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DYNAMIC NEW ZEALAND, DYNAMIC EARTH

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RECONCILING EXPERIMENTAL AND STATIC-DYNAMIC NUMERICAL ESTIMATIONS OF SEISMIC ANISOTROPY IN ALPINE FAULT MYLONITES

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Quartzo-feldspathic mylonites and schists are the main contributors to seismic wave anisotropy in the vicinity of the Alpine Fault (New Zealand). We must determine how the physical properties of rocks like these influence elastic wave anisotropy if we want to unravel both the reasons for heterogeneous seismic wave propagation, and interpret deformation processes in fault zones. To study such controls on velocity anisotropy we can: 1) experimentally measure elastic wave anisotropy on cores at in-situ conditions or 2) estimate wave velocities by static (effective medium averaging) or dynamic (finite element) modelling based on EBSD data or photomicrographs. Here we compare all three approaches in study of schist and mylonite samples from the Alpine Fault.

Volumetric proportions of intrinsically anisotropic micas in cleavage domains and comparatively isotropic quartz+feldspar in microlithons commonly vary significantly within one sample. Our analysis examines the effects of these phases and their arrangement, and further addresses how heterogeneity influences elastic wave anisotropy. We compare P-wave seismic anisotropy estimates based on millimetres-scale ultrasonic waves

under in situ conditions, with simulations that account for micrometre-scale variations in elastic properties of constituent minerals with the MTEX toolbox and finite-element wave propagation on EBSD images. We observe that the sorts of variations in the distribution of micas and quartz+feldspar within any one of our real core samples can change the elastic wave anisotropy by 10%. In addition, at 60 MPa confining pressure, experimental elastic anisotropy is greater than modelled anisotropy, which could indicate that open microfractures dramatically influence seismic wave anisotropy in the top 3 to 4 km of the crust, or be related to the different resolutions of the two methods.

THE PHYSICAL PROPERTIES OF ALPINE FAULT CATACLASITES THAT DRIVE ITS ELASTIC WAVE VELOCITIES

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Studying the Alpine fault, which is late in its cycle of stress accumulation, is a unique opportunity to understand the subsurface conditions ahead of a large earthquake. It is the physical properties of the rocks in the damaged zone around the fault that will control the mechanisms of rupture and propagation. Here we present a comprehensive study of the physical properties of Alpine Fault cataclasites and their relation to elastic wave speed and moduli. We study 12 cataclasite samples from core extracted from the DFDP-1A and -1B

wells from the first Alpine fault DFDP campaign.

Sonic log P-wave velocities in the cataclasite sections in DFDP wells vary between 2000 and 6000 m/s and there is little quantitative understanding on the nature of this variability. We have performed high (up to 100 MPa) and low (pressure at the core depth, 2-4 MPa) pressure P- and S-wave ultrasonic velocity measurements on the water-saturated cataclasites. Our laboratory velocities match the well data at the pressures representative of the core depths, but as expected, velocities at higher pressures do not agree with the log. To understand which micro-scale physical properties affect the P- and S-wave velocities, we have performed computerized tomography scanning and analysis, semi-quantitative XRD, XRF, porosity and grain density from pycnometry and fracture estimation from rock physics modelling. Preliminary data indicate that fractures and porosity are not the principal controls on wave speed variability. Moreover, we will discuss the challenges of studying the physical properties in cataclasite rocks in the context of atmospheric vs. confining pressures.

TRADITIONAL AND VIRTUAL FIELDTRIPS AS PREPARATION FOR FURTHER GEOSCIENCE LEARNING

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Fieldtrips are often seen as crucial learning experiences for undergraduate students. In the field, students apply knowledge and skills from prior courses to real world scenarios that

more closely match those likely to be encountered in future career opportunities. However, fieldtrips are also a stressful experience, requiring students to work long hours and to produce an integrated finished product (e.g., a map) in a relatively short period of time.

At the University of Canterbury, we identified that students felt underprepared for fieldwork and that the current laboratory-based field training was not an adequate lead in for independent field mapping trips. Therefore, we developed a one-day fieldtrip “boot camp” to replace laboratory teaching. In the boot camp, we introduced the students to basic field concepts in an authentic field setting, which helped to improve their self-efficacy before attempting their first overnight independent field mapping course.

Here, we present our initial findings on student self-efficacy as a result of our fieldtrip changes. We also present ongoing curriculum development into the benefits of repeated field skills exercises as a preparation to further learning in later degree fieldtrips which require more independence and critical thinking from undergraduate students. We then discuss implications of our data for the development of future real and virtual fieldtrips.

INTEGRATED INTERPRETATION OF AEROMAGNETIC AND GEOLOGICAL DATA TO IMAGE THE SUBSURFACE GEOLOGICAL PATTERNS (DISCONTINUITIES) WITHIN THE COROMANDEL VOLCANIC ZONE (CVZ)

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The paucity of bed rock exposures due to dense vegetation cover, and a lack of uniform coverage of high-resolution geophysical data in the Coromandel Volcanic Zone (CVZ) make imaging of the subsurface geologic patterns difficult. We compile companies' deposit scale high-resolution aeromagnetic surveys and integrate with the surface geological data as constraints to illustrate the subsurface geologic features and their relationship with surface patterns. Despite the inherent ambiguity associated with aeromagnetic interpretation, the data provide an opportunity to recognise the occurrence of magnetic source bodies at different subsurface depths by isolating the long and short wavelength anomaly components. In this regard, we particularly use the multiscale edge detection (worming) technique on the gradient enhanced aeromagnetic grid to indicate locations where there exist maximum contrasts in the susceptibility of the subsurface geology. The technique images the subsurface contrast interfaces retrieved at different resolution by combining the horizontal gradient and upward continuation techniques.

Our integrated interpretation reveals the spatial distribution, geometry and relative depth persistence of magnetic source bodies, which are inferred to be associated with known stratigraphic and structural features. For example, we interpreted three relative depth occurrences of magnetic source bodies,

which broadly coincide with the surface geology, including: a) > 3 km deep andesite intrusives, b) 0.5 – 2 km deep andesite/dacite intrusives and extrusives, and c) < 1 km deep andesite/dacite and rhyolite extrusives. Similarly, the data show prominent NW-SE, and NE-SW oriented, strong and linear to semi-linear structural discontinuities and anomaly boundaries, which we interpret as deep-seated structural patterns that broadly reflect the control of regional basement structures.

SEDIMENTARY PROCESSES OF THE COOK STRAIT CANYON SYSTEM

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Submarine canyon systems provide a major conduit for transport of marine and terrestrial sediment from shelf to deep-ocean. Sediment flow processes and triggering mechanisms that drive flow processes vary greatly from canyon to canyon. Variation of flow processes is affected mainly by the canyon geomorphology and sediment type. This investigation was undertaken in the Cook Strait Canyon System, which includes Opouawe, and Campbell canyons. This canyon system covers approximately 1800 km², which consists of multiple branches incised into the continental shelf. The Cook Strait Canyon System is located in the eastern Cook Strait; a body of water that separates the North and South Islands of New Zealand. This canyon transports sediment derived from the Cook Strait off the shelf into the Hikurangi Channel.

A total of six sediment cores were collected throughout the study site, high resolution visual core logging, CT scanning, Geotek analysis and laser grain size analysis were done on the suite of cores. 3 radiocarbon dates were derived from basal sediments within 3 cores in order to define a maximum age for the overlying sediments.

From the data attained through these analyses 5 facies have been described with six sub-facies within these. The facies were determined based on depositional characteristics in order to define the varying flow processes within the canyon system. The canyons exhibit a variety of flow processes as the sediments vary in size from pebble to silt. Low clay content in the canyons cause all flows to remain non-cohesive. Smaller grain-sized beds normally graded from sand to silt are interpreted as turbidity currents. Larger grain flow beds were found to contain a mixture of high density turbidity currents and grain flows. Most beds exhibit waning flow characteristics and are likely triggered by seismic sources making the area a potential site for paleoseismic investigation.

DISPLACEMENT OF LARGE BOULDERS ACROSS COASTAL ROCK PLATFORMS SOUTH OF WOLLONGONG, NSW, BY LARGE STORM WAVES OR TSUNAMI?

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This research reports large boulders, or blocks, that have been displaced across coastal rock platforms south of Wollongong, Australia. In some cases imbrication of the blocks is evident. One block in particular measures approximately 1.5x2x4 m in size, is composed predominantly of fine-grained sandstone and

siltstone, and weighs approximately 10-15 tonnes. Sedimentological and physical volcanological evidence is used to identify the original *in-situ* position, indicating that the block was transported 42 m across the rock platform and rotated 110°. More movement has occurred within the past few years, of about 1 m sideways whilst being rotated back 50°. Another larger block weighing at least 30 tonnes at another location has been observed to move at least 10m upslope of the platform and rotate approximately 45°, during the last 5 years. The movement is attributed to large storm waves. No scraping across the underlying rock is evident, suggesting that they may have been lifted, or floated, indicating the potential energy of the wave after travelling 40 to 50 m across the rock platforms. Calculations suggest that a wave of considerable height and wave length is required to detach, lift and displace the block across the platform in one event, however, results are problematical due to the errors associated with the factors concerned. An inversion algorithm may assist with producing a meaningful scenario. Other examples of both recent and less recent block movements are shown. The findings indicate that shore platforms along the New South Wales south coast are prone to occasional large storm waves capable of moving large heavy blocks and boulders. The research contributes to the growing body of information regarding erosion and natural hazards at coastlines, particularly applicable to climate change and associated sea level rise.

**TUFFS, DYKES, FLOWS, FOSSILS,
DROPSTONES AND GLENDONITES;
EARLY VOLCANISM AND SEDIMENTATION IN
THE MID-PERMIAN
SOUTHERN SYDNEY BASIN**

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This research investigates the volcanology and sedimentation of the Mid Permian Southern Sydney Basin. A number of newly identified tuffs interspersed with the shallow marine sediments are described. These tuffs are laterally extensive, hence chronostratigraphic markers and are both mafic and felsic. Trace and body marine fossils are associated with some of them, including death assemblages. The dykes along the coast south of Sydney have been reported as being generally Jurassic to Tertiary in age, however, many dykes are found intruding unconsolidated wet sediments, hence being penecontemporaneous with sedimentation. These are more likely associated with the proximal volcanoes responsible for the early latite eruptions of the Gerringong Volcanics (GV). At least one of these Permian dykes contains xenoliths, with at least one syenitic type originating from a lower crustal source beneath the Basin. Dropstones, which sometimes exceed 1 metre in cross section, of extrusive igneous material, both mafic and felsic, from eruptions prior to the first recognized flows of the GV are also described. These dropstones usually occur in conglomerate horizons, probably transported from coastal sea ice due to short and long term climatic cycles. Intercalated glendonite and concretion horizons which occur

throughout the sedimentary units, especially the tuffs, often exhibit very different morphologies, possibly due to the local heat regime during or post formation. Evidence suggests that the sources for these eruptions and intrusions were from volcanoes situated initially off the present day coastline to the south east, followed by at least one island volcano at Jervis Bay, with later development of a volcanic arc to the north east, also off the present day coastline, which was responsible for the later GV latite flows. It is likely that these volcanoes were associated with stress and tension related to subduction and foreland loading from the Currarong Orogen to the east, the south-easterly extension of the New England Orogen.

