellington city among a range of scenarios considered so far. For many simulated source scenarios, the long-period spectral accelerations are generally larger than those corresponding to the current New Zealand design levels. Furthermore, long-period ground motions are greatly amplified by the presence of accretionary wedge sediments in the northeast coast of the North Island of New Zealand.

THE TEMPORAL AND SPATIAL DIFFERENTIATION OF CLIMATE CHANGE FOR LAST 140 YEARS ?? RECORDS FROM THE SEAS AROUND CHINA

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Using multiple marine dataset (AIPOcean1.0 (1993-2006), Ishii (1945-2010), SODA (1871-2010)), contrast and analysis temperature change rate and trend from surface to the deep in the East-South China Seas and adjacent waters to the Northwest Pacific Ocean (NPO), for past 140 years, the results showed a larger differentiation at space and time: on the surface, the warming has emerged at the whole studying area for last 140 years; the warming rates appeared that over the 25 years > 50 years > 100 years > 140 years. But the largest rate was at the layer around the depth of 50m. In the continental shelf area of the East China Sea (ECS), the temperature was rising at upper layer to 100 meters, some area deeper than 120 meters has appeared cooling. In the Kuroshio of the ECS (the ECS Kuroshio) and the Okinawa trough region, from the entrance to export of the ECS Kuroshio, the sea was warming at upper 300 m, the warming rate decreased with depth; 500-700 meters in some areas appear to be cooling; the layer deeper than 700 meters appears warming trend again. At the NPO adjacent to the ECS, the upper 200 meters appear to warming, a cooling trend at 300-1200 meters, not change or appear weak warming below 1200 meters. In the South China Sea (SCS), the upper 200 meters has an emergence of warming, 200-1000 m cooling, the layer below 1000 meters has been warming again. In the NPO adjacent to the SCS, the upper 250 meters has heating, 250 -2500 m cooling, 2500 m below the change was no obvious. Throughout the study area, where deeper than 700 meters, the temperature changes show in the three layers structure, the temperature rise in the upper layer, the middle cooling, the deeper change is not obvious.

PRELIMINARY VOLCANIC HISTORY OF LAVAS AND VENT STRUCTURES AT THE BOMBAY QUARRY, SOUTH AUCKLAND VOLCANIC FIELD

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Monogenetic volcanic fields consist of individual, commonly mafic volcanoes, each built in a single relatively short-lived eruption cycle. Small volcanoes in the South Auckland Volcanic Field (SAVF) take the form of scoria cones, tuff rings, maars or tuff cones, or volcanic complexes comprising a combination of these. Lavas associated with lava shields, as well as the smaller volcanic centres, occur throughout the field. The SAVF was active between 1.59 to 0.51 Ma. The Bombay volcanic complex (BVC) is exposed in two large quarry pits at the Bombay Quarry, and may be related to the large Bombay lava shield to the east. A 1.0-1.2 Ma rhyolitic tephra is intercalated within the basaltic succession. Gibson (2011, University of Waikato MSc thesis) studied the southern 'Waikato pit' and identified multiple eruptions that generated at least one tuff ring, a tuff cone, numerous scoria and spatter cones, and a large ponded basalt lava. A second ponded basalt in a separate palaeovalley has been exposed in the recent northern 'Auckland pit'. Operating drilling methods, geological studies and resource modelling generally indicate that the basalt deposit comprises a stratigraphic succession of at least three, separate lavas of differing petrographic characteristics.

The aim of this study is to produce a volcanic history of the Bombay volcanic complex with emphasis on the Bombay Quarry. The project will involve producing stratigraphic logs from company drill cores representing key cross-sections across the quarry. Further advanced methods include petrographic microscopy; X-ray diffractometry (XRD); X-ray fluorescence spectrometry (XRF); scanning electron microscopy (SEM); electron probe microanalysis (EPMA); and K-Ar dating. We will present the stratigraphy, facies architecture and preliminary volcanic process interpretations of the Bombay volcanic complex.

UPDATING THE GOLDEN CROSS STORY IN THE COROMANDEL VOLCANIC ZONE: A GEOPHYSICAL PERSPECTIVE

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Golden Cross is a volcanic-hosted epithermal Au-Ag quartz vein deposit located 8 km northwest of Waihi in the Hauraki Goldfield. The area was mined in the late 1880s, 1920s, and in the 1990s. The Gold Exploration Models (GEM) research programme, a collaborative project between GNS Science, the universities of Auckland, Waikato and Otago, and industry partners, aims to understand how regional structures influence the flow of hydrothermal fluids resulting in mineral deposits. The southern Hauraki Goldfield is a key location for this study, because it contains New Zealand's largest known epithermal gold deposits.

Airborne geophysical surveys have been used to help interpret and map the geology, structure, and hydrothermal alteration at regional scales. More detailed studies have been carried out on individual deposits using a variety of geophysical survey methods. At Golden Cross a large amount of ground-based resistivity and electromagnetic data, and airborne magnetic data was collected in the period 1980-90 over the steeply west-dipping quartz vein system. These data are available through the NZ Petroleum & Minerals technical database in open-file reports submitted by the companies that operated the licences.

Modern processing methods allow the airborne magnetics, and ground-based resistivity and electromagnetic data, to be inverted, producing 3D volumes of rock properties that can be correlated with drill-hole and outcrop geology. The comparison of magnetic and electrical anomalies allows us to test models of fault block geometry, alteration, and post-mineralisation volcanic cover. Initial results show a resistive and moderately magnetic western block (Waipupu Fm), conductive rocks with low magnetisation in the eastern block (dacite and andesite), a zone of variable magnetization and resistivity coincident with the dipping vein system, and a veneer of cover rocks with moderate resistivity and magnetisation. These detailed deposit scale models currently being studied will be up-scaled into a regional 3D geological and geophysical study.

FOLIATION FANNING IN THE HANGINGWALL OF THE ALPINE FAULT, CENTRAL SOUTHERN ALPS: CONSTRAINING MODELS OF DUCTILE FLOW IN THE LOWER CRUSTAL SHEAR ZONE

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The foliation in the hangingwall mylonite zone of the Alpine Fault (AF) in the Central Southern Alps is often assumed to be subparallel to the fault plane. Up-section, the non-mylonitic precursor to that foliation has escaped obvious deformation related to Neogene shearing, however, it may have absorbed an increment of Neogene ductile deformation, suggested by a progressive fanning of the non-mylonitic foliation between a steeply SE or subvertical dip—and NNE strike—distant from the mylonite zone; to a shallow dip—and NE-SW strike—adjacent to it. Additionally, the inherited (pre-Neogene) lineation in the schist transitions from SW plunging to NE plunging on entry into the mylonites.

We plan to use the curved foliation trajectory pattern near the AF to 1) model patterns of ductile flow in the shear zone related to AF shearing; and, 2) to determine whether the spatial transition in foliation dips can be used to estimate the dip of the AF, both at depth and across transitions between strike-slip and thrust segments in the near surface. To do this we combined field structural measurements of surface outcrops across the zone of foliation fanning in 7 transects along strike of the AF, with 3D analysis of drillcore from the Amethyst hydro scheme (Hari Hari transect) and down-hole imaging of foliation dips from the DFDP-2B project (Whataroa transect). At least two transects capture the junction region between strike-slip and thrust segments. At these locations, one of which is the DFDP-2 site, the mylonitic foliation dips uniformly at 50-60° throughout the mylonite zone, which we interpret as reflecting the mean dip of the main AF plane at depths below the near-surface zone of segmentation. Elsewhere, the mylonitic foliation dips vary depending on the adjacent type of fault segment.

LATE HOLOCENE RUPTURE BEHAVIOUR AND EARTHQUAKE CHRONOLOGY ON THE HOPE FAULT, NEW ZEALAND

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Paleoseismic trenching and radiocarbon dating of faulted late Holocene sediments on the Hurunui segment of the Hope Fault are used to derive an earthquake chronology that extends from the historic 1888 Mw 7.1 Amuri earthquake to ~300 A.D., thereby providing the longest chronologic record of earthquakes on the Hope Fault. Six earthquakes identified at A.D. 1888, 1740-1840, 1479-1623, 819-1092, 439-551, and 373-419 indicate a mean recurrence interval of ~298 ± 88 yr with inter-event times ranging from 98 to 595 yrs. The large variance in inter-event times is explained by (1) coalescing rupture overlap from the adjacent Hope River segment on to the Hurunui segment at the study site including the 1888 Mw 7.1 Amuri earthquake, that results in apparently shorter inter-event times at the study site compared to mean recurrence intervals from adjacent fault segments, and (2) earthquake temporal clustering on the Hurunui segment, which could result in inter-event times that are significantly shorter or longer than inter-event times and mean recurrence interval predicted by a periodic earthquake rupture model, and/or (3) 'missing' events, which could result in inter-event times and mean recurrence intervals at the study site that are longer than the actual mean recurrence interval. Options (1) and (2) are preferred to explain earthquake chronologies and rupture behaviour on the Hurunui segment, given the detailed nature of the geologic and chronologic investigations. We provide the first evidence for coseismic multi-segment ruptures on the Hope Fault (i.e., 1888 Amuri earthquake). Paleoearthquake records near geometrically complex segment structural boundaries on major strike-slip faults may show temporal recurrence distributions resulting from earthquake ruptures that variably arrest or propagate through proposed segment boundaries. We point out that earthquake recurrence along major strike-slip plate boundary faults may vary between more periodic and more episodic end-members, even on adjacent, geometrically-defined segments.

"*I CAN LIVE WITH THIS*" TALKING TO COMMUNITIES ABOUT NATURAL HAZARD RISK: THE BAY OF PLENTY REGIONAL COUNCIL PUBLIC ENGAGEMENT PROCESS

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Talking to people about a risk they might face in the future as a result of decisions they make in the present is notoriously hard; even when the consequences are quite apparent. Talking to entire communities about the risks of natural hazard events can seem almost impossible. Most of us, unless we have direct and recent experience of natural hazard disasters, simply lack the language and tools to imagine all the ways these could affect us.

However, the world we live in is changing, and talking to communities about likely hazard events such as greater and more dramatic storm and flood events, sea level rise, or coastal erosion is something that local government agencies have to do more and more. Moreover, as well as communicating what is known about the science of natural hazards, local governments have to talk about the possible impacts and the risk. One of the most important questions local agencies and communities face is "*what can we live with and what must we do something about*?"

In this presentation we look at the way one local government agency – the Bay of Plenty Regional Council (BOPRC) took on the challenge of talking to their community about planning for future land use that takes account of natural hazard risk. They used an innovative process that helped people understand complex risk concepts; reflect on both the consequences and likelihood of hazard events and then consider the implications for themselves and their community. The process relied on new research into risk based planning by GNS Science, and, in particular, converted a framework of measurements of potential impacts from natural hazards into meaningful scenarios for the Bay of Plenty. This process: engaged the public imagination and produced a robust response that could be evaluated alongside technical input on risk thresholds and integrated into final decisions in the BOPRC Regional Policy statement.

ARCHAEOMAGNETIC DATA AND DATING OF MAORI HANGI SITES IN NEW ZEALAND

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Burnt or fired archaeological artefacts often retain a record of the magnetic field in which they were last heated and cooled. Over the past three years we have collected oriented hangi stones from 13 archaeological sites spread across the North and South Islands of New Zealand. The stones vary in lithology from andesites, originating from the central North Island volcanoes, favoured by Maori for their durability and with remanent magnetization up to 30 A/m, to sandstones and schists from the main axial ranges, with magnetizations as weak as 10^{-4} A/m. Radiocarbon dating of charcoal fragments retrieved from amongst the stones indicates that the sites span from ca. 1400 AD to the present.

We have calculated site mean palaeomagnetic directions (Declinations between 348° and 18.7° and Inclination between -50.9° and -67.7°.) from thermal and alternating field demagnetization data. These are in good agreement with recently published palaeosecular variation records from lake sediments. We have also carried out palaeointensity determinations using a modified Thellier method with consistency checks and selection criteria designed to suit our work. Palaeointensities range from 55μT to 76μT. Rock magnetic experiments contribute to our understanding of the mineralogy, domain state and blocking temperature spectra.

We compare our data with predictions of the global field models ARCH3k and pfm9k, and suggest that the addition of our new data will improve these models for the SW Pacific region for the most recent time period. Archaeomagnetic measurements can be also used to date hangi sites by matching the palaeo-direction and/or intensity to an established archaeomagnetic dating model, NZPSV1k. We will show a series of examples in which archaeomagnetic dating agrees with the radiocarbon dates, resolves ambiguities in the calibration of radiocarbon dates, and shows up inconsistencies due to unreliable source material for radiocarbon dating.

THE CHANGING MICROSTRUCTURAL ARRANGEMENT OF GRAPHITE DURING DEFORMATION AND HYDROTHERMAL ALTERATION OF AMPHIBOLITE-FACIES MYLONITE, ALPINE FAULT, NEW ZEALAND

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Graphitisation in a convergent plate boundary setting, such as the Alpine Fault, New Zealand, is associated both with fault weakening and orogenic gold mineralisation. Previously, these processes have been investigated in rocks that experienced mineralisation at maximum of greenschist-facies conditions (e.g. Hyde-Macraes graphitic shear zone). However, metals are most mobile at upper greenschist- to amphibolite-facies. We examine the microstructural record of mobilisation of graphite at these conditions due to dislocation and diffusion creep in the Alpine Fault zone and as a function of varying shear strain magnitude.

We have mapped graphite distribution across a strain gradient in samples, recovered from Deep Fault Drilling Project (DFDP) boreholes, by using reflected light and scanning electron microscopy. In the schists graphite occurs as very fine (1-5µm), dusty grains, dispersed as inclusions in the main mineral phases (quartz, anorthite, muscovite, biotite). Further into the protomylonite and mylonite zones, the modal proportion of graphite gradually increases, it forms clusters and appears as aligned with the foliation. In the brittlely-deformed rocks (cataclasites and gouges) graphite is most abundant (<50%), locally occurring as patches.

Raman spectrometry revealed the presence of two structurally different types of graphite. Graphite appears as highly crystalline (indicating peak metamorphic temperature ~ 580°C) in all of the examined samples, however in the cataclasites graphite with lower degree of maturity was also identified (corresponding to ~450°C).

We infer shear deformation under both ductile and brittle conditions concentrates the graphite. Independent evidence demonstrates fluid transport and consequent alteration was most important in the brittlely deformed rocks (Sutherland et al., 2012, Geology 40, 1143; Schleicher et al., in press. N.Z. J. Geol. Geophys.). We thus infer hydrothermal enrichment caused graphite remobilization, re-deposition, and enrichment in structurally controlled microstructural sites. We will discuss implications of these microstructural and mineralogical changes for strain localisation and deformation-induced permeability.

DETAILED INVESTIGATION OF THE ACTIVITY AND EVOLUTION OF A BASALTIC PARASITIC CENTRE OF RUAPEHU VOLCANO: OHAKUNE VOLCANO, NEW ZEALAND

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The Ohakune Volcano is a late Pleistocene tuff ring – scoria/spatter cone complex located south of Ruapehu volcano. This small-volume volcano consists of an outer E-W elongated compound tuff ring-like edifice and three inner scoria-spatter cones, located on the Ohakune Fault. Activity began with a shallow phreatomagmatic phase characterized by an almost continuous generation of a low eruptive column that was accompanied by wet pyroclastic density currents, together with the ejection of juvenile fragments and accidental lithics from the surrounding country rocks. Subsequent activity was dominated by a variety of Strombolian eruptions exhibiting differing intensities that were at times disrupted with sudden phreatic blasts or phreatomagmatic explosions due to the interaction with external water and/or quick changes in magma discharge rate. At least three major vent-shifting events occurred during the eruption which is demonstrated by the truncation of the initial tuff ring and the infilling of the truncated area by several coarse grained surge units. The changes of styles eruption can be quantified accurately through systematic sampling and the determination of grain size distribution, componentry, density and vesicularity from key stratigraphic marker beds. Using a Digital Terrain Model coupled with stratigraphic data, we can also determine the volume of each identified unit and individual edifices within the Ohakune Volcanic Complex. Run out distances of pyroclastic density currents were also determined through sedimentological observations at medial and distal locations, which

contributes to an overall understanding of hazards from this type of event. The alternating eruption styles of the Ohakune Volcano and the variety of the emplacement mechanisms of the deposits studies demonstrate the unpredictable nature of small-volume volcanism. This behaviour is likely considered typical for similar future eruptions within the Taupo Volcanic Zone.

LATE OLIGOCENE TO EARLY MIOCENE GLACIMARINE SEDIMENTATION OF THE CENTRAL ROSS SEA AND IMPLICATIONS FOR THE EVOLUTION OF THE WEST ANTARCTIC ICE SHEET

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Today the West Antarctic Ice Sheet (WAIS) is grounded mostly below sea level, making it sensitive to oceanic temperature and circulation changes. However, recent reconstructions of the Cenozoic bedrock topographic evolution of West Antarctica have suggested that the WAIS may have first formed as a terrestrial ice sheet at the Eocene-Oligocene boundary (33Ma), when there was up to 20% more land area in West Antarctica. At some point during the Oligocene or Miocene (23-5Ma) vast areas of West Antarctica became an over-deepened marine-based continental shelf, as is observed today. The evolution of the WAIS through this transition is largely unconstrained, but as atmospheric CO_2 fluctuated between 600 and 200ppm over the past 34Ma, determining the development of a marine-based WAIS is critical in the context of understanding the sensitivity of ice sheet systems to environmental change. Our research re-examines the sediment cores recovered from the central Ross Sea, a principal drainage area of the WAIS, at Deep Sea Drilling Project Site 270. These cores contain a glaciomarine sequence of late Oligocene to early Miocene age. Sedimentological (visual core description, facies, grain size analysis), geochemical (x-ray fluorescence), geophysical (seismic) techniques, and physical properties (magnetic susceptibility) are used to construct a sedimentation model of this sequence, in order to track the evolution of the WAIS through this time period. The late Oligocene warming (25-23Ma) and Mi-1 glaciation (23Ma) are examined in detail because proximal Antarctic geological records of ice sheet extent, proxy environmental data, and atmospheric CO_2 appear to be at odds with the composite $\delta^{18}O$ record of global temperature and ice volume at this time. Moreover, our research provides insights into the sensitivity of marine-based ice sheets, and our preliminary results also indicate that the WAIS may have been responsive to orbital forcing during the late Oligocene to early Miocene.

GROUNDWATER FEATURES AT THE TAVUA GEOTHERMAL ZONE, FIJI

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Self-potential (SP) signals are a significant geophysical parameter that provides useful information regarding sub-surface features at any geothermal field. With an aim to study groundwater features at the Tavua geothermal field, detailed SP surveys were conducted in profiles during December 2014 to February 2015. Standard geophysical procedures were practiced while conducting SP surveys. SP measurements were performed using non-polarisable $Cu|CuSO_4$ electrodes. The measurements were conducted at 247 stations within a gridded area and were repeated to identify any potential anomalies. Joint interpretation of SP data with altitude successfully delineated the Tavua geothermal surface features. A typical negative gradient was observed, which suggests hot water upwelling zone. The present study discusses several aspects of the results acquired from this remote location and provides pathway for further detailed research to be conducted in this area. To our knowledge, there is no recent published literature concerning geophysical studies in geothermal zones in Fiji making this the first of its kind investigation.

HIGH REDUNDANCY MULTIBEAM SEAFLOOR BACKSCATTER OVER THE STRONGLY CONTRASTED RELIEF OF BROTHER VOLCANO

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The backscatter delivered by a multibeam echosounder (MBES) on flat seafloors and unique substrate is characterized by a response decreasing with incidence angles and a conspicuous strong response at nadir (specular). Over flat areas variations due to incidence angles are removed using an angle compensation curve and the resulting reflectivity maps are easily interpreted. Over strong relief, the seafloor incidence angles vary in non-trivial ways so that the resulting reflectivity maps are usually difficult to process, and interpret.

High-redundancy MBES backscatter coverage of was acquired over Brother Volcano (Kermadec Arc) on board RV Tangaroa, in medium-to-deep water. The survey consisted of a set of parallel lines 50-m apart. These data enable one to cast a fresh eye on the angular backscatter response: one potentiality is the generation of local backscatter angular responses associated to various geographical spots; a second one is the generation of reflectivity maps where the whole area is covered according to one narrow incidence angle sector. This is dramatically different from previous approaches where non-overlapping swaths implied that angular responses at high and low angles could correspond to different substrates.

The Brothers Volcano consists of hard volcanic rocks sometimes draped with soft sediments, therefore well suited for this type of comparison. The area is also documented with a wealth of ground-truth data which are used to validate the substrate map generated with this new data set.

We used the *Sonarscope*® Software from IFREMER, for the processing of the backscatter and full water column dataset, and generated backscatter angular responses. The reflectivity maps generated at fixed incidence angles are rid of specular reflection and are better suited for segmentation and generation of predictive substrate maps. Comparisons with backscatter response and reflectivity maps obtained from classical coverage are presented and analysed.

REVEALING KAPITI ISLAND'S SUBMARINE LANDSCAPE – MAKING KAPITI AN INTEGRATIVE PART OF ITS MARINE SURROUNDING AND LOCAL COMMUNITY

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The seafloor surrounding Kapiti Island is of significant cultural and environmental value to New Zealand. The Kapiti Island Marine Reserve was established in May 1992 and is divided into eastern and western sections. The eastern section is 1825 ha and extends across to the mainland adjacent to the Waikanae Estuary Scientific Reserve. This passage between the mainland and Kapiti Island is characterised by a 70 m-deep channel that experiences strong currents, and that has been, until the turn of the twentieth century, a well-known passage for whales. The western seaward component is 342 ha and encompasses a dynamic and rugose sea floor that creates suitable habitat for a diverse and abundant group of fish and iconic invertebrates such as paua and rock lobsters. The reserve provides popular recreational dive locations. The geology surrounding Kapiti Island is dynamic with several active faults running along both sides of the island.

Bathymetric and seabed habitat maps are prerequisites to proper management. Information about the seafloor morphology around Kapiti dates from the late 1990s and has a low level of accuracy.

We used a Kongsberg EM2040 installed on NIWA's 14 metre-long RV *IKATERE* to produce sub-meter accuracy maps of the reserve and surrounding. While bathymetry data reveal the shape and depth of the seafloor, the strength of the return signal (backscatter or imagery) provides valuable information on the bottom types and habitats. In addition, data recorded throughout the full water column (from echo-sounder to seafloor) can be used to characterise habitat type and water masses, identify seeps and plumes, detect fish schools and other features not normally imaged in the bathymetry data.

The outcome will be a greater ability to effectively manage the area and promote awareness of the richness, diversity and complexity of the seafloor of the Kapiti Island region and the biota it supports. The project will evolve to encompass mapping

critical habitats such as the nationally protected rhodolith beds (coralline red algae "balls").

The amount of data collected uses ~222 Gb of disc space, collected over 8 days. The definition of the data is outstanding. We can image blocks on the seafloor that are around 1 m in size and once the data are properly processed, we will increase this resolution to objects less than 50 cm wide in 20 m of water. The project is funded by NIWA, Victoria University of Wellington, the Department of Conservation and Land information New Zealand (LINZ).

CONTINENT SCALE STRIKE-SLIP ON A LOW-ANGLE FAULT BENEATH NEW ZEALAND'S SOUTHERN ALPS: IMPLICATIONS FOR CRUSTAL THICKENING IN OBLIQUE COLLISION ZONES

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New Zealand's Southern Alps lie adjacent to the continent-scale dextral strike-slip Alpine Fault, on the boundary between the Pacific and Australian plates. We show with a simple 2-D model of crustal balancing that the observed crustal root and erosion (expressed as equivalent crustal shortening) is up to twice that predicted by the orthogonal plate convergence since ~11 Ma, and even since ~23 Ma when the Alpine Fault formed. We consider two explanations for this, involving a strong component of motion along the length of the plate-boundary zone. Geophysical data indicate that the Alpine Fault has a listric geometry, flattening at mid-crustal levels, and has accommodated sideways underthrusting of Australian plate crust beneath Pacific plate crust. The geometry of the crustal root, together with plate reconstructions, require the underthrust crust to be the hyper-extended part of an asymmetric rift system which formed over 500 km farther south during the Eocene – the narrow remnant part today forms the western margin of the Campbell Plateau. At ~10 Ma, the hyper-extended margin underwent shallow subduction in the Puysegur subduction zone, and then was dragged over 300 km along the length of the Southern Alps beneath a low angle (<20°) section of the Alpine Fault. We speculate that prior to 10 Ma, more distributed lower crustal shortening and thickening occurred beneath the Southern Alps, accommodating southward extrusion of continental crust in the northern part of the plate boundary zone, providing a mechanism for clockwise rotation of the Hikurangi margin.

SURFACE TRACES AND STRAIN PARTITIONING OF THE ALPINE FAULT NEAR THE DFDP-2 SITE, WHATAROA

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LiDAR and geomorphic mapping combined with paleoseismic trenching and seismic interpretation have located several active traces of the Alpine Fault in an area of strain partitioning on the true left side of the Whataroa River. A NE-trending, 1.2 m high scarp, which is the remnant of a frontal surface trace, was trenched on the recently abandoned river terrace (designated tw4) above the river. The trench exposes a record of a single reverse-slip fault movement with little to no strike-slip movement. The faulting event occurred post-AD 1677 and is believed to be the AD 1717 Alpine Fault earthquake event. These observations place the frontal trace of the Alpine Fault c. 1300 metres NW of the DFDP-2 hole at this location, dipping moderately to the SE (45-60°) in the trench.

Within the rangefront, the wider fault zone comprises 2-3 ENE-striking fault traces. These faults deflect streams (e.g. Mint and Arthur creeks) and offset topography by tens to hundreds of metres. Two trenches and their stratigraphy are combined with radiocarbon and OSL dates from terrace deposits to elucidate the age of surfaces and processes within the rangefront. Reconstruction of offset streams and spurs in conjunction with post-glacial and early Holocene ages indicate dextral slip rates in excess of 20 mm/yr across this rangefront zone. Together, the rangefront and frontal faults indicate shallow partitioning of dip-slip and strike-slip motion on the Alpine Fault near Mint Creek, transitioning from strike-slip to NE-striking oblique-slip motion north of the Whataroa River.

RETRACING HECTOR'S FIRST OTAGO FIELDTRIPS (APRIL - JULY 1862): DUNEDIN, TUAPEKA, MATAURA, POMAHAKA, MANUHERIKIA, OAMARU

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James Hector arrived in Port Chalmers on 15 April 1862 to take up employment as the first Otago Provincial Geologist. Within 4 days, he was examining outcrops around Dunedin and making geological observations. On 30 April, he set off on a 3 week long fieldtrip, visiting Kaitangata, Tuapeka, Mataura Falls, Landslip Hill, Oyster Creek, Pomahaka and Moa Flat. After a week back in his newly established Geological Survey Office, Hector was again in the field (30 May), travelling via Shag Point to Manuherikia, in Central Otago. On 10 July (mid winter) he travelled north to Oamaru and the Waitaki Valley, making field notes on Shag Point, the Moeraki Boulders, and Oamaru limestones and pillow lavas. In his first 100 days in Otago, he spent more than 50 days in the field, covering about 1000 km on horseback and on foot. His copious observations were recorded in field notebooks with numerous annotated field sketches: however, most of these have never been transcribed, as the illegibility of Hector's handwriting was noteworthy even at the time of writing.

Hector recorded observations on building stones, coal, gold, schist, volcanics, and fossiliferous sediments of Jurassic to Quaternary age, documenting (and presumably collecting) fossils. Unfortunately, few of his promised detailed reports on the geology of Otago were published, and many of his field observations are confined to the notebooks. Many sites visited by Hector in 1862 such as Pomakaha, Landslip Hill, Lake Manuherikia and Oamaru Volcano are the subject of current geological research. We have attempted to decipher and transcribe Hector's field notebooks, revisiting some of the same outcrops, and recollecting fossil sites. Where exactly did he go, and why did he go there? What geological observations did he make? And, how do his observations stand up after 150 more years of geological research in Otago?

WELLINGTON FAULT EXPOSURE AT MANOR PARK, HUTT RIVER: CONSTRAINTS ON FAULT LOCATION AND RUPTURE TIMING

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Natural exposures of the southern portion of the Wellington Fault are rare, and those containing datable material (e.g. wood) are even rarer. The Hutt River has steadily eroded its western bank at Manor Park, exposing an outcrop of the Wellington Fault. The fault is characterised by an ~1.5 m wide zone of rotated gravel clasts that separates highly deformed greywacke from young alluvial gravels and sands. It can be traced to ~4 m above current river level, where it is unconformably overlain by an ~3 m thick layer of alluvial gravel. The outcrop is capped by ~4 m of anthropogenic fill.

Six samples (wood, including logs) from faulted deposits were radiocarbon dated and have ages ranging between ~2500 & 5700 cal BP. This confirms that the Wellington Fault at Manor Park has ruptured within the last ~2500 years, consistent with previous work suggesting that this portion of the Wellington Fault has ruptured several times within the last ~2500 years (and most recently within the last ~310 cal BP).

Four samples from unfaulted deposits were dated; two have ages ranging between ~2100 & 2700 cal BP, and the next youngest sample has an age of ~480 cal BP. These three samples are all older than the timing of the most recent rupture of the fault, and are probably reworked from older deposits (and/or have inherited age). The stratigraphically highest sample has an age of 0-270 cal BP.

Because of the reworking of old wood into younger alluvial deposits along this portion of the Hutt River at Manor Park, the above radiocarbon ages provide little additional constraint on the previously established rupture history of the Wellington Fault. However, the Manor Park exposure does provide important age control on the sediments that comprise the floor of the Hutt Valley.

HAMMER AND THUMPER SOURCES: A COMPARISON OF PENETRATION DEPTH

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The glacio-fluvial sediments of the Whataroa Valley contain a geological record the change in climate and tectonics of the valley following the retreat of Pleistocene glaciers. This record is greatly affected by the 23 $mmyr^{-1}$ horizontally and 10 $mmyr^{-1}$ vertically that has occurred on the Alpine Fault over the same period.

A new survey conducted in July 2015 in the Whataroa Valley, builds upon a 2013 survey, and used Otago University's new thumper source to supplement data from the original survey. The supplementary line, Line 07, is shot in the same location as the 2013 Line 05. Line 07 is a 600 m long profile, 120 m longer than line 05 in the direction of the coast. These high-resolution data sets will be used for three purposes: (1) comparing the hammer and thumper seismic sources, (2) locating the near surface trace of the Alpine Fault, and (3) characterising the presumably glacial sediments deposited on the coastal plain. Both lines made use of sources consisting of five 'hits' at each shot point (shot interval = 10 m) that were then stacked together to reduce random noise and enhance reflections/refractions. Individual and stacked shots are compared as well as processed stacks of each line.

Results of shot and stack comparisons show that one thumper strike is similar to five hammer strikes. However, the thumper still has greater penetration depth. This is likely due to both the lower frequency signal of the thumper source and its strength of the source. Greater penetration depth along line 07 will improve resolution of the upper 700 m of glacial sediment, enabling a more accurate interpretation of the glacial and tectonic history of the Whataroa Valley.

BROADENING THE CATALOG OF ROCKS AVAILABLE FOR ABSOLUTE PALEOINTENSITY STUDIES: A COMPARISON OF NON-HEATING TECHNIQUES

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Data of the strength of Earth's magnetic field in the geological past (paleointensity) are crucial for analysing the geodynamo and the formation of the earth's inner core. Better understanding in these areas can best be achieved through the study of the broadest possible range of rock types, age ranges, and locations. Conventional methods for determining absolute paleointensity (e.g. the Thellier-Thellier method) are based on comparing the decay of a sample's original thermal remanent magnetism with the growth of an artificial thermal remanent magnetism. As a result, these methods require heating a sample to a high temperature in one or more steps. Consequently, many rocks are unsuitable for these methods due to heating-induced experimental alteration.

Alternative methods have been developed to estimate paleointensity using non-thermal remanences. In doing so, the aim of these methods is to produce an absolute paleointensity determination without any heating steps, thereby avoiding any potential thermal alteration. Six of these non-heating methods (pseudo-Thellier, ARM, REM, REMc, REM', and FORC methods) were tested using synthetic magnetite-bearing samples of differing magnetic domain states. The same methods were also tested using natural samples from Lemptégy Volcano, France, a 32,000 year-old cinder cone.

Two methods, the pseudo-Thellier and ARM methods, produced the most accurate results for synthetic samples, while only the pseudo-Thellier method was able to produce a reasonable paleointensity estimate consistent with existing paleointensity data for the natural samples. Based on our results, the pseudo-Thellier method appears to be the best alternative to heating-based absolute paleointensity methods.

ANTARCTIC ICE SHEET SENSITIVITY TO ATMOSPHERIC CO_2 VARIATIONS DURING THE EARLY TO MID-MIOCENE

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The Early to mid-Miocene (23 to 14 million years ago) is a compelling interval to study Antarctic ice sheet sensitivity to changes in atmospheric CO_2 as oceanic and atmospheric circulation patterns in the southern hemisphere were broadly similar to present and reconstructed atmospheric CO_2 concentrations were analogous to those projected for the next several decades. This time interval includes the Miocene Climatic Optimum (MCO), a period of global warmth during which average surface temperatures were 3 to 4°C higher than today. Miocene sediments in the AND-2A drill core from the Western Ross Sea, Antarctica provide direct information regarding ice sheet variability through this key time interval and offer insight into the potential Antarctic contribution to future sea level rise. A multi-proxy dataset derived from AND-2A identifies four distinct environmental "motifs" based on changes in sedimentary facies, fossil assemblages, geochemistry, and paleotemperature. Four major disconformities in the drill core coincide with regional seismic discontinuities and reflect transient expansion of marine-based ice across the Ross Sea. They all correlate with major positive shifts in benthic oxygen isotope records and episodes of sea-level fall, and generally coincide with intervals when atmospheric CO_2 concentrations were below current levels (~400 ppm). Five intervals reflect ice sheet minima and air temperatures warm enough for significant ice mass loss during episodes of high (>400 ppm) atmospheric CO_2. These results suggest that polar climate and the Antarctic Ice Sheet (AIS) were highly sensitive to relatively small changes in CO_2 during the early to mid-Miocene, which is supported by numerical modelling studies.

A FUSCOSPORA MAST SIGNAL FROM THE LAKE OHAU POLLEN RECORD AND ITS POTENTIAL FOR GENERATING LONG HISTORY RECORDS

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New Zealand beech (Fuscospora spp.) is one of a number of plants in New Zealand that exhibit a masting habit. The timing of mast years appears to be environmentally controlled, with mast-seeding plants often producing high seed crops the year after a warm spring or summer. In New Zealand, mast frequency in coming decades is of considerable interest to the conservation biology community, as there is a strong relationship between seedfall and introduced predator populations. Here we present a pollen record from 1973 to 2014, recovered from varved sediments from Lake Ohau New Zealand, to demonstrate the potential for generating a long (centuries – millennia) record of Fuscospora spp. masting. Longer historical records of this phenomenon would significantly improve our understanding of the environmental controls of masting and prediction of future mast frequency and intensity, and could also be used as a proxy for past climate reconstruction.

FAULT DAMAGE ZONES OF THE M7.1 DARFIELD AND M6.3 CHRISTCHURCH EARTHQUAKES CHARACTERISED BY FAULT-ZONE TRAPPED WAVES

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To characterize the subsurface structure of the damage zones caused by the 2010-2011 Canterbury earthquake sequence in New Zealand's South Island, we installed two linear seismic arrays, Array 1 across Greendale Fault (GF) surface rupture and Array 2 over the surface projection of the blind

Port Hills Fault (PHF) that ruptured in the 2010 M7.1 Darfield and 2011 M6.3 earthquakes, respectively. We recorded 853 aftershocks for ~4 months after the Christchurch earthquake. Fault-zone trapped waves (FZTWs) were identified at Array 1 for aftershocks occurring on both the GF and the PHF. The post-S duration of these FZTWs increases as focal depths and epicentral distances from the array increase, showing an effective low-velocity waveguide formed by severely damaged rocks existing along the GF and PHF at seismogenic depths. Locations of aftershocks generating prominent FZTWs delineates the subsurface GF rupture extending eastward as bifurcating blind fault segments an additional ~5-8 km beyond the mapped ~30-km surface rupture into a zone with comparably lower seismic moment release west of the PHF rupture which extends westward along Christchurch aftershock lineament to within 5.3 ± 1 km of the subsurface GF. The propagation of FZTW through the intervening 'gap' indicates moderate GF-PHF structural connectivity. We interpret this zone as a fracture mesh reflecting the interplay between basement faults and stress-aligned microcracks that enable the propagation of PHF-sourced FZTWs into the GF damage zone. Preliminary simulations of observed FZTWs suggest that the GF rupture zone is ~200-250-m wide, consistent with surface deformation observations, with velocities reduced by 35-55% and the maximum reduction in the ~100-m-wide damage core zone corresponding to surface and shallow subsurface evidence for discrete fracturing. Our study also illuminates a potential approach to investigate the blind segment of a rupture zone using FZTWs recorded at the seismic array deployed across its surface section.

PREPARING FOR THE NEXT LOCAL VOLCANIC ERUPTION IN AUCKLAND, NEW ZEALAND

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The Determining Volcanic Risk in Auckland (DEVORA) research programme is a multi-agency, multi-disciplinary effort with a mandate to investigate the Auckland Volcanic Field (AVF), a (mostly) monogenetic volcanic field which spatially coincides with Auckland, New Zealand's most populous city. DEVORA has three main themes: the geological context of the AVF, its volcanic hazards, and the risk these pose to Auckland. Here we discuss how volcanic hazard and risk research, specific to Auckland and also more generically, is used to evaluate volcanic risk for Auckland, and how DEVORA findings are used by civil defence and emergency managers to prepare the city for a future volcanic eruption. Following a detailed hazard evaluation, a series of hazard intensity maps have been developed for the volcanic edifice (tuff rings and scoria cones), pyroclastic surges, lava flows, tephra fall, and ballistics. The DEVORA team has also developed and populated a suite of volcanic fragility functions quantifying damage, loss of functionality, and clean up from basaltic eruptions expected in Auckland. These hazard intensity maps and fragility functions, along with asset databases from supporting lifeline organisations and Auckland Council, have been added to RiskScape, New Zealand's multi-hazard risk assessment tool. The next step is to evaluate impacts from specific eruption scenarios, one detailed example of which will be presented by Blake et al. (this conference). This multi-volcanic-hazard impact calculation represents a culmination of the first 7 years of DEVORA; probabilistic risk assessment will be developed in the future. DEVORA research findings are being used to inform the revised AVF Contingency Plan. In the next few years, DEVORA will continue to ensure fundamental science forms the basis for key decision-making in the preparation for and response to a future AVF eruption.

GEONET: DATA FOR THE RESEARCH COMMUNITY

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In the last few years GeoNet has been upgrading instrument networks and added retrieval methods for automatically collected data as well as our less commonly used manually-collected volcano data. We're also continuing to develop new features for our mobile app 'GeoNet Quake' including instrument shaking in real-time.

GeoNet technicians have been focussed on the backlog of network upgrades brought on by numerous large earthquakes diverting funding from scheduled maintenance. Only a handful of new stations have been built recently, mostly in the top half of the South Island. In the last few years, network development has shifted focus to upgrading existing stock. Sensors at the approximately 200 strong-motion stations around the country have had their instruments upgraded, enabling all stations to transmit data continuously.

We've introduced modifications to the design of the new instrument boxes from lessons we've learned from the Canterbury earthquake deployment. We now use a hermetically sealed box for all strong-motion instruments in case of liquefaction or flooding, and install the boxes away from walls to minimise building shaking impacting on sensors.

Accessing GeoNet data has also evolved to include the easy to navigate Quakesearch or URL-based web feature service (WFS) to get any of our 500,000+ earthquake information. Following the specifications defined by the International Federation of Digital Seismograph Networks (FDSN) we have added a new way to download seismic waveform (miniseed) and station metadata that is in-line with these international standards.

Lastly, we have introduced field time series (FITS) – a database and interface accessing our GPS daily solutions and lots of small data sets (e.g. White Island and Ruapehu gas flux and soil gas temperature). We have been collecting some of these data sets for decades.

RELATIONSHIP OF QUARTZ LPO FABRICS IN MYLONITES NEAR THE ALPINE FAULT, NEW ZEALAND TO THE ATTITUDE OF THE SHEAR ZONE BOUNDARY

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The Alpine Fault exhumes its own ductile shear zone and has known kinematics. Within ~1 km of the fault, the mylonitic foliation is subparallel to the boundary of the amphibolite-facies ductile shear zone in which it formed. Using EBSD, we analysed quartz Lattice Preferred Orientations (LPOs) of mylonites along the central Alpine Fault, sampling rocks that accommodated a range of finite strains with diverse quartz contents. All LPOs feature a single or strongest girdle of [c]-axis girdle forward-inclined ~28 ±4° from the pole to the SZB plane. A maximum of <a> axes is inclined at the same angle to the SZB. The girdle is perpendicular to C' extensional shear bands in the rock, whereas the <a> maximum is parallel to the slip direction of the bands. Our observations suggest that quartz [c]-axis girdles do not necessarily form perpendicular to the SZB, and are unreliable indicators of SZB attitude. We interpret the alignment of the quartz LPOs to the C' bands as resulting from these forming in a general shear zone stretching parallel to the shear direction. LPOs and C' planes may have aligned themselves with planes of maximum shear-strain-rate at 45° to the contractional instantaneous stretching axis (ISA). If so, then our data can be explained by a kinematic vorticity number (W_k) of ~0.7 in the Alpine mylonite zone. Another model is that the shear bands formed at ~30° to the contractional ISA, subparallel to the inclined eigenvector of the flow, where they would be rotated slowly and could have accrued large slips. This latter scenario implies a W_k of ~0.85. It is supported by Schmid Factors for our LPOs being highest for loading at 30°, and by inversions of seismic focal mechanism data in the central Southern Alps that yield an orientation of σ^1 inclined ~30° to the C' bands.

ASSEMBLY OF ZEALANDIA'S MANTLE LITHOSPHERE: IN WITH THE NEW AND IN WITH THE OLD

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The Phanerozoic (< 300 Ma) continental crust of West Otago, New Zealand, is intruded by Cenozoic diatremes that have erupted harzburgite and dunite mantle xenoliths. These peridotites have rhenium depletion Os model ages that vary from 0.5 to 2.7 Ga, firmly establishing the record of an Archean depletion event. This is the largest crust-mantle decoupling known on Earth. However, the vast range in depletion ages does not correlate with melt depletion or metasomatic tracer indices and therefore provides little support for the presence of a significant volume of ancient mantle root beneath this region. Instead, the chemical and isotopic data are best explained by mixing of relict components of Archean depleted peridotitic mantle residues that have cycled through the asthenosphere over Ga timescales, along with more fertile convecting mantle. Extensive melt depletion associated with the docking of these melt residues beneath the young crust of Zealandia, and overprinting by metasomatism, explains the decoupled age relationship that we observe today. Hence, the newly formed lithospheric root incorporates a mixture of ancient and modern mantle derived from the convecting mantle, metasomatised and cooled and accreted in recent times. We argue that, in this case, the ancient components played no earlier role in continent stabilization but their highly depleted nature (along with that of their younger counterparts) now represents a highly viscous and stable continental keel. This model could account for the large spectrum of ages observed in fertile to moderately depleted peridotites sampled from lithospheric mantle beneath Southeast Australia, West Antarctica and other locations in Zealandia, as well as the oceanic mantle.

A TEPHROSTRATIGRAPHIC FRAMEWORK FOR DETERMINING THE HISTORY OF PALEOHYDROTHERMAL ACTIVITY AND FAULTING OF NGAKURU SINTERS

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Locations of geothermal fields in central Taupo Volcanic Zone (TVZ) follow a northeast-trending alignment, similar to that of the volcanic centres and orientation of major faults in the region. The Ngakuru Graben in central TVZ is now largely thermally inactive, but evidence of several fossil geothermal systems has been mapped throughout the area parallel to the Whirinaki Fault (WF). Geothermal systems and fields often lack materials suitable for dating, but marker beds such as tephras can be used to infer the developmental history of geothermal features if well-preserved. By using characterised and correlated tephras of known ages, the movement of faults may be dated based on cross-cutting relationships. Determining a more detailed history of hydrothermal activity and faulting in the Ngakuru Graben may therefore be possible via tephrochronology.

Fieldwork was undertaken at Hossack Road, Ngakuru. A paleoseismic trench was excavated across a strand of WF, exposing a succession of Holocene tephras and paleosols overlying siliceous sinter. The stratigraphy is disrupted by three main fault planes. On the downthrown side of the fault, thick Taupo deposits infill a paleovalley, and older units are obscured. Cores were extracted below the trench floor to assess displacement of units older than Taupo Formation identified on the upthrow.

Ferromagnesian mineral assemblages and electron microprobe analyses of volcanic glass indicate most tephras observed in the trench originated from Okataina Volcanic Centre. One of the fault planes displaces Taupo Formation, suggesting movement occurred along the fault strand within the last ~1800 years. Prior fault displacements are currently being analysed.

The study will provide new information on the geological history of the Ngakuru Graben with regard to the extent and age-range of paleohydrothermal activity and its relationship with fault-rupture events along WF. Information about

paleoseismic activity at the site will be incorporated into the National Seismic Hazard Model.

THE SMOKING GUN: TEPHRA SEISMITES IN LAKE SEDIMENTS RECORD AT LEAST THREE SEISMIC EVENTS IMPACTING THE HAMILTON BASIN SINCE ~15,600 YEARS AGO

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At least four hidden faults occur in the Hamilton Basin, three within Hamilton (see de Lange et al. "Hidden faults in the Hamilton Basin"). Injection structures (dykes) associated with seismic liquefaction within Late-Pleistocene volcanogenic alluvium (Hinuera Formation) have been identified at two locations within the Hamilton Basin (one at Endeavour School, north Hamilton; one near Cambridge), and ^{14}C-dates on the dykes indicate they were caused by 1 or 2 seismic events after ~21,000 cal BP, associated possibly with the Kerepehi Fault in Hauraki Basin or with the newly-identified faults in Hamilton Basin (or both). Analysis of 84 cores extracted from 12 shallow lakes formed ~20,000 cal BP in the Hamilton Basin has revealed that three tephra layers ~2-5 cm in thickness and comprising mainly fine-medium sand (ash) preserved in organic-rich lake sediment (gyttja) have been liquefied in some (but not all) lakes by seismicity, forming 'tephra seismites'. The seismites show (i) ash-filled cracks beneath the tephra (with sharp terminations); (ii) funnels and voids, some infilled with lake sediment, within the tephra; (iii) disrupted bedding or dislocated layers; and (iv) wavy to convolute contacts at tephra boundaries. Tephra layers, denser than the organic gyttja, do not become buoyant as occurs in terrestrial settings upon liquefaction but instead are injected downwards forming distinct cracks as pore-water pressure is dissipated. The tephra seismites include Rotorua (~15,600 cal BP), Waiohau (~14,000 cal BP), and Mamaku (~8000 cal BP). Of these, Rotorua tephra is liquefied in three lakes only, all north of Hamilton but relatively close to Endeavour School and newly-identified faults Kukutaruhe and Horotiu, and hence likely reflects local movement; Waiohau and Mamaku tephras are liquefied in 6 to 8 more-widely distributed lakes and hence could reflect movement on Kerepehi Fault (known to have moved ~7700 $\pm$ 500 cal BP) and/or the Hamilton faults.

ACTIVE SEAFLOOR PROCESSES OF THE REINGA-NORTHLAND BASIN, NEW ZEALAND

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The composite Reinga-Northland Basin is thought to be an important depocentre for contemporary terrestrial sediment accumulation, however little is known in regards to the seafloor processes, sediment distribution or pathways within the area. Over recent decades, the Reinga-Northland Basin has been widely acknowledged as a frontier basin with hydrocarbon potential based on seismic surveys and geological correlations drawn from the nearby Taranaki Basin. The aim of this presentation is to demonstrate how newly acquired high-resolution (25 m) multibeam echosounder data (bathymetry and backscatter) and 3.5 kHz sub bottom profiler data are utilised to perform a detailed morphometric analysis of a sediment wave field within the Reinga-Northland Basin to determine if their origin is linked to: 1) bottom currents, 2) turbidity current overbank flow processes, or 3) marine soil creep processes. A manual method of feature extraction was utilised to systematically obtain cross sectional profiles from a digital elevation model across the sediment waves, while a MATLAB code allowed for the quantification of key parameters, including: 1) wavelength, 2) wave height, 3) asymmetry, and 4) slope. This then provides high resolution geomorphometric data for analysis and comparison to existing literature on sediment wave dimensions. In addition to surficial data, sub bottom profile data, which penetrates up to 5 metres into the substrate allows sediment wave migration to be quantitatively characterised in the shallow subsurface with the existing sedimentation rate of the area then used to determine a sediment wave migration rate. Seismic data from the REI09 survey shows a lack of deeper turbidite channel architecture, indicating that the area has been primarily influenced by bottom currents in the past and/or present. Combining the various data sources together allows an interpretation on the formation mechanism of the sediment wave field and influences on the modern sedimentary processes within the Reinga-Northland Basin.

AN INTEGRATED STRATIGRAPHY OF TAURANGA HARBOUR

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Tauranga Harbour is one of the largest estuaries in New Zealand, formed during the most recent post-glacial marine transgression. It is part of Tauranga Basin, a tensional graben, which is infilled with significant thicknesses of volcaniclastic sediments. The basin is in a tectonically active coastal marine setting, which typically have rapid delivery of sediments and incised channels.

As part of a project studying the sedimentary history of the harbour, we have logged 86 vibracores and obtained XRF, grainsize, magnetic susceptibility and optical petrography data from samples of these cores. These data have been used to develop a facies model, comprising five major units (three major sand units and two major silt units), and several more sub-units. Using this and pre-existing seismic data, we present a three-dimensional facies model of the harbour. We use these data to investigate changing sediment provenance and hydrodynamic conditions within the harbour.

MORPHOSTRUCTURAL AND PALEO-SEISMIC ANALYSIS OF FAULT INTERACTIONS IN THE OXFORD–CUST–ASHLEY FAULT SYSTEM, CANTERBURY

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LiDAR analysis identified surface expression of several previously unrecognised active fault traces across the low-relief aggradation surfaces of the Northwest Canterbury Plains consistent with predictions of a fault relay exploiting the structural mesh across the region. This is characterised by interactions of northeast-striking contractional faults with a series of re-activating, inherited Late Cretaceous normal faults; the latter now function as E–W-striking dextral transpressive faults. LiDAR allowed detailed surface expression analysis of individual faults and folds across the Cust Anticline and associated contractional restraining bend which is an evolving “pop-up” structure within the newly established dextral shear system exploiting the inherited, now re-activated, basement fault zone. Paleo-seismic trenches confirmed the location and structural style of north-northeast-striking faults and an E–W-striking fault associated with the development of this structural culmination. Review of available industry seismic reflection lines revealed structural styles characteristically associated with inversion tectonics, with each structural culmination having the same underlying deformation driver but varying degrees of development and surface expression. Therefore, based on LiDAR surface mapping and preliminary re-analysis of industry seismic reflection data, four fault zones are identified across the relay of restraining bend structural culminations, which together form the proposed Oxford–Cust–Ashley Fault System.

The 2010–2012 Canterbury Earthquake Sequence showed many similarities to the structural pattern established across the Oxford–Cust–Ashley Fault System, emphasising the importance of identification and characterization of presently hidden (and partially hidden) fault sources, and the understanding of fault network linkages, to improve constraints on earthquake source potential and stress triggering. These potentially-interactive fault sources in Northwest Canterbury, with potential for combined initial fault rupture and spatial and temporal rupture propagation across this fault system, can be included in regional probabilistic seismic hazard analysis, which is essential for suitable land-use zoning and sustainable future social and economic development.

VAPOR TRANSPORT OF TRACE METALS IN THE MAGMATIC-HYDROTHERMAL SYSTEM OF WHITE ISLAND: PRELIMINARY RESULTS

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A better knowledge of volatile transport in volcanic systems will help us understand the processes of formation of ore deposits, as well as constraining the emission of heavy metals by volcanoes. Volatile trace metals present in andesitic magmas may have different pathways to the surface, depending on their solubility and their compatibility with the different phases found along their way. After their exsolution from the cooling and crystallizing

magma, trace metals rise towards the surface forming compounds with major species, reacting with other fluids and the surrounding environment. White Island is a subduction-related magmatic-hydrothermal system located off the North Island of New Zealand. Easily accessible and quite active in the recent years, it stands as the perfect laboratory for this study.

The compositions of the magmatic reservoir and the different discharges allow us to constrain the vapor transport of trace metals. Aerosols in the volcanic plume were collected from the crater rim using the filter pack technique. Water, sediments and suspended particles from the crater lake were sampled in the view of having an integrated picture of trace metals in the system. Collection of fumarolic gas condensates and sublimates was performed from the most active and hottest accessible fumarole. We will show how the trace metal compositions of different features highlight preferential partitioning of elements into different phases. Analysis of the aerosol fraction shows efficient transport of Tl, Bi, Pb, Cr by the volcanic plume. The first emission rates estimates for As and Sb are 43-111 kg/day and 1.2-4.5 kg/day, respectively. Despite their lower concentrations, fumarolic gases show enrichment in As, Sb, Zn, Ti, Sn and Ga. Future work includes studying the trace metal content of melt inclusions from the 1977-2000 eruptive sequence, monitoring the trace metal composition of discharges over time, and thermodynamic modelling.

GEOLOGICAL MAPPING OF OTAGO RESOURCE AREAS AT 1:50 000 SCALE, STARTING WITH THE MIDDLEMARCH REGION

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Airborne geophysics can transform geological understanding in areas of high deformation, remote location and dense vegetation. GNS Science will publish geological maps of resource areas using regional, airborne geophysics from Northland, Westland and Otago. Using the 2007 helicopter-borne Glass Earth geophysical survey in Otago, GNS Science will publish detailed (1:50 000 scale) and up-to-date geological maps and text, starting with the Middlemarch region. This area is coincident with the LINZ Topo50 map series for Middlemarch (map CD16), contains historic gold mining sites, is being actively explored for gold and is adjacent to the mineralised Hyde-Macraes shear zone. The maps and text will be delivered digitally, using the free GNS Web Maps portal (http://maps.gns.cri.nz/geology/wms), and will be useful to explorationists, researchers and the general public.

Novel aspects to the Otago digital map products, differentiating them from the QMAP 1:250 000 geological maps for example, include a resource focus, finer scale, processed geophysical datasets (magnetic, electromagnetic, gravity), geophysical interpretation and modelling, updated resource locations and a detailed review of mineral, aggregate and groundwater resources. More traditional datasets such as structural measurements, cultural features, digital elevation models and lithology are also included. This will all result in updated geological interpretations (e.g. a surface geology map, cross section). Highlights of the new Middlemarch map include a schist tor map (250 000 outcrops), the identification of kilometre-scale greenschist units from outcrop and geophysical modelling, a summary of historical production figures, geology, mineralisation and modern exploration history at Barewood and Nenthorn gold deposits, new magnetic susceptibility and whole-rock chemistry measurements, updated structural interpretations, new fieldwork, sub-division of the Dunedin Volcanic Group and classification using the new high level stratigraphic names nomenclature for New Zealand. The Rise and Shine shear zone / Bendigo area, the Hyde-Macraes shear zone and the Serpentine Diggings will be future mapping priorities.

SYSTEMATIC GEOCHEMICAL AND ISOTOPIC BASELINE MAPPING OF SOUTHERN NEW ZEALAND SOILS

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Worldwide, geochemical baseline surveys have measured element concentrations in surficial materials, particularly soils. Natural factors controlling soil geochemistry include soil parent material, organisms, topography and climate. Human activities alter soil geochemistry through industrial, agricultural, mining and forestry practices. The natural and anthropogenic components of soil geochemistry are a new means of geochemical exploration and act as environmental tracers. When contamination levels are high, health impacts can also occur, either indirectly through the food chain or directly through accidental ingestion or inhalation. GNS Science and partners have undertaken a systematic geochemical baseline survey of Southland and southern Otago soils. Samples from 8 km-spaced grid locations were collected by hand-auger from an "A-depth" (0-30 cm) and a "B-depth" (50-70 cm). The entire sample set has been analysed by ICP-MS for 65 elements, by XRF for 12 elements and oxides, by hand-held XRF and for magnetic susceptibility. Quality was monitored using standards, duplicates, randomisation, replicates and blanks, and was generally better than limits defined for comparable surveys overseas. The analyses have been collated into element variation maps.

The results show that concentrations of many elements coincide with the underlying basement geology, however, exceptions occur. Remobilisation of chromite grains sourced from the Dun Mountain ultramafics is observed along alluvial outwash plains of the Oreti River. A strong association between intensively farmed exotic pasture and high phosphorous, sulphur and manganese concentration highlight prolonged fertilizer application and high lead concentrations around urban centres represent a legacy of vehicle and industry emissions. The soil B-depth samples appear to record dispersal of elements from mineralised schist rocks of central Otago. These data can be accessed as an atlas and online (http://pet.gns.cri.nz) and will inform public health and forensic studies, agriculture research and mineral exploration. This is the first step towards a national geochemical baseline programme.

CONSTRAINTS ON FRACTURE MODELS IN GEOTHERMAL RESERVOIRS FROM TERRESTRIAL LASER SCANNING OF LAVA FLOWS: A CASE STUDY FROM MT RUAPEHU

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Geothermal reservoirs hosted in volcanic rocks typically contain fracture networks that control fluid flow. The spatial distribution and geometries of those fracture networks are often poorly understood due to limited data and complex deformation histories. To better understand the distribution of fractures formed during lava emplacement, we study andesitic flow exposures from Mt Ruapehu, Taupo Volcanic Zone. Terrestrial laser scanner (TLS) data acquired on three 50–200 m^2 outcrops provide large 3D point clouds which represent the shape of the outcrop. Thousands of fractures are delineated semi-automatically using local geometrical constraints, including a shape detection algorithm that detects planar and curved surfaces, and validated using high-resolution panoramic photographs and manual scanline measurements. Fracture orientation, length, area, and linear (P10) and areal (P20) densities from the TLS data are the key parameters required to constrain fracture network models. Steeply dipping cooling joints are highly connected to each other and to sub-horizontal joints coincident with vesicular layers. Most of the cooling joints terminate within or at the brecciated margins of individual flows which contrast mechanically with

the massive flow interior. Highly connected and curved fractures are thus mostly confined to lava flows. Unconfined compressive strength (UCS) tests reveal a mechanical anisotropy which is reflected in the dominant fracture orientation.

The results of this study provide a framework for developing numerical models of fracture networks for geothermal reservoirs based on empirical observations of intrinsic fracturing and the host rocks' mechanical anisotropies. Fractures in individual lava flows may be interconnected in the reservoirs via a combination of cooling joints, tectonic fault zones and hydrothermal fractures. The use of terrestrial laser scanner data, augmented by high-resolution panoramic photographs and manual measurements, provide detailed information on fracture geometries and connectivity. UCS tests yield a mechanistic explanation of the development of the fracture networks.

STRUCTURAL ANALYSIS OF ACOUSTIC IMAGE LOGS FROM THE DFDP-2B BOREHOLE, CENTRAL ALPINE FAULT

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The DFDP-2B borehole was drilled in 2014 in the hangingwall of the Alpine fault, near the township of Whataroa in South Westland. A total of 19 km of wireline logging data including >4.5 km of acoustic borehole televiewer (BHTV) imagery data were acquired during repeated runs in the open-hole section of the borehole (264–893 m measured depth), providing an exceptional opportunity to describe the schist protolith and mylonitic fault rocks in the hangingwall of this active fault. The high resolution of the BHTV logs and the varying DFDP-2B borehole's inclination (2°-46° from vertical), provide good conditions to make a detailed structural interpretation of the BHTV logs acquired in the 264–888 m depth interval.

Foliation, appearing as a series of thin sub-parallel and sub-planar features, can be regularly identified to a depth of 808 m (n=406). The mean orientation of foliation planes (dip of 57° towards 145°) is quite consistent throughout the logged interval and may reflect the orientation of the underlying Alpine Fault. Sub-planar, discordant features with low acoustic amplitude are classified as "discontinuities". The majority of these 1650 discontinuities are sub-parallel to the foliation and may represent deformed veins or other mineral segregations that contribute to the foliation's internal structure, or fractures. A subordinate group of discontinuities has a NW-SE strike, approximately orthogonal to the foliation, and are most likely fractures. Truncations or offsets are observed on approximatively 20 discontinuities, suggesting either faulting or a relative chronology between the features concerned. No stress-induced feature were confidently identified.

CHEMICAL AND ISOTOPE COMPOSITIONS OF DRILLING MUD GAS OF THE DEEP FAULT DRILLING PROJECT (DFDP) 2B BOREHOLE, WHATAROA, NEW ZEALAND

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The Deep Fault Drilling Project (DFDP) aims to improve our understanding of the Alpine Fault Zone, a tectonically active mature fault system in New Zealand known to rupture in large events, by deep scientific drilling. The borehole DFDP-2B approached the Central Alpine Fault at depth, reaching a final depth of 892m (820m true vertical depth). Online gas analysis (OLGA) while drilling tracked changes in the composition of gases extracted from the circulating drill mud. The composition of fluids from fault zones can provide

information about their origins, flow rates and paths, fluid-rock interactions, and the permeability structure of the faulted rock mass.

Apart from an atmospheric input, the gases in drilling mud derive from the pore space of rock, crushed at the drill bit, and from permeable layers intersected by the borehole. The rapid formation of mud wall cake seals the borehole from further fluid inflow, allowing formation-derived gases enter mostly at the depth of the drill bit. Significant gases analysed were: Ar, CO_2, CH_4, He, and H_2 on a mass spectrometer, hydrocarbons CH_4, C_2H_6, on a gas chromatograph, and Rn using a lucas-cell detector. Gas was sampled for offline analyses on noble gas and stable isotopes to complement the OLGA dataset.

Principle formation-derived gases found during drilling of DFDP-2B were CO_2, and CH_4, with smaller component of H_2 and He_2. High radon activity is interpreted to reflect intervals of active fluid flow through highly fractured and faulted rock. The $^3He/^4He$ values measured at 236m and 610m are very similar to those measured in hot springs along the Alpine Fault, e.g. Fox River (0.64 Ra), Copland (0.42 Ra), Lower Wanganui (0.81 Ra). We will compare these data to those gathered using OLGA and discuss the implications.

MICROSEISMICITY IN THE NGATAMARIKI GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE: DETERMINATION AND APPLICATION OF A MATCHED-FILTER THRESHOLD

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The high-temperature, fluid-dominated Ngatamariki geothermal field is located in the central Taupo Volcanic Zone (TVZ), and is used to generate electricity via an 82 MW power plant. Injection wells have been in operation since June 2012. Geothermal stimulation and production may trigger microearthquakes by fluid flow through the reservoir. Close clustering of microseismic events' hypocentres relative to the source-receiver distance results in many events having similar waveforms. We capitalize on this using a matched-filter detection method in which high-quality seismograms corresponding to a well-recorded earthquake ("templates") are cross-correlated against continuous data to reveal additional earthquakes with similar characteristics. As in matched-filter detection studies elsewhere, we require that the sum of correlation coefficients across the network exceed a noise-based threshold in order to recognise a detection. The threshold is defined by RxMAD, where R is a scalar coefficient and MAD is the median absolute deviation of the correlation coefficient sum throughout the day. The R coefficient is a function of the recording environment, network geometry and time-varying noise characteristics, and we estimate it empirically using synthetic testing. By seeding the continuous data with scaled versions of representative templates, we examine how the amplitudes of detectable events are compared with correlation and detection efficiency. Synthetic testing yields a minimum threshold for this geothermal region of R=7.1. Using this threshold, events with amplitudes as small as ~2% of the original templates' amplitudes are detected with 95% confidence. The matched filter detection of microseismic events allows further interpretation of geologic structure at Ngatamariki and of the relationship between production, injection and seismicity.

CATACLASITE DEVELOPMENT IN THE ALPINE FAULT: APPLICATIONS OF IMAGE ANALYSIS

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The first phase of the Deep Fault Drilling Project (DFDP-1) collected a continuous lithological transect through fault rock surrounding the Alpine Fault. Toy et al. (2015) distinguished rock units in the DFDP-1 boreholes as gray and dark-green ultramylonites, brown-green-black ultramylonites, upper unfoliated cataclasites, upper foliated cataclasites, gouges, lower cataclasites, breccias and Quaternary gravels. In the upper unfoliated cataclasites and the lower cataclasites it is notable that the extent of cataclastic fabric development (i.e. how much the original intact rock has been fractured, clasts have been rotated, and a foliation has developed) varies, so these rocks are classified in the range between "ultracataclasite" and "fractured protolith" according to the scheme of Woodcock and Mart (2008). For these units, textures indicate that multiple cycles of brecciation and cementation occurred in the generation of these rocks. In the

unit of the upper foliated cataclasites, foliation planes defined by thin (<1 mm) layers of opaque minerals or clay-sized phyllosilicate grains are most common near the principal slip zone (within <10 m). Fabrics are better developed with increasing depth in the core accompanying gradual color changes, suggesting change in alteration mineralogy.