**LATE CRETACEOUS RIFTING OF THE
CANTERBURY BASIN DURING ZEALANDIA
INTRA-CONTINENTAL EXTENSION**

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Zealandia comprises continental crust that rifted from Gondwana during Cretaceous breakup. The Canterbury Basin is one of Zealandia's rift basins formed during intra-continental extension initiated around 105Ma. By ~86.5 Ma, the locus of the primary extension shifted to the West Antarctica and South Zealandia spreading centre. Extension in the basin was active for over ~20 Ma. Typically in Canterbury, the extensional basins are under-filled with sediments, as the rate of sediment supply was lower than the rate of accommodation space creation.

Interpretation of mainly 2D seismic reflection

lines and petroleum wells indicates that mid-Cretaceous rifting (~105-86.5 Ma) formed in association with NE-SW, E-W and NW-SE striking normal faults that accrued displacement synchronously. These faults formed due to distributed extension prior to Gondwana breakup, with maximum throws of 2-3 km typically greatest on NE striking faults sub-parallel to the subsequent mid-ocean ridge system that formed between New Zealand and Antarctica.

E-W and NW-SE faults are mainly located in northern parts of the basin where deep seismic reflectors within basement highlight E-W trending thrust faults and folds. These contractional structures are interpreted to have formed during Mesozoic subduction along the eastern Gondwana margin and were reactivated during mid-Cretaceous extension.

In the offshore Canterbury Basin top lap of syn-rift reflectors onto post-rift reflectors is consistent with erosion of syn-rift growth-strata. In the Clipper-1 well an unconformity between syn-rift terrestrial strata and Lower Haumurian post-rift marine sedimentary rocks represents a 10 Myr hiatus. An unconformity of similar age has been described in the Taranaki Basin and could record regional uplift of Zealandia following Gondwana break-up.

SEDIMENTOLOGY & MICROPALAEONTOLOGY OF A MID- MIOCENE MAAR LAKE SEDIMENT

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The Mid-Miocene Climatic Optimum (MMCO) was an interval of high global temperatures that lasted from 17-15 Ma. Palaeoclimate evidence for this period has primarily come from deep marine sediment cores with minimum resolution of thousands of years. The Hindon Maar Complex (HMC), located ~22 km NW of Dunedin CBD, consists of four maar craters of mid-Miocene age (~15 Ma), coinciding with the end of the MMCO. Laminated lake sediments are found in Maar 1, and in a depression between Maar 2 and Maar 3. These sediments are composed almost entirely of organic matter and biogenic silica. Due to the high organic matter content, laminae are hard to discern; however, maar lake sediments are frequently characterised by seasonal to annual layers, and we assume that the Hindon deposits are very highly resolved compared to contemporary marine deposits. Sediments in the HMC thus provide a unique opportunity to reconstruct climate and environment in New Zealand at an unusually high resolution during a period of high global temperatures.

This project aims to characterise compositional and ecological variability in one of the Hindon Maar lake deposits and use these to infer climatic and environmental conditions. Microfossil assemblages are composed of freshwater diatoms, sponge spicules, and chrysophycean cysts. Biogenic silica and total organic carbon contents are estimated using Fourier transform infrared spectroscopy (FTIRS) and verified using wet chemistry. Here we present preliminary results and palaeoenvironmental inferences.

EVOLUTION OF THE DUNEDIN VOLCANIC COMPLEX: INSIGHTS FROM ALLANS BEACH

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Intraplate volcanism is a widespread phenomenon throughout the world with the Auckland Volcanic Field being a currently active example in the New Zealand region. The onset of such volcanism is poorly understood. An understanding of the evolution of small eruptive centres has been attained through sampling of their entire sequences. However, studying the evolution of long-lived complexes is more difficult as their earliest products are often inaccessible. The Dunedin Volcanic Complex (DVC) was a long-lived volcanic centre, active from 16 Ma to 10 Ma, within an intraplate setting. Allans Beach on the southeastern coast of Otago Peninsula is one of the oldest known exposed sections of the DVC. This exposure offers a unique window into the eruptive and magmatic processes taking place during the onset of volcanism in the Dunedin area. Intraplate volcanism is known to produce chemically primitive magmas, with few examples of evolved compositions. At Allans Beach, however, a wide spectrum of compositions (basanitic to phonolitic) and textures are observed within the volcanoclastic and intrusive material. These units have complex cross-cutting relationships, in a small area (< 1 km). Field and petrographic analysis has enabled re-interpretation of the events that led to their formation. A phonolitic pumice host is cross-cut by diatremes, cross cut further by dikes ranging from alkaline basalt to phonolite. Some of these diatremes formed penecontemporaneously with intruding dikes. A wide range of magma compositions emplaced in a relatively short time span is an indication of complex magmatic processes

occurring during the onset of a long-lived intraplate complex.

A RECORD OF NATURAL AND HUMAN-INDUCED ENVIRONMENTAL CHANGE FROM PUNAHAU (LAKE HOROWHENUA)

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Lake sediment records provide invaluable archives of the environmental changes both within the lake, and the surrounding catchment. Such archives are now increasingly being used to provide baseline data for informing environmental restoration efforts. Lake Horowhenua (Punahau) is a shallow dune lake located in the Horowhenua District. The lake is owned privately by the Muaūpoko people who have a special cultural and spiritual connection to the lake. Punahau has poor water quality, high turbidity and is hypertrophic due to agricultural and horticultural runoff, groundwater transport, and storm water overflow. However, knowledge of the lakes' inception and evolution, changes in vegetation of the surrounding catchment and sedimentation rates due to land-use change are poorly quantified. In order to rectify this, sediment cores have been collected from Punahau. Stratigraphy and initial radiocarbon dating results indicate that the modern lake began to form at approximately 7100 cal yr BP following a marine incursion, which may be attributed to the Holocene high sea level stand, or possibly a tidal surge associated with a tsunami. Ongoing research involves palynology, charcoal analysis, sedimentology/grain size, XRF geochemistry,

radiometric dating (^{14}C , ^{210}Pb and ^{137}Cs) and other elemental analyses to construct a detailed history of the lake to assess the impact of human-induced environmental change resulting from Polynesian and European settlement. The archive of information retrieved from the sediments of Punahau will be a key resource informing lake restoration efforts currently underway as part of the Lake Horowhenua Accord as well as Te Mana O Te Wai projects.

THE INTERPLAY OF TECTONIC, VOLCANIC AND EUSTATIC FLUCTUATIONS DURING THE NEOGENE SEQUENCE OF NORTH CANTERBURY BASIN, NEW ZEALAND

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The Neogene sequence of northern Canterbury basin is dominated by thick siliciclastic deposits formed as a consequence of uplift and erosion of the Southern Alps. Throughout the eastern basin these sequences are locally pierced and intercalated with volcanogenic rocks, which include the volcanoes of Banks Peninsula.

We aim to understand how the interplay of tectonic events, eustatic fluctuations in sea level and volcanism controls the Neogene morphology and progradation of the shelf-slope along the eastern margin of New Zealand's South Island. We use a large collection of onshore and offshore seismic reflection lines calibrated with logs, biostratigraphic, radiometric and lithological data from exploration wells and outcrops. These data constrain the architecture of five chronostratigraphic sequences proximal and distal to volcanic centres. The resulting

insights have been combined with data from the literature to evaluate the role of allogenic and autogenic processes that control the stratigraphy of the northern Canterbury basin.

Although the current literature indicates that self-slope construction and the associated stratigraphic sequences of Canterbury basin are exclusively controlled by eustatic cycles and tectonic pulses, we observed that two important magmatic events strongly influenced progradation of the shelf: 1) a group of volcanic cones, lavas (?) and pyroclastic deposits erupted during the Middle Miocene, here referred to as Resolution Volcanic Field, which is located 50 km offshore of Ashburton. 2) Banks Peninsula Volcanic Complex a trachytic/andesitic volcanic group composed of three large shield volcanoes and several minor eruptive centres, which were active during the Late Miocene.

The area beneath the edifices was intensively deformed, uplifted by magma emplacement and experienced local subsidence due to the weight of the volcanoes compacting underlying marine siltstones. The presence of the volcanoes form elevated areas of more than 4000 km² and produce distinctive retrogradation migration of the shelf slope not observed elsewhere in the basin.

DISTRIBUTION OF SURFICIAL SEDIMENTS IN THE OCEANS AROUND NEW ZEALAND

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New Zealand has a large marine territory. Data from >300 published, unpublished, national and international databases covering approximately 30,000 sediment datasets was compiled to produce a series of maps characterising the surficial sediments of the entire New Zealand Exclusive Economic Zone for the first time. Sediment grain size and carbonate distributions around New Zealand show some distinct spatial patterns. We also discuss other sedimentological features such as the presence of nodules of various types. The sedimentary patterns can primarily be explained by past and present climate, onshore geology and terrigenous flux, tectonics and volcanic activity, complex bathymetry, oceanographic circulation, and diagenetic alteration. The interaction between these various facets permit recognition of distinct regions of deposition such as the east of the North Island where tectonism, source rocks and climate collectively produces extreme sediment fluxes so that the shelf is mantled by modern sands and muds.

FLUID-ROCK INTERACTIONS AND FAULT-ZONE WEAKENING ALONG THE ACTIVE MAI'IU LOW-ANGLE NORMAL FAULT, WOODLARK RIFT, PAPUA NEW GUINEA

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Field observations indicate that a majority of fault slip on the low-angle Mai'iu Fault, Woodlark Rift, Papua New Guinea, occurred along fault rocks comprising a narrow (< 2 m) core. The frictional properties of these fault rocks, in large part predicated by mineralogy,

likely governs the mode of fault slip. We sampled gouges, cataclasites, and protolith metabasite and serpentinite from three exposed normal faults: the active Mai'iu Fault, an abandoned part of the Mai'iu Fault, and the Gwoira splay fault in the hanging wall of the Mai'iu Fault. Quantitative XRD results indicate that all three faults formed primarily within footwall Gorupu metabasalts. Significantly, the active and abandoned Mai'iu Fault localities accommodate slip within fault gouges comprise up to 65% corrensite and saponite. Hydrothermal friction experiments were conducted on six different fault rocks at varying values of sliding velocity ($v=0.3-100 \mu\text{m/s}$), normal stress ($\sigma_n=30-210 \text{ MPa}$), and temperature ($T=50-450^\circ\text{C}$) to simulate progressively deeper levels of fault activity. Saponite-bearing fault gouges exhibited extremely low friction coefficients ($\mu=0.13-0.15$ and $\mu=0.20-0.28$) and velocity-strengthening behaviour conducive to fault creep. At the highest temperatures ($T \geq 150^\circ\text{C}$) and lowest sliding velocities ($v=0.3-3 \mu\text{m/s}$) tested, the frictional velocity dependence of the saponite-bearing gouges transitioned to velocity-weakening, indicating the potential for unstable slip. Hydrothermal friction experiments conducted on frictionally stronger ($\mu=0.37-0.78$) cataclasite, ultracataclasite, and protolith metabasalt and serpentinite samples similarly showed a temperature-dependent transition to velocity-weakening behaviour with simulated depth; the potential for unstable slip was most pronounced in the temperature range of 200 to 350°C. Our experimental results support geodetic, seismological, field, and microstructural evidence for both seismic and aseismic slip on the long-lived Mai'iu Fault.

FRICIONAL PROPERTIES OF HIKURANGI PLATEAU SEDIMENTS AND APPLICATION OF THE RESULTS TO SLOW-SLIP PHENOMENA

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The North Island of New Zealand overlies the Hikurangi Subduction Zone (HSZ), which accommodates westward subduction of the Pacific Plate at a convergence rate that varies from 50-60 mm/yr in the North to around 20 mm/yr in the South. The Hikurangi Subduction Zone décollement occurs within Late Cretaceous-Paleogene (70-32 million-year-old) marine sediments. We measured — for the first time — the frictional strength and stability of Paleocene and Eocene marine sediments deposited on the Hikurangi Plateau and recovered from 419.3 m to 434.56 m below the sea floor during IODP Leg 181 at Site 1124 (Hole 1124C; -39.4984°S, -176.5316 °E). Hydrothermal friction experiments were conducted on nine different samples at a constant effective normal stress of 60 MPa with hydrostatic pore fluid pressure and varying sliding velocities ($v=0.001-30 \mu\text{m/s}$) and temperatures ($T=25-225^\circ\text{C}$). Highly calcareous sediments are frictionally strong ($\mu=0.48-0.66$). Calcareous and noncalcareous clayey sediments are frictionally weak ($\mu=0.18-0.30$) and contain the mineral smectite. The HSZ décollement likely localises in the weakest, smectitic sediments. The friction rate parameter ($a-b$) was determined from velocity steps conducted at temperatures of 25°C, 75°C, 150°C, and 225°C. Whereas velocity-weakening ($-a-b$) materials may nucleate earthquakes or slow-slip events,

velocity-strengthening ($+a-b$) materials are prone to aseismic creep. At every temperature tested, the highly calcareous sediments are predominantly velocity-weakening. The smectitic sediments are predominantly velocity-strengthening. However, when tested at sliding velocities equal to, and slightly faster than, the plate convergence rate ($v=0.001-0.003 \mu\text{m/s}$) at 25°C, the smectitic sediments exhibit velocity-weakening behaviour. The experimental results are significant because: (1) pore-fluid overpressures may not be required for fault-zone weakness or slow slip; and (2) the smectitic sediments overlying the Hikurangi Plateau demonstrate the capacity for hosting an instability at conditions comparable to those along the shallow décollement.

A VIOLENT PHREATOMAGMATIC ERUPTION THAT FORMED A MAAR IN AN INTRA-MOUNTAIN BASIN AT ARXAN-CHAIHE VOLCANIC FIELD, INNER MONGOLIA, CHINA

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The Arxan-Chaihe volcanic fields (ACVF) in NE China consist of about 30 young scoria cones with pahoehoe to aa-type basaltic lava flows and at least 4 maars, together covering an area of c. 1000 km². Volcanism initiated in the Pliocene and continued through the Late Pleistocene to Holocene (c. 2000 cal yrs BP). Recently, tephra of 14,200 cal yrs BP age has been identified, preserved in a crater lake, suggesting a Holocene violent phreatomagmatic explosive eruption from an unknown source. This has intensified the search for potential phreatomagmatic volcanoes in the ACVF. Tongxin Tianchi volcano in the eastern ACVF forms a steep-walled, flat floored basin filled with a lake and

is suspected to be a maar. The depression is surrounded by a c. 400 m high escarpment of Mesozoic crystalline rocks that gradually drops toward the south. Dune-bedded base-surge-dominated successions are at least 40 m thick in the south and diminish toward the higher cliffs in the north. Abundant accretionary lapilli beds, accidental lithic-rich tuffs with impact sags, cored bombs, blocky pyroclasts, as well as glassy, non-to-low vesicular juvenile particles, all point to a sustained and energetic phreatomagmatic explosive eruption forming this volcano. The uniform basaltic composition of the juvenile pyroclasts indicates that phreatomagmatism played a key role in the eruption and the volcano likely was capable of producing a large volume of ash, which could have accumulated in other crater and maar lakes in the ACVF. The pyroclastic deposit characteristics, stratigraphy and microtextures suggest that Tongxin Tianchi is a maar volcano; however, the present day depression is not necessarily identical to the structural margin of the maar crater.

SOCIAL RESPONSIBILITY FOR GEOSCIENCE IN THE UNCONVENTIONAL WORLD

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The very mention of FRACKING can elicit an emotional response, polarising attitudes for and against. In the USA the advent of hydraulic fracturing (aka. fracking) has meant for some economic salvation, while to others it spells environmental doom. In France and Germany fracking has been banned while in the UK (and New Zealand) the waters are being still tested amongst considerable public outrage.

Here I look at the UK's hydraulic fracturing issue and how geoscience lies at the foot of

shale oil and gas exploitation: the initial resource assessment by the BGS and the way politicians swallowed the big numbers : the response of the regulatory authorities in allowing exploration by a few minor oil companies: and the public protests arising from environmental concerns so freely promulgated on social media.

Shale oil and gas is recognised as an 'unconventional' energy source since it doesn't conform with the science as practised (and taught) by most active petroleum geologists. Without a conventional database it begs the question as to how trustworthy and independent is the geoscientific opinion (including my own) ?

The fracking story characterises many other resource developments (deep sea oil, gold & iron sand mining, freshwater dams) and is symptomatic of an ever increasing and hungry population. The need to conform can easily be driven by political, economic and social pressures; as such it is suggested that technical discussion take place within the informed geoscience community prior to it's airing within the world that includes Government, Resource and Environmental Court Proceedings, Facebook etc.

However I suspect the polemic is well established and the time for dialogue has passed. But in New Zealand we are fortunate not to have 'academic freedom' bills before legislature and can educate and engage the 'public' with grassroots geoscience as with the GNS Science initiative.

THREE KINGS OR A WHOLE DYNASTY? A COMPLEX VOLCANO IN THE HEART OF AUCKLAND

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The city of Auckland is situated within the confines of the omonymous intraplate volcanic field, which consists of at least 53 individual volcanoes. Understanding the mechanisms driving magmatic activity and the impact of the resulting volcanic processes is essential to prepare for a potential future eruption. The Three Kings volcano is situated in the central portion of the volcanic field and can therefore yield crucial information on the core of the magmatic system. It consists of a tuff sequence that formed a ring surrounding a crater subsequently infilled by scoria and lava flows (mostly quarried away), which tipped out of the crater and formed some lava tubes.

We collected stratigraphically controlled samples from the tuff sequence in both proximal and distal deposits for chemical and physical analyses, as well as samples from the scoria and lava in the central portion of the volcanic complex. The composition ranges from basanite to alkaline basalt. The tuff sequence is more strongly alkaline showing a stratigraphic trend towards decreasing alkalinity. The subsequent lava and scoria deposits have a distinct composition with higher MgO, Cr and Ni, and lower P₂O₅, Ba and Zr. Tephra consist of mostly (>60%) juvenile glass components (2phi fraction) with a broad decrease of lithic fragments up-stratigraphy.

The eruption at Three Kings began with basanitic magma feeding phreatomagmatic volcanism. As eruption proceeded magma became progressively less strongly alkaline (tending to *sensu stricto* alkaline basalt) and more magmatic (strombolian) in character. The last phase of the eruption formed spatter mounds/lava flows with the least alkaline composition distinct from preceding products. Three Kings illustrates another example of complex monogenetic volcanism fed by distinctly stored magma batches within the mantle.

RAPID MAGMA ASCENT FOLLOWING COMPLEX STORAGE AT PUPUKE MAAR, AUCKLAND VOLCANIC FIELD

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Eruptions in monogenetic volcanic fields are unpredictable both spatially and temporally. Nonetheless as magma makes its way to the surface to erupt seismic signals are produced, which can give some indication of unrest. The timescale between initiation of unrest and eruption onset is not clear, and depends on magma ascent rates. Understanding these relationships is paramount when eruptions may occur within densely populated areas such as the Auckland Volcanic Field.

Magma ascent rates can be estimated in monogenetic basaltic volcanoes by investigating their crystal cargo. Olivine xenocrysts from the mantle lithosphere that have been entrained by the ascending basaltic magma are not in equilibrium with the melt,

and will therefore exchange chemical elements with the host melt through diffusion. The time necessary for this process to occur can be quantified through element diffusion modelling.

We sampled a suite of olivine xenocrysts from a strombolian fall deposits at Pupuke Maar to understand the magma ascent duration and mechanisms from mantle depths. Olivine xenocrysts have forsteritic cores (Fo#91-92) and Cr-spinel inclusions indicative of their upper mantle origin. Diffusion profiles length ranges from few tens of microns up to ~200 microns. Fe-Mg, Ca, Ni and Mn diffusion modelling of the observed profiles results in residence times for the mantle derived xenocrysts of mostly less than a week. A few crystals have more complex diffusion profiles that may indicate longer periods of storage up to two years and interaction with magmas with different compositions.

We propose a model for the plumbing system of Pupuke volcano, in which magmas ascend from their mantle source and interact with magmas with variable composition derived from different levels within the mantle. Trigger for ascent is given by the arrival of a final magma batch, generally more alkaline, which raises rapidly and promotes ascent of other ponded magmas.

DEVELOPING THE LINK BETWEEN ELASTICITY AND CONTROLLING PHYSICAL PROPERTIES IN NEW ZEALAND'S COALS AND CARBONACEOUS MUDSTONES

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Coals and carbonaceous (“coaly”) mudstones are the primary sources of oil and gas in most of New Zealand’s sedimentary basins. These types of petroleum source rocks are regionally significant, however; they are less common globally. Our ability to identify and characterize them in the subsurface is a critical component of prospecting for new oil and gas accumulations. Predicting their nature from geophysical measurements (i.e., seismic and wireline logs) is constrained by a lack of calibration between the geophysical attributes of coaly rocks and their physical properties. These results are part of a broader project, which aims to characterize the inorganic and organic constituents of coaly source rocks based on indirect geophysical field observations.

This study will construct models specific to coaly source rocks for correlating their physical properties, geophysical signatures, and petroleum potential. New Zealand is an excellent location to conduct such a study as it hosts a near complete spectrum of coal ranks (peat through anthracite). Samples will be collected from each of these as well as adjacent lithologies (i.e., shaly coals and coaly mudstones) to experimentally measure and model the seismic signatures resulting from variations in organic versus inorganic sediments, coal rank, and wave anisotropy.