This study focuses on application of image analysis (e.g. the methods developed by Webster, 2015, to determine particle size and shape) to measure the extent of cataclasite development. We will present preliminary results of analyses to thin section scans.

AIRBORNE GRAVITY ACROSS NEW ZEALAND - FOR AN IMPROVED VERTICAL DATUM

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Land Information New Zealand in collaboration with GNS Science and Victoria University has 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.

A repeatability of approximately 2 mGal has been achieved and the data has an agreement with existing terrestrial gravity measurements of 3.5 mGal after downward continuation along two calibration lines. Overall the airborne data have a cross-over error of around 5.4 mGal and a difference from existing terrestrial data with a standard deviation of around 8 mGal and zero mean.

The airborne gravity data have been corrected for the gravitational effect of topography using an 8m digital elevation model and augmented with the GNS terrestrial gravity database, by least squares collocation, to produce a gridded Bouguer anomaly map at the topographic surface and Faye anomaly map at the surface of the geoid. These maps have unprecedented uniformity and internal consistency. They will be used to determine the new gravimetric geoid in the near future. There will also be opportunities to use the new anomaly map for geological and geophysical studies.

ANTARCTIC MARINE ICE SHEET RETREAT IN THE ROSS SEA DURING THE EARLY HOLOCENE

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Geological constraints on the timing of the retreat of the Last Glacial Maximum (LGM) Antarctic Ice Sheets provide critical insights into the processes controlling marine-based ice sheet stability. The over-deepened, seaward shallowing bathymetry of Antarctica's continental shelves is ideally configured to promote past, and potentially future, marine ice-sheet instability. The retreat history of the LGM ice sheet in the Ross Sea region is primarily constrained by C-14 ages on coastal beach ridges and relict penguin colonies along the Transantarctic Mountain front in the Western Ross Sea. Although these terrestrial sites offer more reliable dates than imprecise C-14 chronologies derived from bulk marine sediments, they may reflect retreat of local piedmont glaciers derived from East Antarctic outlet glaciers rather than representing the timing of retreat of the ice sheet in the central Ross Embayment. We present a sedimentary facies succession and foraminifera-based C-14 chronology from a core collected beneath the Ross Ice Shelf via a hot water drill access hole used for the ANDRILL Coulman High site survey. The site is to the east of Ross Island and distal from the coast, and yields a minimum age for glacial retreat that is approximately 1000 yrs earlier than suggested by coastal records along the nearby Victoria Land coast. We examine the implications of this constraint on the timing of ice sheet retreat in the context of model simulations and multi-beam

bathymetry data acquired in the Western Ross Sea. On the basis of these data we hypothesize that marine-based ice sheet retreat was triggered by oceanic forcings along most of the Pacific Ocean coastline of Antarctica simultaneously, but continued retreat in the Ross Sea occurred primarily as a consequence of marine ice sheet instability.

EXPLORING NEW ZEALAND'S SUBSURFACE USING BOREHOLE IMAGES

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Borehole imaging has been used worldwide since the 1950s to capture vital geological information on the lithology, structure, and stress conditions of the Earth's subsurface. In New Zealand both acoustic and resistivity based borehole image logs are utilised to explore the geological nature of the sedimentary basins that host our oil and gas resources, the basement and volcanic rocks that contain our unique geothermal reservoirs, and shed light on the nature of the Alpine Fault that runs through Southern New Zealand.

Analysis of borehole image logs from petroleum wells from the East Coast Basin provide data on the stress field, and insights into the effects of fracturing on potential clastic and carbonate reservoir and seal rocks, in a tectonically complex area. Non-structural borehole image fabrics provide information that identifies the depositional and diagenetic processes at work in the East Coast Basin, assesses the sedimentary architecture, and calibrates petrophysical determinations.

Borehole image logs in wells from geothermal fields in the Taupo Volcanic Zone (TVZ) provide the first, direct, subsurface, structural orientation measurements in New Zealand geothermal reservoir lithologies. While showing an overall structural pattern aligned to the regional tectonic trend, heterogeneities are observed that provide insight into the complexity of the structurally controlled, geothermal, fluid flow pathways. Analysis of imaged stress induced features informs us that the stress field orientation in the TVZ is not homogenous, but is variable at a local scale.

Lastly borehole images acquired during the Deep Fault Drilling Project have captured the structural architecture of the Alpine Fault, providing insights into feature morphology, orientations, and highlighting a decrease in fracture density close to the principal slip zone.

GRAIN FLOW AT HIGH STRESSES

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Transport mechanisms of rapid long-runout rock avalanches were hotly debated when I came on that scene in 1967. So how come they are still debated today? My explanation is that it results from poor peer review, poor comprehension, and technological advances outpacing intellectual advances. Why think about a problem when we can model it! So let's think. Shreve's rock avalanches fell upon and trapped a layer of air. What physics is this? It is how loose feathers and Autumn leaves fall. When my rock avalanches fly they use the physics of projectiles and fly like bricks. But their main transport mechanism isn't flight. The dominant impression from watching a rock avalanche in motion is of fluid flow, as Heim described in 1882. Rock avalanches are very large grain flows. Bagnold studied dispersive grain flows, but why should we assume that rock avalanches are dispersive grain flows, as many do. A more common grain-flow type is a dense grain flow: rock avalanches are dense grain flows with enough weight to generate very high stresses at grain contacts. Brittle rock deforms elastically up to its compressive strength, whereupon it breaks, releasing elastic strain as transient elastic strain (seismic energy to a seismologist, acoustic energy to a physicist). Melosh and others showed that grain masses can be fluidised by acoustic energy. The physics behind grain flow at high stress is simple: when grains break, the released elastic strain has to go somewhere, and it goes everywhere principally by transmission though grain contacts. Depending on the state of stress at the grain contact, the contact will pass the stress or will slip at conventional values of Coulomb friction. Enough thinking! A physical model of the process is too big for any laboratory, so a numerical model will have to do.

GEOTHERMAL ACTIVITY AND VOLCANIC EVENTS IN THE TAUPO VOLCANIC ZONE: A LONG-TERM RELATIONSHIP

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During the last 1.8 Ma, the hot and dynamic central part of Taupo Volcanic Zone (TVZ) has been the focus of numerous and often large-scale eruptions and extrusions of magma from multiple volcanic centres. Hosted within this region are 22 high-temperature (>220°C) geothermal systems. It is apparent that many of these systems have been disrupted but not destroyed during volcanism occurring in the same location. This suggests a deep heat source or structural control is focusing fluid flow and younger shallower volcanism, enhancing the development of the hydrothermal system.

Volcanic events of virtually any scale are expected to change the stress field, and to modify the structure and fluid flow of a nearby hydrothermal system. While reservoir dynamics may change, it appears that even after caldera-scale eruptions, the general location of the hydrothermal system stays the same.

Evidence that ancient hydrothermal events affected *in situ* volcanic and sedimentary deposits at Kawerau, Ohaaki, Wairakei and Ngatamariki (e.g., revealed as buried polymict hydrothermal breccia) is provided by geothermal drilling and high precision dating. The textures and alteration mineral assemblages in these units are incongruous with current reservoir conditions, and instead are relics of previous hydrothermal activity in the same location.

Geophysical studies of TVZ have discussed the notion of fixed geothermal plume positions (e.g., Bibby et al., 1995). Shallow magmatic intrusions 10^2-10 km^3 may not sustain heat flow to geothermal systems for greater that 10^2-10^4 years, yet there is clear evidence that several systems including Kawerau and Ngatamariki have rejuvenated in virtually the same geographic location over a 10^4-10^6 year timescale. Our dating gives a time frame for frequent local volcanism and also supports the presence of long-lived mid-crustal heat sources throughout TVZ and the utilisation of deep basement structures in re-establishment of fluid pathways into renewed geothermal systems.

PRELIMINARY RESULTS OF TECTONIC GEOMORPHIC ANALYSIS OF THE ACTIVE DAYMAN DOME CORE COMPLEX, SE PAPUA NEW GUINEA

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The rapidly slipping Mai'iu low-angle normal fault in SE Papua New Guinea has exhumed a smoothly curved, corrugated fault surface that extends >25 km in the up-dip direction. Emerging at a dip of ~21° N near sea level the fault flattens over the crest of the Dayman Dome core complex to dip S. Despite its high rainfall setting and >2900 m of relief, the exhumed fault surface is well preserved — a situation that can be attributed to is high slip rate (probably >7 mm/yr). These ideal conditions allow us to use geomorphology to evaluate ongoing deformational and fluvial processes that have accompanied the exhumation of this fault scarp. In addition to fieldwork, we have analysed aerial photography and a digital elevation model constructed from 30 m shuttle radar topography mission data. Abundant geomorphic evidence, such as windgaps perched on the crest of the dome, attest to the progressive back-tilting of streams during their upward tectonic advection as a result of fault slip, leading to a reversal in stream drainage direction at high elevation. Other streams that originally drained longitudinally (either E or W) along the foot of the fault scarp were later advected up the scarp, where they are now preserved as EW stream courses or windgaps. Finally, we show that the exhumed footwall (also modern range front) is cut in an antithetic-sense by high-angle faults that strike parallel to the main fault at ~112° creating uphill facing scarps. These have a mean cross-strike spacing of ~1520 m and throws of <5 m to 120 m. We attribute these faults to back-flexure that has accompanied rolling-hinge style exhumation of the main fault, the first time that such features have been identified globally on a continental metamorphic core complex.

THE ROLE OF HALLOYSITE IN SENSITIVE SOIL LANDSLIDES IN THE BAY OF PLENTY

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Sensitive soil failures in the Tauranga area commonly occur after heavy rainfall events, causing considerable infrastructure damage. Notable landslides include a large failure at Bramley Drive, Omokoroa in 1979, the Ruahihi Canal collapse in 1981, and landslides at Otumoetai in May 2005; recently the Bramley Drive scarp was reactivated in 2011 and 2012. Sensitive soil failure is marked by a significant loss of strength following remoulding of the landslide debris, leading to characteristic long run-out debris flows.

These failures are associated with materials loosely classified as the Pahoia Tephras: a mixture of weathered rhyolitic pyroclastic and volcaniclastic deposits. In these materials hydrated halloysite (not allophane) is the principal clay mineral. The regular deposition since c. 0.93 Ma of siliceous pyroclastic deposits from ongoing explosive rhyolitic volcanism in TVZ, together with high natural water content and low permeability, have created a locally wet environment in the stratigraphic sequences. This generates Si-enriched pore water from the weathering mainly of rhyolitic volcanic glass shards and plagioclase, providing conditions suitable for halloysite formation.

Morphologically the halloysite comprises short tubes, spheroids, plates, and, uniquely, books. The varied morphologies of halloysite minerals within the microstructure create an open network with small pores, allowing high natural water contents yet low permeabilities, while the low cation exchange capacity of halloysite results in low plasticity. Hydrolysis of glass shards at early stages of weathering releases cations that promote cohesion between clay minerals and allow weathering to proceed while maintaining an open structure. Eventual leaching of these cations reduces cohesion between clay minerals, resulting in low cohesion, low field strength (CPT tip resistance) and sensitive behaviour on failure.

PROPOSED SSP FOR PORANGAN/BORTONIAN STAGE BOUNDARY

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A thin, ca. 10 m, section of Wanstead Formation exposed in Tahuokaretu Stream (U24 934 829; 40° 24.691' S 176° 20.414' E ± 4m) is proposed as a new stratotype for the base of the Bortonian Stage (stratotype section and point: SSP).

The type section for the Porangan Stage, Te Uri Stream in Southern Hawkes's Bay, is now an isolated outcrop of Wanstead Formation in the middle of the stream without reference to underlying or overlying stages. The original Bortonian Stage type section, at Bortons in northern Otago, is equally poor and a "lectostratotype" at Hampden, North Otago, has been erected. However, the base of the Bortonian at Hampden is poorly exposed in condensed greensands at the Kurinui-Hampden formational contact and is usually obscured by beach sands. Thus, none of these sections provides a suitable SSP.

The proposed Bortonian Stage SSP at Tahuokaretu Stream:

A) is near the original Porangan type locality, 16 km south-west of Te Uri Stream, and is from the same formation;

B) is easily accessed from Tahuokaretu Road, near Weber in Southern Hawkes Bay; and most importantly —

C) has rich and diverse foraminiferal and dinoflagellate assemblages and is expected to contain good calcareous nannofossils.

Eight samples in stratigraphic sequence were collected through the Tahuokaretu Stream section. The key Porangan benthic foraminifera, *Elphidium saginatum*, is recorded from the five lower samples, and the key Arnold Series planktic foraminifera *Globigerinatheka* index occurs with *Acarinina primitiva* (Waipawan-Bortonian) in the two highest samples. The base of the Bortonian Stage is placed at the position of the lower of these latter samples.

Dinoflagellate diversity generally increases up-section, although most species are long ranging and show no particular occurrence patterns. *Cerodinium medcalfii* last appears in the same sample as *Elphidium saginatum*, just below the Dp-Ab boundary.

DOUBLE DATING OF ZIRCON GIVES NEW INFORMATION ON TIMING OF OTAGO SCHIST DEPOSITION, METAMORPHISM AND EXHUMATION

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Zircon-bearing greyschists were collected along a 25 km long NE-SW structural profile along the Cairnmuir and Dunstan Ranges of Central Otago. The ends of the profile are in chlorite zone greenschist facies textural zone III Otago Schist, and also in the hangingwall blocks of the low-angle Thomsons Gorge Fault and Cromwell Gorge Fault Zones. The central part of the profile is in garnet zone greenschist facies textural zone IV Otago Schist that forms a core footwall block between the two fault zones.

Six samples from the profile were dated by LA-ICPMS U-Pb methods. Four of these gave detrital zircon age populations that match expected Permian to Triassic Caples and Torlesse-Rakaia Terrane protoliths. One sample gave a youngest detrital U-Pb age peak of 322 Ma (Carboniferous) and another sample 108 Ma (latest Early Cretaceous). Our new data confirm the interpretations of Jugum et al. (2013) and Cooper & Ireland (2013) that a simple two terrane (Caples and Rakaia) model no longer applies to the Otago or Alpine Schist.

Eight zircon (U-Th)/He ages along the structural profile record when the samples were last at c. 180-200°C. The hangingwall samples give mean ZHe ages of 93-92 Ma and the footwall samples 70-85 Ma. The difference in footwall and hangingwall ages confirms that both faults moved in the Late Cretaceous.

To explain these new U-Pb and (U-Th)/He geochronological observations, we present a regional tectonic model in which a slice of Pahau Terrane (younger Torlesse) rock was underplated beneath the schist accretionary wedge after 108 Ma. The presence of 108 Ma Pahau schist protoliths drastically reduces the amount of time in which to subduct, metamorphose and exhume parts of the Otago Schist high grade core. Exhumation of the metamorphosed Pahau Terrane, assisted by movement on low-angle faults, ceased shortly after 85-93 Ma.

THE VESPA RESEARCH CRUISE (VOLCANIC EVOLUTION OF SOUTH PACIFIC ARCS): A VOYAGE OF DISCOVERY TO THE NORFOLK, LOYALTY AND THREE KINGS RIDGES, NORTHEAST ZEALANDIA

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VESPA was a successful 25 day research cruise on R/V *l'Atalante* that took place in May and June 2015. The main aim was to acquire new rock samples from extinct volcanoes on the Norfolk, Loyalty and Three Kings ridges, which connect New Caledonia and New Zealand. The samples will be used to test various hypotheses of Late Cretaceous-Miocene SW Pacific tectonic development relating to (i) nature and duration of magmatism on the ridges; (ii) timing of subduction initiation east of northern Zealandia; (iii) postulated subduction polarity changes.

A total of 3400 km of 'sismique rapide' shallow reflection seismic data were acquired and processed onboard. The seismic lines provided a very useful structural-stratigraphic framework for the rock dredging. Combined with multibeam bathymetry data they allowed intelligent targeting of acoustic basement (lavas) and specific seismic reflectors (sedimentary strata) on rocky slopes and fault scarps. Different stratigraphic levels of the Loyalty and Three Kings Ridge volcanic piles were sampled by dredging at different water depths on the Cook Fracture Zone and Cagou Trough fault scarps.

By the end of the cruise, 43 dredges had been attempted and 36 of them yielded igneous or sedimentary rocks potentially useful to the VESPA project. Onboard use of a portable X-ray fluorescence unit confirmed the presence of intraplate (but no arc) volcanoes on the Norfolk Ridge and presence of arc, intraplate and shoshonitic volcanoes on the Loyalty and Three Kings Ridges. A total of 770 kg of rock was retained for post-cruise analysis in New Caledonia, France and New Zealand. Future work will include

micropaleontological dating of sedimentary rocks, U-Pb and Ar-Ar isotopic dating of igneous rocks, and whole rock geochemical and tracer isotope analyses. We are optimistic that many of the initial research hypotheses will be able to be tested.

Here we present results from the early stages of our ongoing analysis of the ash component produced during the 2012 Havre eruption, and place them in the context of our current understanding of the overall eruption.

DIGGING INTO A BIG EXPLOSIVE SUBMARINE ERUPTION TO UNDERSTAND SEAFLOOR VOLCANISM

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In 2012 the largest recorded submarine eruption in history was produced by Havre Seamount on the Kermadec arc north of New Zealand. This eruption produced a 400 km^2 pumice raft and an atmospheric steam plume despite erupting from a depth of 700-1300 m below sea level. Eruptions from such a water depth producing effects at the sea surface were previously unknown. In March/April 2015 an international group of scientist on a US-funded research cruise using the remote submersible vehicle Jason collected a broad suite of samples from the sea floor along with comprehensive video and photographic documentation of the several dives' paths. Along with this a uniquely detailed, meter-scale resolution, map of the caldera volcano and 2012 eruptive features was produced by the mapping vehicle Sentry.

The processes and conditions of explosive volcanism at this depth are poorly understood and until recently some considered such eruptions to be impossible. The processes of subaerial explosive magma fragmentation are relatively well studied due to the hazards fine ash poses to human health and to industrial and commercial processes. It has been shown that the presence of external water in eruptions produces differences in the magma fragmentation mechanisms that can allow products of wet versus dry eruptions to be distinguishable from one another, but interpretation is not simple. Not every fragment from a “wet” eruption will carry a signature of water interaction. In addition to this it is unclear how the additional effects of increasing pressure and the differences in thermo-chemical properties of ambient seawater will affect magma fragmentation and eruption style in deep subaqueous volcanic eruptions.

ANTARCTIC ICE-SHEET VARIABILITY ACROSS THE EOCENE-OLIGOCENE BOUNDARY CLIMATE TRANSITION

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About 34 million years ago (Ma) Earth’s climate cooled and an ice sheet formed on Antarctica as atmospheric CO_2 fell below ~750 ppm. Sedimentary cycles from a drill core in western Ross Sea provide the first direct evidence of orbitally-controlled cycles of ice-sheet expansion and retreat between 34 to 31 million years ago. Initially, under atmospheric CO_2 levels ≥ 600 ppm, a smaller Antarctic Ice Sheet (AIS) restricted to the terrestrial

continent was highly responsive to local insolation forcing. A more stable continental-scale ice sheet, calving at the coastline, did not form until ~32.8 Ma, coincident with the first time atmospheric CO_2 levels fell below ~600 ppm, after which an expanded Antarctic Ice Sheet displayed progressively stronger orbital hysteresis. Our results imply strong coupling between Antarctic ice sheet dynamics and the carbon cycle, and provide new insights into the potential of the AIS for threshold behaviour, and its heightened sensitivity to atmospheric CO_2 concentrations above present day levels.

JAMES HECTOR AND THE FIRST GEOLOGICAL MAP OF NEW ZEALAND

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When James Hector was appointed to set up the New Zealand Geological Survey in 1865, one of his first priorities was to produce a national geological map. He was able to use information from Hochstetter (Auckland, Waikato and Nelson), Crawford (Wellington), Haast (Canterbury and Westland) as well as his own work in Otago.

Hector's first geological map was completed in August 1865, and he hoped to have it printed in Britain. Financial cutbacks meant that this was deferred, and the map became out of date as more fieldwork was undertaken. A revised version – the first published geological map of New Zealand – was published in 1869.

JAMES HECTOR – FATHER OF GEONET

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Although James Hector was primarily employed to find minerals, he was always fascinated by natural hazards. When weather recording and forecasting were added to his responsibilities in 1867, he also started recording and analysing felt earthquakes around New Zealand – the forerunner of the modern GeoNet system. Hector also described the impact of tsunamis and volcanic eruptions. Much of the credit for the excellent records of late 19th century phenomena kept by Hector should be shared with his conscientious clerk and administrator, Richard Gore.

AGE OF OROCLINAL BENDING AND NEW ZEALAND PLATE BOUNDARY DEFORMATION

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Oroclinal bending of basement terranes through New Zealand are a key element of the geology. The sense and magnitude of this shear is consistent with displacement on the Alpine fault and Cenozoic sea-floor spreading data. Unbending of the orocline by retro-deformation during the Cenozoic produces a near-linear Gondwana subduction margin, however, it also generates a large triangular region of continental crust in the North Island. Cenozoic shortening, crustal thickening and vertical-axis rotation data in the North Island do not strongly support the prior existence of the triangle zone or the ≥90° clockwise vertical-axis rotation required to form the orocline. To constrain the timing of oroclinal bending we examine the map-view angular relationships between basement terranes and linear strain markers including Cretaceous fault traces and the margins of Zealandia continental crust. We also re-analyse paleomagnetic vertical-axis rotations for Oligocene and younger strata. The available data are consistent with the conclusions of others (e.g.[1-3]) in suggesting that bending of basement terranes formed due to a combination of mid Cretaceous and Cenozoic deformation. Immediately west and north of the Alpine fault basement terranes dip steeply, with as little as 0-30° of Cenozoic (<30 Ma) clockwise bending. By contrast, basement terranes east of the Alpine fault in the central and northern South Island were rotated up to 100° clockwise in association with Cenozoic right-lateral shear. After these Cenozoic shear strains are accounted for a large oroclinal bend remains with a near 90° swing in the strike of the terranes at approximately the present location of the Alpine fault. We speculate that pre-Cenozoic bending of basement terranes formed in the mid Cretaceous (100-120 Ma) due to collision of the Hikurangi Plateau and continental Zealandia associated with jamming of the Mesozoic

subduction system in the region of the Chatham Rise.

[1] Bradshaw et al. 1996. NZJGG 39, 461-468. [2] Kamp 1987. JGS London 144, 641-652. [3] Mortimer 2014. JSG 64, 32-38.

DISTRIBUTION, AGE AND UPLIFT PATTERNS OF PLEISTOCENE SHORE PLATFORMS ALONG THE SOUTH COAST OF THE NORTH ISLAND, NEW ZEALAND

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We investigate the uplifted Pleistocene (>12 ka) shore platforms along the south coast of the North Island. Based on new geological mapping, GNSS surveying, and Optically Stimulated Luminescence (OSL) dating of the overlying beach deposits (20 new ages – the first radiometrically-determined ages for the majority of these terraces), we have mapped the distribution of the shore platforms and correlate these features based on their age of formation.

Formed as a result of sustained erosion and weathering of coastal bedrock, generally during climatic highstands (warm periods such as interglacials or interstadials) these shore platforms are conveniently arranged along the south coast in a direction that is near-parallel to the Pacific-Australian plate motion, providing a valuable set of markers with which to undertake a direct study of tectonic deformation across the Hikurangi margin.

We have identified six different shore platforms, some to heights of up to ~400 m above current day sea level, occurring discontinuously between Cape Terawhiti and Cape Palliser. Our OSL data, together with stratigraphic and geomorphic data, indicate that the best-preserved and most laterally continuous terraces most likely formed during Marine Isotope Substages (MIS) 5a, MIS 5c and MIS 5e respectively.

Overall, the terraces are gently tilted (decreasing in elevation) towards the west, with the maximum uplift occurring on terraces closest to the subduction trench (~200 m for the ~125 ka terrace near Cape Palliser). We also document offsets across known and newly identified faults that cross the coast. Finally, we look into the possible mechanism(s) responsible for the pattern of uplift observed on the shore platforms.

WHAT GROWS UP, MUST FALL DOWN: MEASURING THE SPATIO-TEMPORAL VARIABILITY OF THE BIOLOGICAL PUMP IN THE DEEP OCEAN AND ITS RELATIONSHIP TO THE GLOBAL CARBON CYCLE

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One of the key aspects of the global carbon cycle is the efficiency and spatio-temporal variability of the biological pump. Issues remain in terms of the methods that are used to estimate the strength of the biological pump and quantifying the amount of carbon that is being sequestered by the deep ocean, especially in light of predicted alterations of marine foodweb structure and functioning under anthropogenic-induced climate change. Without better knowledge of the processes affecting and involved in the transfer of carbon to the deep-sea via the biological pump, there are limitations on what we can say about how the global carbon cycle might respond to ocean changes in the future.

The results from an 11 year time-series of sediment trap particle fluxes, integrated with remotely sensed satellite and hydrographic data, help shed light on these factors in the context of the two main water masses of the New Zealand region: subtropical (STW) and subantarctic waters (SAW). With high levels of variability, fluxes in SAW were markedly lower than in STW, reflecting the picophytoplankton-dominated communities in the iron-limited, high nutrient-low chlorophyll SAW. Austral spring chlorophyll blooms in surface STW were near-synchronous with elevated fluxes of bio-siliceous, carbonate and organic carbon-rich materials to the deep ocean, probably facilitated by diatom sedimentation. In contrast, the highest biogenic fluxes in SAW occurred in spring when surface chlorophyll concentrations were low, while highest annual chlorophyll concentrations were in summer with no associated flux increase. Particle fluxes in STW are similar to that of other mesotrophic to oligotrophic waters (~6-7 mgC m^{-2} d^{-1}), whereas export from SAW is below global averages (~3 mgC m^{-2} d^{-1}), suggesting differences in the efficiency of the biological pump in these two water masses.

RECONSTRUCTION OF HISTORIC FOSSIL CO_2 EMISSIONS USING RADIOCARBON MEASUREMENTS FROM TREE RINGS

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This project aims to reconstruct historic, fossil CO_2 emissions from two closely related point sources. We use the Vector gas processing plant and the Ballance agri nutrients ammonia urea plant at Taranaki, New Zealand, which emit ~0.16 Tg C^{-1} as CO_2 since 1970. Previous work using air samples found 2-5 ppm mole fraction CO_{2ff} 600 m downwind of the plant. This study will extend the data set back 30 years using radiocarbon measurements in tree rings.

Trees incorporate CO_2 from the local atmosphere during photosynthesis as cellulose in annual growth rings. The amount of fossil fuel sampled by the tree can be calculated from the decrease of $\Delta^{14}C$ in the cellulose caused by the addition of ^{14}C free fossil CO_2. All other sources of carbon dioxide have a $\Delta^{14}C$ signal close to ambient air.

Core samples were collected from trees growing immediately downwind of the Vector plant and from clean air locations in Taranaki and Wellington. Annual rings in the tree cores were counted and cut into one-year growth increments. Testing was performed on two cellulose extraction methods to confirm removal of ^{14}C enriched material before the cellulose component was chemically isolated, combusted, graphitised, and $\Delta^{14}C$ measured by accelerator mass spectrometry.

The results show that Wellington tree and Taranaki clean-air trees compare well with the Wellington atmospheric record, whereas trees growing downwind of the Vector plant demonstrate lower $\Delta^{14}C$ values consistent with uptake of CO_{2ff}. We will compare historic CO_{2ff} emissions as sampled by the trees with reported emissions from the Vector plant to quantify and evaluate the ability of the technique to monitor changes in fossil CO_2 emissions. We will demonstrate how this technique could be applied alongside complimentary methods to evaluate fossil CO_2 emissions at point sources worldwide to determine compliance of CO_2 emitters with emission reduction targets.

TAKING THE PULSE OF THE LAND WITH COSMOGENIC NUCLIDES

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In-situ produced cosmogenic nuclides have been used globally to determine millennial-scale denudation rates for drainage basins ranging in size from less than 1km^2 to the entire Amazon at 6.1 million km^2. The results have played a key role in understanding the drivers and feedbacks between tectonics, erosion, and climate. Many studies have shown similar strong relationships between denudation and tectonics. However, other studies have indicated that temperature and precipitation can exhibit strong control over weathering and erosion. A climatic control on denudation rates likely stems from higher regolith production rates at higher mean annual temperatures and precipitation.

New Zealand is a prime location for testing the relative importance of tectonics and climate on denudation. Strong gradients in rock uplift rates occur over relatively short distances on both the North and South islands. There are likewise large variations in mean annual precipitation and temperature which result in significant differences in modelled soil production rates across New Zealand. We measured ^{10}Be concentrations in alluvial sediments, soil and bedrock and in order to determine rates of catchment-wide denudation, soil production rates and soil erosion rates.

Samples of ~5kg river sand were collected from 10 rivers on the southern North Island and northern South Island. These basins span a large range in mean annual precipitation and temperature as well as uplift rates. These basin-averaged denudation rates are supported by bedrock and soil derived soil production and erosion rates from greywacke terrains. Our results inform recent low temperature thermochronometry studies which suggest that tectonics controls erosion in the Southern Alps, even where extreme precipitation rates might be expected to dominate.

THE ROLE OF CLIMATE IN BALANCING SOIL PRODUCTION AND SEDIMENT YIELD IN NEW ZEALAND

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New Zealand hosts some of the highest specific sediment yields on the planet reaching up to nearly 30,000 t km^{-2} yr^{-1}. Sediment yields measure the export of sediment from a basin and give an indication of erosion from hillslopes. In New Zealand high sediment yields correlate with high annual precipitation and high rates of tectonic strain. It is, however, unclear how soil production keeps pace with such extreme erosion. Here, this question is investigated by modelling soil production as a function of local climate parameters. When applied to ~30 year climate data, these models highlight the variability of potential soil production across New Zealand. Due partially to high annual rainfall, some of the fastest sediment yields on the west coast of the South Island are nearly in balance with soil production. In other regions such as the east coast of the North Island, hotspots exist where annual sediment yields exceed reasonable soil production rates such that additional mechanisms must operate to generate sediment and make up this deficit.

Globally, precipitation tends to increase and temperature decreases with increasing elevation. In New Zealand, increasing elevations also roughly correlate with an increase in mean basin slope angle and the percent of a basin at >30° slopes. As a result, modelled soil production also tends to increase with increasing mean basin slope angle. This correlation is independent of erosion feedbacks on the modelled soil production rates. This relationship presents an intriguing scenario in which the topography of the mountain range may be maintained by climate through variations in soil production.

THERMOCHRONOLOGICAL STUDIES ON THE DAYMAN DOME, PAPUA NEW GUINEA

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The Suckling-Dayman massif in SE Papua New Guinea is a smooth domal landform extending from Mount Suckling (3676 m) in the west to Mount Dayman (~2900 m) in the east. The footwall consists primarily of metamorphosed basalt with minor limestone and pelite. In the vicinity of Mount Suckling, these are structurally overlain by serpentinized peridotite and intruded by granitic and monzonitic stocks. The dome is bounded to the north by an active low-angle normal fault, the Mai'iu fault, which geodetic data suggests is slipping at more than 7-9 mm/year. The spectacularly fresh fault scarp is exposed over a width of >25 km in the transport direction, and is increasingly incised in an up-dip direction. Near sea level, at the base of the scarp, the fault emerges from the ground at a dip of ~21° where it exposes greenschist facies mylonites in its footwall. Farther south, the fault progressively flattens to more gentle dips, ultimately rolling through the horizontal to dip southward near the Main Divide. There, less deeply exhumed very low-grade fabrics are preserved. We have so far collected eighteen samples taken from Mount Dayman at elevations between ~2900 m and ~200 m in a transect parallel to the tectonic transport direction, and three from Mount Suckling between ~3400 m and ~2000 m. We plan to use thermochronological data from these samples to constrain the cooling, exhumation and slip histories of the Suckling-Dayman massif. Fission-track and/or (U-Th)/He thermochronology of epidote, magnetite, sphene, zircon and apatite with closure temperatures between 260 °C and 55 °C will elucidate the cooling and exhumation history, and perhaps also constrain the original dip of the fault at depth. This analysis will be supported by undertaking Raman spectroscopy on carbonaceous material which will allow us to map contours of maximum temperature on the footwall.