**ENGINEERING GEOMORPHOLOGY OF AN
ACTIVE SUBURBAN LANDSLIDE: WALLIS
ROAD LANDSLIDE COMPLEX, KAITI HILL,
GISBORNE**

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The geomorphological character of the Wallis Road coastal landslide complex, Gisborne, is presented here from site investigations, LiDAR and UAV-acquired imagery. Instability at the eastern end of Wallis Road (80 m asl) has been recognised for several years, resulting in No. 1 Wallis Road being demolished in 2015. Within the complex evidence for prior instability includes relict slump-blocks and revegetated hummocky paddocks marking former earthflows are visible. However, the historic nature of instability is unknown. Recent deformation has occurred throughout the 2017 winter, culminating in an earthflow from the complex depositing a 100 m × 60 m fan onto Kaiti beach, below. The upslope extent of the landslide forms a broad headscarp, and lateral scarps, with back-tilted blocks, ponded surface water, and tilted telegraph poles indicating rotational slumping. Cone penetrometer testing and boreholes indicate the slip base at c. 6 m depth in the upper section, marking the boundary between the surficial early Pleistocene Mangatuna Fm (estuarine, river sediments, ignimbrite) and underlying mudstone of the Miocene Tunanui Fm. A photographic time-series indicates slumping and subsidence at the end of Wallis Road proceeds at up to 0.35 m d⁻¹. Below the upper area of rotational-slumping, a transition zone occurs, and below this, a channelized earthflow c. 10 m wide has formed. This is characterised by levees on each side, and

smoothed internal surfaces caused by scouring from rapid sediment discharge. The channelized flow then descends the 70° cliff, prior to forming a scoured parabolic channel through the fan at the cliff base. Repeat surveys show creep-rates increase following heavy rainfall. Hence, the Tunanui Fm mudstones are acting as an impermeable barrier to groundwater infiltration from the overlying (deforming) Mangatuna Fm. Slumping retrogressively extends the complex inland along Wallis Road, visible from warping and scarplets around No. 3 Wallis Road.

**ENGINEERING GEOLOGICAL ROCK MASS
CLASSIFICATION OF UNDERGROUND COAL
MINES: CARBOROUGH DOWNS MINE,
QUEENSLAND, AUSTRALIA**

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Developing an accurate engineering geological model and realistic delineation of variation in rock mass conditions are important prerequisites for slope stability analyses, tunnel design, mine planning and risk management. In coal measures rocks, knowledge of discontinuities may yield improved understanding of coal seam permeability, which is important for coal seam gas (CSG) reservoir behaviour. Rock mass classification schemes such as Rock Mass Rating (RMR), Coal Mine Roof Rating (CMRR), Q-system and Roof Strength Index (RSI) have been used for a range of engineering geological applications, including transport tunnels, “hard rock” mining and underground and open-cut coal mines. Often, rock mass

classification schemes have been evaluated on subaerial exposures, where weathering has affected defect characteristics and intact strength. The focus of this evaluation of the above classification schemes is an underground coal mine in the Bowen Basin, central Queensland, Australia, 15 km east of the town of Moranbah. The mine targets the Late Permian Rangal Coal measures. Rock mass classification was undertaken at 68 sites across the mine. Both the target coal seam (Leichhardt Seam) and overlying rock show marked spatial variability in terms of rock mass properties, and this is reflected in their RMR, CMRR and Q classification results. However, RSI showed limited sensitivity to changes in rock mass condition. Relationships were developed between different parameters with varying degrees of success. A mine-wide analysis of faulting was undertaken, and compared with in situ stress field and local-scale measurements of joint and cleat. While there are no unequivocal relationships between rock mass classification parameters and faulting, a central graben zone shows heterogeneous rock mass properties. The corollary is that if geological features can be accurately defined by remote sensing technologies, then this can assist in predicting rock mass conditions and risk management ahead of development and construction.

**FIRST VIEWS INSIDE PYROCLASTIC SURGES
REVEAL NEW MECHANISMS BEHIND THEIR
THERMAL AND DYNAMIC PRESSURE
HAZARD POTENTIALS**

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Pyroclastic surges are fast, variably hot and highly destructive mixtures of particles and gas, which constitute one of the most frequent hazards at volcanoes worldwide. Their highly variable thermal energy, dynamic pressures as well as their ability to surmount topography make hazard prediction extremely challenging.

Previous studies have been carried out to understand the surge hazard potential by analysing their deposits, by direct observations from distance or through numerical modelling. However due to the lack of data of the inner flow structure and dynamics, assessment of hazard potential from field data and current numerical models remains mostly qualitatively and involves large uncertainties.

Large-scale experimental simulations conducted at the eruption simulator PELE in New Zealand produced first insights into the inner structure of pyroclastic surges, which were synthesized with a number of invariable and variable initial- and boundary conditions. During the experiments space- and time-variant gas-particle transport and sedimentation characteristics were recorded as well as time- and space-variant temperature, turbulence, velocities, concentrations and deposit characteristics.

First results reveal strong pulsing in the flow which is associated with the passage of the head and rear of the head flow regions. These pulses of dynamic pressure are not only recorded in the frontal and fastest part of the flow, but they also occur inside the flow. The occurrence of multiple pulses of high dynamic pressure, quite similar to multiple seismic

shocks during Earthquake events, strongly increases the destruction potential of surges on infrastructure. Thermal imaging of the internal structure of the experimental surges shows strong time-variance in thermal energy during flow passage, which is currently not captured in volcanic hazard models.

In this talk we will illustrate internal velocity, density, dynamic pressure and thermal structure of experimental pyroclastic surges and discuss space- and time variant hazards with regards to updating existing hazard models.

TECTONIC CONTROLS ON SEDIMENTATION IN THE SOUTHERN TARANAKI BASIN DURING THE MIOCENE: IMPLICATIONS FOR PLATE BOUNDARY DEFORMATION

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The rate of sediment deposition and its distribution in the southern Taranaki Basin (STB) during the Miocene record both local and New Zealand plate boundary scale vertical deformation. Evidence from up to 3 km of Miocene strata, examined using 2D and 3D seismic reflection data tied to exploration well stratigraphy, indicate four main phases of basin development: (1) The Early Miocene (24-18 Ma) featured bathyal water depths and deposition of local clastic fans proximal to the Taranaki Fault System (TFS) along the eastern basin margin, strongly influenced by vertical motion on the TFS and regional subsidence produced by subduction of the Pacific Plate beneath northern New Zealand. (2) In the Mid Miocene (~16-14 Ma) sand-rich basin floor fans of the Moki Formation were deposited in

the central STB, preceding (3) rapid northward progradation of the shelf break between 14 and 7 Ma. Episodes (2) and (3) reflect increasing terrigenous input. Sedimentation patterns in the STB during episode (3) are temporally consistent with conglomerates deposited in West Coast basins, which are interpreted to be derived from the proto Southern Alps located ~300 km south of the STB. Furthermore, the Mid-Late Miocene (~16-7 Ma) was dominated by sediment transport directions perpendicular to the shelf break in the STB where sedimentation rates exceeded fault-displacement rates. (4) Latest Miocene (~7-5 Ma) saw widespread erosion and uplift in the STB. Increasing sedimentation and erosion rates observed in this study are temporally aligned with increases in plate boundary convergence and tectonic shortening rates.

FAULT RUPTURE PATTERNS DURING THE M_w7.8 2016 KAIKOURA EARTHQUAKE IN THE REGION BETWEEN THE LEADER AND CHARWELL RIVERS, NORTH CANTERBURY, NEW ZEALAND

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Surface rupture and slip during the Mw 7.8 2016 Kaikōura Earthquake have been mapped in the region between the Leader and Charwell rivers using field mapping and LiDAR data. The eastern Humps, northern Leader and Conway-Charwell faults ruptured the ground surface in the study area. The ENE-NE striking Humps Fault runs along the base of the Mt Stewart range front, appears to dip steeply NW and intersects the NNW-NNE Leader Fault which itself terminates northwards at the NE striking Conway-

Charwell Fault. Although the Mt Stewart range front is bounded by the Humps Fault, in the study area neither this fault nor the Leader Fault were known to have been active before the earthquake. The eastern Humps Fault is up to the NW and accommodates oblique slip with reverse and right lateral displacement. Net slip on the Humps Fault is ≤ 5 m and produced ≤ 4 m uplift of the Mt Stewart range during the earthquake. The Leader Fault strikes NNW-NNE with dips ranging from $\sim 10^\circ$ west to 80° east and accommodated ≤ 4 m net slip comprising left-lateral and up-to-the-west vertical displacement. Like the Humps west of the study area, surface-rupture of the Leader Fault occurred on multiple strands. The complexity of rupture on the Leader Fault is in part due to the occurrence of bedding-parallel slip within the Cretaceous-Cenozoic sequence. The earthquake produced both faulting and folding at the ground surface.

HOT SPRINGS AND THE SEARCH FOR EARLY LIFE ON EARTH AND MARS

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Continental hot springs are key 'extreme environments' utilised in the search for early life (>3 billion years, Ga) on Earth and Mars as they harbour diverse microbial communities in varied habitats with well-defined pH-

temperature gradients, from near-boiling spring-vents and mounds, to cooler apron terraces, pools and geothermally influenced marsh, fluvial, and lacustrine settings. Furthermore, thermal spring discharges contain relatively high concentrations of dissolved ions and thus may fossilise microbial remains in situ within mainly siliceous sinter and travertine deposits, as well as in less common iron-silica occurrences. Therefore, they represent an array of distinct microbially dominated textures encompassing the upper temperature limit for life on land, with a geological record recently extended back to at least the early Archean (ca. 3.5 billion years). Early mineralisation, particularly by silicification, is paramount for preserving high-quality biosignatures in ancient hydrothermal settings because the fluids effectively infiltrate sediments and entomb microbes to sometimes form lagerstätte-style (exceptional) preservation of textural biosignatures. Recent detailed comparisons between unusual silica deposits discovered by the Spirit rover in Gusev crater and terrestrial hot springs at El Tatio, Chile, indicate that distinctive nodular digitate fabrics may represent stromatolites and warrant further study as well as potentially a Mars sample-return mission in the coming decades. Similar features have been recognised in modern hot springs of the Taupo Volcanic Zone, and are currently under detailed assessment. Quaternary sinters of the TVZ and Jurassic sinters of Patagonia contain parallel features to those of the 3.48 Ga Dresser Formation, Pilbara craton, Western Australia, and therefore provide opportunities to examine processes of formation and diverse paleoenvironmental conditions of the oldest life thus far discovered on land.

THE PAPATEA FAULT RUPTURE, NOV 14 M_{7.8} KAIKŌURA EARTHQUAKE: WAS IT PULLED OR WAS IT PUSHED?

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The Papatea fault ruptured spectacularly during the Kaikōura earthquake, producing vertical displacements of the hanging wall >8 m (average = 7.4 m) and left-lateral strike-slip of >5 m (average = 3.5 m) on a single and in places double fault strand. In association, fault-triggered landslides (Seafront slip and Limestone Hills slip) occurred where the west-dipping fault cut a series of limestone hills with east-facing hillslopes. The surface rupture extends 13 km along-strike where the fault is exposed on land, and a further 6 km offshore. Strike varies from WNW to NNW, with the greatest contraction across a NNE striking section where the fault crosses the Clarence River and dips steeply west (75°). In places the fault trace follows or closely parallels geological contacts in Cenozoic cover sequences but this relationship does not persist proximal to the NE-striking Kekerengu Fault, which was also active during the earthquake (up to 10 m right-lateral strike slip). Fault kinematics and surface trace morphology defined from field mapping, orthophoto interpretation and differential LiDAR, vary according to strike. These patterns are in accord with SE migration of the hanging wall block as defined by displacement vectors constructed proximal to the fault trace using differential LiDAR and image

comparison. Distal to the fault trace, the hanging wall moves south, raising the possibility of additional fault activity west of the mapped rupture. The inclination of surface displacement vectors varies from 41° to 74°, perhaps reflecting the geometry at depth. Here we consider the context of the Papatea fault and explore controls on its rupture.