MODELLING OF GAS HYDRATE DISSIOCIATION, CASE STUDY THE CHATHAM RISE, NEW ZEALAND

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The Chatham Rise south east of New Zealand has been observed to have seafloor depressions, each between 1-11 km in diameter, covering an area of >20,000 km^2. These seafloor depressions have been interpreted as pockmarks related to past fluid escape. These are interpreted to be caused by the sudden release of overpressured gas generated by gas hydrate dissociation during glacial sea-level lowering. We simulate the evolution of the gas hydrate system through glacial-interglacial cycles in the study area using Tough+Hydrate. The Chatham Rise provides a unique opportunity for the study of the effects of depressurization from sea-level lowering to gas hydrate systems because it is a bathymetric barrier preventing the Sub-tropical Front separating sub-tropical and sub-Antarctic waters from migrating during glacial-interglacial cycles. This bathymetric barrier enables us to assume constant bottom-water temperatures. Our results show more gas is released water depth is lower at constant temperatures, which relates to the position of the large pockmarks in the Chatham Rise. However, the results from paleoceanographic studies indicate that in reality bottom-temperatures may have varied locally. These temperature changes may have a more significant effect on the shallow gas hydrate system in the study area than the relatively gradual decrease of pressure associated with sea-level lowering.

BOUNDARIES OF PLIO-PLEISTOCENE WHANGANUI BASIN OVERLAP BOTH THE PALEOGENE-NEOGENE TARANAKI AND EAST COAST BASINS

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The boundaries of New Zealand sedimentary basins have up to now been defined by major structural features and in the case of some offshore basins by seafloor physiography. Recent work in central and lower North Island show the Plio-Pleistocene Whanganui Basin may extend beyond the traditionally accepted boundaries and in part overlie older basins. The accepted western basin margin has been the upfaulted basement block comprising the Patea-Tongaporoutu High and its offshore southward continuation while the North Island axial ranges have been adopted as the eastern margin.

Matemateaonga Formation and Tangahoe Mudstone in the Whanganui Basin extend over the basement high and across into eastern Taranaki Peninsula where they are known aquifers. Mangapanian to Castlecliffian strata present along the western side of the axial ranges can be mapped across the Saddle Road to the Waewaepa Range and its eastern bounding Makuri-Waeweapa Fault. These Plio-Pleistocene sediments are important aquifers to the west and east of the axial ranges. The authors propose that Whanganui Basin is not geographically discrete but overlies eastern Taranaki Basin and, in places, the East Coast Basin.

Uplift of the axial ranges is constrained by the presence of rhyolitic tephra together with biofacies to the Castlecliffian to Recent. A range front thrust fault zone mapped in the lower Pohangina Valley controls the eastern side of the Ruahine Range and uplift of the ranges has isolated the easternmost part of the basin.

ARE SACKUNGEN DIAGNOSTIC FEATURES OF (DE)GLACIATED MOUNTAINS?

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Deep-seated gravitational slope deformations (DSGSDs) with characteristic sackung landforms (e.g., double crests, trenches, uphill-facing scarps, and toe bulging) are considered by some researchers to be diagnostic features indicating past mountain glaciations. Sackungen occur across a diverse spectrum of mountain types, with different morphoclimatic histories, including regions that

have never experienced glaciation. To reinforce that sackungen may originate independently of glaciation, we present two case studies from the Western Carpathians (Czech Republic and Slovakia) which are supported by detailed geomorphic mapping, trenching and absolute dating (^{10}Be, ^{14}C, and OSL). On the Ondřejník ridge (Outer Western Carpathians, Czech Republic), sackungen occur in the mid-Holocene in the medium-high mountains which are beyond the Pleistocene glacial limits. On the Salatín Mt. (Tatra Mts., Slovakia), the sackungen, which occur in formerly glaciated terrain, date between ~7.5 and 4.2 ka BP, representing a >4 ka time lag after the disappearance of glaciers. This suggests that the direct link between the ice retreat and the onset of sackung formation is not obvious, even in the case of the once glaciated mountain range. Although paraglacial stress release is undoubtedly one of the crucial causes of sackung genesis, in many mountain regions, it is not the only important mechanism. Therefore, despite occurring in numerous (de)glaciated mountains, sackung features cannot be considered as proof of past mountain glaciations, e.g., during analysis of extra-terrestrial settings.

HAVE WE DISCOVERED THE LATE EOCENE CLIMATIC OPTIMUM?

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The Eocene (~56-34 Ma) marks an interesting epoch in which Earth's climate underwent major changes. The primary proxy record (δ^{18}O of benthic foraminifera) reveals a trend from an early Cenozoic greenhouse climate to an icehouse climate which culminated in the positive δ^{18}O excursion in the earliest Oligocene[1], interpreted as the first major glaciation of Antarctica. The long-term cooling trend was interrupted by several short-lived events: The Middle Eocene Climatic Optimum (~40 Ma) and the Priabonian Oxygen Isotope Maximum (PrOM), a cooling event during the late Eocene (~37 Ma), which might have resulted in some ice-build-up on Antarctica[2]. Further climatic oscillations are reported for the late Eocene, like the late Eocene warming event[3], albeit its biological implications are not yet fully elucidated. Nannofossil assemblages from the Kerguelen Plateau (Southern Indian Ocean) show an increase in temperate-water taxa and a decrease in cool-water taxa associated with that warming event[4].

Here we present the integration of radiolarian assemblage data with new stable oxygen and carbon isotopes for DSDP Site 277, Campbell Plateau, to reconstruct oceanic changes during the Eocene across the Southwest Pacific. The late Eocene radiolarian assemblage increases in abundance, diversity and high-latitude taxa during the PrOM event. However, at ~36.4 Ma, the late Eocene warming event is evident in decreasing δ^{18}O values and a corresponding decline in radiolarian abundance, diversity and high-latitude taxa (e.g. *Lithomelissa* spp.), whereas cosmopolitan taxa become abundant. Closer to New Zealand, more evidence for a warm late Eocene Runangan stage is inferred from incursions of warm-water taxa like the low-latitude genus *Hantkenina*[5], as well as the Oamaru Diatomite, which is interpreted as a subtropical depositional environment[6].

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LANDSLIDE HAZARD AND SUSCEPTIBILITY IN WHANGAREI

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The aim of this work is to understand the landsliding mechanisms and assess landslide hazard and susceptibility in the Whangarei region, North Island, New Zealand. The interpretation of landslide mechanism has major implications for landslide hazard assessment. The study uses 0.5m and 8m resolution LiDAR-derived DEM combined with aerial photographs from 1940, to extract geomorphic parameters to use in the landslide hazard assessment. It allowed for semi-automatic classification and detection of landslide features, landslide activities and geological structures.

The geology of the region has a strong influence on the landscape and to the evolution of landslides in the study area. The main causative factors affecting landsliding are weathering, slope angle and lack of toe support. The main triggering mechanisms for shallow landslides are due to rainfall in Northland region. The influence of slope angle on shallow landslide hazard is significant. Historically, the majority of deep seated landslides in New Zealand are earthquake induced, the hazard for deep seated landslides in the study area is low because of the lack of seismicity in the Northland region.

Cyclonic events such as Bola in 1988 and storms in 2004/2005 and in 2007 in Northland have caused significant shallow landslides resulting in damage to people and property. Landslides are also linked to land use zoning. The frequency of landslides will increase with devegetation.

POST SEISMIC DEFORMATION AFTER THE 2010-2012 CHRISTCHURCH EARTHQUAKE SEQUENCE

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This paper summarizes the post-seismic deformation from the 2010-2012 Christchurch earthquake sequence measured with continuous GNSS (cGNSS) sites, plus six surveys of a ~30-station GPS network observed between January 2012 and January 2015. Results indicate that measurable post-seismic deformation has been occurring since the 2010 Darfield earthquake. Displacement rates of individual GPS sites are 6 mm/yr or smaller. The vectors are consistent with dextral shear along an extension of the rupture plane of the Darfield Earthquake and shows a clear ~5 mm/yr of east-northeast motion for sites in the northern part of Christchurch relative to Banks Peninsula in the south. Strain tensors were calculated for the velocity field. Aside for a small region covering Banks Peninsula, where the strain rates were not significant, the strain rate tensors are consistent with predominantly shear strain. The orientation of the principal axes of the strain rate tensor for the western network is in good agreement with regional stress axes from Sibson et al (2011) and are consistent with dextral movement on the Greendale Fault. Strain rates are high, with the principal axis of contraction ~60 ppb/yr. The velocity field does not show any obvious change between the areas covered by the rupture planes of the 2010 Darfield earthquake and the 22 February 2011 earthquake and the region between the two events that did not rupture during the Christchurch earthquake sequence.

We have studied the rates of post seismic relaxation using the two nearby GeoNet/PositioNZ sites (LYTT and MQZG) that are the only stations that record the entire Christchurch earthquake sequence. Assuming a logarithmic decay function our modelling is consistent with the time constant being of the order of 0.3 years. This is probably caused by a mixture of processes with poroelastic contributing in the early phase and afterslip and/or viscoelastic dominating later on.

THE GENESIS OF THE LATE MESOPROTEROZOIC MIDCONTINENT RIFT – PALEOMAGNETISM AND GEOCHEMISTRY OF THE ~1144 MA LAMPROPHYRE DYKES (ONTARIO, CANADA)

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The ~1145-1085 Ma North American Midcontinent Rift (MCR) is one of the best preserved Precambrian continental rift zones. It provides an excellent opportunity to study ancient rifting processes and gives an insight to the past mantle dynamics and plate tectonics. The MCR formed during a time of extensive magmatism and rifting experienced by the entire southwest margin of the ancient Laurentian craton from Greenland to California at ~1280-1080 Ma. This long-lived tectono-magmatic zone is comparable to the size and duration of the present day East African Rift, but its origin and the tectonic setting are still highly debated.

The ~1144 Ma lamprophyre dykes exposed around the east and northeast margins of the MCR are alkaline in composition, and, together with the coeval and similarly alkaline Abitibi dykes, appear to fan radially from a suggested plume head centre. The mean paleomagnetic directions and

corresponding poles obtained from the lamprophyre and Abitibi dykes are statistically indistinguishable. The paleomagnetic and geochemical similarity together with the apparent fanning support the hypothesis of a mantle plume origin for the MCR. On a larger scale we favour the model of a super-plume residing under Laurentia at ~1300-1000 Ma forming extensive magmatism and rifting either along the margins of the craton or at pre-existing weakness zones inside the continent. In addition our analyses of the Greenland and Laurentian poles between ~1400-1000 Ma suggest periodical True Polar Wander events.

SOUTHWEST PACIFIC EARLY HOLOCENE CIRCULATION AND BIOPRODUCTIVITY

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The sparse data available suggest sea surface temperatures in the Southwest Pacific during the early Holocene ranged up to 3°C above present, but timing and magnitude of warming appears to have varied across the region. The early Holocene sedimentary archive has great potential to provide well resolved records of past regional variability in a warmer world.

We report on a model-data comparison project for the early Holocene, 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. Additional proxies (faunal and floral assemblage data, bulk sediment properties, nitrogen isotopes, and measurements of sedimentary iron concentration) are used to infer semi-quantitative estimates of primary productivity and the position of frontal systems during the early Holocene.

OLIGOCENE TO QUATERNARY NEW ZEALAND TEMPERATURE FROM 80 YEARS OF POLLEN ANALYSIS

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We have estimated terrestrial temperature of the New Zealand landmass for the last ~30 million years, using analysis of fossil pollen and spore taxa from >2400 samples recorded in the New Zealand Fossil Record Electronic Database (FRED), and temperature estimated from the known temperature ranges of nearest living relatives. The record shows warming through the late Oligocene to the early Miocene, peak warmth during the middle Miocene, and punctuated cooling through the reminder of the Neogene. This pattern is very similar to estimates of global ice extent, although our regional signal will includes the ~5-10° equator-ward plate tectonic drift of the New Zealand landmass over this time period, and the increase of higher altitude biomes due to late Neogene and Pliocene uplift of the Southern Alps. Seasonal temperature estimates suggest low seasonality during the middle Miocene, and that subsequent Neogene cooling was largely due to cooler winters.

A REVISED CALIBRATION OF THE NEW ZEALAND GEOLOGICAL TIMESCALE: NZGT2015

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The New Zealand Geological Timescale (NZGT) is a regional geochronological timescale for the Permian to Pleistocene and comprises a sequence of stages defined in New Zealand outcrop sections. These stages have served an important role in fine-scale geological mapping since the mid-20th Century, and continue to provide a standard for stratigraphic subdivision by integrating biostratigraphic data from various fossil groups with other stratigraphic criteria.

Many of the most useful fossil groups for subsurface exploration in New Zealand Mesozoic-Cenozoic basins have essentially local biogeographic distribution, or local ranges which differ from those of other regions because of differences in paleoclimate or ocean circulation. Thus, the sequence of local stages which is closely tied to local fossils provides a more internally consistent, precise, and refined chronostratigraphy for routine use than international stages. Nevertheless, correlation with the International Geological Timescale (IGT) is required for communication with the international community, and age-calibration of stage and substage boundaries for estimation of rates of geological processes and correlation with numerical age data from radiometric and other methods.

The status of the New Zealand stages is reviewed in a new publication (Raine et al. 2015, GNS Science Report 2012/39) focussed on age-calibration of the stage boundaries. This revised calibration is based on calibration of the IGT by Gradstein et al. (2012, "The geological time scale 2012", Elsevier B.V.), and is consistent with the International Chronostratigraphic Chart 2015/01 (Cohen et al. 2015, International Subcommission on Stratigraphy). In the Cenozoic, calibration has relied mainly on correlation of planktic bioevents with the Geomagnetic Polarity Timescale (GPT), with input also from tephrochronology and isotope stratigraphy; in the Mesozoic and Paleozoic, the main approach has been biocorrelation of stage boundary and intra-stage bioevents with the IGT, with minor input from radiometric dating, carbon isotope stratigraphy and GPT.

INTEGRATED STUDY BASED ON SEISMIC VELOCITY STRUCTURE OF THE LITHOSPHERE AND GRAVITY ANOMALIES TO UNDERSTAND THE TECTONIC INTERACTIONS AND THE UNDERLYING DYNAMICS OF NE INDIAN REGION

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The Northeast Indian region is one of the interesting and complicated regions of the world in terms of geology and tectonics. The tectonic pattern of this region is very complex because of the interaction between the active north-south convergence along the Himalayan arc and the east-west convergence of the Indian plate along the Burmese arc. To address these issues and clarify the tectonic interactions and the underlying dynamics, we made an attempt based on the observed considerable lithospheric seismic velocity anomalies in conjunction with gravity anomalies observed in the study region. This in turn allows us to arrive at a common consensus on the geodynamics of the study region. We have analysed the data obtained from ISC bulletin for the years, September, 1998 to August, 2013, contributed by regional seismic networks in the northeast India (run by the India Meteorological Department, IMD, under the Ministry of Earth Sciences, Govt. of India). In total, we have used the data from available 24 seismic stations installed in the selected study region. In total, 11814 of picks including 6395 P- and 5419 S-arrival times from 1499 events in the study region (lying between 20°-32° N to 87°-101°E) were selected for this study. The tomographic image shows very heterogeneous and complicated lithospheric structure. The patches of high/low P- and S- velocity anomalies and high/low Vp/Vs zones are widely distributed at various depths but at some places more prominent relatively at shallower depths that may correlate with the high strain rate zones. The distributions of high Vp/Vs ratio patches may represent strongly fractured rocks with likely fluid content. We interpret that this correlates with the areas of significant seismicity. The inspection of the observed seismic anomalies pattern in conjunction with the gravity anomalies shows obvious correlation with the subsurface and fit well with the existing tectonic elements in the study region. We thus suggest and illustrate that the observed differences in the seismic anomalies patterns show differences in the geometry and structure of the lithosphere with different compressive forces at different places, governed by the underlying dynamics.

FUTURE-PROOFING GEOLOGICAL MAP INFORMATION

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Geological maps and their working compilations form the basis of GNS Science's Regional Geological Map Archive & Datafile (RGMAD), a listed Nationally Significant Database & Collection. Its contents include published and unpublished geological maps ranging back to the earliest 1900s. These maps contain information that could be very expensive to re-acquire (for example, in difficult country), impossible to re-acquire (for example, where land surface modification has occurred in mined areas and cities) and/or show insightful interpretation. These maps are used by research and resource exploration geologists for these unique observations and interpretation. The collection is being scanned and the images are available at several resolutions and formats through an image map server via an online dataset metadata catalogue http://data.gns.cri.nz/metadata/srv/eng/search. Right now there are 4906 maps that can be searched for, viewed and downloaded on a number of criteria including location, date and author. The remaining geological maps in the collection will be scanned and made available by mid-2016.

Near-universal adoption of digital mapping technologies in geological surveys around the world has created challenges around how geological map information can be preserved and re-used in the future. Hard copy representations of these digital geological maps are increasingly unsatisfactory with the complexity of information underpinning GIS dataset features and the emergence of 3D geological models. Software-tied digital map information, however, runs the risk of becoming unreadable through software obsolescence, media deterioration or other poor data management. Strategies to mitigate this revolve around robust data management practise, quality metadata and adoption of data exchange standards. Furthermore 3D geological models have inherent and spatially varying uncertainty in terms of feature locational accuracy and feature existence. Conveying uncertainty and retaining geological insight are additional challenges for long term future-proofing of valuable information in these models and innovative solutions are needed.

THE JAGGED ROCKS COMPLEX (AZ, USA) – AN EXAMPLE OF A MONOGENETIC VOLCANIC PLUMBING SYSTEM

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Monogenetic volcanoes have limited magma supply and lack long-sustained magma plumbing systems. They are born, erupt once, often from multiple vents and sometimes over several years, and then die. The course of these eruptions is very sensitive to the last stages of magma ascent at shallow crustal depths (< 1 km), which yield a spectrum of eruptive styles including weak to moderate explosive activity, violent phreatomagmatism, and lava effusion. Jagged Rocks Complex in the Hopi Buttes Volcanic field (AZ, USA) reveals the frozen remnants of the feeding systems for one or a few monogenetic volcanoes, and holds information on how a shallow magmatic plumbing system evolved within a stable shallow non-marine sedimentary basin, and on why magma flowing through the dikes began to fragment in developing conduits.

The complex, exposed 300-350 m below the pre-eruptive surface, consist of a NW-SE striking suit of intrusive sheets, a semi-circular saucer-shaped intrusion, and some sub-surface volcanic features that comprise in varying proportions fragmental and coherent rock, and which represent different styles and extents of fragmentation at depth. In particular, we have recorded i) buds formed as widened sections developed from dikes, ii) layered volcaniclastic massifs, which are bodies of outcropping igneous deposits projecting well above the ground surface, and iii) a poorly-exposed and debris-filled diatreme.

The diversity within the intrusive complex reveals that the plumbing system of a monogenetic volcano is not just simple and straight feeder dikes, and we infer that changes in the local stress field, in response to addition or removal of magma and country rock associated with surface eruptions, allowed subterranean magma diversion into sills and along dikes. We further infer that bud widening, massif emplacement and diatreme excavation represent different intensities of shallow-depth fragmentation, which may develop successively or/and at different sites during evolution of a monogenetic volcano.

SEDIMENTOLOGY AND TEPHROCHRONOLOGY OF A WAVE DOMINATED ESTUARINE SEQUENCE CONTAINING A MID TO LATE PLEISTOCENE VOLCANIC RECORD FROM THE TVZ: TAKAPARI FORMATION AND KAI IWI GROUP SEDIMENTS, POHANGINA, NEW ZEALAND

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Takapari Formation and Kai Iwi Group sediments exposed in tributaries of the Pohangina River, Manawatu record Mid to Late Pleistocene deposition within the south-eastern Whanganui Basin. The succession is characterised by predominantly fine grained sedimentation within shallow marine, estuarine and fluvial environments. A 71 m measured section records past depositional environments, local paleogeography and eruptive events from the Taupo Volcanic Zone (TVZ). Inner-most shelf, near-shore, estuarine and fluvial depositional environments are recognised. The Inner-most shelf environment is characterised by suspension fall out and traction current deposition. Near-shore environments are represented by fine grained rippled to laminated sands attributed to wave action and tidal currents. Fluvial deposition is characterised by coarse pumiceous sands displaying, cross bedding and channel cut and fill. The wave dominated estuarine environment is characterised by carbonaceous muds and is associated with the occurrence of *Austrovenus stutchburyi* and layers of lignite. Grain size analysis confirms a dominantly fluvial influence within the estuarine/fluvial sequence while in comparison the overlying Kai Iwi Group sediments display a characteristic marine signature. The Takapari Formation and Kai Iwi Group sediments were deposited within a shallow marine to transitional coastal plain setting within the south-eastern Wanganui Basin, during Late Nukumaruan to Early Castlecliffian time (1.8 Ma – 800 ka). These sediments record seven distinct volcanic eruptions from the TVZ ranging from 1.58 Ma to 800 ka. Scrimmys Tephra (new) located 12 m below Potaka Pumice is identified based on its unique geochemistry. Eruptions are identified via the influx of volcaniclastic sediment within overbank flow deposits and the preservation of air-fall tephras within quiet back-swamp environments.

CLIMATE CHANGE: CAN THE PAST INFORM THE FUTURE?

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Modern understanding of the climate history of the earth, derived from analysis of ice cores and the geology and chemistry of the earth's crust, is one of the great scientific achievements of the past century. The climate system has undergone major swings, from ice age to interglacial, hothouse to icehouse and back again. Ice sheets have waxed and waned and sea levels have varied hugely, typically over time scales of tens of thousands of years. At present, extremely rapid increases in atmospheric greenhouse gas concentrations have initiated changes in the climate system that are set to proceed at a vastly accelerated rate compared to what we have seen in the past, and which are likely to play out for centuries to come. Knowledge of past climate conditions derived from the geological record helps constrain our picture of the future, but detailed numerical modelling is needed to flesh out the details. The development of global climate models coupling atmosphere, oceans, cryosphere and biosphere, capable of simulating past glacial climates, present-day El Niño events, and projections of the climate of coming centuries, stands as another great scientific achievement of the past 50 years. This presentation will discuss what paleoclimate studies can tell us about the future of the climate system, how climate models give us a comprehensive picture of key physical processes and their interactions, and what may be in store for future generations.

WHERE IS THE SOUTHERN EDGE OF THE HIKURANGI PLATEAU BENEATH OTAGO?

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Tomographic inversions for crustal structure have shown that the amount of Hikurangi Plateau subducted at the Gondwana Margin and subsequently underplated after detachment of the leading oceanic crust is much larger than previously supposed. Fine-scale tomography using events in the Canterbury earthquake sequence has revealed that the plateau underlies this region at ca. 10 km depth, and played a major role in storing strain before the large earthquakes. So how much further south does this underplated plateau extend? We have initially studied earthquake waveforms at sparse GeoNet seismographs throughout the southern South Island. Many of these waveforms from larger regional earthquakes show a very fast (ca. 8.4 km/s) high frequency (4-9 Hz) P-wave precursor. These results are explained by propagation through a dipping layer of order 10 km thick with seismic velocity around 8.5 km/s. This layer is interpreted as eclogite at the base of the ca. 35 km thick plateau produced during plateau formation. To get better resolution on where the plateau underplates this southern region, we deployed a 20-station broadband seismograph network in the south eastern South Island during the period March 2014 – April 2015. The network operated between Riverton and Dunedin for the first half of this period, and between Dunedin and Temuka for the second half. Analysis of the excellent data from this network is on-going. But the data already shows evidence for an extensive plateau beneath the region. Not only do we see fast P-wave precursors across the network from larger crustal earthquakes (e.g. the Wilberforce earthquake sequence in January 2015), but we also see fast P-wave velocities of ca. 8.5 km/s across the network from deeper earthquakes in the central Southern Alps and in the Fiordland subduction zone.

DETERMINATION OF LAVA RHEOLOGY AND NUMERICAL RUN-OUT SIMULATION OF POTENTIAL LAVA FLOWS WITHIN THE AUCKLAND VOLCANIC FIELD, NEW ZEALAND

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The run-out distance of an erupting lava flow is a critical variable necessary for risk-based decision making, in land-use planning, and emergency management in volcanically active regions. Rheologic properties (a function of magma composition, crystallinity and temperature) of a lava will exert a significant control on the ultimate run-out distance. We know very little about the range in rheological properties of the Auckland Volcanic Field (AVF) lavas, and have only basic models for magma effusion rates. The goal of this study will be to understand the role that rheology plays in the run-out of AVF lavas. Specifically, we will determine the physical properties of a range of lavas to inform how lava rheology impacts flow run-out and provide more robust inputs into numerical models. This study will target three different volcanic eruptions with short (Otuataua), medium (Rangitoto) and long (Mt. Saint John) lavas. These volcanoes were chosen specifically because they represent significant variations in composition, run-out distance, and pre-eruptive topography. This work will combine data on melt composition, crystallinity, crystal size distribution and crystal and vesicle distribution, allowing for a more accurate determination of magma viscosity to ultimately improve models of lava flow run-out. Electron microprobe analysis will be used to determine melt compositions and provide backscatter imaging for crystal and vesicle distribution analysis, coupled with X-ray diffraction analysis of groundmass and whole rock crystallinity. Using the measured constraints on the rheological parameters, numerical modelling of lava flow paths will be conducted. The modelling will be done using the cellular automata model MAGFLOW in conjunction with LIDARDEM's to better constrain the effects of topography on the lava flows. Any systematic relationship observed between rheology and space will be explored via spatial interpolation methods such as Kriging to see the viability of such methods in predicting the nature future flows.

NEW LATE EOCENE GIANT PENGUIN FROM THE KYE BURN IN THE MANIOTOTO, CENTRAL OTAGO

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We report New Zealand's first Central Otago fossil penguin (OU 22761). This large penguin from the southernmost inner margin of the Cretaceous – Cenozoic Canterbury Basin is a significant addition to the fossil record for marine tetrapods in New Zealand. The *Palaeeudyptes*-like sphenisciform is from a glauconitic sand from the upper Kye Burn, Maniototo. The unit is decalcified and has been dated to late Eocene – earliest Oligocene (Runungan – lowermost Whaingaroan) with dinoflagellates; pollen supporting a probable late Eocene age. Age diagnostic taxa include *Stoveracysta kakanuiensis*. We interpret this unit to be a stratigraphic correlation to the Wharekuri Greensand of the Waitaki Valley, as opposed to the previously suggested Naseby Greensand, a locally-used formation that doesn't incorporate a wider Canterbury Basin lithostratigraphic context. The specimen is represented by an articulated, associated partial skeleton, deposited on an undisturbed seabed. The fossil has arranged cervical and upper dorsal vertebrae, forelimb and pectoral girdle elements (including well preserved humeri), and some hindlimb material. The specimen is referable to *Palaeeudyptes* due to distinct humeral characteristics. Similarities involve both size and shape of the head, relatively small tricipital fossa, slight preaxial angle, minor anterior angulation, slight sigmoidal shaft, and condyle orientation. Differences from described *Palaeeudyptes* species include the form of the internal tuberosity and capital incisura. To indicate size, the humerus is about 84% as long as that of the late Oligocene *Kairuku grebneffi* for which standing height was about 1.28 m. Late Eocene penguins, including *Palaeeudyptes*, provides a problematic polytomy in the penguin phylogeny. More associated specimens, such as the Kyeburn penguin, enable better comparisons between Late Eocene taxa from across the Southern Hemisphere. One of the most complete upper body Eocene specimens from New Zealand, this specimen expands our understanding about stem penguin body plans and phylogenetic relationships.

ACTIVE FAULTS AND LASER BEAMS: DEVELOPING A FRAMEWORK FOR MAPPING ACTIVE FAULTS FROM LIDAR DATA

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Lidar ('laser radar') datasets collected from aircraft provide a highly detailed and extremely accurate depiction of the ground surface. Digital Elevation Models (DEMs) and 'hillshade' models of DEMs derived from lidar data show topographic relief with unprecedented clarity. In New Zealand there is a rapidly increasing coverage of lidar that will provide an unprecedented opportunity for visualising, identifying, analysing and quantifying fault-related (tectonic) landforms at a cadastral scale. Currently there is no agreed or standardised approach for the spatial representation and attribution of active fault mapping based on lidar.

We are proposing to develop a framework that can standardise the collection of hazard data by all agencies (i.e. researchers or consultants) allowing implementation of hazard planning with few impediments and with a minimum amount of duplicated effort. The goal is to produce a documented national standard method for mapping active faults from lidar data that meets the needs of planners, researchers and scientists while also containing all relevant data that are needed to facilitate the application of the Ministry for the Environment Guidelines – Planning for Development of Land on or Close to Active Faults. The intent is to encourage capture of new information on active faults in a standardised form that can readily be absorbed into the New Zealand Active Fault Database, the National Seismic Hazard Model, risk models, geological hazard models and tectonic research. The framework could be used for all active fault mapping at a scale suitable for land-use planning and provide a platform for a national cadastral active fault database. We will present the preliminary framework and how we plan to apply it at a regional scale.

SHOALS, SEAWAYS AND SUBMARINE FANS: A REVISED PALAEOGEOGRAPHY OF THE OLIGOCENE PAPAROA TROUGH

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Previous palaeogeographic maps of the Paparoa Trough date back to the 1970s and 1980s. Over the last 35 years, more data has been collected and new and improved facies models proposed. Spurred by the ongoing, albeit modest resource interest in West Coast basins, the authors subdivided these strata (Nile Group) into a revised set of lithofacies and constructed a corresponding set of palaeogeographic maps for the Paparoa Basin during the Oligocene.

The basin contains three primary lithofacies, each extending 10s to 100s of kilometres and corresponding with formation-scale stratigraphic subdivisions.

Interbedded cross-bedded quartz sandstones and cross-bedded and bioturbated coralline algae grainstones comprise the nearshore facies association. These shallow marine facies encircle terrestrial and marine palaeohighs, marking the shallowest preserved environments.

A variety of cross- and horizontally-bedded bryozoan-rich grainstones and packstones comprise the seaway association. Cross-bedded units record more or less continuous, unidirectional currents. In contrast, bioturbated and horizontally-bedded units record relatively low-energy, wave-dominated conditions in a topographically constricted seaway.

Lastly, the submarine fan association encompasses massive and bioturbated planktic foraminifera wackestones and packstones locally interbedded with carbonate and siliciclastic sandstones, grainstones, and breccia. These lithofacies are interpreted as fine-grained background, hemipelagic sedimentation punctuated by coarse-grained sediment gravity flows. Together they record sedimentation on a submarine fan at the base of a marine slope and/or scarp.

These new palaeogeographic maps of the Paparoa Trough reflect more complex topography than previously inferred. A cross-section perpendicular to the basin axis reveals unexpected shallowing of the seafloor basin ward, followed by rapid deepening. These abrupt and seemingly erratic transitions are associated with modern fault systems and consistently proximal to lithofacies of the submarine fan association. Understanding these small-scale complexities is essential for meaningful extrapolation of basin geometry to other parts of the Paparoa Basin as well as the nearby subsurface and Challenger Plateau.

IS SURVEYING THE ENABLER OF GEOSCIENCE AND DISASTER RISK REDUCTION?

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Surveying involves precisely measuring a feature and consequently allows it to be spatially located in relation to other features. It can include survey of the land (topographic surveying), sea (hydrographic surveying), property (cadastral surveying), constructed features (engineering surveying) and the size, shape and nature of the earth (geodetic surveying).

By enabling information about a particular feature or location to be viewed in relation to other features, surveying allows geoscientists, applied geographers (e.g. land use planning and natural hazard management) and engineers to more easily combine their work in order to make better-informed decisions. For example, surveying enables the location, extent and features of a proposed land development to be precisely described. This information is used by local authority decision-makers during the consent process to understand the nature of the proposed development and its relationship to features that could be the source of a natural hazard such as rivers, the coast and fault lines. Surveying provides precise location information to assist decision-makers make better-informed decisions about natural hazard management. Improving location information through better surveying techniques and infrastructure can have a significant impact on national and local decisions.

With an increasingly multi-sectoral and interdisciplinary approach being taken to disaster risk reduction, we are making further efforts to understand how surveying can best contribute to geoscience and hazard risk management. We are working to identify how natural hazards might impact survey infrastructure and subsequently how this could impact communities, particularly during the recovery phase following a civil defence emergency. We are also seeking to understand how

we can build resiliency in the survey system so it is better able to assist communities before, during and after natural hazards events.

UNRAVELLING THE QUATERNARY STRATIGRAPHY OF THE SOUTH WESTERN RING PLAIN OF MOUNT RUAPEHU

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Mount Ruapehu is one of New Zealand's most active volcanoes in the late Quaternary period producing a wide spectrum of primary and secondary volcanic deposits. These include tephra fall, pyroclastic density currents, lava flows, laharic mass flows and sector collapses. Defining the frequency and magnitude of these past events is key to establish a probabilistic understanding of current and future volcanic hazard. However, a significant part of the geological record comprised in the south western ring plain of Ruapehu remains undiscovered.

The aim of this research is to develop a constructional history of the southwestern Ruapehu ringplain and to improve the understanding of the mass flow hazard. Detailed mapping of mass-flow units and cover-bed stratigraphy preserved over a 300km^2 study area offer the best clues to unravel this history. Paleosols, loesses and rhyolitic and andesitic marker beds in combination with marine isotope stages provide a framework to develop a regional stratigraphy. Lahar surfaces have been identified and characterised based on key outcrop descriptions and surface morphology and categorised into aggradational surfaces. Many of the older laharic surfaces have seen significant tectonic alteration adding to the complexity of interpretation. A compounding system of faults related to the southern termination of the Taupo Volcanic Zone adds to the geomorphic complexity of the study area. Late Miocene to early Pliocene mudstones belonging to the Matemateaonga formation underlie much of the southwestern ringplain and protrude the ringplain surface. These two factors have acted as the primary controls that determine the paths of mass flows and fluvial channels in the study area. This research will contribute to the understanding of the frequency, characteristics and distribution of mass flows and their triggering mechanisms in this sector of the Ruapehu ringplain and will assist future hazard assessments.

ALONG ARC FLUCTUATIONS IN MAGMATIC VOLATILES AND VOLATILE METALS IN NEW ZEALAND

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The behaviour of magmatic volatiles are important in understanding shallow crustal magmatic processes such as the transport of metals in magmatic ore formation and magmatic pressurization related to volcanic eruption triggering. In addition, magmatic volatiles contents are important for deciphering subduction zone processes such as the cycling of material from subducting plates to volcanic arcs. Here, we examine the relationship between volatiles and volatile metals in volcanic systems along the New Zealand volcanic arc, interpreting variations in in individual volcanic centres as well as whole-arc systematics (from Mt. Taranaki to White Island). Utilising both crystal chemistry and silicate melt inclusions, this study presents results of S and Cl content, as well as volatile metals (Li, Cu, +/- As, Mo, Sb, Sn, W, and Tl). Analyses were conducted in all major mineral phases in the intermediate-composition magmas of this study. Melt inclusion compositions range from basaltic (51 wt% SiO_2) to high-Si rhyolite (81 wt% SiO_2), however are predominantly andesitic to dacitic. Sulfur and Cl melt compositions are also highly variable, with concentrations from below detection limit up to ~2000 ppm S and 5300 ppm Cl. Silicate melt inclusions from Mt. Taranaki are significantly enriched in volatiles compared to along-arc volcanoes (Tongariro-Ruapehu, Mt. Edgecumbe, and White Island). Although Cu and Li are the only elements analysable in every mineral phase, Cu contents tend to be highly variable compared to other volatile metals and may suggest the influence of a combination of diffusion-crystallization processes. New crystallization experiments on hydrous dacite are used to reassess partitioning

data and the potential for volatile fluxing and diffusion in intermediate-silicic magmatic compositions.

THERMOCHRONOLOGY AND EXHUMATION AT THE ALPINE FAULT 'BIG BEND'

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In the South Island, the main source of seismic hazard is the Australian-Pacific plate boundary Alpine Fault. The ~650 km-long Alpine Fault is remarkably straight at a regional scale, except for a prominent S-shaped bend in southeast Nelson. This is a restraining bend, and has been referred to as the 'Big Bend' due to similarities with the Transverse Ranges section of the San Andreas Fault (Yeats & Berryman 1987). The timing of Big Bend development is poorly constrained to the Neogene. We are using the fission-track and $^{40}Ar/^{39}Ar$ thermochronometers, together with basin-averaged cosmogenic nuclide ^{10}Be concentrations, to quantify Neogene–Quaternary exhumation rates of the Australian and Pacific plates adjacent to the Big Bend. The thermochronologic data will also constrain the onset of Alpine Fault-related exhumation.

Exhumation rates are expected to be on the order of a few millimetres per year, and greater than those for adjoining sections of the Alpine Fault (~3 mm/year). Slightly to the north of the study area, a mean exhumation rate of 0.7 mm/year for the Middle Miocene–Pliocene has been estimated from apatite fission-track thermal history models (Sagar 2014). Apatite fission-track cooling ages indicate that exhumation of the Australian Plate related to the Alpine Fault had begun prior to 16–10 Ma, and ~5.5 km of exhumation has occurred since that time. The steepness of stream channels draining mountains either side of the Big Bend indicate equilibrium between uplift and erosion. The implication of this is that Quaternary erosion rates estimated from ^{10}Be concentrations will approximate uplift rates. These uplift rates will help to better constrain the likely frequency and magnitude of earthquakes generated by the Alpine Fault Big Bend in the National Seismic Hazard Model.

UNDERSTANDING KEY RISKS ON PETROLEUM PROSPECTIVITY IN THE CANTERBURY BASIN USING 2D BASIN MODELLING

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There is a working petroleum system in the Canterbury Basin, as suggested by two sub-commercial gas-condensate discoveries. However, no significant discovery has been made in the basin. To evaluate basin prospectivity it is important to understand the key risks associated with the petroleum system elements. To address this, an updated series of facies maps in the offshore Canterbury Basin was produced to show source, reservoir, and seal rock distribution. These facies maps were used to build a 2D PetroMod model to assess how source, reservoir and seal rock distribution, and timing of expulsion relative to seal quality development impacts the basin prospectivity.

Key risks in the basin are; the requirement for seal to preserve early expulsion from the mid-Cretaceous source rock, heterogeneity in potential reservoir rocks, and limited maturity of Late Cretaceous source rocks. Mid-Cretaceous rocks are predicted to have expelled hydrocarbons since the Early Paleocene, peaking before the end of the Eocene. Early seal development during the Paleocene–Eocene is necessary to trap these expelled hydrocarbons. The modelling results combined with the absence of an economic hydrocarbon accumulation at Clipper-1 suggest that the presence of a good quality reservoir is also a major risk for the mid-Cretaceous interval in this basin. However, reservoir quality may vary within facies belts depending on their provenance and sedimentary architecture.

In the current model, beneath prograding Neogene foresets, seal capacity above the Herbert Formation (85–75 Ma reservoir interval) started to develop at the end of the Late Miocene and these seals withhold small accumulations originally expelled from the mid- or Late Cretaceous source rocks. Additional multi-1D/3D modelling is required to identify structural/stratigraphic traps with good quality reservoir and top seal in locations suitable to receive charge from mature source rock kitchens.

EFFECT OF MICROSTRCTURAL HETEROGENEITY ON STRAIN LOCALISATION IN THE ALPINE FAULT

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Fluids and minor phases have an important influence on the bulk rheology of a deforming rock mass, but they are not uniformly distributed at any scale within fault zones. These heterogeneities, such as grain-boundary pores and fine-grained secondary phases, impede grain-boundary mobility and cause a transition in deformation mechanisms from grain-size insensitive dislocation creep to grain-size sensitive creep, which is recognized as a weakening mechanism that promotes strain localisation.

At present, it is unclear how the distribution of grain-boundary pores within Alpine Fault mylonites reflects the bulk mineralogy and phase arrangement, which is a function of shear strain. We have used micro-computed x-ray tomography (μ-CT), scanning electron microscopy, and energy dispersive spectroscopy (EDS) analyses to examine how the distribution of grain-boundary pores varies in relation to the arrangement of secondary phases in exhumed mylonites within the actively-deforming Alpine Fault zone, and in samples acquired from the Deep Fault Drilling Project (DFDP). Additionally, electron backscatter diffraction (EBSD) is coupled with μ-CT and EDS analyses to characterise the evolution of microstructures in three dimensions across a finite strain gradient. Here we examine the relationship and competition between grain-boundary cavitation and microstructural processes during deformation in a high-strain shear zone, and discuss the implications of these grain-scale deformation processes on strain localisation and continental fault zone dynamics.

FROM SCIENCE TO PRACTICE: A FRAMEWORK FOR RISK-BASED LAND USE PLANNING FOR NATURAL HAZARD RISK REDUCTION

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Land-use planning is often described as an opportune tool available for reducing or even eliminating risks to natural hazards. To assist in fulfilling its potential, a risk-based land use planning toolkit was launched in New Zealand in 2013. Two years on, many local governments are taking a risk-based approach to their plans, and natural hazard risk is being proposed to be included in land use planning legislation. So what is risk-based planning, and how is it different from hazard-based approaches?

Rather than being hazards based (i.e. a focus on likelihood only), a five-step risk-based approach (i.e. with a focus on consequences and likelihood) to natural hazards has been developed, with associated community engagement and consultation at each step. The five steps are:

1. Know your hazard;
2. Determine the severity of the consequences;
3. Evaluate the likelihood of an event;
4. Take a risk-based approach; and
5. Monitor and evaluate.

The result is a framework where land use is assessed on risk, with a focus on consequences. It is about *smarter* development, not necessarily *no* development. This innovative approach provides a real opportunity for natural hazard and risk science to be incorporated into land use planning – the ultimate tool in reducing risks from natural hazards.

This poster presents the risk-based approach developed in New Zealand, which enables levels of risk to be qualified and measured.

CHALLENGES AND OPPORTUNITIES OF INCLUDING NATURAL HAZARD SCIENCE IN LAND USE PLANNING – THE CASE OF PETONE PLAN CHANGE 29

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Land use planning provides a key opportunity to reduce future risks from natural hazards. However, even in a post-Canterbury earthquake environment, decision makers are still struggling to incorporate natural hazard science into their land use plans. This can result in decisions that sometime surprise natural hazard scientists who are aware of the possible risks. Recent events in Petone, Lower Hutt provide a good example of the challenges and opportunities both scientists and decisions makers face.

In June 2012 the Hutt City Council notified a plan change (known as Plan Change 29) within the south western portion of Petone, Lower Hutt. This plan change allowed for an increased level of development and encouraged mixed-use development. Prior to the plan change, the land use was predominantly business and commercial; this plan change proposed introducing residential, educational and emergency facilities.

The proposed plan change area is subject to a number of natural hazards including fault rupture, ground shaking, subsidence, sea level rise, liquefaction, flooding, and tsunami. The previous district plan provisions for the area had very limited rules to address and mitigate the risks from natural hazards, and no new rules were proposed as part of this plan change. Being a good 'corporate citizen' of Hutt City, GNS Science lodged a submission opposing the plan change based on the range of natural hazards that were not addressed in the plan change.

While the plan change still went ahead, natural hazard provisions were improved through the submission process. Many aspects of the submission were based around the natural hazard research and social science undertaken within the It's Our Fault project (IOF), and other core-funded GNS Science research, largely undertaken within the Natural Hazards Research Platform.

This presentation will outline the natural hazards of the Petone Plan Change area, and the challenges and opportunities of natural hazard science being incorporated into land use plans.

SHEAR WAVE SPLITTING OF LOCAL EARTHQUAKES NEAR THE ALPINE FAULT

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We characterize seismic anisotropy along the Alpine Fault near the Deep Fault Drilling Project (DFDP) boreholes using shear wave splitting of local earthquakes. We combine data from the SAMBA network of 2 Hz borehole seismometers, the DFDP10 short-period surface network, and the GeoNet broadband network. Using the MFAST automatic shear wave splitting program, 1.5 years of data yielded 15,902 measurements. Of these, 1291 measurements from 23 stations were of high quality (grades of A or B). Their fast azimuths tend to be N/S or NE/SW, subparallel to the Alpine Fault for paths travelling east of the fault, and for paths close to the fault, fast azimuths are subparallel to the azimuth of maximum horizontal compressive stress of N110 E. Some stations show a single population of fast directions and others show two or more populations, which are related to the earthquake locations. We consider that the orientations are likely caused by a combination of stress-controlled, crack-induced anisotropy and structure-controlled anisotropy associated with the fault fabric and its interaction with the dominantly schistose rocks in the region. Delay times for the highest-quality measurements average 0.067±0.002 s, consistent with small splitting of the high-frequency phases (dominant frequencies 6.9±0.07 Hz) with short path lengths (4.5±0.09 s travel-time). If the anisotropy is present along the entire path, the percentage anisotropy is 1. 5%. However, delay times do not increase much with hypocentral distance, suggesting that near-surface effects are dominant and hence that anisotropy is greater near the surface. To ensure the shear-wave splitting results do not depend on the particular algorithm used, a second semi-automated processing routine with different shear-wave splitting criteria is applied. A comparison of the results is anticipated to help to identify and mitigate any possible artefacts.

STRUCTURAL CONTROLS AND GEOCHEMICAL FOOTPRINTS AS VECTORS TO ORE-GRADE GOLD MINERALIZATION: INSIGHTS FROM THE KARANGAHAKE AU-AG EPITHERMAL DEPOSIT, NEW ZEALAND

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The Karangahake epithermal Au-Ag deposit is located approximately 6 km southeast of Paeroa, in the southern province of the Hauraki Goldfield, New Zealand. Mining and exploration in the area has been active intermittently over the past 150 years, resulting in a substantial amount of legacy data. Existing historical datasets (with good 3D exposure provided by drill core and underground workings), augmented with new structural and geochemical data provide a unique opportunity to identify structural controls and geochemical vectors towards high-grade ore.

Here we present preliminary geochemical results for a 3D model displaying hydrothermal alteration geochemistry and mineralogy within a structural framework. The spatial trends of the geochemical footprint were analyzed using coarse rejects and select pulps of over 500 channel samples, with industry standard materials and software: Portable X-Ray Fluorescence (pXRF), short-wave infrared (TerraSpec), Leapfrog and ioGas. The pXRF and TerraSpec allow us to analyze a large suite of samples relatively rapidly and non-destructively and collect precise multi-element geochemistry and alteration mineralogy data respectively. Portable XRF data is validated using lithogeochemical standards and lab-based X-Ray Fluorescence on fused beads and pressed pellets. Structural data from oriented drill core and underground mapping provide the structural framework.

The significance of these findings with respect to understanding fluid flow in paleohydrothermal systems and identifying vectors to mineralized structures will be discussed. The overall aim of this study is to use the conceptual model for the Karangahake deposit to create an exploration model for epithermal gold deposits in general, reducing exploration risk.

NORTHERN TARANAKI BASIN: SEISMIC-STRATIGRAPHIC RECORD OF THE TRANSITION FROM MESOZOIC SUBDUCTION TO CONTINENTAL BREAKUP, AND THE DEVELOPMENT OF THE MODERN NEW ZEALAND PLATE BOUNDARY

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Interpretation of seismic reflection lines in the northern Taranaki Basin constrains New Zealand plate boundary deformation. The tectonics, stratigraphy and petroleum systems in the northern Taranaki Basin have been examined using 2D and 3D seismic reflection surveys tied to 31 exploration wells. These seismic lines image a mid-Cretaceous to Recent sedimentary succession (<c. 100 Ma) up to 11 km thick that unconformably overlies Paleozoic to Mesozoic basement. Seismic correlation indicates that mid-Cretaceous strata are more extensive beneath the Northern Graben than previously interpreted. These seismic data have been used to generate regional cross sections, structure contour, isopach, erosion and paleogeographic maps, and a preliminary regional 3D model for 12 horizons. The sedimentary sequence typically comprises early rift (c. 100–55 Ma) and transgressive strata (55–23 Ma) followed by Early Miocene and younger broadly regressive units. The strata record multiple phases of deformation. Thrust faults, west of the Taranaki Fault, primarily displace mid-Cretaceous strata suggesting early Late Cretaceous shortening. Early contraction followed by rifting is recorded by half grabens infilled by up to 7 km of mid- to Late-Cretaceous rocks deposited during two separate phases of rifting. The two phases of rifting are delineated by fault trends and sediment thicknesses.

Cretaceous rift and thrust faults (including the Taranaki Fault) strongly influence later reverse and extensional fault geometries associated with the development of the modern plate boundary. The northern Taranaki Basin tectonic data are

consistent with Mesozoic subduction continuing to c. 90 Ma and two phases of Cretaceous-Paleocene Gondwana break-up (c. 100–55 Ma). Miocene and younger shortening along the eastern margin of the basin, and Mid-Miocene to Pleistocene rifting, are interpreted to reflect Cenozoic subduction (<40 Ma), which is initially dominated by contraction followed by intra-arc extension in association with, or, as a consequence of slab steepening.

HISTORIC TARGETS AND PARAGENESIS OF THE BIG RIVER SOUTH – ST GEORGE AU DEPOSITS, REEFTON

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Visible gold occurs within the little-known historic Big River South and St George deposits in the SE of the Reefton Goldfield. Au-bearing stockworks at each deposit are located on the sub-vertical eastern limb of the Big River syncline. Reconstruction of historic working has revealed that the mineralised zones comprise three discreet reef systems. These reefs are located on faults striking sub-parallel to bedding (N-S). In places the reef systems are offset by a later stage of E-W faulting. Detrital mineral textures are common in the alteration zone, but pyrite and needle-like auriferous arsenopyrite are disseminated throughout and the rocks exhibit a pale green-grey colour due to the formation of sericite. The individual halos extend 10s of meters from the principle mineralisation providing an extended target for excavation. Visible gold occurs in quartz veins adjacent to sulphitic stylolites. Gold is associated with the introduction of As, Fe, Cu, Pb and Sb complexes. Observations so far suggest that mineralization occurred throughout an initially ductile stage and was subsequently reworked during a brittle event.

TERMINATION OF THE EARLY EOCENE CLIMATIC OPTIMUM IN THE SOUTHWEST PACIFIC: CALCAREOUS NANNOFOSSIL PALEOBIOGEOGRAPHY AND PALEOCLIMATIC IMPLICATIONS

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Calcareous nannoplankton live within the photic zone of the ocean and are therefore important recorders of surface water conditions at the time of their existence. Variations in the biogeographic distribution and diversity of nannoplankton provide critical information about changes in the marine environment resulting from fluctuations in global climate. Expansion of the biogeographic range of modern coccolithophores has been linked to changes in sea-surface temperature, nutrient availability and ocean chemistry [1]. Additionally, nannofossil assemblage analysis has been demonstrated to be a useful tool in the reconstruction of paleoenvironmental conditions during the Paleogene [2, 3].

This study focuses on early Eocene calcareous nannofossil assemblages from three locations in the southwest Pacific along a latitudinal transect from Campbell Plateau to Lord Howe Rise (paleolatitude ~60°S to 53°S respectively). In particular we examine the turnover of nannofossils at the termination of the Early Eocene Climatic Optimum (EECO; ~50 Ma) and the changes in assemblages during the period of cooling that followed. At the mid-Waipara River section, Canterbury Basin, the termination of the EECO is marked by a distinct turnover event, with a decrease in *Toweius* spp. and a concomitant increase in *Reticulofenestra* spp. A significant decline in the *Discoaster*/*Chiasmolithus* warm-water index is also observed at mid-Waipara, indicating a pronounced cooling phase following the EECO. On-going analysis of assemblages from Campbell Plateau and Lord Howe Rise sites will help to determine the extent of a warmer, more oligotrophic water mass in the high southern latitudes and how it evolved through time.

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REFINING THE HYPOCENTRES OF MICROSEISMIC EVENTS FOR RESERVOIR MONITORING WITH THE FULL WAVEFORM

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The estimation of the hypocentres of seismic events is crucial in the interpretation of subsurface structure and tectonics, but also forms an important tool in geothermal and hydrocarbon reservoir monitoring. Historically, hypocentre estimates are based on the picks of distinct wave phases (primary and secondary body waves, mainly), but our approach has been to study the full waveform in the time and frequency domain.

Micro-seismic events were detected by borehole seismometers, as part of a CO_2 sequestration project from the Aneth Oil field in Utah, USA. These events were originally clustered based on their P wave similarity, but further sub-clustering of these events based on their full waveform reveals important information about the spatial distribution of events.

Refining the hypocentre estimates is commonly done by studying the relative distance between events in a cluster, called double difference tomography. Now that our full-waveform analysis has provided additional information about which events in a large cluster belong together, we discuss the process of double difference tomography, with and without the additional information from our full waveform analysis. We conclude that the double difference tomography on the sub-clustered events improves the spatial information in relocated hypocentres.

WHAT ACTIVATES THE CATFISH? STRUCTURAL PERSPECTIVES ON EARTHQUAKE ACTIVITY IN NEW ZEALAND

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The 'World Stress Map' demonstrates that 'Andersonian' stress states (with one of the three principal compressive stresses vertical) prevail over the vast bulk of the crust. Frictional fault mechanics appears to work well in the upper continental crust where a high proportion of damaging earthquakes originate. In this seismogenic zone (commonly 10-20 km thick) fault shear strength is approximated by a Coulomb criterion,

$$\tau_f = c_{flt} + \mu_s \sigma_n' = c_{flt} + \mu_s(\sigma_n - P_f)$$

where τ and σ_n are, respectively, components of shear and normal stress acting on the fault, P_f is the pore-fluid pressure, $c_{flt} < C_{rock}$ is residual fault cohesion and μ_s is the static coefficient of friction (typically ~ 0.6, near the bottom of the 'Byerlee' range). Two principal drivers to fault failure are thus changes in the stress state (increasing τ, and/or decreasing σ_n), and increases in P_f.

Plate tectonics can only work if plate boundaries are weak with respect to plate interiors. Plate interiors have comparatively high levels of differential stress ($\sigma_1 - \sigma_3$), emphasized recently by earthquakes induced by injection of waste fluids into crystalline basement (e.g. Colorado, Oklahoma, Basel). The important question then is what weakens plate boundaries? Along fluid-rich subduction systems, various forms of fluid-induced weakening (lowering of effective stress from fluid overpressuring to produce critical stress-overpressure states, hydration reactions, stress corrosion cracking, diffusive mass transfer, etc.) probably dominate. Indeed, subduction megathrust interfaces appear fluid-overpressured to near-lithostatic levels over their full seismogenic depth (40+ km). Fluid-induced weakening may also affect the crust overlying dehydrating subducting slabs.

While a broad range of earthquake science is undertaken throughout New Zealand, research into tectonic stress and fluid overpressure as the fundamental causes of fault instability has not been emphasized. A 'crustal rock mechanics' approach is warranted incorporating: (1) full analysis of the contemporary tectonic stress field with construction of stress trajectory maps; (2) documentation of the fabric of known active and inherited faults (L >10 km) throughout the country; (3) assessment of the 3D geometry of individual faults to the fullest extent possible; (4) combining fault geometry with established stress fields to carry out 'slip-tendency' analysis for individual structures; (5) investigations of the physical conditions of seismogenesis for different tectonic domains using electrical and seismic sounding techniques; and (6) exploring the stress/fluid-pressure conditions for individual fault structures to assess their reactivation potential.

FANGS EXPOSED: CT-SCAN PROCESSING OF A MOSASAUR JAW SEGMENT FROM THE MAUNGATANIWHA SANDSTONE

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The Late Cretaceous Maungataniwha Sandstone, inland Hawke's Bay, has produced many vertebrate bones since the first were discovered in the late 1950s. Although the bones are mostly of marine reptiles, a dozen or so isolated dinosaur bones have also been found. There is still much to be discovered there, but traditional extraction, involving mechanical preparation and acid etching, is labour-intensive, costly and extremely time-consuming. A recent spectacular find of a segment of a large mosasaur jaw was collected and prepared virtually via CT-scanning. The 590 mm length boulder containing a partial mosasaur jaw (200 mm in length) with three teeth was scanned in a GE Brightspeed 16 slice system CT-scanner at 120 kV at the Pacific Radiology Laboratory at Southern Cross Hospital, Wellington. The scan was acquired using a 0.625 mm slice thickness and interval, with two series being produced (soft and sharp). The reconstructed soft series was then transformed from DICOM files to .bmp images and processed using the software CTAn (Skyscan, Belgium). Jaw and teeth were isolated from associated matrix, virtually, using threshold manipulation and manual selection. This processed dataset was then transformed into a 3D volume using CTVox (Skyscan, Belgium). Images from different angles and positions were then obtained, and movie clips were produced. The 3D volume was further processed using Mimics (Materialise, Belgium) to smooth the outer surface and remove coarse traces of the boundary between slices. An .obj dataset was then produced, which will allow 3D printing of the object. This virtual preparation allowed the specimen to be preserved in situ without the risk or time of traditional extraction and leaving an unblemished boulder. The resources produced (images, video clips and 3D prints) represent unrivalled sources of material for both scientific purposes and for science engagement and outreach.

CAN STALACTITES YIELD RELIABLE PALEOCLIMATE RECORDS?

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Stalagmites have a number of advantages for paleoclimate reconstruction, but a tendency for discontinuous growth often leaves gaps in a climate record. It is now standard practice to develop continuous climate time-series by combining multiple stalagmite samples that overlap in time. However, obtaining enough specimens to generate a continuous record can be challenging, especially as excessive destructive sampling is ethically and aesthetically undesirable.

These ethical challenges are partly circumvented by the use of naturally broken stalagmites recovered from cave-floor rubble. Unfortunately, natural breakage of stalagmites most commonly occurs through cave roof-collapse which tends to bury the specimens, making them rare to find. In contrast, stalactites often break naturally through roof delamination, and can commonly be found lying atop cave-floor rubble, especially in tectonically-active locations.

Despite their more common occurrence, stalactites have received little attention as possible paleoclimate archives, largely due to their more complex growth form, hence internal structure in longitudinal-section. However; in cross-section stalactites resemble tree-rings, with radial traverses representing simple chronological sequences.

Here I present initial results from a research project aimed at assessing the suitability of stalactites as paleoclimate archives. Utilizing high spatial-resolution analysis (laser-ablation ICP-MS for trace elements and micromilling for stable isotopes), I compare multiple radial traverses to evaluate how consistently geochemical time-series reproduce; a necessary prerequisite for stalactites to capture reliable paleoclimate information. Preliminary results indicate that inconsistent ('patchy') growth along different radii may impose a practical minimum on the temporal resolution of reconstructed paleoclimate time-series. However, $\delta^{18}O$ and several trace elements show fair reproducibility, suggesting that stalactites do have some potential as paleoclimate archives.

WIDE-ANGLE SEISMIC IMAGING, TO MANTLE DEPTHS, OF THE MIOCENE PLATE BOUNDARY BENEATH THE TARANAKI FAULT ZONE AND WANGANUI BASIN

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We report strong, wide-angle, seismic reflections from the mantle and crust beneath the Taranaki Fault Zone (TFZ), southwest North Island, New Zealand. We attribute these reflections to a serpentinised, fault zone that accommodated large amounts (~100km) of shortening and mountain building during the Miocene. The 2011 SAHKE experiment carried out multi-component, active-source seismic surveys along a length of about 300 km across the southern North Island. The middle 100 km of the line is on land. Twelve large explosions (500 kg weight) were detonated onshore into an array of ~ 900 vertical component and 300 horizontal component seismographs in the on land section. Deep reflections are evident on both the land and marine seismic data. At 30 s two-way travel-time (twtt) are ~ 100-km-deep reflections that have been interpreted to come from the base of the subducting Pacific plate*. But at 20 s twtt there are back-dipping reflections/diffractions that when migrated are located in the mantle wedge of the overriding Australian plate. These reflections are in the depth range of 40-70 km and dip ~45 degrees to the southeast. Coincident S-S reflections are also seen on the horizontal geophones of the land array coming in at ~ 34 s twtt. Zoeprittz equation solutions show that if both P-P and S-S arrivals are generated from a common reflector a negative impedance contrast is required. We suggest serpentinite is the most likely cause of the reflectivity. Marine reflection data show low-frequency reflections around the Moho depths that we also associate with both serpentinite, and recently documented slow-slip events on the subducted plate interface. Overall, the crust and mantle beneath the TFZ appears to be highly altered by faulting and serpentinisation, and this is now modulating seismogenesis in central NZ to varying degrees.

* Stern T.A. et al (2015), doi10.1038/Nature14146.

AUCKLAND'S BURIED FAULTS AND THEIR INFLUENCE ON ITS GEOLOGY

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Gridded images of Bouguer gravity data reveal previously undocumented ~NE-trending faults in the basement rocks beneath Auckland. These structures are interpreted from offsets in the dominant NNW-trending gradients sourced from density contrasts between the Waipapa Terrane, inferred Dun Mountain Ophiolite and Murihiku Terrane. Outcropping examples of these structures offsetting basement rocks are observed in Clevedon, the Hunua Ranges and on Waiheke Island. On the Auckland isthmus these structures do not have a strong signature within the Waitemata Group sedimentary rocks and they are apparently not associated with significant pre-volcanic paleotopographic lows. However, form surface mapping and further interpretation of geomorphological lineaments around Auckland show that this fault trend is common within the Waitemata Group and structures that can be linked to the basement occur between Whangaparaoa and Takapuna as well as between Mission Bay and Howick.

Although there does not appear to be significant post-Miocene offset on many of these structures, their potential for dilation is high within the current geodynamic setting of Auckland. This, coupled with their potential for basement-tapping depth extents makes them excellent candidates for the control and ascent of magma during the formation of Auckland's volcanic field. NE-trending dykes have been inferred previously within the Auckland Volcanic Field and a case can be made for vent alignment in some situations. The control of NE-trending faults on vent alignment is well founded in the South Auckland and Ngatutura volcanic fields adding weight to the observations made here. However, additional complexities in vent positions in the Auckland Volcanic Field may be attributable to the intersection of the newly interpreted faults with the prominent NNW-trending terrane boundary structures, particularly above inferred the Dun Mountain Ophiolite and its numerous interpreted fault slices.

The tectonic significance of these faults may shed further light on the localisation of other basalt volcanic fields in the northern North Island and has implications for regional hazard analyses (e.g. seismic, landslides).

USING CLAY MINERALOGY TO DETERMINE EVENT SEQUENCES IN THE 2012 TE MAARI HYDROTHERMAL ERUPTIONS, TONGARIRO

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The hydrothermal eruption at Te Maari, Mt Tongariro, on 6 August 2012 was triggered by landslide failure of the SW crater flank. The eruption started in an area above Upper Te Maari Crater, resulting in ejection of ballistics and fall deposit emplacement to the NE. Emplacement of surge deposits to the E was also inferred. A few seconds later a vertical blast from the Upper Te Maari crater resulted in an 8-10 km high plume that dispersed to the E, to form the eastern and main tephra lobe. It was accompanied by emplacement of surge deposits to the W. A subsequent, smaller eruption occurred in November 2012.

Preliminary XRD data showed differences in mineralogy between the N and E tephra lobes. Ash deposits and source area hydrothermal material contained cristobalite, tridymite, quartz, feldspar, pyroxene, pyrite, gypsum and kaolin minerals. Kaolin dominated highly altered source area zones while gypsum and pyrite were more abundant in less weathered materials. This study examined mineralogical assemblages in a wider range of Te Maari phases. The north tephra lobe contained gypsum and pyrite with little kaolinite and is thought to result from initial destruction of the hydrothermal cap. Surge deposits contain kaolin and no gypsum or pyrite, suggesting deposition of the N tephra lobe was not a result of ash generated by surge emplacement. The E lobe also contains kaolin and little pyrite or gypsum, suggesting that the surges and the eastern tephra tapped a more highly altered part of the hydrothermal system than the northern lobe tephra. The mineralogical data thus provides constraints on event relationships in this short duration eruption episode.

The November 2012 event mineralogy is also kaolin-dominated with only traces of pyrite and gypsum, consistent with the further activity being from the Upper Te Maari vent.

MAPPING MID-WATER BUBBLE (GAS) PLUMES FROM LAKE ROTOITI AND CALYPSO VENTS; A NEW TOOL FOR DECIPHERING ACTIVE LACUSTRINE AND SUBMARINE HYDROTHERMAL SYSTEMS

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A mid-water column study of bubble plumes from two different locations, Lake Rotoiti (Rotorua) and Calypso Vents (Bay of Plenty) has been undertaken for the first time. Lake Rotoiti sits astride the northwestern margin of the geothermally active Haroharo Caldera of the Okatanina Volcanic Centre. Fifteen line-kilometers of water column and swath multibeam data were collected using a Kongsberg EM2040C MBES over this site. The Southern Vent Field of Calypso Vents is located 17 km south of White Island and is a known site of active hydrothermal venting. Here, 63 line-kilometers of water column and swath multibeam data were collected using a Kongsberg EM3002D MBES.