STRUCTURE AND ALTERATION IN THE BROKEN HILLS DISTRICT, COROMANDEL PENINSULA

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The Broken Hills District is located in the Puketui Valley, on the Coromandel Peninsula, and encompasses the Broken Hills and Golden Hills prospects, as well as the smaller Triumph, Monarch, Coronation and Golden Bug prospects. The discovery of gold occurred in outcropping breccia pipes near the Tairua River in 1893 and the prospects were mined intermittently until 1952 with varying success. During this time, over 43 million ounces of bullion was recovered. The Broken Hills mine was then restored in 1999 and has been active since.

The region was volcanically active approximately 6 to 7 million years ago, and the local stratigraphy consists of andesite flows overlain by flow-banded, spherulitic and pyroclastic rhyolites. Various faults are present in the district, dominated by the NNE-trending Tairua fault; this faulting localised hydrothermal fluid flow, causing widespread clay alteration, strong silicification and quartz veining. In the past, mapping has been carried

out at various scales. A number of drillholes have been obtained, particularly in the Broken Hills prospect area, and various geochemical and geophysical surveys have been carried out across the district.

We have undertaken new surveys in this region and produced new geological maps, which both integrate and improve upon previous mapping. Samples collected during our field studies are to be analysed using TerraSpec, x-ray fluorescence, 4-acid digest ICP-MS, petrography and other techniques based on the results obtained from these analyses. These will be integrated with historical data and mapping to produce an overall conceptual model of the hydrothermal system and footprint in the Broken Hills District. The findings of this study will add substantial value to the previous work undertaken in the area, and contribute to the broader scale understanding of the regional tectonic structure.

THE MUD VOLCANOES OF TAIRAWHITI

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The world is a big place, so the mud volcanoes of the East Cape Tarawhiti region are not unique, with some known from Azerbaijan, Romania, Trinidad, Iran, Java, India, Pakistan, Venezuela, Columbia, and Yellowstone USA. They are not even unique in New Zealand with one reported from Coalgate, one in Northland and another from Hawkes Bay. The mud volcanoes of Tairawhiti have been previously studied but this study is probably the most comprehensive and has resulted in poorly reported features being located and significant new mud volcanoes located. Diapiric features, some quite substantial in

size have been identified, and at least one rising diapir has been identified in seismic lines.

The mud volcanoes are distributed across the region from Hangaroa in the south to the Waikura Valley in the north. There is a concentration of features in an east-west line on the northern edges of Gisborne City, a further concentration in the Waimata Valley. New mud volcano fields have been identified at Te Puia, while the Otopotehetehe Mud lake (Waikura Valley) is now also classed as a substantial diapir and mud volcano field. The Otopotehetehe diapir is around 2.8km long and around 100m above the Waikura River. New unerupted diapirs have been identified near Tolaga, and adjacent to Gisborne City. Locally, the mud volcanoes are a natural hazard and do not present a good building platform despite providing an elevated vista.

A number of the mud volcanoes have exhibited renewed activity following the September 2016 Te Araroa Earthquake with uplift and rupturing occurring at the Hangaroa and Waimata fields (Halls, Savages and Uttings mud volcanoes), with the earthflow associated with the Savages Mud Volcano field displacing 11.2m within a 24 hour period. The Gisborne mud volcanoes (Kirkpatrick, Knapdale, Wheatstone Road, Goodwins, Taumotu) on the other hand, remained quiescent.

DETECTING REAL EARTHQUAKES USING IMAGINARY EARTHQUAKES: MATCHED-FILTER DETECTION WITHOUT A-PRIORI INFORMATION

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Matched-filter techniques are demonstrably the best way of detecting repeating and near-repeating earthquakes in noisy data, but they rely on *a-priori* knowledge of the source. Matched-filter methods rely on the cross-correlation of previously determined waveforms with continuous data; detections are made when the cross-correlation is significantly above the background correlation level. Therefore, they are able to detect events with overlapping waveforms, and events below the noise-level, settings where standard detection methods fail. Matched-filter techniques have been applied successfully to a range of settings, including detection of: repeating earthquakes, low-frequency earthquakes, explosions, and aftershocks. In all cases, pre-defined templates have to be constructed of the waveforms of the events to be detected, which limit their application to only finding signals from previously known sources. In this presentation, we will demonstrate the use of synthetic templates to detect real earthquakes in a range of settings. By generalising the templates, the matched-filter method can be applied to seismicity throughout the crust and does not need to be restricted to near-repeating earthquakes. By using such synthetic templates, we are able to detect earthquakes within swarms that were otherwise missed by standard detection techniques and extend the catalogue of low-frequency earthquakes beneath the central Southern Alps to better characterise where slip is occurring on the deep-extent of the Alpine Fault.

SEISMIC IMAGING OF STATIONARY MESO-SCALE EDDIES EAST OF COOK STRAIT

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Meso-scale (10 to 300 km) eddies contribute significantly to the exchange of heat and nutrients in the world's oceans and can also enhance biological production. In a few locations, meso-scale eddies have been imaged using multi-channel seismic reflection data. While these eddies are generally moving unrestricted in the open ocean, New Zealand waters host several relatively stationary eddies, which provide the opportunity for longer-term or repeat surveys of their detailed internal structure.

In this study we present multi-channel seismic images of three stationary eddies located in the vicinity of the Hikurangi Trench east of Cook Strait. We briefly explain the differences in the data processing sequences between conventional and water column marine seismic reflection data. Aided by hydrographic and satellite data we then explore the fine-scale structures of these three eddies and their interaction with each other. We also examine similarities and differences between eddies in the Hikurangi Trench and those previously studied in other settings.

The largest and best known eddy in the Hikurangi Trench is the Wairarapa Eddy. Its fringe has been imaged in several of the seismic lines examined here. One surprising feature of the Wairarapa Eddy is the existence of sharp continuous reflection at its lower boundary. This is uncommon in other eddies from the same region or those imaged in

previous work outside this region.

EXPLORING LABORATORY SCALE, FLUID INDUCED VOLCANIC EARTHQUAKES

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Low frequency volcanic seismicity has long been associated with resonance in fluid-filled cracks or conduits driven by pressure perturbations at depth. In volcano monitoring, fluid movement, fracturing and the conduit geometry are interpreted based on field observations, laboratory experiments, and numerical models. Fluids in a volcanic environment include gasses, brine and magmas with different viscosities. Magma viscosity is a key influence on eruptive behaviour. For example, increasing magma viscosity is known to favour explosive eruptions. How different fluids affect volcano seismicity is not well understood.

Here, we explore the effects of fluid type on volcano seismic signals. Frequency content in the signal, frequency of the events, source mechanism and quality factor are studied. We simulate volcano tectonic (fracturing) and volcano seismic (fluid movement) signatures in a controlled laboratory environment using a range of rock samples, fluid types and pressure conditions. The viscosity of the fluids spans six orders of magnitude, representing realistic volcanic fluids.

Microseismicity is generated by venting pressurised fluids through pre-generated

fracture networks in cylindrical rock core samples and detected by an array of 18 ultrasonic transducers. We fracture samples of two lithologies: 1) low porosity impermeable granite samples and 2) a permeable volcanic ash tuff sample. Permeability and porosity in the granites are due to a fracture network, while in the tuff a high porosity matrix (~40 %) and a fracture network interact.

We generate and detect a myriad of seismic event types, some of which resemble well-known families of volcano-tectonic, low-frequency, hybrid and tremor-type seismicity. Samples with fluids of lower density and viscosity generate a higher number of seismic events. We will present an integrated analysis of event types, frequency content, source locations and mechanisms. In addition, we explore the importance of seismic wave attenuation by studying the relationship between wave path and event frequency content.

A BIT OF STRIFE: EXTINCTION RISK IN ANCIENT AND MODERN SEAS

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A major hurdle to conservation effort is the patchy coverage of extinction risk estimates for living taxa. The International Union for the Conservation of Nature assesses species risk level, but their process is necessarily slow, and at present less than 5% of the world's biota has been classified under their scheme.

However, the ability to identify both at-risk taxa and geographic hotspots where many at-risk taxa occur is essential to our ability to mitigate potential biodiversity loss, in New Zealand and around the world. Many factors, biotic and abiotic, contribute to a species' vulnerability to extinction, and the pattern of past extinctions in the fossil record, to a first order, acts as a summary of those factors and the resulting propensity of a clade towards extinction. We present a method of quantifying Extinction Risk In Species (ERIS) based on modern geographic distribution patterns and paleontological data on clade extinction rates, built and tested on the marine Bivalvia. This large group mirrors many global shallow-marine diversity patterns and has an excellent fossil record. We test the metric using survivorship analyses of Pliocene bivalve faunas from New Zealand, California, and the Southeastern United States. Across all three faunas, species with high ERIS scores in the Pliocene are increasingly likely to have gone extinct in the Pleistocene, suggesting that ERIS captures extinction dynamics well and may approximate extinction risk in the modern fauna.

When ERIS is calculated for the modern Bivalvia, New Zealand is one of the highest-risk areas of the globe. We discuss the implications of a high or low ERIS score in the context of the Plio-Pleistocene extinction, and its applicability to Recent faunas given the potential mechanisms of modern biodiversity loss.

MORPHOTECTONICS AS A LANDSCAPE TEMPLATE FOR ASSESSING SEDIMENT TRANSFERS AND FLOOD VULNERABILITY

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While most flood risk assessments are founded on hydraulic and hydrologic models, a review of high-resolution digital topography in the upper Ruamahanga catchment, Wairarapa, implicates tectonism as a template for structuring flood risk assessment. Multiple, active oblique strike-slip faults cross river valleys, and geomorphic analysis has identified subcatchment, channel, floodplain, and terrace forms that suggest ongoing influence of the southern North Island Fault System on channel and catchment behaviour. Contemporary river paths on inhabited floodplains draining the Tararua Ranges differ from prevailing prehistoric river alignments, and paleofluvial signatures suggest changes may have been abrupt (i.e. avulsion). Overfit and underfit valleys suggest coseismic land deformation may selectively predispose certain communities to avulsion or break-out flooding. In addition, headwater drainage captures, initiated by faulting, have likely altered discharge regimes and, possibly, sediment dynamics.

Several fluvial process zones are identified where reach-scale form (e.g. confinement and channel pattern) and dominant processes (e.g. erosion or deposition) and behavioural tendencies (e.g. lateral movement or incision) can be expected to differ. Subreach

fluvio-tectonic signatures in proximity to mapped faults are also observed away from mapped geologic structures, but along lineaments, implicating a potentially more extensive network of geologic structural control than presently published. We believe differentiating tectonically-forced features from landforms that are purely fluvial in origin will help estimate sediment transfer dynamics and predict channel behaviour, particularly at reach and sub-reach scales.

These more detailed, localised investigations are nested within the fluvio-tectonic assessment template hierarchy. Repeat high-resolution (structure-from-motion) surveys are in progress along four valley segments that will inform geomorphic differencing for sediment budgeting and hydraulic modelling in support of Greater Wellington Regional Council's (GWRC) flood protection planning.