Water column data were processed and analysed by FMMidwater, a plug-in to the QPS Fledermaus software suite. Parameters and statistics were recorded for each individual plume before being exported as three different views. A method comparison analysis was also undertaken to determine the best way to select data to create a 3D volume object for individual plumes. Water column data provides an insight into the physical nature of bubble venting and when combined with high-resolution bathymetric data, outlines the spatial constraints of a lake/seafloor hydrothermal system.

At Lake Rotoiti, 277 plumes were analysed within an area of 635 x 920 m. Two venting styles were identified: continuous (near) vertical plumes, and bubble clusters. The latter were focussed areas of high acoustic backscatter that could be either bubbles or fish. Plumes range in height, with some reaching the lake surface; the majority of plumes originate from the centre of one of the many craters. The Southern Vent Field had two active vent sites, with some plumes from these sites also extending to the sea surface. Plumes in this data set were similar in nature to the continuously venting (near) vertical plumes identified in Lake Rotoiti.

MID-CRETACEOUS TO PALEOCENE BASIN EVOLUTION OF NORTHWESTERN ZEALANDIA: IMPLICATIONS FOR RIFT HISTORY AND PETROLEUM SYSTEMS

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We present the results of new regional seismic mapping in the offshore northwestern sector of New Zealand, which includes the Taranaki, Deepwater Taranaki and Reinga-Northland basins. An updated model for the rift history of these basins has been produced, and can be related to regional Gondwana breakup tectonics. Inferences can also be made as to the likely presence of key petroleum systems elements, particularly source rock and reservoir facies, crucial to future exploration efforts in the region.

An early 'mid' Cretaceous rift phase, long inferred in the Deepwater Taranaki Basin, is now recognised as being widespread in the proximal Taranaki Basin and throughout the Reinga-Northland Basin. Extension, orientated roughly NE–SW, was related to initial Tasman Sea rifting and ceased when sea floor spreading began at c. 83 Ma. 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 Zealandia-wide tectonic event associated with Gondwana breakup.

A brief (<4 Myr) period of uplift and erosion followed breakup, and coincided with the deposition of the thick Taranaki Delta in Deepwater Taranaki. In southern parts of Taranaki Basin, this uplift event led to only small erosional remnants, often tilted and folded, of the early rift-related strata being preserved beneath Late Cretaceous to Paleocene strata.

A second, Late Cretaceous–Paleocene rift phase (c. 80–55 Ma) 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 significantly affect more distal areas, such as Deepwater Taranaki or Reinga-Northland basins. Extension was orientated NW–SE to E–W, roughly orthogonal to the first rift phase.

DIVERSE USES OF PETLAB: NEW ZEALAND'S NATIONAL ROCK AND ANALYTICAL DATABASE

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Petlab is New Zealand's online national rock and analytical database. It provides an accessible, structured and permanent data repository of locations, descriptions and analyses of rock and mineral samples from onland New Zealand, the offshore New Zealand region, Antarctica and worldwide. The major data contributors are GNS Science and Auckland, Massey, Waikato, Victoria, Canterbury and Otago universities, all of whom use the database as a digital catalogue for their rock and mineral collections. The size and scope of the database continues to grow, with >194,000 samples catalogued as at September 2015.

As a scientific tool, the database greatly enhances and complements pure and applied solid earth research. Some specific applications and general uses include:

1. Environmental studies: establishment of local, regional and national baseline concentrations, for example of toxic elements in soil.
2. Mineral prospectivity studies: ability to search for the distribution of pathfinder elements (i.e. As, Sb) and identification of anomalous versus background values.
3. Geophysics studies: capacity to establish the U, Th and K contents by rock unit for heat flow and gamma log interpretations, and the magnetic susceptibility of different rock types and stratigraphic units (useful for comparison with airborne geophysics i.e. radiometrics, aeromag)
4. Basic data discovery tool: identifying, via the web map, who collected what material from a particular onland or offshore area, where hand samples are now located and what analyses were done.
5. Innovative querying of geochemical and petrophysical data: using the Litho2014 stratigraphic scheme limestone purity data can be queried by supergroup, granitic rock compositional data by igneous suite, and magnetic susceptibility data by terrane.

The value of the database to the New Zealand geoscience community is enormous, as all sample information and geoanalytical data can be uploaded, queried, viewed and downloaded at http://pet.gns.cri.nz.

HYDROTHERMAL VENTING AT HINEPUIA SUBMARINE VOLCANO

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Hydrothermal plumes at Hinepuia volcano, along the Kermadec Arc, were first recorded during the 2004 NZAPLUME III cruise. In 2013, the *Shinkai 6500* submersible was used to explore Hinepuia for hydrothermal venting and collect four hydrothermal fluid samples. Significant CO_2 degassing, native sulphur mineralisation, and heavy white smoke were observed around the venting. Typical magnesium end-member diagrams suggest the hydrothermal system at Hinepuia is dominated by water-rock interactions. However, gas emissions and mineralisation suggest a magmatic hydrothermal system. We contrast the characteristics of water-rock and magmatic hydrothermal system models and fluids, and present a new ternary diagram to better distinguish the water chemistry of these fluids. Although Hinepuia samples fall at the intersection of the fluid types, Hinepuia is ultimately classified as a magmatic hydrothermal system due to predominant degassing and native sulphur.

EXTREME HYDROTHERMAL CONDITIONS NEAR AN ACTIVE GEOLOGICAL FAULT, DFDP-2B BOREHOLE, ALPINE FAULT, NEW ZEALAND

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The DFDP-2B borehole sampled rocks above and within the upper part of the Alpine Fault, New Zealand, to a depth of 893 m in late 2014. The experiment was the first to drill a major geological fault zone that is active and late in its earthquake cycle. We determined ambient fluid pressures 8-10% above hydrostatic and a geothermal gradient of 130-150 °C/km in rocks above the fault. These unusual ambient conditions can be explained by a combination of: rock advection that transports heat from depth by uplift and oblique slip on the fault; and fluid advection through fractured rock, driven by topographic forcing, which concentrates heat and causes fluid over-pressure in the valley. Highly-anomalous ambient conditions can exist in the vicinity of active faults, and earthquake and mineralization processes occur within these zones.

MONITORING OF SEASONAL INFLUENCES ON A COASTAL AQUIFER IN NEW ZEALAND USING DC RESISTIVITY TRAVERSING

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Increased private and commercial use of bore water on the Kapiti Coast in New Zealand has raised concerns about saline intrusion into the shallow aquifers of the area. Processes influencing the dynamic environment of the saline interface and mixing zone are not well understood to date and extensive field studies in different geological and hydrological settings are required to gain further insight. A DC resistivity monitoring study carried out along three transects perpendicular to the shore in the Te Horo Beach township showed a distinctive difference of the position of the saline interface between wet winter and dry summer months. This is apparent by means of an approximately 10 meter shift of the saline interface towards the township during summer time. Decreased fresh water flow towards the coastal discharge point of the aquifer could explain the saline water intruding further inland during dry months. While this is very distinct at the Te Horo Beach location, long-term resistivity monitoring of the coastal aquifer about 15 km south in Waikanae Beach did not reveal any significant shift of the saline interface during the entire monitoring period of almost one year. This shows the need for investigations of saline intrusion in different environments and using different complementing methods in order to understand the highly complicated processes that can lead to saline intrusion into coastal aquifers and help managing groundwater take in those areas. Connections with natural recharge and discharge processes of the aquifer need to be taken into account along with domestic and commercial groundwater abstraction rates. Geochemical analysis of bore water can be used to constrain the geophysical inversion and hence increase the reliability of the inversion

models. An integrated analysis of the different approaches shall lead to a better picture of the dynamics that lead to saline intrusion into coastal aquifers.

STARTING A SUPERERUPTION: A MULTIPLE VENT BEGINNING TO THE 2.1MA HUCKLEBERRY RIDGE TUFF, YELLOWSTONE PLATEAU VOLCANIC FIELD

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In contrast to the traditional view that large silicic eruptions occur over 'hours to days', it is becoming evident through detailed field analysis that many are episodic and prolonged in nature. Understanding how and why these types of eruptions start and stop is of significant importance for a greater insight into these caldera-forming eruptions and their associated hazards.

The ca. 2.1Ma Huckleberry Ridge Tuff (HRT), the first of two supereruptions from the Yellowstone Plateau Volcanic Field (YPVF), is the second largest Quaternary eruption with a deposit of ca. 2,500km^3. It consists of three ignimbrite packages and two fall-deposits. Detailed field analysis indicates it is prolonged and episodic in nature with months to years separating each of the ignimbrite packages. The initial fall-deposit which preceded member A is a microcosm of this eruptive style with several horizons showing evidence of reworking indicating time-gaps and hiatuses in activity. Investigation of the earliest phases of large, caldera-forming eruptions can reveal valuable information about the initiation of such eruptions.

Major and trace-element analysis of glass and the mineral assemblage from several horizons within the fall-deposit reveal distinct clustering of compositions. These are interpreted as representing different vents tapping subtly different magma from different cupolas in the upper part of the large-scale melt-dominant body. The presence of glass and crystals in the same horizon representing different cupolas indicates that multiple vents were simultaneously active during the early stages of the HRT but these vents were episodic in activity, possibly controlled by external tectonic forces.

HIGH RESOLUTION ANALYSIS OF MARINE ISOTOPE STAGE 3: ASSESSING ABRUPT CLIMATE EVENTS AROUND NEW ZEALAND

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Marine Isotope Stage 3 (MIS 3) runs from 60 Ka to 24 Ka. It is an unusual interstadial with $\delta^{18}O$ values that are considerably higher in comparison to the other interstadials of the Late Quaternary. MIS 3 also contains several short term, millennial scale events. These events are characterised by a rapid warming followed by rapid cooling and are known as Antarctic Isotope Maxima (AIM) events.

This study aims to construct a high resolution marine record for MIS 3 looking for evidence of millennia scale events in the marine sediment cores MD97-2121 and TAN1106-28. These cores were collected from either side of the Subtropical Front (STF) off the eastern and southern coast of New Zealand respectively. Evidence of millennial scale events in the cores will give an indication of the STF permeability for the Antarctic signal.

Stable isotope analysis from planktic and benthic foraminifera, grain size analysis, carbonate content and trace metal analysis from these cores will be used to build a comprehensive understanding of the processes and climate conditions occurring around New Zealand during MIS 3. These results will then be compared with other marine core records from the Southern Ocean, ice core data, terrestrial records from New Zealand, and model outputs in order to develop a large scale representation of spatial variability and processes instigating the millennial events in the south-west Pacific sector during MIS 3. This research is part of a larger scale project called SHAPE (Southern Hemisphere Assessment of Palaeo-Environments) which aims to build a high resolution, comprehensive representation of spatial variability in the southern hemisphere over the last 60 Ka.

BUILDING BETTER VOLCANIC HAZARD MAPS THROUGH COLLABORATION AND TESTING

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All across the world, information about natural hazards is shared and communicated using maps. These hazard maps show, in varying ways, which locations are potentially exposed to hazards of varying intensities. Unlike earthquakes and tsunami, which typically produce one dominant hazardous phenomenon (ground shaking and inundation, respectively) volcanic eruptions can produce a wide variety of phenomena that range from near-vent (e.g., pyroclastic flows, ballistics) to distal (e.g., volcanic ash, lahar inundation), that vary in intensity depending on the type and location of the volcano. This complexity poses challenges in depicting volcanic hazard on a map, and to date there has been no consistent approach, with a wide range of hazard maps produced and little evaluation of their relative efficacy. Moreover, in traditional hazard mapping practice, scientists analyse data about a hazard, and then display the results on a map that is then presented to stakeholders. This one-way, top-down approach to hazard communication does not necessarily translate into effective hazard education, or, as tragically demonstrated by Nevado del Ruiz, Columbia in 1985, its use in risk mitigation by civil authorities. Furthermore, messages taken away from a hazard map can be strongly influenced by its visual design. Thus, hazard maps are more likely to be useful, usable and used if relevant stakeholders are engaged during the hazard map design process to ensure that the map a) meets both scientists' and stakeholders' messaging needs, and b) is designed in a way that is clearly and easily understood. Here, we present the results of recent research into hazard map communication, outline the goals of the IAVCEI Commission on Volcanic Hazards and Risk's newly formed Hazard Mapping Working Group, and introduce new work which aims to take an iterative, collaborative, and evidence-backed approach to hazard map design.

ROCKS2GO2: A WEB BASED GUIDE TO GEOLOGICAL FIELD SITES IN NEW ZEALAND FOR EDUCATORS AND PUBLIC

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Many school teachers have commented that the absence of accessible local information about geology field trips in their area can be a barrier to developing hands-on geological investigations for their students.

A large number of diverse rock outcrops and landforms around New Zealand have an interesting geological story to tell to non-specialists, either for a brief visit (public and tourists) or a more in-depth field study (teachers, hobbyists).

We see an opportunity to source geoscience expertise from across New Zealand to co-create a publically accessible online mapping platform with field-based geological information for public and educational use. The information featured could include: short introductions to individual outcrops, more evolved field trip plans for school and tertiary students, geohazard information, traditional knowledge (Matauranga Māori) and the option for users to comment on and rate the locations. As well as targeting the education community, this resource would be of value to anyone wanting guidance to investigate our landscapes and geological features.

This presentation outlines how this idea might be structured and implemented, with the hope that interested individuals in the geoscience community may wish to contribute content to build this quality assured, accessible New Zealand geological information resource.

LONGITUDINAL GEOCHEMICAL VARIATIONS AT THE SOUTHERN KERMADEC ARC: NEW CLUES ABOUT ELEMENT CYCLING IN ARCS

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Distinct geochemical variations exist in rocks from the Southern Kermadec Arc front volcanoes and Havre Trough backarc oceanic crust south of 34°S. This variable geochemical composition indicates the contributions of different sources with different geochemical composition in the generation of melt beneath the Kermadec arc and Havre Trough backarc system. For example, systematic large-scale, along-Kermadec-arc isotopic variations were previously attributed to the imprint of geochemical signatures from the subducting Cretaceous Hikurangi Plateau [1]. Although the origin of the enriched components is not fully understood, evidence suggests that geochemically enriched domains are likely located in the vicinity of the Moho forming a geochemically heterogeneous crustal - mantle boundary layer as imaged by seismic tomography in the lzu Arc [2]. How and when these enriched domains formed, however, remains unclear. New geochemical data from the southern part of the Miocene Colville Ridge and recent Kermadec arc seafloor rocks suggest that distinct low $^{143}Nd/^{144}Nd$ domains are present in the mantle wedge and beneath the arc crust near the Moho. These domains likely formed throughout the history of the Miocene Colville and recent Kermadec arc. During the opening of the Havre Trough and related rifting of the arc crust and the underplated domain opened pathways of ambient mantle melts to ascend to the surface forming Havre Trough crust. This likely created a 'patchwork' of old and young mantle domains. Partial melting of these domains plus recent overprint of fluid-derived elements from the subducting slab then creates the geochemical composition of the overlying Kermadec arc front and backarc rocks.

[1] Timm et al. 2014. *Nature Communications* 5:4923, DOI: 10.1038/ncomms5923.
[2] Takahashi et al. 2009. *Geochemistry, Geophysics, Geosystems* 10, Q09X08, doi:l0.1029/ 2008GC002146

MAKING ICE CREEP IN THE CLASSROOM

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Understanding the creep of ice has direct application to the role of ice sheet flow in sea level and climate change and to modelling of icy planets and satellites of the outer solar system. Additionally ice creep can be used as an analogue for the high temperature creep of rocks, most particularly quartzites. We adapted technologies developed for ice creep experiments in the research lab, to build some inexpensive (~$400) rigs to conduct ice creep experiments in an undergraduate (200 and 300 level) class in rock deformation. The objective was to give the students an experience of laboratory rock deformation experiments so that they would understand better what controls the creep rate of ice and rocks. Students worked in eight groups of 5/6 students. Each group had one deformation rig and temperature control. Each group conducted two experiments over a 2 week period. The results of all 16 experiments were then shared so that all students could analyse the mechanical data and generate a “flow law” for ice. Additionally thin sections were made of each deformed sample so that some microstructural analysis could be incorporated in the data analysis. Students were able to derive a flow law that showed the relationship of creep rate to both stress and temperature. The flow law matches well flow laws from published research. The class did provide a realistic introduction to laboratory rock deformation experiments and helped students understanding of what controls the creep of rocks.

THE SUB-PLINIAN PAHOKA ERUPTION, TONGARIRO VOLCANIC CENTRE, NEW ZEALAND

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A brief period of intense, large-scale explosive volcanism at Mt. Tongariro produced the Pahoka-Mangamate eruptive sequence between 10-11.5 ka BP. The first of these, the 0.5-0.7 km^3 Pahoka event produced a distinctive lapilli fall bed (the Pahoka Tephra), mapped to at least 52 km from source, along with at least one pyroclastic flow deposit. The blocky and platy (often blade-like), microvesicular juvenile pumice lapilli of this unit show distinctive mm-scale olive/grey colour banding. The pyroclastic deposits are also unusual in containing clinopyroxene>orthopyroxene>hornblende>olivine assemblages. Hornblende is very rare in the Tongariro/Ruapehu eruptives. The hornblende compositions and groundmass crystallisation suggests that prior to the eruption a resident magma body was degassing and crystallising at ~10 km depth. The eruption was triggered by rapid intrusion of a new water-rich magma that quickly destabilized the resident magmatic system. The new magma was of very similar composition, but a higher volatile content. Plagioclase phenocrysts show that initial magma temperatures of ~1220°C (core), dropped to ~1040°C (rim) on rise to eruption. Within the conduit, the two contrasting magmas (one with higher groundmass crystallinity than the other) mingled, and as they began to vesiculate, two distinct textures developed. The rapid rise led to late bubble nucleation, isolated vesicles and elongated microvesicular textures, with larger vesicles developing in the low-crystallinity later magma. The vesicles within pyroclasts formed from the original resident magma show polylobate, irregular shapes with thick rims. Those of the second magma have more spherical vesicles with thin, partly collapsed rims, indicating expansion, coalescence, and rupturing during the explosive eruptive activity. The distinctive blocky particle shapes show that fragmentation was influenced by interaction with near-surface groundwater, especially in the early phases. The coarsening upwards grainsize and changing texture and shape of the fall deposits shows that the latter stages of the eruption, was associated with the highest eruption columns and was dominated by a dryer eruption of the second-magma.

PETROPHYSICAL, STRUCTURAL, AND HYDROGEOLOGICAL CHARACTERISTICS OF THE ALPINE FAULT HANGING WALL BASED ON DFDP-2 WIRELINE LOGGING, TEMPERATURE, AND HYDRAULIC MEASUREMENTS

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Fault rock assemblages reflect the combined effects of interaction between deformation, stress, temperature, fluid, and chemical regimes on distinct spatial and temporal scales at various positions in the crust. Here we summarize the petrophysical, structural, and hydrogeological characteristics of the Alpine Fault's hanging wall based on measurements made during the second stage of the Deep Fault Drilling Project (DFDP-2) in late 2014. In total, more than 19 km of wireline logging data including 4.8 km of borehole televiewer imagery were acquired during the three-month drilling operation, which reached a maximum depth of 893 m (817 m true vertical depth). In conjunction with manual and automatic measurements of hydraulic parameters, on-site analysis of rock cuttings and fluid geochemistry, and post-drilling temperature measurements, the wireline data permit detailed analysis of bulk rock properties, fracturing, and fault zone structure. We focus in particular on understanding how the hydraulic conductivity of individual fractures relates to the high bulk conductivity of the hanging-wall, and thus to the transport of fluids and heat through the shallow crust.

ESTIMATING CO-SEISMIC SUBSIDENCE IN THE HUTT VALLEY RESULTING FROM RUPTURE OF THE WELLINGTON FAULT, NEW ZEALAND

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Ground deformation can contribute significantly to losses in major earthquakes. Areas that suffer permanent ground deformation in addition to strong ground shaking typically sustain greater levels of damage and loss than areas suffering strong ground-shaking alone. The lower Hutt Valley of the Wellington region, New Zealand, is adjacent to the active Wellington Fault. The long-term signal of vertical deformation there is subsidence, and the most likely driver of this is rupture of the Wellington Fault.

Recent refinement of rupture parameters for the Wellington Fault (and other faults in the region), based on new field data, has spurred us to reassess estimates of vertical deformation in the Hutt Valley that would result from rupture of the Wellington Fault. Using a logic tree framework, we calculate subsidence for an "average" Wellington Fault event of ~1.9 m near Petone, ~1.7 m near Ewen Bridge, ~1.4 m near Seaview, and infer ~0 m in the Taita area. Such a distribution of vertical deformation would result in large areas of Alicetown-Petone and Moera-Seaview subsiding below sea level with the subsequent topography similar to pre-1855 elevations (i.e., elevations prior to the Wairarapa earthquake uplift in 1855). We also calculate "minimum" and "maximum" credible subsidence values. In a "best case" scenario describing the minimum credible per event subsidence, the Petone area would experience ~1 m of subsidence, with smaller amounts up valley and to the east. This would mainly impact low-lying areas adjacent to the Hutt River and its tributaries by impairing drainage. In a "worst case" scenario, the Petone area would experience a ~2.8 m drop, with large parts of the lower Hutt Valley subsiding below current sea level.

This ground deformation hazard certainly has societal implications, and we are working with local and regional councils to develop a range of mitigation strategies.

DISTRIBUTION OF SURFACE LIQUEFACTION CAUSED BY THE SEPTEMBER 2010 AND FEBRUARY 2011 CANTERBURY EARTHQUAKES

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Strong ground shaking during the 2010-2011 Canterbury earthquake sequence resulted in extensive and repeated liquefaction of susceptible sediments underlying parts of the eastern Canterbury Plains. Peak ground accelerations (PGAs) were in the range of 0.2-0.3 g over wide parts of the plains during the September 2010 M_w 7.1 Darfield Earthquake and, more locally, 0.3-0.6 g during the February 2011 M_w 6.3 Christchurch Earthquake. Consequently, liquefaction occurrences were widespread, but generally restricted to areas adjacent to waterways, affecting the most susceptible materials.

Evidence of liquefaction includes sediment (predominantly silt to fine sand) and/or water ejected to the ground surface, and the presence of lateral spreading cracks. Liquefaction appears to be related to recent alluvial systems and is more prevalent along existing waterways and abandoned stream channels, where young, normally consolidated and poorly compacted sediments are water-saturated.

We present maps showing the extent of the surface manifestation of liquefaction for these two events. The maps include detailed interpretation from aerial photograph mosaics and satellite images captured after each event, and incorporate ground-based surveys of liquefaction occurrences.

Comparison of mapped liquefaction distribution reveals that 2.5% of the total area assessed

(2536 km^2) underwent liquefaction during the Darfield Earthquake, compared with 3% of the same area during the Christchurch Earthquake. Mapping based on affected land parcels shows that about 5% of the Christchurch urban area (134 km^2) underwent liquefaction in the Darfield Earthquake (with only the most susceptible materials affected), whereas liquefaction during the Christchurch Earthquake affected 30% of the Christchurch urban area. Despite the lower magnitude, the epicentral proximity of the Christchurch Earthquake and locally higher ground shaking affected even moderately susceptible materials beneath the city. The farthest distance from the epicentre of mapped liquefaction for both events (74 and 34 km, respectively) is generally in agreement with published distance-magnitude relationships.

BEDROCK GEOLOGY OF THE DFDP-2 DRILL-SITE

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Bedrock was encountered in DFDP-2B at drilled depths (MD) of 238.5–893.18 m (vertical depths of 238.40–818.00 m). Continuous sampling of cuttings revealed the bedrock is composed predominantly of ductilely sheared mylonite-series lithologies exhumed from the roots of the Alpine Fault zone. The protolith is interpreted to be amphibolite facies metasediments classified as part of the Aspiring Subdivision of the Torlesse Supergroup. Onsite description of whole cuttings and thin sections made within a few hours of sample recovery allowed identification of progressive structural changes. Fabrics were schistose in the upper part of the hole, but at greater depths we observed increasing indications that the rocks had been subjected to simple shear deformation. These macro-and micro-structural features are consistent with those that typify the Alpine Fault mylonite sequence previously described, and were used as input to drilling decisions. The structural features found to be the most useful indicators of ductile simple shear strain accommodated by the recovered rocks were the occurrence of shear bands; changes in mean quartz grain size; changes in maximum mica grain size; and redistribution of or changes in microstructural setting of accessory phases (e.g. graphite). The quartz:mica ratio based on mass was also determined but the extent to which this reflects true lithologic variations is unclear, as washing and winnowing of the samples (both by circulating drill fluids and during the sample collection process) probably modified bulk mineralogy in different particle size domains. Nevertheless, the quartz:mica dataset suggests a dramatic change in mineralogy at 730 m MD (vertical depth of 695 m). This coincides with a pronounced step in the temperature gradient, possibly related to large changes in hydrogeology.

A CRYOSTRATIGRAPHIC RECORD FROM AEOLIAN SILT HORIZONS IN UNIVERSITY VALLEY, ANTARCTICA

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Aeolian silt infiltrates and accumulates beneath many well-developed desert pavements, causing inflation of the subsurface over time. Although common in hot deserts, the process behind the formation of inflationary horizons is poorly understood and remains undescribed in polar deserts. However, in the McMurdo Dry Valleys of Antarctica, inflationary silt horizons have recently been found in ice-cemented sediment cores taken from University Valley. Because ground ice in University Valley occurs jointly with the silt, it allows the unique possibility to use isotopic signatures retained in the ground ice to understand the environmental conditions of inflationary horizon formation. This project uses ice-cemented sediment cores taken from University Valley in 2009 to investigate these inflationary silt horizons with four primary aims: (1) determining the origin of the silts using petrographic microscopy and X-ray diffraction, (2) deriving past environmental conditions from geochemical analyses of meltwater, (3) creating a model of the weathering history of University Valley using meteoric Beryllium-10 measurements and grain size analysis, and (4) determining the accumulation rate and deposition age of the silts using optically stimulated luminescence (OSL) dating. While sediments in this area were previously thought to be too old for OSL dating, this project has successfully produced 12 OSL ages for these cores. OSL dating combined with $\delta^{18}O$ and δD isotopic ratios show that these

horizons contain a cryostratigraphic record with paleoclimate significance for the last 200ka. University Valley is one of the best terrestrial analogues for the frozen hyper-arid conditions on Mars, and therefore results from this project may have implications for understanding surface processes and past climate evolution on Mars.

60 YEARS OF SOUTHERN HEMISPHERE $\Delta^{14}CO_2$ OBSERVED AT WELLINGTON, NEW ZEALAND

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Atmospheric $\Delta^{14}CO_2$ measurements have been made at Wellington, New Zealand (41°S, 175°E) since December 1954. This is the longest direct atmospheric trace gas record from anywhere in the world, predating the "Keeling curve" CO_2 measurements from Mauna Loa by four years. The Wellington $\Delta^{14}CO_2$ record records the ^{14}C "bomb spike" in the early 1960s and documents the movement of bomb ^{14}C into the Southern Hemisphere and throughout the global carbon cycle. In more recent times, the spatial and temporal changes in $\Delta^{14}CO_2$ are dominated by two main drivers: (i) the addition of ^{14}C-free, fossil-fuel derived CO_2, emitted mainly over Northern Hemisphere continents, and (ii) the ocean-to-atmosphere flux of ^{14}C-depleted CO_2, most strongly from the Southern Ocean. Southern Hemisphere $\Delta^{14}CO_2$ records in particular have the potential to elucidate the mechanisms that drive Southern Ocean carbon exchange, a key component of the global carbon cycle.

We will present a revised Wellington $\Delta^{14}CO_2$ record, updated to span more than 60 years from 1954 to 2015. The record is primarily based on ~2 week integrated samples collected by static absorption of CO_2 into NaOH solution. We have thoroughly reviewed and revised the entire record, through which there have necessarily been many changes in methodology. We will discuss updated record and compare to other (shorter-term) atmospheric $\Delta^{14}CO_2$ records. We use new modeling tools to examine the causes of the temporal variability and the implications for fossil fuel CO_2 emissions and Southern Ocean carbon exchange.

ANTHROPOGENIC INFLUENCES ON SOUTHERN NEW ZEALAND SOILS REVEALED BY STABLE ISOTOPES

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Stable isotopes are increasingly being used in environmental studies as tracers of anthropogenic influences. A multi-isotope analysis of a subset of the samples collected for the recently completed geochemical baseline survey of Southland and southern Otago soils has been undertaken. The hypothesis is that stable isotope ratios are influenced by human impacts on New Zealand's landscape. Carbon, nitrogen and sulphur isotopic data have been acquired for soils sampled across a variety of land uses (e.g. pristine national park versus intensively farmed pastures), climates (e.g. Fiordland >6000 mm annual rainfall, Middlemarch <500 mm annual rainfall), topography (ranging from sea level to >2300 m elevation), and soil parent materials (e.g. sandstone, schist, basalt).

The results show that sulphur isotopes vary according to underlying lithology, soil type and anthropogenic influences. In southern New Zealand, extensive application of sulphur-bearing fertilizers to pastures is shown to affect the sulphur isotope composition of soils. The majority of analysed soils have $\delta^{34}S$ values between +10 and +20‰, consistent with a rain and/or fertilizer signature. However, 8% of soil analyses have $\delta^{34}S$ values within a range from -8‰ to +10‰ and these are interpreted to reflect a stronger lithological influence, such as leaching from underlying low-S schist or Cenozoic sedimentary rock. Sulphur isotopes are also more enriched in the shallower samples, which may reflect a top down (i.e. fertilizer) or bottom up (i.e. underlying lithology) effect. Elevated nitrogen isotopes correlate to dairy farms, while the lowest nitrogen isotopes (<2‰) correlate to soils sampled in Fiordland National Park. Carbon isotopic values are largely homogeneous (-29 to -26‰), with the highest values correlated to samples collected from swamps, reflecting the soil samples high organic matter content.

NEW GEOMAGNETIC PALAEOSECULAR VARIATION MASTER RECORDS FOR NEW ZEALAND: APPLICATIONS FOR DATING AND FIELD MODELLING

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We present new palaeosecular variation master records for New Zealand on both archaeological and Holocene timescales. These have been compiled using continuous data from the detrital remanent magnetization of lake sediment cores with high-resolution C-14 based chronology, and are constrained and calibrated using directions and absolute palaeointensities obtained from the thermoremanent magnetizations of archaeological materials and volcanic rocks. All data has been "migrated" to a standard geographical location (40°S, 175°E) using a virtual geomagnetic pole (VGP) transformation. By a reciprocal VGP process, the master records can be used to calculate accurate palaeosecular variation records for all locations within the New Zealand region. The geomagnetic field alternates between active periods of high amplitude swings from 12000 to 8000 BP and over the past 4000 years, and a relatively inactive period from 8000 to 4000 BP. The current field (Dec = 21.5° E, Inc = - 65.4°, F = 55.4 μT at 40°S, 175°E) represents a rare steep and easterly extreme in direction, but is close to average in intensity. The palaeointensity record mirrors to some extent the variation of the virtual axial geomagnetic moment seen in the global dataset, but shows some notable differences. We also investigate the effect of including the Holocene record in global spherical harmonic-based and regional field models.

PREDICTING ROCK FAILURE AS A FUNCTION OF THE TOTAL STRESS STATE: AN EXAMPLE FROM THE WESTERN SOUTHERN ALPS

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The western Southern Alps of New Zealand are shaped by high rates of relative motion across the Australian/Pacific plate boundary in conjunction with a dynamic climatic regime and consequent rapid rates of landscape evolution. The result is a tightly linked and dynamic landscape of high relief, subject to rapid surface processes that is difficult to capture with traditional flux-based landscape models. Understanding the drivers of landscape development here requires consideration of both multi-frequency tectonic and geomorphic components and their interactions. To do so, we develop a formulation, the Failure Earth Response Model (FERM), which unifies the description of tectonic and geomorphic forcings and responses within a single framework. FERM relies on two basic assumptions about the 3D stress state and material rheology at the Earth's surface: (1) Both tectonic (e.g., faulting) and geomorphic (e.g., fluvial or glacial incision, landsliding) material displacement occur when local forces overcome local resistance, and (2) Large displacements, whether tectonic or geomorphic in origin, alter Earth material properties resulting in a long term strain memory contained within the topography. FERM allows us to gather stresses generated by far field tectonic processes, topography and surface processes into a single stress state for every point. We explicitly consider the contribution that pore pressure fluctuations, seismic accelerations and fault damage make toward failure of the rock mass. We present the concept of FERM using a generic topography that allows us to explore individual components of landscape evolution including strain weakened fault rocks, glacial loading and unloading, and fluvial erosion. We then use the Waikukupa River area of the Alpine Fault, Westland and surrounding topography as a real example. Constrained by field observations and based on actual topography, these models allow us to predict where failure, and hence erosion, are likely to occur and under what conditions.