MECHANISMS OF RAINFALL-INDUCED LANDSLIDING IN WELLINGTON FILL-SLOPES

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Large rainfall-induced landslides in poorly compacted fill-slopes are a global hazard. Engineered fill-slopes are common across Wellington, and have been constructed at various scales through varying engineering practices during the cities development. Whilst the regions topography, climate and seismic activity makes its slopes susceptible to landsliding, limited research has considered how different fill-slopes may perform in response to rainstorms. Our study uses a dynamic back-pressured shear box (DBPSB) to study shear surface development in fill materials subject to elevated pore water

pressures associated with periods of prolonged and heavy rainfall. The novel DBPSB is based on a standard direct shear device, but modified to allow the measurement and control of pore water pressure whilst controlling both the normal and shear stresses. Here we have used the DBPSB to replicate stress conditions within slopes comprised of fills with different particle size characteristics, and subjected them to varying pore water pressure scenarios anticipated during rainstorms. We measured the deformation of the shear surface during each test to analyse when and how landslide shear zones form and develop within fill-slopes.

Our study provides new knowledge on the landslide failure potential of Wellington fill slopes during rainstorms and the hazard they may pose.

WHAT ROLE FOR TUSKS IN AN OLIGOCENE DOLPHIN (LATE OLIGOCENE, AWAMOKO VALLEY)?

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Several extinct Oligo-Miocene dolphins from New Zealand have delicate, tusk-like, procumbent teeth, unlike any living dolphins. Previously described tusked specimens include species of Kentriodontidae and Waipatiidae, however, other undescribed fossils, including key specimen OU 22397 from Awamoko Valley, may belong to a new clade. OU 22397 is from the transitional Kokoamu Greensand - Otekaike Limestone, in a mid-shelf setting, upper Duntroonian stage (Chattian stage), at about 26 Ma. Key elements include a well-preserved long-jawed

skull, mandible, teeth and earbones. Vertebrae and ribs are also present. Preliminary phylogenetic studies indicate that OU 22397 belongs in the Platanistoidea, a clade which includes the endangered modern South Asian river dolphin *Platanista gangetica*.

What did OU 22397 use its teeth for, and how did they work? The dolphin has ten double-rooted triangular posterior teeth in the upper jaw, grading forward into more horizontally procumbent conical tusks. Five of the seven tusks are very prominent. The right anterior tusk-like tooth shows significant wear at an angle of about 20° to the tooth's long axis. This unusual wear pattern could shed light on the use of the tusks. Options include feeding (by spearing), foraging for buried prey species, and display. Apart from the narwhal, with its prominent tusk used in display, there are no modern cetacean species with similarly prominent teeth.

HOW RISK MODELLING FOR TSUNAMI INUNDATION INFORMS LOCAL GOVERNMENT NATURAL HAZARD MANAGEMENT POLICIES AND PROCEDURES.

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Whilst it is generally understood that risk management can reduce the likelihood and consequences of natural hazards, it continues to hit barriers relating to communication, perception, and efficacy. This in turn affects the value and success of policies and procedures employed for its application. This research focuses on those barriers to natural hazard risk management, specifically on how risk modelling for tsunami inundation informs the development of risk management policy

and procedure within Local Government in New Zealand. As such, the project studies the interface between:

- tsunami – a severe but unlikely hazard that has limited public risk understanding;
- risk modelling – a more modern tool for assessing and communicating risk, beset with its own assumptions and uncertainties, and;
- Local Government policy and procedure – the coal-face for managing natural hazard risk for New Zealand communities, challenged by ignorance of natural hazard risk data within councils, abstracted and jargon-filled risk terminologies, subjective and varying risk perceptions, little appreciation of low probability risks, and a disconnect between science and practice.

This research uses qualitative methods to engage with local government natural hazard risk managers (e.g., emergency managers, resource planners and policy developers) within councils at risk of tsunami originating in the Hikurangi Subduction Margin. Participants are presented with a tsunami impact consequences using 'RiskScape' – a New Zealand centric risk modelling tool, using an 'all of boundary' scenario along the Hikurangi Subduction Margin. Participants are asked to collaborate with the researcher, using an action research approach, to co-produce a better understanding of where the barriers to risk communication, perception, and efficacy lay, how the use of risk modelling can overcome those barriers, and enable improved policy and procedures for tsunami risk management.

RISK MODELLING AS A TOOL TO SUPPORT NATURAL HAZARD RISK MANAGEMENT IN NEW ZEALAND LOCAL GOVERNMENT

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Demand for natural hazard risk modelling has significantly increased over the last few decades as we seek to use risk modelling to assess the consequences for hazard scenarios we have little historical information about. By giving an estimate of loss, risk models provide policy makers and decision makers with a starting point for the risk communication process and decisions for natural hazard management. However, while local government can see the value in risk modelling, some fundamental challenges limit its use related to: uncertainty over council natural hazards management, limited use of 'knowledge brokers' and 'gate keepers', and immaturity of risk modelling and its data. This poster provides some recommendations to circumvent these barriers and enable risk modelling in local government: legislate greater mandate for natural hazard risk management; adopt effective and meaningful participatory approaches; enable the movement of knowledge through the development of 'knowledge broker' and 'gate keeper' roles; and enable greater capacity and capability building for collecting, managing and using natural hazard risk data.

MORPHOLOGY AND STRUCTURE ASSOCIATED WITH ROUGH SUBDUCTION – NORTHERN HIKURANGI, NEW ZEALAND

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The subducting basement of the Pacific Plate along the obliquely convergent Hikurangi subduction margin comprises the Hikurangi Plateau, a Cretaceous large igneous province of anomalous oceanic crustal thickness and topographic roughness. Subducting seamounts associated with the plateau have had a profound impact on the structure and morphology of the accretionary wedge. They have also previously been proposed to influence the nature of subducting sediments beneath North Hikurangi, and to possibly relate to spatial variations in fault slip behaviour. In support of several on-going research initiatives, including upcoming IODP (International Ocean Discovery Program) drilling expeditions (372 & 375) to study slow slip fault behaviour, we investigate the impacts of rough crust subduction, including the interplay between accretionary wedge morphology, fault structure, subducting seamounts, and trench sediment thickness.

We use regional multi-channel seismic reflection and 30 kHz multibeam bathymetric survey data to characterise the northern Hikurangi margin, between Hawkes Bay and East Cape. This 250 km long section of the margin is characterised by (1) a generally

steep (~10°) lower continental slope, (2) a narrow, discontinuous frontal accretionary wedge, (3) evidence of seamount subduction including large seamount impacts scars that reflect frontal tectonic erosion, and (4) sediment thickness in the Hikurangi Trough of about 1.0-1.5 km. Detailed mapping of the tectonic structure and morphology of the margin allow us to identify the ephemeral and overprinting nature of deformation, together with the characteristics of deep-seated mass failure, that are associated with the passage of subducting seamounts of various scale and relief. We compare this section of the margin with offshore northern Wairarapa, where a relatively smooth plateau basement overlain by thick (3-6 km) trench sequences has allowed the formation of a wide, low taper (<4°) accretionary wedge.

ENGINEERING ROCK MASS CLASSIFICATION OF THE EAST COAST BAYS FORMATION, AUCKLAND

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The East Coast Bays Formation (ECBF) is one of the most prominent rock formations in Auckland and covers a large proportion of Auckland's East Coast. The formation consists of weak interbedded sandstone, siltstone and claystone with lenses of Parnell Grit throughout, and has previously been characterised as a "flysch" deposit. Recent slope failure events and damage to infrastructure and housing, along with transport tunnelling projects has drawn attention to the engineering properties and failure mechanisms of the Formation. Hence, classifying the engineering characteristics and likely failure mechanics is of importance for

land-use planning, calculating set-back distances, as well as excavation design. Here, we applied a selection of established rock mass classification schemes to the East Coast Bays Formation at coastal cliff exposures at Waiake Beach, Stanmore Bay, and Bucklands Beach. This study utilized the Rock Mass Rating (RMR) and Rock Mass Strength (RMS) classification schemes. The two classification schemes were used in conjunction with the slope angle of the exposed outcrop in order to determine the strength-equilibrium state of the exposed rock mass. This theoretical relationship can be used to determine whether the exposed slope is likely to fail, and is useful when compared with kinematic analyses of possible failure mechanics. Results indicate, firstly, that the East Coast Bays Formation are of 'weak' to 'moderate' engineering strength. Second, at most sites, the rock mass exposures are oversteepened with respect to the slope angle, and given the likely friction angles. Third, kinematic analyses show that a range of failure mechanics are possible, as a result of the combination of bedding-plane defects, pervasive subvertical defects, and local-scale faulting. Given the engineering properties and failure mechanics, we conclude that many residential properties lie within theoretical set-back distances, are sited too close to cliff edges, and are therefore within zones where loss to property and life is at an elevated risk.

THE CRUSTAL STRUCTURE OF THE EASTERN CHATHAM RISE REGION - RESULTS OF THE 2016 GEOPHYSICAL SURVEY SO246 BY THE R/V SONNE

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The easternmost Chatham Rise is a key focus area for understanding the Cretaceous tectonics of the New Zealand region. It is the region where seafloor spreading between New Zealand and Antarctica first initiated. The West Wishbone Ridge, a major 1200 km long, northeast trending, gravity and bathymetry lineament intersects the Chatham Rise immediately east of where the Hikurangi Plateau LIP abuts the northern Chatham Rise, and 150 km east of the Chatham islands. The southeast Chatham Rise was once adjacent to Marie Byrd land in Antarctica, a key research focus area for the Alfred Wegener Helmholtz Institute (AWI), Germany.

A seven-week seismic reflection/refraction and volcanic rock-dredging survey was conducted across the eastern Chatham Rise by the Alfred Wegener Helmholtz Institute in early 2016 using the new R/V Sonne research vessel. The survey collected four crustal scale seismic reflection and refraction lines across the eastern Chatham Rise, two seismic reflection lines across the Wishbone Ridge complex, and numerous dredges of seafloor volcano structures on the southeast Chatham

Terrace, guided by multibeam swath data. GNS Science operated their gravity meter and magnetometer throughout most of the survey.

The initial results from the survey will be presented and linked with existing data and concepts on the structure of the Chatham Rise accretionary prism structure (Rakaia versus Pahau) and its onshore South Island prolongation. The nature of the West Wishbone Ridge and similar Cretaceous fault structures and their role in Gondwana breakup will also be discussed.

INFLUENCE OF THE EARTH TIDE ON GROUND MOVEMENTS AT OMOKOROA

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Diurnal ground movement may contribute to slope failure at Omokoroa due to cyclic loading of a sensitive layer within volcanoclastic deposits. Inclinometer measurements indicate that differential movement of the main stratigraphic units (Te Puna Ignimbrite, Pahoia Tephra, Hamilton Ashes, and Rotoehu and younger tephra) occurs in response to the Earth tide. Other processes also contribute to the observed deformation of the inclinometer borehole, including temperature, rainfall and microseisms. A monitoring programme has been run at the landslide at Bramley Drive since 2013 to assess the effects of cyclic loading. This includes a 3-axis accelerometer to measure ground movements at the surface. Although microseisms induced by ocean waves breaking on the open coast of

Matakana Island are present, they do not appear to have a significant effect on ground movement or slope stability. The uppermost stratigraphic unit (Rotoehu and younger tephra) shows a strong diurnal response to soil temperature, which is attenuated by increasing water content. However, the largest ground movement affecting the upper 3 units occurs when the Earth tide peak vertical displacement occurs close to the maximum horizontal displacement. The timing of both maxima is a function of the Moon's declination, while the amplitude of the displacements depends on the distance between the Earth and the Moon. For Omokoroa, the combination of Earth tide maxima coincides with landslide initiation, consistent with previous studies linking the occurrence of small landslides with the orbital motion of the Moon.

USING A WRONG MODEL TO OBTAIN USEFUL INSIGHTS: FORECASTING INDUCED SEISMICITY IN THE NETHERLANDS

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The statistician George Box famously wrote "All models are wrong but some are useful." I will try to demonstrate how this can be the case, using for illustration a model of earthquakes occurring at Western Europe's largest gas field, Groningen, in the Netherlands.

This model makes several simplifications in its attempt to capture earthquake physics (nucleation, rupture, arrest), subsurface heterogeneity, and the interactions between an evolving gas reservoir and the surrounding rock. A Markov-Chain Monte Carlo method was used to calibrate this model against 600

past earthquakes so as to infer (under uncertainty) the values of underlying stress and poroelastic parameters. This exercise suggests that the pre-1960 reservoir was not critically stressed prior to exploitation. It further reveals an instance of parameter surrogacy, wherein the stress path coefficient takes on a physically unrealistic value to compensate physics missing from the model.

Extrapolating the calibrated model 7 years into the future yields a spectrum of possible outcomes – a forecast – for each of three different operating scenarios. Accounting for both epistemic (parameter) and aleatoric (random-process) uncertainty, it can be shown that the likelihood of an earthquake exceeding the previous largest event (an M 3.6 in 2012) is between 17 and 25%. The likelihood that the largest event exceeds M 4 is approximately 5%. Earthquakes of these magnitudes are concerning given their shallow depth (~3 km) and a building stock that largely comprises unreinforced masonry. Weighing the impact on local communities against the economic value of the remaining gas is an ongoing challenge for the Dutch government.

PHYSICAL ROCK PROPERTIES AT IN-SITU CONDITIONS OF PYROCLASTIC ROCKS FROM NGATAMARIKI GEOTHERMAL FIELD, NEW ZEALAND

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A better understanding of the seismic properties of volcanic rocks will benefit

geothermal exploration and volcanology in general. Little experimental analysis of the in-situ rock elasticity and its correlation to the rock physical properties exists. We study volcanoclastic and pyroclastic rocks from Ngatamariki Geothermal Field. P- and S-wave velocities, CT scans, pycnometer and Archimedes porosity, SWIR data, and XRD/XRF measurements are used to recognize mineral assemblages and alteration, degrees of fluid saturation, and pore micro-structure of the rocks. This information helps define rock physics models to match the elastic measurements made at in-situ confining and fluid pressures.

CT scans reveal lithic fragments and cracks in volcanoclastic rocks. Some of these fragments are high porosity tuffs which significantly decrease the elastic wave velocities. XRD and SWIR are combined to get a finer quantitative representation of the mineral constituents. Rock alteration is the second dominant parameter on the elastic wave velocities, with alteration to chlorite resulting in an increase in wave velocities. We will also present results on estimates of elastic wave attenuation for these volcanoclastic samples. We interpret these experimental data by testing several rock physics theories and models, which have seldom been studied for volcanic rocks.

These results add to the existing knowledge gap in the rock physics literature on the properties of volcanoclastic/pyroclastic rocks for which empirical and theoretical models developed for clastic sedimentary rocks must be judiciously applied. Finally, free software to aid the velocity picking of ultrasonic P and S waves with their respective uncertainties is made available.

DETAILED ANALYSIS OF THE HAUTAWA SHELLBED

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Charles Fleming's foundation work recognised the Hautawa Shellbed as a marker of cooling conditions expressed by the influx of a sub-Antarctic molluscan assemblage into Whanganui Basin. The major index fossil of this cold assemblage is the queen scallop *Zygochlamys delicatula*. It has previously been shown that outcrops of the Hautawa Shellbed adjacent to the Whanganui River were deposited in a shallower environment than those proximal to the Rangitikei River – a result of the basin depocenter being closer to the modern Rangitikei catchment. Although outcrops of the shellbed are known to extend over 50 kilometres laterally, there has been little focus on investigating the preserved paleoenvironmental variation beyond relative water depth.

The Hautawa Shellbed is a compound shellbed made up of lower and upper shellbed units. The majority of specimens in the lower shellbed have been, to varying degrees, transported prior to deposition. This lower shellbed formed a stable substrate which supported development of the upper shellbed. Accordingly, the assemblage of the upper unit is dominated by colonizing epifauna of brachiopods and bryozoa likely deposited in situ.

This study focuses on findings from one site of a MSc research project which aims to capture lateral paleoenvironmental changes observed in the Hautawa Shellbed shown by detailed analysis of sedimentary, taphonomic, and macrofaunal assemblage variability. Previously, paleoenvironmental

interpretations have been largely based solely on the macrofaunal content. Foraminiferal assemblages preserved in the silty units directly below and overlying the condensed shellbed provided further restriction on paleo-water depths in this study.

ESTIMATING BOREHOLE SEISMOMETER ORIENTATION USING AMBIENT NOISE FOR AMBIENT NOISE TOMOGRAPHY OF THE AUCKLAND VOLCANIC FIELD USING MULTI-COMPONENT DATA

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In the active Auckland Volcanic Field, earthquake-generated seismicity is low and a high ambient noise level hinders the investigation of structural eruption controls by most passive seismic imaging. There have been only a few studies using active sources. We applied ambient noise tomography using the vertical seismic waveform data from pairs of seismometers to compute 1D crustal shear-wave velocity models beneath the Auckland Volcanic Field, and interpolated data onto a grid to obtain pseudo-2D models. These shear velocity models penetrated 25 km deep, almost to the Moho. The resulting overall velocity variations in the crust correspond well with previous models, major known surface geological features, and tectonostratigraphic terranes deeper. We are currently working to increase the resolution and the penetration depth to include the entire crust by using multi-component ambient noise. This requires estimating the orientation of the horizontal components of 8 borehole seismometers from the Auckland Volcano Seismic Network. We do this by applying a Rayleigh wave polarisation

technique to estimates of the Rayleigh wave Greens Functions estimated from ambient seismic noise and validate this method using earthquake sourced p-wave polarisation.

LAKE KANONO: INVESTIGATING CLIMATE OSCILLATIONS USING HIGH RESOLUTION WIND AND PRECIPITATION ITRAX PROXIES

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The South Westerly Winds (SWW) are a belt of winds that are the driving force of wind and precipitation in New Zealand and shift north or south with temperature changes. An annually resolved Itrax record spanning 2200 years was constructed from sediment core stratigraphy from Lake Kanono, Northland to investigate the correlation of shifts in the SWW on inter-annual, decadal, and centennial time scales thought to be caused by cyclic climate patterns such as El Niño Southern Oscillation (ENSO).

Previous work shows that there is a good correlation between temperature and ENSO in New Zealand and that the link between precipitation anomalies and ENSO in New Zealand vary by region. Specifically, there is a positive rainfall anomaly associated with the La Niña phase of ENSO in the Northland region where Lake Kanono is located. Various Itrax proxies representing organic processes, nutrient fluctuation, and detrital changes were compared with regional wind gust data, rainfall data, and the Southern Oscillation Index (SOI) in order to verify which Itrax proxies are best suited as wind and/or precipitation proxies. The Itrax proxies with the best correlations were analysed with a wavelet transform to identify periodicities.

In general, even though the 3 categories of data have different results, there are periodicities present in these data sets at inter-annual, decadal, and centennial oscillations, although the timing of the periodicities in the sequence is different depending on what type of proxy is analysed. Land use changes associated with different phases of human settlement in New Zealand complicate the environmental signal and affect the wavelet results – which is most evident in the raw detrital proxy.

USING PYROCLASTIC COOLING HISTORIES TO UNDERSTAND DYNAMIC ERUPTIONS: CASE STUDIES FROM THE AUCKLAND VOLCANIC FIELD

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During the transition from phreatomagmatic to predominately magmatic eruptions, the alleviation of external water from the process changes the eruption style. A proposed model for the crystallinity values associated with both phreatomagmatic and magmatic eruptions is that of an inverse relationship with respect to magmatic cooling rate. Thus, we propose that as cooling rates decrease, associated with the mitigation of external water sources, the groundmass crystallinity should increase. Groundmass from juvenile pyroclasts collected from Motukorea (Brown's Island) and Maungauika (North Head volcano), New Zealand, can yield insight into the availability of external water, complexity of eruption processes, and changing eruption styles.

We have specifically targeted a limited number of surge/fall deposits for analysis which track changing interactions with external water to test the impact on clast characteristics. Sample cleaning and separation is particularly challenging for surge deposits where materials are well cemented, requiring multiple rounds of ultrasonic cleaning, scraping, and treatment in weak HCl solutions- this intricate cleaning procedure however is necessary for isolation of the juvenile clasts for analysis. Juvenile clasts were characterized texturally and analysed by X-ray diffraction (XRD) to determine mineralogy and crystallinity. XRD diffraction patterns were analysed using the AMORPH software for determining the crystallinity and characteristics of the amorphous material. Sample sizes range from <250 micrometers to ~ 2 cm. Multiple clasts were analysed per sample (up to 15) to better characterise the heterogeneity of each sample. Interestingly, preliminary results from Motukorea suggest the opposite characteristics, that for the smallest clast sizes (250-600 micrometers), juvenile clasts from the surge deposits uniformly contain higher crystallinities compared to “magmatic” units. These initial results point to the complexity of processes involved in phreatomagmatic eruptions and the need for high sampling density to properly investigate these dynamic systems.

THE GEOLOGICAL ORIGIN OF THE CHOCOLATE HILLS OF BOHOL

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The 1776 approx. and possibly counting, Chocolate Hills of Bohol are outstanding geological features. The Chocolate Hills are 66 Ma years in age. This paper examines their

geological, hydrological and rate of tectonic uplift responsible for the harmony in their formation. The recent September 2017 discovery, by the author, of densely forested, forming younger Chocolate Hills on the isolated Anda Peninsula, of East Bohol, is presented.

After the M7.2 Bohol Earthquake of 15 October 2013, two scientific expeditions were made on the palaeontology of the Wahig River in central Bohol. Paleo earthquake induced landslides were located. Earthquakes have also had a profound scientific effect on the formation of the morphology of the Chocolate Hills. Paleo evidence exists with the runout distance of earthquake induced fallen boulders from the Chocolate Hills.

Research is slowly continuing and invitational overseas (from Philippines) research opportunities are presented.

Keywords: Karst landscape, Chocolate hills, geological harmony, earthquake damage, research opportunities.