TOPOGRAPHY AND PERMEABLE MOUNTAINS LEAD TO A VERY HIGH GEOTHERMAL GRADIENT IN THE NEAR SURFACE OF THE WHATAROA VALLEY ADJACENT TO THE ALPINE FAULT

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Temperature measurements in the deeper of the two boreholes drilled during the first phase of the Deep Fault Drilling Project (DFDP-1B) yielded a geothermal gradient of 62.6 ± 2.1 °C/km from a depth of 126 m where the borehole intersected the Alpine Fault principal slip surface beneath Gaunt Creek (Sutherland et al. 2012). In the DFDP-2B borehole at Whataroa River, a geothermal gradient of at least ~130°C/km was determined, a value considerably higher than had been predicted. Ambient fluid pressures in DFDP-2B were 8-10% above hydrostatic.

Three-dimensional coupled temperature/fluid flow models have been constructed for the Whataroa Valley and the DFDP-2 drill site. Modelling confirms that the following features, present in the Whataroa Valley, are a requirement for a geothermal gradient of ~130°C/km at a depth of 1km beneath the valley: significant rock advection of heat due to high exhumation rates; high topography; permeability on the order of 10^{-15} m^2 in both the mountains and beneath the valleys to depths of > 1km below the valley floor; and abundant fluid. The high permeability and large topographic driving force lead to abundant meteoric water flowing downward through the mountains, hitting the permeability barrier of the Alpine Fault and being pushed upward into the valleys. The high geothermal gradient of the DFDP-2B borehole implies that the valleys also have a very high permeability which is likely a result of rock damage along the Alpine Fault.

THE ART OF THUMPING: A PURPOSE-BUILT SEISMIC SOURCE FOR USE IN ICE ENVIRONMENTS

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The thumper, a purpose-built, trailer mounted, weight-drop seismic source, is being used in November 2015 in Antarctica, to image the bathymetry and sediments underneath the Ross Ice Shelf (RIS), about 300 km south of Ross Island. In the target area, the RIS is approximately 350 m thick, lying over about 350 m of water before the seafloor is reached. Seismic data collection on ice and snow has unique challenges. In particular snow is very good at attenuating seismic energy. Given the setting, a conventional hammer survey is unlikely to produce enough energy to image the seafloor. Our research aims include determining bathymetry, imaging the upper few metres of sediment, and identifying ice layers within the ice shelf.

The thumper consists a heavy weight (250 kg) that is dropped on a large steel plate to create a percussive sound that can be used to image the subsurface. Compared to explosive sources, it is less damaging to the environment and can be used where explosives cannot, for example in urban areas. Additionally, the thumper has a more repeatable, higher-energy signal compared to sledge hammer sources that are commonly used in similar settings. Surface conditions and the type of ground surface (e.g., ice, soil, or gravel) do need to be considered, as the coupling of the steel plate is largely dependent on this.

Initial comparisons of hammer and thumper shots in Otago and the West Coast show a vast improvement in data quality when the thumper is used.

INCORPORATING ROCK SITE EFFECTS INTO GROUND-MOTION PREDICTION MODELS FOR HAZARD ASSESSMENT: DUNEDIN CASE STUDY

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Seismological parameters that describe rupture physics, wave propagation and site effects rarely enter seismic hazard calculations. This makes it difficult to accurately predict ground-motion at sites with strongly unique regional seismic signatures. This study calculates region-specific seismological effects associated with the intraplate geological structure around the New Zealand city of Dunedin. The effects considered are site attenuation and crustal amplification. A value of the site attenuation parameter, κ_0, was calculated to have a mean value of 0.008 s, with an uncertainty of ± 0.006 s. This value is typical of intraplate environments. This study derives a 1D shear-wave velocity (V_S) profile of the crust beneath Dunedin, using ambient noise tomography, which will be then used to calculate the crustal amplification function. To obtain this V_S profile, five temporary broadband seismometers were deployed across the city of Dunedin for a period of six weeks. With the rock site characteristics defined, existing ground-motion prediction equations (GMPEs) are then adjusted to represent these region-specific effects. Given that there are multiple GMPEs in the literature, adjustments are applied to four models to examine the epistemic uncertainty. By analysing the GMPE uncertainty space using a 'scaled backbone' approach, new GMPEs have been derived that satisfy a mutually exclusive, collectively exhaustive (MECE) criterion. This defines the median model and its uncertainty. However, for calculation of the seismic hazard, the aleatory (i.e. random, unexplainable) variability of ground-motion is of great importance. Given that site-specific effects are known in this study, part of the GMPE variability (the ergodic assumption) can be removed from the hazard calculation, which prevents overly-inflated hazard estimates. Nevertheless, calculating the seismic hazard using this study's ground-motion characterisation model suggests the peak ground acceleration (PGA) hazard is significantly larger than current estimates that control building design standards.

THE 2015 NEW ZEALAND STRONG MOTION DATABASE

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The 2015 New Zealand strong-motion database contains nearly 4,000 strong-motion recordings from 1968-2015, and updates the previous database from 1995. For 272 events, source information such as origin time, moment magnitude, location, focal mechanism and tectonic type (i.e. subduction interface, subducted slab, shallow crust) have been compiled into a source table. Moment magnitudes for the events range from 3.5 to 7.8, with all of these values are directly calculated from the seismic moment, and none inferred from empirical correlations with local or surface-wave magnitude. Events were relocated using several different location algorithms, and a preferred location has been indicated for each event. From these locations and the focal mechanism solutions, a total of 129 of these events have been classified as 'shallow crust' events, with 33 events located on the Fiordland subduction interface and 7 on the Hikurangi subduction interface. Eight events are deemed to have occurred within the subducted slab of the Australian Plate at the Fiordland interface, and 94 events within the subducted slab of the Pacific Plate at the Hikurangi margin. 11 of the new events in the database have co-seismic slip distribution models available. The database consists of uniformly processed accelerograms, RotD50 and RotD100 response spectra for a variety of damping levels, 5%-damped vertical response spectra, and both horizontal and vertical Fourier amplitude spectra. Site classification, fundamental site period, Vs30 and depth to bedrock data have been updated for more than 150 sites in the GeoNet network using data where available. Parametric uncertainty has been considered for Mw and the site characterisation parameters. The database will be publicly available upon request.

THE ROLE OF PRIMARY EXPLOSIVE PROCESSES ON THE FORMATION OF DIATREMES: THE NGATUTURA DIATREME, NEW ZEALAND

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The variable nature of monogenetic volcanism is strongly controlled by hitherto poorly understood subsurface processes. At a typical monogenetic volcano magma is inferred to rise through the crust and encounter an assemblage of rock/sediment layers before reaching the surface. The interaction of magma with host rock/sediment may, for example, lead to the formation of a diatreme in the presence of sufficient amounts of groundwater. Explosions would occur when magma encounters water-saturated sediment, forming a pipe-like structure which would gradually be filled with volcaniclastic debris.

A unique opportunity presents at the Ngatutura Volcanic Field, c. 60 km south of Auckland, where an almost complete diatreme structure is preserved in a cliff face, along with associated dykes and lava flows. The host rock stratigraphy is also well defined. Two vertical profiles within the diatreme structure were photographed and sampled. Four groups of lithics, each with unique visual and lithological properties, can readily be identified in photographs and thin sections of the diatreme fill, thus enabling an analysis of the distribution of the different kinds of lithics. Our data show that each lithic group has a unique distribution: The abundance of fragments of older host rocks decreases with height, while younger host rock fragments are absent in deeper parts of the diatreme. This provides evidence that explosions occurred at different locations and at variable heights. Discreet abundances of components also suggest that recycling of sediment is an unimportant process. The degree of baking of host rock fragments was also analysed, indicating that larger lithics were incompletely baked due to variable and transient heating of sediment. The notion of individual explosions occurring at different heights and locations in the growing diatreme provides an alternative model to understand diatreme growth as a much more complex process than a simple downward migration of explosion loci through time.

INTEGRATING CHRONOLOGICAL UNCERTAINTIES FOR LAMINATED LAKE SEDIMENTS USING INDEPENDENT CHRONOLOGY AND LAYER COUNTING IN A BAYESIAN AGE MODELLING FRAMEWORK

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Annually resolved (varved) lake sequences are extremely important paleoenvironmental archives as they offer a direct and incremental dating technique for high-frequency environmental and climatic change. Despite the importance and utility of varved lake records, establishing a robust chronology and quantifying its precision and accuracy (estimations of error) remains an essential but challenging component of developing these records. We provide a framework for building reliable independent chronologies, testing the accuracy of layer counts and integrating all chronological uncertainties to provide quantitative age and error estimates for complex varved lake sequences. The framework incorporates (1) varve counts and estimates of counting precision; (2) novel targets for ^{14}C dating to derive a high density of independent chronology and (3) the application of Bayesian age modelling to varve chronologies generating an integrated age model. The developed framework is tested and applied to the case study of a complex, annually resolved sedimentary sequence spanning the last c. 1400 years from Lake Ohau, New Zealand. The resultant age model encapsulates the combined uncertainties of the age determination and therefore provides a statistically more robust chronology. The framework is designed for applications to complex varve stratigraphies but should be applicable to all varve lake sequences.

RAPID WEAKENING DURING RECRYSTALLISATION: INSIGHTS FROM ULTRASOUND AND EBSD MEASUREMENTS OF ICE IN CREEP

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Understanding the flow of ice in glaciers and ice sheets is of increasing importance as climate change moves to the forefront of modern scientific investigation. Robust ice flow modelling is crucial to predicting sea level, ocean circulation and ocean climate interactions in a warming world.

The highly anisotropic visco-plasticity of ice leads to development of strong crystallographic preferred orientations (CPO). Ice like many other minerals shows significant weakening after only a few % strain. Although this is loosely linked to CPO development the weakening mechanism is not clear.

We will show results from a unique set of experiments, where we measure ultrasonic velocities to monitor the development of acoustic anisotropy in deforming ice in real time. These results are compared to elastic models derived from CPO data, measured by Cryo-EBSD, in the same experimental samples. We show how velocity anisotropy evolves as a function of strain and CPO evolution.

In ice undergoing uni-axial shortening at high homologous temperatures, c-axes concentrate into an orientation cone symmetric about the principle shortening direction. Rapid weakening initiates at ~3% shortening, even though the CPO is not strongly developed at this stage. The weakening occurs because recrystallization creates a linked network of weak grains that deform in shear. Recrystallization continues and the network shear is replaced by more homogenous deformation at decelerating strain rate.

PALEOENVIRONMENTAL AND DIAGENETIC CONTROLS ON THE PETROLEUM GENERATION CHARACTERISTICS OF THE LATE PALEOCENE WAIPAWA FORMATION OF THE EAST COAST BASIN, NEW ZEALAND

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The Late Paleocene Waipawa Formation is the most prospective source rock unit of the East Coast Basin (ECB). We examine the paleoenvironmental and diagenetic controls responsible for variations in the richness and type of organic matter throughout a freshly exposed road cut in the Taylor-White section, upper Angora Road, southern Hawke's Bay. This section preserves transitional contacts with the underlying and overlying Whangai and Wanstead formations, respectively. Samples spanning a continuous ~56 m thickness of the Waipawa Formation were analysed for stratigraphic changes in geochemistry and compared with other ECB outcrop samples from the Raukumara Peninsula, Hawke's Bay, and Wairarapa. Multiple proxies indicate cyclical changes affected the quantity and type of organic matter preserved. C_{30} 24-*n*-propylcholestane biomarkers from bitumens diagnostic of marine chrysophyte algae were correlated positively with pulses of increased total organic carbon (TOC) and hydrogen index (HI). Kerogens also display similar cyclical variations of elevated phenol concentrations, likely derived from land-plant remains. Independent of biotic inputs there is evidence of early diagenetic variations affecting the preservation of organic matter. Total sulphur (TS) concentrations correlate positively with TOC and HI and may indicate enhanced preservation associated with sulphurisation. T_{max} values correlate negatively with TS, suggesting relatively weak sulphur-carbon bonds were preferentially cleaved at lower temperatures, which may induce earlier and shallower generation of petroleum. Reduced sulphur species were formed by bacterial sulphate reduction (BSR). Sulphur isotope values adjusted for Late Paleocene seawater sulphate signatures are consistent with active BSR, which requires at least dysoxic conditions at shallow sediment depths. BSR rates were variable and where highest, likely resulted in up to a 2 wt.% reduction in preserved marine organic matter, with concomitant reduction in oil potential. The diverse and highly variable nature of

these geochemical processes requires dramatic changes to have occurred during the deposition of the Waipawa Formation.

THE NEW ORGANIC GEOCHEMISTRY LABORATORY OF GNS SCIENCE AND VICTORIA UNIVERSITY OF WELLINGTON

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Recently Victoria University of Wellington and GNS Science have partnered to create the VUW/GNS Organic Geochemistry Laboratory (OGL). The primary aim of this laboratory is to provide a safe and open space, with modern equipment and technical support, to produce a vast range of organic geochemical- and environmental-based studies. Capabilities include the detection, characterisation, and quantitation of organic compounds including: saturated and aromatic hydrocarbons in petroleum and source rocks, polar compounds such as phospholipid fatty acids and polar ether lipids in water, soils, and sediments. OGL has the ability to produce compound specific carbon and deuterium isotope measurements of leaf waxes and other volatile compounds. This laboratory has autosampler-driven thermal desorption, pyrolysis and thermochemolysis capability for the fast and easy characterisation of aerosol, soil, sediment, and rock samples. This technique is ideal for the detection and quantitation of lignin and other plant biomarkers in soils and sediments or polyaromatic hydrocarbons (PAHs) in aerosols and soot. Furthermore, we are currently developing the ability to isolate and measure polar ether lipids, such as bacterial and archaeal *glycerol dialkyl glycerol tetraethers* (GDGTs), for paleoclimate reconstruction and have acquired authentic GDGT lipids standards for unambiguous compound identification and quantification. Other types of compound classes, such as long chain-length (C_{37}-C_{39}) alkenones for UK'^{37} sea surface temperature reconstructions can likewise be separated and measured. OGL has a full range of sample preparative techniques including milling, freeze-drying, solvent extraction (by sonicated bath or Accelerated Solvent Extraction), liquid gravity column chromatography. The detection of molecular constituents in sample extracts can be achieved by OGL's analytical equipment which includes: EA, HPLC, GC-MS, GC-FID, PyrGC-MS, and GC-IRMS. This facility is available for all students to fulfil research needs and to develop future research directions. Please contact any of the above authors for further details.

MAAR-DIATREMES: LARGE-SCALE EXPERIMENTS AND NATURAL ANALOGUES

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This work is a study of some dynamic processes involved in phreatomagmatic eruptions. The processes have been reproduced experimentally by artificial explosions at the field scale, and were conceived to study specific processes involved in forming a Maar-Diatreme volcano.

Here I focus on video analysis of eruptive jet shape and its evolution through time, including measures of maximum height of the jet.

A result of this study confirms the reliability of an important parameter for such explosions. The scaled depth, a parameter that relates explosion depth to explosion energy, is here shown to have specific relations to jet spreading-angle (angular coefficient) and to the maximum height of the jet; neither has been previously demonstrated.

Some explosions are characterized by "jet fingers". In nature they are comparable with cock's tail jets, the typical structures of Surtseyan explosions. These are narrow sub-vertical jets, black and dark grey, of mixed water vapour and coarse material, observed and widely described in the literature. This activity is mainly impulsive, which is reflected in cock's tail-jet deposits, which are discontinuous in time and limited in spatial distribution. Some examples of cock's tail deposits are described from the Vulsini volcanic district (central Italy), where field research focused on the recognition of possible cock's tail phreatomagmatic deposits.

The main results are these. 1) New relationships are shown between scaled depth, jet evolution through

time, and maximum height of cock's tail jets. 2) Deposits of cock's tail jets are characterized by bombs or coarse material and fine ash, usually associated with bomb sags; 3) this, in addition to relationships previously found, to give strength to scaled depth, a concept increasingly used in planning and evaluation of artificial explosions. The final goal is to get more-accurate estimates of volcanic hazard arising from explosions of a given magnitude and depth.

UNKNOWN FAULTS UNDER NEW ZEALAND CITIES: A NATION-WIDE INITIATIVE

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The two most devastating earthquakes of the 2010-2011 Canterbury sequence, the September 4, 2010 Darfield and February 22, 2011 Christchurch earthquakes occurred on unknown faults. The 2010 event was associated with rupture of the previously unmapped, concealed Greendale fault, and other smaller fault segments that did not reach the surface. The 2011 event occurred along a fault that did not rupture the surface. The Canterbury Earthquakes Royal Commission (CERC) recommended that "Research continues into the location of active faults near Christchurch and other population centres in New Zealand, to build as complete a picture as possible for cities and major towns". The 2010-2011 events demonstrated that for areas of low seismicity, it is essential to understand whether active faults may lie under or close to major cities.

To address the CERC recommendation, we are starting to develop a nation-wide initiative to coordinate research in New Zealand cities, the aims of which are to assess locations of potentially active faults and estimate their activity. We have started a pilot study within the city of Dunedin co-funded by the Natural Hazards Research Platform 2015 Contestable Fund, GNS Science Core Funds, and University of Otago. For Dunedin, the project aims to map and examine potentially active faults through the city, with a focus on two known candidate structures, integrating geology, gravity, onshore and offshore seismic reflection, microseismicity, InSAR and GNSS observations in order to evaluate these potential earthquake sources. The results will be used to assess and possibly update seismic hazard estimates for Dunedin. The long-term aim is to integrate and coordinate a new generation of comprehensive seismic hazard research among New Zealand research organisations, and seek interest from stakeholders.

ZR-IN-RUTILE, A THERMOBAROMETER FOR ECLOGITES

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The use and interpretation of Zr concentration data in rutile from subduction-exhumation settings can be improved by applying the Zr-in-rutile thermometer, and the thermometer restructured as a barometer, to Zr concentration data collected along detailed transects across individual rutile grains. By this means, it is possible to: (1) identify parts of rutile grains which grew or re-equilibrated at $P < P_{max}$; (2) demonstrate that rutile enclosed in refractory porphyroblasts like omphacite or garnet largely escapes the effects of Zr re-equilibration during uplift and cooling; and (3) potentially gain *P-T* constraints on the subduction, P_{max}, and exhumation history of eclogite samples. For a mafic eclogite from the youngest exhumed eclogites on Earth, rutile with bell-shaped Zr concentration profiles is interpreted to have grown during subduction. If the high Zr concentrations in these rutile cores are unrelated to P_{max}, the very high Zr-in-rutile temperatures obtained on that basis (to > 900 °C, for (U)HP conditions close to coesite stability) are not geologically meaningful. These cores may have begun growth at P as low as ~10 kbar, and T near ~800 °C. Rutile with a flat Zr concentration profile inside an omphacite rim yields an estimate of ~790 °C and ~27 kbar, providing constraints on the conditions associated with fluid-mediated transport of Zr, Ti and P into the rock, beginning near P_{max}. A rimward compositional plateau in a large bell-profile rutile in an omphacite margin yields comparable conditions (~810 °C and

~27.3 kbar). Abundant coarse rutile that occurs together with coarse zircon and quartz in areas outside garnet and omphacite has flat Zr concentration profiles, and probably records conditions associated with exhumation, and underplating, spreading, thinning, and cooling of the surrounding host gneisses upon arrival at the base of the crust. Ti-in-zircon thermometry results indicate that this cooling continued down to ~635 °C.

A PROPOSED LANDSLIDE ORIGIN FOR THE HILLOCKS ALONG THE EGLINTON VALLEY, FIORDLAND

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The misinterpretation of landslide deposits as glacial landforms is an issue when considering paleoclimatic reconstructions as it can lead to false indicators of regional climatic events, and miscounts the hazard or geomorphic significance of landslides. A collection of hummocks in Southland, New Zealand, previously suggested to be of glacial origin, are proposed here to be rock avalanche deposits. The hummocks protrude ≤15 m above the modern Eglinton River floodplain and are protected by the New Zealand Geopreservation Inventory, which describes the deposits as glacial kames.

Geomorphological, sedimentological, and geophysical (ground penetrating radar) techniques are being applied to help map and interpret the formation and source of the Eglinton hillocks. In addition, the application of a novel terrestrial in situ cosmogenic nuclide method of surface exposure dating using ^{10}Be in pyroxene, is being used to constrain the ages of the hillocks and other landforms in the valley that are rich in mafic minerals. Initial results suggest that the sedimentary and morphological characteristics are consistent with formation by one or more rock avalanches subsequent to glacier retreat, and there is evidence to suggest that there may have been temporary blockage of the Eglinton River. Internal sedimentology of the proposed rock avalanche deposits consist of monolithic, interlocking, angular to sub-angular clasts ranging from sand to boulder size. Similar characteristics have been identified elsewhere in the region.

The reinterpretation of these landforms contributes to the development of the New Zealand landslide inventory, which ultimately can be used to explore how patterns of landslide activity may relate to changes in seismicity, climate, and topography during the Late-Glacial and Holocene.

USING ACTIVE SOURCE DATA TO DETERMINE THE DYNAMICS OF THE 13 OCTOBER 2012 TE MAARI, NEW ZEALAND DAM BREAKOUT LAHAR AND ITS IMPLICATIONS FOR MONITORING MASS FLOWS

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On 13 October 2012 saturated sediments and trapped lake water from a 50,000 m^3 ephemeral lake overtopped a debris flow dam at 11:20 UTC, thus creating a lahar approximately 10 minutes later at 11:30 UTC through remobilizing the older debris flow deposits. The lahar lasted for about 30 minutes flowing down the channel through a succession of multiple surges that could possibly be attributed to a series of down cuts and subsequent breakouts of the debris flow dam. To understand the dynamics of the 13 October 2012 lahar, active seismic source data collected in February 2013 from the same flow channel was correlated with the 2012 lahar seismic data. In comparing the two data sets a frequency band of 3-10 Hz is used to estimate the lahar energy at 4.87x10^9 Nm. The best correlated location for the lahar from the active source data is estimated to be at the ephemeral lake or within 1.0 km down channel. With the use of the active source method, the understanding of lahars at Te Maari can be better characterized and provide more information for future warning and prediction for mass flows.

SEISMIC ATTRIBUTE ANALYSIS FOR CHARACTERISING CONCENTRATED GAS HYDRATE DEPOSITS ON NEW ZEALAND'S SOUTHERN HIKURANGI MARGIN

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We re-processed and analysed Bruin 2D seismic data (recorded in 2005) from New Zealand's Hikurangi subduction margin that show widespread evidence for presence of gas hydrates. We chose six seismic lines from the Bruin seismic survey to re-process with the aim of obtaining a higher resolution image of the shallow subsurface. Each of these lines shows bottom simulating reflections (BSRs) that are important indicators for the presence of gas hydrate. These higher resolution seismic sections are used to explain how free gas migrates into the gas hydrate stability zone. Fault zones and dipping strata, that could be pathways for the migration of free gas into the gas hydrate stability zone, are more easily interpreted on these seismic sections. Moreover, these high resolution sections are useful to detect the highly concentrated gas hydrate deposits and their associated seismic reflections.

We also carried out detailed seismic velocity analysis. Stacking velocities were converted into interval velocities with the Dix equation, and these showed that the locations of anomalous velocity zones coincide with the locations of BSRs. Thus velocity, in addition to BSRs, is a good diagnostic for detecting gas hydrates in the subsurface.

We identified several highly concentrated gas hydrate deposits above BSRs, as well as gas packages beneath BSRs. The lines we have analysed show a number of promising features that point towards concentrated gas hydrate deposits, including the existence of BSRs, strong reflections above BSRs in the gas hydrate stability zone, enhanced reflections below BSRs, and associated velocity anomalies.

USING HIGH GROUND AS TSUNAMI VERTICAL EVACUATION REFUGE IN LAND-USE PLANNING – A CASE STUDY IN THE WESTERN BAY OF PLENTY REGION OF NEW ZEALAND

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Strategies for mitigating tsunami loss have generally involved evacuating to areas of naturally occurring high ground outside of tsunami inundation zones. In some locations, high ground may not exist, or tsunamis triggered by local events may not allow sufficient warning time for communities to evacuate to high ground outside the evacuation zone. A potential solution to this is vertical evacuation into the upper levels of structures or high grounds (also called berms) which are designed to resist the effects of a tsunami and provide people with safe refuge above maximum inundation height, while remaining within the inundation zones. In this study, we investigated on using existing high grounds inside potential tsunami inundation areas as vertical evacuation refuges to reduce the potential loss of life in the western Bay of Plenty region.

The western side of the Bay of Plenty region in New Zealand has been identified as potential growth areas for a variety of uses including residential, business and commercial activities on proposed altered ground levels. Recent studies indicate that most of this future development area on these altered ground levels would be flooded in a worst case tsunami scenario from southern Kermadec subduction interface. Assisted with numerical simulations and following FEMA guidelines on vertical evacuation, approximately six hectares of the existing high grounds on the southern edge of this development area were identified as being sufficient height to avoid becoming inundated during the modelled tsunami scenario. These high ground areas were recommended to remain as vertical evacuation refuges in the future developments in order to reduce the potential life safety risks from a tsunami. Advantages of using high ground for vertical evacuation include the potentially high refuge capacity when compared to vertical evacuation buildings, and also the ease of access.

THE 04/05/2015 ML5.8 WANAKA EARTHQUAKE: BUILDING AN AFTERSHOCK CATALOGUE USING MATCH-FILTER CROSS-CORRELATION

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The 04/05/2015 ML5.8 'Wanaka earthquake' was the largest earthquake in Central Otago east of the main divide for over 70 years and the largest shallow event in the region since GeoNet records began. The earthquake occurred 30 km northwest of Wanaka, 9.1 km beneath the Matukituki Valley, and was felt widely across South Island, although no damage was reported. Using data from seven GeoNet and eight temporary broadband seismograph sites (part of the COSA network), one of which is 8 km from the mainshock, we catalogue the earthquake sequence and identify a structure responsible. We use the mainshock and 99 aftershock waveforms as template events to perform match-filter cross-correlation detection of further aftershocks. This highly specific detection method allowed us to detect 2544 aftershocks over 26 days after the mainshock, 27 times more than recorded by GeoNet. No foreshocks were detected in the two month period prior to the mainshock. Magnitudes of detected aftershocks range from M_L5.4 (34 seconds after the mainshock) to M_L0.6 and follow an exponential relationship with a b-value of 0.81 and M_C1.1. We compute high precision locations of detected events by generating lagged single channel cross-correlation derived phase picks. Our relocated aftershocks highlight a steeply northwest dipping (c.70°) fault striking at c.250°. This orientation is consistent with the mainshock focal mechanism for a dextral strike-slip earthquake on a sub-vertical plane sub-parallel to the plate convergence direction (249°). Analysis of slip vectors shows that aftershocks principally occurred on secondary synthetic Riedel shears oriented 25° clockwise (striking at 275°) from the principal slip zone. Aftershock locations migrate in the down-dip direction away from the mainshock, slowing with a 1/log(time) relationship consistent with observations from other aftershock migration studies.

WHAT CONTROLS SLIP DIRECTIONS OF DIFFUSE MICROSEISMICITY IN CENTRAL SOUTH ISLAND?

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In South Island, oblique convergence of the Australian and Pacific plates is accommodated in a wide (up to 150 km) zone, with ~75% of the total motion (~37 mm/yr) taken up on the Alpine Fault. We examine diffuse shallow (0—20 km) crustal microseismicity in a region SE of the Alpine Fault, where most of the remaining relative plate motion is accommodated. Focal mechanisms have been determined for 152 events in Central Otago, recorded in a broadband seismic network (COSA) over 15 months (June 2012—October 2013). One approach is to interpret these mechanisms in the context of a uniform stress field, assuming slip occurs in the direction of maximum shear stress on randomly orientated fractures, with an equal probability of slip on either nodal plane. This way, a stress field inversion of these mechanisms produces an estimate of S_{Hmax}=114°, an orientation inconsistent with the principal contraction direction derived from GPS (105°) and gravitational based calculations. Instead, the dip directions of all nodal planes indicates that slip may be occurring subparallel to the plate convergence direction (~070°) on a limited set of linked fractures, organised into strike-slip and thrust segments. This same segmentation is observed along the main Alpine Fault trace, which is partitioned into strike-slip and thrust segments at a 1-10km scale. In other words, the earthquake slip directions may be kinematically controlled, accommodating the plate convergence, rather than the response of randomly orientated fractures to a uniform stress field. Near-vertical fractures aligned with the plate convergence direction are preferentially slipping and dominate the microseismicity in central South Island. We show that large >M5.5 events are controlled by the same kinematic process, using data from the 04/05/15 M_L5.8 Wanaka earthquake, where the mainshock occurred on a steeply-dipping dextral fault aligned at 070° and subparallel to the plate convergence vector.

VERTICAL AND HORIZONTAL DEFORMATION OF A REGIONAL EROSION SURFACE IN WESTERN WELLINGTON: A MODERN APPROACH TO THE WELLINGTON K SURFACE

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Measuring and describing horizontal motion in plate boundary zones is relatively straightforward. Vertical movements are, on the other hand, more difficult to document but they are important as they provide important insights to crustal and upper mantle dynamics.

This study is directed towards learning about the vertical movements of a regional erosional surface, termed the K Surface, in the Wellington region. Sir Charles Cotton (1912) was the first to draw attention to this physiographic feature that dominates the landscape of the western Wellington region from Makara in the south, to Paraparaumu in the north.

We apply the following methods to examine the K-Surface: 1) Cosmogenic nuclide techniques to constrain the timing of uplift and/or degree of erosion; 2) Topographic analysis of high resolution digital elevation models; 3) Seismic P-wave velocity and porosity measurements in the mudstone of a marine outlier stratigraphically above the K Surface to infer the total rock uplift in western Wellington since K Surface initiation.

Initial results suggest that the K Surface has been tilted and offset vertically and possibly horizontally since its initiation. Broad scale NW-SE doming is also apparent across the surface. P-wave velocity indicates burial depth of ~2000 ± 500 m for the marine outlier which suggests substantial rock uplift.

These constraints on the amplitude and wavelength of the K-surface uplift will provide us insight into the roles of in-plane stress and lithospheric plate flexure in the plate boundary zone of the southern North Island.

HYDROGEOLOGICAL EFFECTS IN CENTRAL NEW ZEALAND OF LARGE (M>5.8) EARTHQUAKES

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A dense hydrological monitoring network in central New Zealand has recorded groundwater fluctuations and streamflow changes induced by recent seismic events. We estimate the importance of seismic (static and dynamic) and hydrological properties as factors governing the observed responses, and the degree to which these are permanent or transient. The assessment utilises 15 years of hydrological data and observations of eight recent large (M>5.8) seismic events that occurred at distances of 30-800 km and shook the monitoring network at Modified Mercalli intensities of I-VII.

For each event we characterise: the presence, nature and magnitude of groundwater level fluctuations and anomalous streamflow; seismic shaking parameters; discharge recession constants; and the evolution of tidal parameters. Hydrological responses occurred at up to 55 boreholes and exhibited different polarities, amplitudes and timescales. Shaking properties were calculated from GeoNet strong-motion accelerometers in terms of peak ground velocity and acceleration, Arias intensity, and spectral characteristics. Recession constants were estimated from as many as 272 stream sites, and hydraulic diffusivities derived using a simplified 1D aquifer model. Fourier transforms of semi-diurnal (M_2) and diurnal (O_1) tidal waveforms and aquifer properties (BK_u) were computed for 107 boreholes using estimates of hydraulic coupling, volumetric strain, and pressure change. Temporal transmissivity and specific storage were derived from amplitude and phase. Recession and tidal parameters were compared before and after each earthquake.

Preliminary analysis suggests that both transient (<1 hour) and persistent (weeks-months) groundwater level perturbations, mostly reflect stress- and strain-induced pressure changes imposed by the earthquakes, rather than large-scale aquifer-damage or changes to hydrogeology. On-going work will examine the thresholds for aquifer pressure change or damage.

SEISMIC VS ASEISMIC SLIP AND RIDER BLOCK ABANDONMENT CHRONOLOGY OF THE ACTIVE MAI'IU LOW ANGLE NORMAL FAULT, SE PAPUA NEW GUINEA

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Low-angle normal faults (LANFs) have induced debate due to their apparent non-Andersonian behaviour and lack of significant associated seismicity. Dipping ~21° to the north, the Mai'iu Fault, Woodlark Rift is an active, rapidly slipping LANF located at the transition between continental extension and seafloor spreading. Based on campaign GPS data (Wallace et al. 2014) the Mai'iu Fault is thought to slip at 7-9 mm/yr, accommodating a large fraction of total basinal extension. However it is uncertain whether slip is seismic or aseismic. Surface geomorphology indicates that the fault scarp is not significantly eroded despite high rainfall and ~2900 m relief. We obtained 15 rock samples (~5 m spacing) from the lowermost Mai'iu Fault scarp in order to determine Holocene slip rates and style over the last ~10 kyr using cosmogenic ^{10}Be in quartz. This slip profile in exposed bedrock is supported by a suite of soil samples for ^{10}Be analysis, which extend our temporal coverage. We model exposure age data through identification of discontinuities within the profile, in order to detect creeping or brittle frictional processes. In addition we analyse the structure of conglomeratic strata and abandoned rider blocks within the Mai'iu Fault hanging wall, which record Quaternary splay faulting and tilting in response to LANF slip. 16 quartz pebble samples were obtained from hanging wall conglomerates in order to calculate cosmogenic burial (^{26}Al/^{10}Be) ages. These constrain the chronology of hanging wall deformation. High-angle (~50°) faulting competes with LANF slip at <1 km depths, with high-angle faults cutting the LANF and exposing footwall metabasalt ~2 km north of the LANF. Past splay faulting is recorded by progressive back-tilting of the Gwoira rider block in a ~1 km deep depression in the corrugated Mai'iu Fault plane. Our results provide new constraints on LANF strength and slip behaviour.

BULK RHEOLOGY AND SIMULATED EPISODIC TREMOR AND SLIP WITHIN A NUMERICALLY-MODELED BLOCK-DOMINATED SUBDUCTION MELANGE

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We investigate the influence of melange rheology in a subduction thrust interface on stress and slip cycling constrained by observations from an exhumed subduction complex at Chrystalls Beach, New Zealand. We model a two-phase mélange dominated by large, competent brittle-viscous blocks surrounded by a weak non-linear viscous matrix. The models produce stress cycling behaviour under constant shear strain rate boundary conditions for a wide range of physical conditions that roughly corresponds to depths and strain rates calculated for instrumentally observed episodic tremor and slip (ETS) in presently-deforming subduction thrust interfaces. Stress cycling is accompanied by mixed brittle plastic-viscous deformation, and occurs as a consequence of geometric reorganisation and the progressive development and breakdown of stress bridges as blocks mutually obstruct one another. We argue that periods of low differential stress correspond to periods of rapid mixed-mode deformation and ETS. Stress cycling rates depend on shear strain rate and pressure/temperature conditions at depth. The time period of stress cycling is principally controlled by the modelled geometry (block distribution and density through time), while amplitudes are controlled by effective stress.

The duration of stress cycling events in the models (months-years) and rapid strain rates are comparable to instrumentally observed ETS. Shear strain rates are 1 – 2 orders of magnitude slower between stress cycling events, suggesting episodic return times within a single model domain are long duration (> 100 years), assuming constant flow stress. Finally, we derive a bulk viscous flow law for block dominated subduction mélanges for conditions 300 – 500°C and elevated pore fluid pressures. Bulk flow laws are non-linear, owing to a combination of non-linear matrix viscosity and development of tensile fractures at rapid shear strain rates. Model behaviour, including the generation of mixed-mode deformation, is highly comparable to the exhumed block-dominated melange found within the Chrystalls Beach Complex.

MINE REMEDIATION IN NEW ZEALAND: LESSONS FROM THE (RECENT) PAST

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Recent experiences with the remediation of two different Coromandel mines; the long abandoned Tui mine site at Te Aroha, and the more recently closed Golden Cross at Waihi (for which remediation planning began long before the closure) are being used to inform future mine remediation planning. There are few established mine remediations in NZ, and the long term success of remediation methods developed and tested overseas, in the typically high rainfall, steep topography terrain hosting many NZ gold and coal mines, has yet to be established. Four surveys of water and sediment quality in the Tui and Tunakohoia streams have been undertaken since 1994, covering the period before, during and after remediation works. These reveal ongoing discharge of mobile elements such as Mn, Zn and Cd, which continue to contaminate stream sediments. Mass load calculations have repeatedly identified the largest source of these trace elements as neutral pH mine water emanating from adits, rather than the acid-generating tailings dam from which metal discharge has been more effectively reduced by recent remediation works. Despite the planned, comprehensive and immediate remediation of the Golden Cross mine, similar problems have been experienced with ongoing elevated concentrations of Mn and other mobile elements in adit drainage. The ability of geochemical models to better predict such remediation issues early in the process of exploration and mine development, is now being tested at representative old, current and potential future mine sites throughout NZ.

NO CRYING OVER SPILT MILK: A VOLCANIC ASH FALL HAZARD EVACUATION DECISION SUPPORT TOOL FOR THE TARANAKI DAIRY INDUSTRY

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The dairy industry is one of New Zealand's leading economic drivers, contributing $18.1 billion in export revenue in the 2013/14 financial year. Approximately 490,000 cows (10% of New Zealand's dairy herd) are located in the Taranaki region, within 45 km of Mt. Taranaki volcano. This is an active re-awakening volcano capable of producing large explosive eruptions and has records of producing widespread ashfall. In the event of an eruption, ashfall is likely to impact large numbers of dairy farms depending on the size, duration and style of the eruption, and climatic conditions. Many studies illustrate that even minor ashfalls can impact dairy farms by: 1) direct impacts to animal health and contaminating feed and water supplies, and 2) by disrupting supporting services and infrastructure (e.g. electricity supplies and transportation networks). Understanding the potential consequences from ashfall hazards to the Taranaki dairy industry is required to inform risk management strategies. This research aims to provide an evacuation decision support tool for the Taranaki dairy industry.

The study uses a Bayesian Event Tree for Volcanic Hazards (BET_VH) framework, and a probabilistic tephra model developed using TEPHRA2, to produce a probabilistic volcanic hazard assessment (PVHA), which allows for long-term ashfall hazard modelling. Vulnerability is assessed through fault-tree analysis for both farms and supporting critical infrastructure (e.g. water sources and power network) to assess compounding downstream impacts from ashfall across the region. Farm inventory characteristics for livestock count, the power transmission network supply, and the property's water delivery method (e.g. municipal water supply, groundwater borehole) are collated from extensive geospatial data to show farm characteristics and interaction with external services. This produces annualised risk probabilities across the region's farms for impacted livestock.

Preliminary findings indicate through sufficient forecasting and cost-benefit analysis, in the event of

a large explosive eruption, livestock evacuation can be advantageous.

IMPACT OF LARGE VOLCANIC EVENTS ON THE MARINE ENVIRONMENT RECORDED IN MARINE CORES

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Explosive silicic volcanic eruptions blanket widespread terrestrial and marine areas in ash, and have a profound effect on climate and local ecosystems. As the composition of foraminifera tests are highly sensitive to changes in their surrounding environment, significant temperature and/or chemistry fluctuations following a large volcanic eruption may be recorded in the tests of live foraminifera, now preserved in marine sediments. Furthermore, pronounced changes in climatic conditions may be reflected in changes to the sediment record after these events. This study examines marine cores (and foraminifera within) that contain tephra units from three major volcanic events to determine if changes can be resolved in ocean temperature and/or chemistry following large silicic eruptions. We will present preliminary data for select cores, focusing on sediment characterisation around the tephra horizons.

The Holocene Taupo, Waimihia and Mamaku tephra units have been identified in a series of marine sediment cores collected from areas with high sedimentation rates off the East Coast of North Island, New Zealand. Seven of these cores contain the Taupo tephra unit with three also containing tephras from the Waimihia, and four containing tephra from the Mamaku eruption. Tephra units vary in thickness from <1cm to 15cm, allowing the effect of ash thickness on foraminifera test chemistry, and by proxy the benthic environment, to be evaluated. Sampling of sediment and foraminifera from these cores has been undertaken at 0.5cm intervals above and below each tephra. This equates to varying sampling resolutions between cores of ~10-30 years, with sufficient sampling taken to establish a stratigraphic record of >100 years either side of each tephra unit. Grainsize analyses show a general increase in grainsize either side of the tephra. Carbonate analyses for all samples are <10%, and in many cases the lowest percentages are from samples taken immediately above the tephra horizons.

REVISED INTERSEISMIC LOCKING MODELS FOR THE NORTH ISLAND, NEW ZEALAND, USING FEM-DERIVED GREEN'S FUNCTIONS

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The Hikurangi subduction margin displays a variation in interseismic coupling behavior along strike, with shallow coupling in the north and deeper coupling in the south (Wallace et al., 2012). With new information such as an improved interface geometry, a New Zealand-wide seismic velocity model and increased density and duration of geodetic networks, it is now possible to provide a much more detailed picture of interseismic coupling than in previous studies. In previous work (Williams and Wallace, 2015), we examined the effects of material property variations on slip estimates for slow slip events (SSEs) along the Hikurangi margin, and found that in cases where the slip is deep or there is good geodetic coverage above the slipping region, heterogeneous models generally predict about 20% less slip than elastic half-space models. Based on those results, we anticipate that interseismic coupling models that account for elastic heterogeneity will also predict lower slip deficit rates in such regions.

To explore these ideas, we are developing a new interseismic coupling model for the North Island. We use a New Zealand-wide seismic velocity model (Eberhart-Phillips et al., 2010) to provide elastic properties and an improved Hikurangi interface geometry (Williams et al., 2013) as the basis for our subduction geometry. In addition to the Hikurangi subduction interface, we generate finite element meshes for 20 additional faults that compose the North Island portion of the elastic block model of Wallace et al. (2012). We generate Green's functions for all faults using the PyLith finite element code (Aagaard et al., 2013), and then use the Defnode geodetic inversion code (McCaffrey, 1995; 2002) to invert for block rotation poles and interseismic coupling. Our revised coupling model should provide better constraints on interseismic coupling in the North Island, and thus provide a

better foundation to inform seismic hazard estimates.

THE VULNERABILITY OF AUCKLAND CITY'S BUILDINGS TO TEPHRA HAZARDS

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A future volcanic eruption from the Auckland Volcanic Field (AVF) will lead to significant damage to buildings located within 3-5 km of the eruptive centre. Whilst evacuations should mitigate loss of human life, impacts to buildings will reduce available housing and commercial activities during the post-eruption recovery and create a large burden on insurance and construction sectors. Both issues have the potential to cause major social and economic impacts. Accurately assessing the likely performance of buildings can inform pre-event recovery planning by forecasting loss of habitable buildings and insurance losses. Unfortunately there is comparatively little data on ballistic hazard and vulnerability for buildings, making accurate ballistic impact assessments challenging.

To quantitatively measure building vulnerability, fragility functions can be used to relate hazard intensity (i.e. energy of ballistic projectile) with what assets are exposed (i.e. building type) to calculate impact. Here we develop fragility functions for residential and commercial buildings by analysing ballistic impacts to roof and wall cladding materials commonly used in New Zealand construction. The functions were developed using damage data from post-eruption building surveys at Mt Ontake and Mt Usu, review of relevant cyclone fragility literature, and novel destructive testing experiments using the University of Canterbury's pneumatic cannon. These fragility functions have been utilised in an impact assessment to determine loss of building habitability and insurance losses for AVF eruption scenarios.

Secondly, the field surveys and experiments have identified common failure mechanisms for a range of construction types with several important implications for life safety and building recovery. In particular, the generation of secondary missiles within impacted concrete buildings, increased ash contamination through ballistic punctures, the presence of low damage ballistic 'shadow zones' and the capacity for timber clad buildings to prevent loss of life despite showing relatively low impact resistance.

QUANTITATIVE CHARACTERISATION OF FRACTURING AROUND THE DAMAGE ZONE SURROUNDING THE ALPINE FAULT USING X-RAY CT SCANS OF DFDP-1 CORE

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Fault damage zones represent the heavily fractured and faulted protolith that surrounds the fault core. Although they only accommodate a small part of the displacement along the fault, damage zones may influence fluid flow around a fault, the stress state and earthquake rupture dynamics. The Alpine Fault represents an internationally important site for damage zone characterisation owing to its unique kinematics, late interseismic state and a wealth of available datasets. In particular, a continuous record of damage zone variation around the Alpine Fault is provided in core recovered from the first phase of the Deep Fault Drilling Project (DFDP-1). Damage zone structures are divided into two types that result from two distinct processes: (1) "off fault damage" induced by stress changes associated with the passage of seismic rupture and (2) "off fault deformation" that represent structures which accommodate strain that was not localised on the principal slip zone (PSZ).

X-ray computed tomography (CT) scans of DFDP-1 core provide exceptional images of these structures and allow their distribution to be calculated with a weighted moving average technique that accounts for orientation bias. This analysis reveals that, within the scale of the damage zone sampled by DFDP-1, there is no increase in density of these structures towards the PSZ. This is in agreement with independent analysis using Borehole Televiewer Data of the DFDP-1B borehole. Instead, we consider the density of these structures to be controlled to the first order by lithology. Comparisons of fracture density to P-wave velocities obtained from wireline logs indicate they are independent of each other, implying that fractures impart no influence on the elastic properties of the rock. This is consistent with the observation that the majority of fractures are cemented. We will discuss how this might influence future Alpine Fault rupture dynamics.

TSUNAMI FRAGILITY FUNCTIONS FOR BUILDINGS: THE NEW ZEALAND CONTEXT

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Fragility functions for buildings are an important component of tsunami risk assessment. These functions express the conditional probability that a particular structural damage state (e.g., 'low', 'moderate' or 'high damage') will be reached or exceeded for a given tsunami intensity measure; such as flow depth. In turn, the functions are used to inform impact and loss estimates for tsunami hazard scenarios with application to tsunami mitigation. Fragility functions are ideally developed using empirical data obtained from previous tsunamis, relating tsunami intensity and damage state at individual buildings for a range of building types. To develop country-specific fragility functions, it is optimal to have functions relating to the building stock in that country. However, a lack of recent damaging tsunami events in New Zealand means the country does not have modern empirical tsunami impact data relating to its own building stock. Thus, to improve tsunami risk assessment in New Zealand based on the latest fragility function approach, it is necessary to adapt and/or apply functions developed in countries with building typologies that are relatively analogous to those here. Comprehensive building damage data were collected during post-tsunami damage surveys following the 2011 Tohoku tsunami in Japan; a country with similar building typologies to New Zealand. We highlight key aspects of applying these data to enhance tsunami risk management in New Zealand, including opportunities, challenges, limitations and future directions.

TIMESCALES OF HUMAN INTEREST IN THE GEOLOGICAL RECORDS OF RHYOLITE ERUPTIONS

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Prehistoric eruptions are generally treated as discrete events, separated from preceding and following events by periods defined by ^{14}C or radiometric dating as centuries or longer. Modern events such as Monserrat (1995-?) or Mount St. Helens (1980-86; 2004-2008) blur this distinction with 'eruption episodes' versus 'separate eruptions' becoming a semantic issue. For rhyolite eruptions, where historic events are scarce, discerning episodicity within, or close spacing between, eruptions becomes important. Time gaps of a few decades or less are challenging to recognise and quantify in eruption products, but important in terms of modelling future events and considering the consequent hazards, economic impacts and associated societal responses. We here consider the geological record for the timing of prehistoric rhyolite eruptions over a range of sizes. In some, such as the Bishop Tuff, there is no evidence in the eruptive stratigraphy to suggest any significant hiatus in activity, and an overall timing of days for the main activity has been inferred. In contrast, evidence from other deposits indicates a prolongation of geologically distinct eruptions, such as the Oruanui (over several months) and Huckleberry Ridge Tuff (over likely over a few decades). Such evidence is in the form of syn-eruptive erosion and reworking, or breaks long enough for successive units to have contrasting welding histories but for the earlier units to still be hot and fumarolically active when the later ones were emplaced. Some eruptions in the young record from Taupo volcano were sourced from widely separated vents, yet have only subtle evidence for time breaks between them, suggestive of years to 1-2 decades. The youngest event at Taupo consisted of the catastrophic 232±5 CE explosive activity (eruption Y), which was followed by a break of 10±5 years before effusive activity (eruption Z) occurred under the re-formed Lake Taupo. The lengths of time breaks within and between rhyolite eruptions are overlapping, and present major challenges for linking field and petrological evidence and considering whether or not an eruption has ended.

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

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The stress field is one of the primary controlling factors of crustal deformation and faulting processes and is therefore important for understanding tectonic dynamics and seismic hazard. In the upper crust cracks that are parallel to the maximum horizontal stress direction (SHmax) are able to remain open and retain fluids. When shear rays traverse through fractured anisotropic crust the fastest polarized wave tends to align parallel to the fluid filled cracks. By measuring this fast direction, via shear wave splitting analysis, the maximum horizontal stress direction can be obtained.

The Seismic Array Hikurangi Experiment (SAHKE) was a large seismic project that was undertaken from late 2009 until mid-2011, across the southern North Island of New Zealand. SAHKE consisted of two phases: 1) A series of active source seismic lines, and 2) A five month passive seismometer deployment consisting of 57 short-period and 10 broad band seismometers. The passive SAHKE stations, complemented with 7 Geonet stations, give good coverage of the seismicity in the wider Wellington region.

We use multiple filter automatic splitting technique (MFAST) to obtain splitting measurements for the passive seismic data collected during SAHKE and infer a model of the upper crustal stress field. Preliminary analysis of the splitting measurements shows that the average fast direction of individual stations tends to align parallel to nearby faults. We also find that the overall trend of the average splitting direction is in reasonable agreement with the stress orientation calculated from broader scale focal mechanism studies.

AN ASSESSMENT OF DISPARATE HEIGHTS IN GRAVITY OBSERVATIONS

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When combining heighted datasets the height datum – or reference surface – may not be immediately clear. For example heights may be stated as ellipsoidal, orthometric, mean sea level or may not be defined at all. The first stage of data integration is to identify these inconsistencies, and then provide a transformation to a common reference surface.

This presentation investigates the challenges attributable to heights when processing historical gravity data and combining them with modern datasets. It includes an assessment of the impact of height errors on gravity reductions, and the possible consequences of using 'rough' coordinates and heights in the field.

COLVILLE VOLCANO: GEOHABITAT OF THE FIRST DISCOVERED INTACT VOLCANO OF THE COLVILLE ARC

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The Colville Arc was active during the Miocene-Pliocene until opening of the Havre Trough separated the arc into the remnant Colville and Kermadec Ridges, and established the present day Kermadec Arc. Until recently little has been known of the structure and composition of the Colville Arc as sampling has been sparse and mapping limited. In 2012, a multibeam survey of a portion of the Colville Ridge (centered on 30° 11' S, 179° 44' E) during the RV *Tangaroa* TAN1213 voyage revealed a dissected largely flat-topped volcanic massif– the first volcano of the remnant Colville Arc to be identified.

Colville volcano has a basal diameter of ~ 20 km and rises some 1800 m from the seafloor, with the summit at 375 mbsl. The summit is eroded and cone reconstructions indicate that it was once at least 2000 m high – comparable to Mt Ruapehu. Small volcanic cones (up to 100 m high) pepper the summit and extend > 10 km to the north. These appear to be significantly younger than Colville volcano, with some occurring on the eroded platform of the edifice. They lie on NNE-tending lineaments parallel to the strike of the major faults of the Colville Ridge (Wright, 1997). However, they themselves are not faulted, suggesting that they formed during rifting of the Havre Trough and that post-rift magmatism continued to occur on the Colville Arc.

Seven rock dredge and epibenthic sled deployments were conducted on Colville volcano and the small cones to the northeast. Rock samples recovered included porphyritic basalts, vesicular basalts, indurated sandstone and breccia and microcrystalline plutonic rocks. Biological specimens numbered over 1000 and included squat lobsters, plexaurid corals, and sponges. Some are new records of species for the New Zealand region, or even globally.

THE SUNDA MEGATHRUST DEFORMATION PROCESS: 15 YEARS OF RECENT GREAT EARTHQUAKES

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We present a comprehensive analysis of the Sunda megathrust deformation using continuous GPS between 1999 – 2014. The complex deformation pattern has been caused by a number of major earthquakes, including the 2004 Aceh, 2005 Nias, 2007 Bengkulu, 2012 northern Sumatra, and also several significant earthquakes events during 2008 and 2010, are discussed. This study includes a number of permanent GPS sites, starting with 16 sites in 1999 and increasing to 150 sites in 2014. These sites are located in Indonesia, Malaysia and the Philippines. The spatiotemporal distribution of decay vector recorded by GPS sites indicated a local anomaly motion within the Sundaland plate caused by the past great earthquakes. The decay amplitude from previous great earthquakes suggests that the central - southern Peninsular Malaysia and central Sumatra are a single region. This region is likely experiencing a poroelastic deformation where a distinctive decay amplitude vector was identified when compared to the northern Peninsular Malaysia, and northern and southern Sumatra. Numerous great ruptures of the Sunda megathrust has caused significant co-seismic offset, as well as viscoelastic relaxation for multiple events that overlap in time on the western Sundaland plate. Earlier studies in Sunda megathrust did not depict an overall post-seismic deformation in spatial term, in fact, this study shows that the extent of the deformation zone was underestimated. The regional variation of post-seismic deformation in Peninsular Malaysia and Sumatra suggests that the region is subjected to intraplate and internal deformation however this result needs further investigation and verification.

ONLINE GEOSCIENCE DATABASES; WHAT THEY REPRESENT AND THEIR USES

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Easily accessible! Needless to say accessibility is one of the most significant benefits of the Internet. Physical presence in a specific location means that the transmission and access of a variety of information is possible for individuals, and geoscientists are not an exception. Through the Internet, geoscientists are able to share their knowledge and improve their understanding of any region of planet Earth, without limitation of place and time. However, production of online databases and their presentation have their own special experiences.

An interesting case within geosciences today is that in some universities, geoscientists are seeing the benefits of sharing their data. It seems that the traditional attitudes for caution about the data sharing are gradually changing and hopefully, a variety of issues in several sectors will be raised via the use of online databases. In this study, we will discuss the challenges of making online databases for geoscience data and then suggest ideas for solving these problems.

A case study of an online stratigraphically and paleontological database from Persia will be

discussed in this presentation. The output of the database forms a website named "Geology of Iran". It contains four parts: palaeontology, stratigraphy, earthquakes and faults of Iran. The first two parts are bilingually presented, whereas data in the second two parts are just shown in Persian. The palaeontology section consists of information about classification, descriptions and pictures of fossils. The stratigraphy section involves data on structural zones, stratigraphic formations, their type sections and accompanying field locations on a map. According to the type of data, visitor statistics, user hits and feedback, numerous national and international geoscientists in different situations have used the mentioned databases. The website provides facilities like search, query, data description and pictures that clients can use to enjoy extensive information in a user-friendly environment.

PETROGRAPHIC AND PETROPHYSICAL PROPERTIES OF THIN-BEDDED EOCENE BEACH-BAR SAND RESERVOIR, DONGYING DEPRESSION, BOHAI BAY BASIN, CHINA

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Thin-bedded beach-bar sand reservoir is widely deposited in the upper fourth member of Eocene Shahejie Formation (Es4s) of Niuzhuang Sag, along the southern gentle slope of Dongying depression. Medium to low permeability, complex stratigraphy and thin-bedded high heterogeneous (due to high frequency sedimentary cycles and resulting carbonate and clay diagenesis) characteristics require some additional and advanced petrographic and petrophysical analyses to interpret the reservoir quality. Petrographic study based on microscopic observation of optical, cathodoluminescence (CL), confocal laser scanning (LSCM) and scanning electron microscope (SEM) along with X-ray diffraction (XRD) is used to discuss the fabric, texture, allogenic and authigenic mineralogy of highly heterogenic sandstone. Despite of the dissolution of grains and numerous fractures, destruction of porosity by cementation and compaction are main causes of diagenetic heterogeneity. Secondary pores are developed with the increasing effect of diagenesis causing the dissolution of feldspar grains. Grain coating smectite clays destruct primary porosity at places while dominating pore filling authigenic illite and illite/smectite clays reduced permeability. It is necessary to understand the complexity of the pore structure and to determine the capacity of flow and trap fluids. Characteristics of pores obtained from Nuclear magnetic resonance (NMR) and mercury injection capillary pressure (MICP) seems appropriate to cover the range of sand microfacies and overcome the individual method limits. Due to high degree of digenetic heterogeneity in beach-bar, it is characterized as middle to low permeable reservoir. The current study reflects significant insight to understand properties of sand and can lead for the comprehensive reservoir characterization and overall reservoir bed quality.

SEQUENCE STRATIGRAPHY, DEPOSITIONAL PATTERN AND SEDIMENTARY FACIES OF EOCENE BEACH-BAR SAND RESERVOIR, DONGYING DEPRESSION, BOHAI BAY BASIN, CHINA

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The objective of this paper is to establish a linkage between sequence stratigraphy, sedimentology and depositional architecture of sand microfacies of Eocene Shahejie Formation (Es4s) of Niuzhuang Sag, along the southern gentle slope of Dongying depression. Seismic, wireline logs, and core observations are used to interpret depositional settings and sequence stratigraphic framework. Es4s is interpreted as third-order sequence, composed of lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST). On fourth order, twenty-nine parasequences and seven parasequence sets have been identified. Sand bodies are mainly deposited in the shore shallow lake beach-bar (clastic beach-bar), semi-deep lake (carbonate beach-bar) and the shallow water channel. Fine grain size, poor sorting, continuous thin interbedded mud layers with

siltstone/fine-sandstone having argillaceous layers in regular intervals and low sedimentological maturity are main causes of depositional heterogeneity. Due to high degree of heterogeneity in beach-bar, it is characterized as middle to low permeable reservoir. Significant insight to understand properties of beach-bar sands can lead for the comprehensive reservoir characterization and overall reservoir bed quality.

KINEMATICS AND DYNAMICS OF THE KIVU RIFT SYSTEM FROM SEISMIC ANISOTROPY, SEISMICITY, AND STRUCTURAL ANALYSES

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The Lake Kivu region in East Africa attracts interest for exploration of hydrocarbon-supersaturated lake waters and underground deposits, but rift seismicity and volcanic hazards remain poorly understood. In this study we integrated multiple types of data to obtain a comprehensive 3-D geodynamic profile of the region. First, we determined the kinematics of active normal faults and their relation to pre-existing basement structures using merged high-resolution CHIRP bathymetric and Space Radar Topography Mission data. As many as 32 new faults were identified under the lake. The majority of faults in the northern sector were found to strike NNE, whereas NE faults were overrepresented in the southern basin, marking the Kivu-Rusizi accommodation zone. To delineate zones of active faulting, we analyzed data from an 8-station seismometer array between March 2012 and April 2013. The majority of earthquakes (excluding the active volcanoes) occurred at depths of 8-20km, but unusually shallow earthquakes (2-4km) occurred along submerged faults within the East Kivu basin suggesting high pore pressures within the upper crust of this region. Next, seismic shear-wave splitting measurements were analyzed to evaluate models of continental lithosphere modification. Results revealed fast polarization directions in close agreement with the apparent plate motion and the NE magmatic fabric of the Eastern Kivu Province. Furthermore, we used simple elastic plate flexure models to evaluate the role of volcanic loading within the Virunga Volcanic Province in the evolution of the Kivu basin. This generated an improved estimate for the maximum plate deflection (~7km), of relevance for local drilling. This and other results suggest that rapid subsidence of the ~400m deep northern basin occurred in response to volcanic construction, and that mantle plume processes have modified the lithosphere. This study provides the first integrated perspective of the Kivu region of significance for resource exploration and geohazard planning.

THE PERITECTIC REACTION GEOSPEEDOMETER

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Using a high resolution ion microprobe with SCAPS imaging, the peritectic reaction of forsterite + silica to enstatite was studied down to submicron level in natural andesitic tephras from the Central Plateau of North Island, New Zealand. The fayalitic component of natural olivines is stable in high-silica melts, and therefore this reaction is in fact a two-step progress: 1. Dissolution of Mg-rich olivine, likely rate-limited by Fe-Mg interdiffusion at the crystal rim, results in enrichment of Fe in the crystal rim and of Mg in the melt boundary layer around the crystal, which is a few microns wide. 2. Magnesian pyroxenes nucleate and grow in this melt boundary layer; as soon as these microlites touch the rim of the dissolving olivine, they shield the crystals from the silica-rich melt, thereby preventing further olivine dissolution. At this point, Fe-Mg interdiffusion (mostly within olivine, but in part between olivine and pyroxene) begins to destroy the Fe-enrichment of the olivine rim. The reaction is completed when the dissolving olivine crystal is completely mantled by pyroxene microlites. Thick orthopyroxene mantles likely indicate further orthopyroxene overgrowth that is not associated with the actual peritectic reaction. The textures observed in the olivine core preserve

information about the reaction history of the grain. Modelling of Fe-Mg interdiffusion in the olivine rim following its shielding from the melt by pyroxene overgrowth yields the rates of olivine dissolution and the rates of pyroxene growth, and in combination with orthopyroxene microlite size distribution data informs the time between olivine crystal uptake into the SiO_2-rich melt and explosive eruption at the surface. The studied sample yields a microlite growth time of less than 60 hours, which is a timeframe suitable for triggering effective hazard mitigation procedures.

STRATOVOLCANOES OF THE HAVRE TROUGH BACK-ARC

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The Kermadec arc – Havre Trough is widely regarded as an archetypical intra-oceanic arc – back arc system. In detail however, magmatism within the back arc rift system has not been well explored and data for very few magmatic samples have been reported. An increased mapping focus on the back arc basins in recent years has revealed large stratovolcanoes present on both crustal highs (plateaux) and lows (basins) of the rifting back arc. The origin and age of these volcanic edifices are unknown. As part of a wider study into the magmatic evolution of the Havre Trough back arc system, we will present descriptions and geochemical data for lavas from two large stratovolcanoes situated within the Havre Trough: Gill and Rapuhia.

Gill Volcano (34°37.22'S, 178°22.81'E), a ~1800 m high edifice rising from a basal depth of 3000 mbsl, was first discovered, mapped (12 kHz data) and informally named during voyage YK06-14 of the Japanese Research Vessel *Yokosuka* in 2006. Gill lies to the northwest of three backarc volcanoes situated on a ~2000 mbsl crustal plateau, including Rapuhia (34°46.57' S, 178°30.32' E), first discovered and mapped during the R/V *Tangaroa* voyage TAN0205. Dredge sampling of the two volcanoes was undertaken during the R/V *Tangaroa* voyage TAN1007. Two dredge deployments rom Gill returned a large amount of mafic pillow lava and boulders. Mafic scoria clasts and volcanic blocks, and a small amount of banded pumice was recovered during two dredges on Rapuhia. Vesicular mafic clasts and blocks of pumice were recovered from a ridge SW of Rapuhia. A single previous dredge deployment on Rapuhia (during the TAN0205 voyage) also sampled dacite, basaltic andesite and pumice from the cone summit. The samples reported here include pyroxene ± plagioclase ± olivine phyric lavas with 5 to 40% phenocryst phases. Vesicularity varies from <5 to 35%.

DEMONSTRATING PERFORMANCE OF C-14 AMS ANALYSES BY THE RAFTER RADIOCARBON LABORATORY

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Rafter Radiocarbon Laboratory is the world's oldest continuously operating radiocarbon lab. We made our first radiocarbon measurement in 1951 and the Southern Hemisphere's first C-14 Accelerator Mass Spectrometry (AMS) measurement in 1983. We have the only AMS system in NZ, a new one installed in 2010. Rafter Radiocarbon has been at the forefront of radiocarbon processing and measurement development and application for over 60 years. Quality of the result and particularly reproducibility of results is our driver.

Our work focuses on the development and applications of radiocarbon particularly in areas of research interest to GNS Science and New Zealand, including atmospheric CO_2, the modern carbon cycle, global environmental change, paleoclimate, and paleohazard events. This means that we cater to a wide variety of sample types and preparation methods.

Consistency (repeatability, reproducibility) in the analytical results is evaluated internally through quality assurance and control measures and externally through the participation in international laboratory inter-comparisons. As is common practice amongst laboratories, we regularly measure processing blanks and secondary standards along with samples of unknown age and primary standards. We will present a concise overview of the various control measures and discuss how they propagate into final uncertainty of samples with unknown age.

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