COMPARISON OF DIVERSION WELL SUBSTRATES FOR THE TREATMENT OF ACID MINE DRAINAGE, BELLVUE MINE, WEST COAST, NEW ZEALAND

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Acid mine drainage is a significant environmental problem globally. Sulphide bearing minerals, exposed as a result of metalliferous and coal mining, interact with air and water to produce acidic run-off, a considerable pollutant of many surface water systems. Bellvue Mine, an abandoned coal mine north of Greymouth, West Coast, is discharging acidic run-off into Cannel Creek,

resulting in low pH conditions and high dissolved metal concentrations. This has led to poor stream ecosystem health and low aquatic biodiversity. Diversion wells are a method of passive treatment of acid mine drainage. A typical well consists of a cylinder-shaped container filled with limestone aggregate, and a pipe centred down the well to allow water from an upstream dam to provide hydraulic head and entry to the system. Dissolution of the calcium carbonate raises the pH of the acidic drainage, adds alkalinity, and allows for precipitation of metal contaminants out of solution. Mussel shells are an alternative source of calcium carbonate and method of passive treatment: this is to be used in a mussel shell reactor at the Bellvue site later this year. Because the reactor is unable to treat acidic discharge during high flow events, a diversion well will allow for treatment of excess acidic discharge during high precipitation events. The use of a diversion well, and mussel shells as a diversion well substrate, has not previously been trialled in New Zealand. This research involves the installation of a diversion well at Bellvue Mine, and chemical analysis of treated waters, to determine the effectiveness of a diversion well using mussel shells in treating acid mine drainage in comparison to the more traditional diversion well using limestone.

A TOOTHLESS SUCTION-FEEDING DOLPHIN FROM THE OTEKAIKE LIMESTONE (WAITAKIAN STAGE, LATEST OLIGOCENE), HAKATARAMEA VALLEY

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A new species of large dolphin from the Otekaike Limestone, Hakataramea Valley, has specialised jaws and reduced teeth, consistent

with a suction-feeding life mode – the first such fossil from the New Zealand mid-Cenozoic. The dolphin is convergently and remarkably similar in skull form to the unrelated living, suction-feeding, beaked whales (Ziphiidae).

The dolphin, OU 22540, is from the upper Otekaike Limestone, just above a diffuse macrofossil rich mollusc and *Protula* shellbed (Waitakian, *Globoturborotalita woodi* zone, latest Oligocene). Massive bedding, well-preserved para-autochthonous macroinvertebrates, and associated skeletons of vertebrates suggest limited traction currents in a mid-shelf setting.

The dolphin has a beak-like upper jaw with massive maxillae, but no alveoli for upper teeth. The lower jaw is straight-edged with an alveolar groove possibly for small teeth; two tiny conical teeth were found with the skull. The face around the nasal passages is strongly asymmetrical and elevated, implying the presence of well-developed soft tissues used in echolocation. Similar features occur in beaked whales (Ziphiidae), albeit constructed differently. All the neck vertebrae are preserved, unfused. The earbones (periotic, tympanic bulla) show features important in phylogenetic placement. Notably, the curved parabullary sulcus on the periotic may characterise archaic platanistoids. Further, the dolphin lacks the enlarged posterior process on the bulla, and enlarged pterygoid sinus fossa – features diagnostic for Ziphiidae.

Otekaike Limestone cetaceans continue to expand the diversity of early species in the two living groups, Odontoceti (dolphins) and Mysticeti (baleen whales). The ziphiid-like dolphin is one of several such fossils globally that mimic beaked whales. Does skull structure in OU 22540 reflect largely pelagic deep-diving habits, or did the dolphin live and feed in shelf settings?

SPELEOTHEM MAGNETISM AND HYDROCLIMATE: AN INVESTIGATION OF HYDROLOGICAL PROCESSES IN WAIPUNA CAVE, WAITOMO DISTRICT

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Speleothem science is a fast-growing subdiscipline of geosciences, with the potential to produce high-resolution, long-duration, well-dated proxy records for terrestrial climate, environment, and surface processes. Traditional speleothem science is based largely on measurement of oxygen and carbon isotopes in speleothem calcite. However, a raft of novel techniques are currently under development to exploit speleothem archives in more detail. One of these is speleothem magnetism.

Allogenic particles are often incorporated into speleothems as they grow. These particles may be sourced from overlying soils via infiltrating waters, or from flooding of subterranean passages. In both cases, the concentration of allogenic particles is indirectly linked to precipitation. The concentration of allogenic particles in speleothems is generally extremely low, making them difficult and time-consuming to quantify by traditional microscopic methods. However, if the allogenic fraction includes ferrimagnetic particles, these can be detected and characterised quantitatively using state-

of-the-art non-destructive magnetic methods. Magnetic particles in speleothems thus potentially represent a high-quality proxy for hydroclimatic variability.

Here we present the initial results of an environmental magnetic investigation of a flowstone from Waipuna Cave, Waitomo District. First-order reversal curve analysis indicates the presence of two populations of magnetic grains which make varying contributions to the magnetic fraction of the speleothem over time. We interpret one of these as representing periodic flooding of the flowstone site, and the other as representing transport of allogenic particles by dripwater (and therefore precipitation). New statistical software allows us to quantify the contribution of each of these processes at each time step, and thereby build a picture of North Island hydroclimate over the last 35,000 years.

GEOCHEMICAL CHARACTERISATION OF OFFSHORE NEW ZEALAND PHOSPHORITES

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Seafloor mineral resources are becoming increasingly attractive for exploitation as land-based resources begin to decline. Phosphorites are a rich source of phosphorus, an invaluable ingredient in agricultural fertilisers which are in high demand globally. Whilst high phosphate content is one of the most important qualities of a phosphorite deposit, knowledge of the associated trace elements is important should some of the

elements be potentially ecotoxic, thus affecting the suitability of a deposit for use as an agricultural fertiliser.

The geochemical diversity of significant New Zealand phosphorite deposits outside of the Chatham Rise is poorly characterised. This study addresses this gap in geochemical information for deposits from Bollons Seamount and offshore South Island, as well as providing new geochemical data for the extensive Chatham Rise phosphorite deposit. Major element contents were measured using X-ray fluorescence (XRF), and trace element contents by inductively coupled plasma mass spectrometry. Micro-XRF and scanning electron microscope energy dispersive spectroscopy maps detail the distribution of major and minor elements within nodules.

Chatham Rise and offshore South Island nodules are characterised by enrichments in Sr, Y, Mo and U with depletion in Sc, Cr, Cu, Rb, Cs, Ba, Ta, Pb, and Th relative to average upper continental crust (AUCC). Bollons Seamount nodules show significant (two to five times) enrichments in first row transition metals; Ni, Co, Cu, Zn, in addition to Sr, Y, Mo, U and depletion in Sc, Cr, Ga, Rb, Cs, and Th relative to AUCC. Low Cd contents (3x AUCC) in all deposits suggests good suitability for use as a fertiliser, as contribution to already high Cd contents in New Zealand soils would be minimal.

This study was conducted as a part of the Enabling Management of Offshore Mining (EMOM) project awarded to NIWA through a Ministry of Business, Innovation and Employment (MBIE) grant (2012-2016).

AUCKLAND VOLCANIC FIELD: SEISMIC TRAVEL-TIME TOMOGRAPHY WITH FAST MARCHING METHOD APPROACH

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The Auckland Volcanic Field (AVF) is a monogenic intraplate volcanic field, located right beneath one of New Zealand's main city, Auckland. However, despite the potential hazard it imposes, much of the structure and driving cause with regards to the AVF are remain to be known. Furthermore, geophysical studies (particularly 3-D) for the deeper structure of the AVF generally lack in resolution. This research looks on this three-dimensional geophysical structure of the Auckland Volcanic Field, focusing on the velocity structure deduced from seismic travel-time tomography. Fast marching method, a grid based eikonal solver is implemented. This method has low computing cost, stable, and robust. The main aspect of this method is that it will converge to one true two-point path between the source and receiver, consistently computing the first arrival travel-time.

The first part of this research is to perform synthetic tests, to see at the potential resolution that can be achieved from this study. The synthetic test that we implement here is the checker-board test, where the size and geometry of the recovered checker pattern will infer the scale and coverage of the resolved features. The second part is to use the first arrival P-wave travel-time data; observed, and predicted using ak135 1-D Earth velocity model. By performing the relative travel-time tomographic inversion, we can produce the 3-D velocity structure beneath the AVF, constructed as positive and negative deviation from the reference model.

FLOW PROCESSES AND PROVENANCE OF SEDIMENT IN THE HIKURANGI CHANNEL: LINKS TO SEISMIC ACTIVITY

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The Hikurangi Channel lies east of New Zealand and is one of the longest submarine channels in the world. The channel runs parallel to the Hikurangi subduction margin, where the Pacific Plate subducts beneath the Australian Plate. It connects submarine canyons that incise and nourish the continental slope east of New Zealand, especially Kaikoura and Cook Strait canyons, with the abyssal basin of the South Pacific. This study analyses a series of sediment cores from within the Hikurangi Channel and adjacent levee to determine sediment provenance, flow processes and deposits, and whether these are linked to seismic events along the Hikurangi subduction zone, such as the Kaikoura Earthquake in November 2016. Can we use these sediment events to investigate the frequency of large earthquakes along the Hikurangi subduction zone?

To characterise the cores, we used a range of different analytical methods including visual logging, laser grain size, carbonate content, total organic matter, X-Ray diffraction (XRD), X-radiography, Computerized Tomography (CT) Scans, magnetic susceptibility, and bulk density.

The cores show turbidity current deposits, with those in the channel significantly thicker than those in the levee cores. Levee cores show grain sizes ranging from very fine silt to fine sand, while channel cores are relatively coarser grained, with grain sizes up to medium sand. XRD analyses on these cores show presence of minerals such as quartz, micas, and feldspars, and a very small proportion of other minerals which change in proportion and composition going along northwards, down channel. Using these data will improve our understanding of the origin of these sediments, and the flow processes that have carried them to the various locations.

**OTOLITHS, TEETH AND SCALES REVEAL
DIVERSE FISH COMMUNITIES IN LATE
OLIGOCENE ESTUARINE TO DEEP-WATER
PALEOENVIRONMENTS IN SOUTHERN
ZEALANDIA**

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Although fish macrofossils are rare, otoliths are common in Cenozoic marine sediments of New Zealand and are essential tools for reconstructing fossil teleost faunas. Here we describe the taxonomy, paleoecology and paleogeography of mainly otolith-based fish faunas from six sites of Late Oligocene age (Duntroonian - Waitakian) in southern Zealandia spread across the Pomahaka, Chatton and Waihoaka Formations. The otolith associations comprise 46 species (14 new) in 9 orders and 24 families, and represent a remarkably diverse range of environments from brackish to estuarine

(Pomahaka), near-shore sheltered bay (Brydone), rocky shore (Cosy Dell), shallow shelf (Chatton, Hedgehope) to a deep marine offshore environment (Grindstone Creek). Species include several eel-like predators (*Moringua*, *Gnathophis*, *Pseudophichthys*, *Rhynchoconger*), a garden eel (*Heteroconger?*), sardines (*Sardinops*), a lantern-fish (*Diaphus*), rock cod and codlets (*Lotella*, *Bregmaceros*), rattails (*Trachyrincus*, *Coelorinchus*), hake (*Macruronus*), pearlfish (*Eurypleuron*), alfonsino (*Centroberyx*), roughy (*Optivus*), flathead (*Platycephalus*), grouper (Serranidae), whiting (*Sillago*), seabream (*Dentex*), grunt (*Pomadasy?*), sandperch (*Parapercis*), opalfish (*Hemerocoetes*), stargazers (*Lesueurina*, *Uranoscopus*), sleeper goby (*Micropercops*) and flatfish (*Arnoglossus*). In addition, one incomplete but articulated percidiform fish, odontaspid (sand tiger) teeth, isolated teleost bones, and cycloid? scales have been uncovered at Pomahaka and an array of fish teeth, including probable seabream (?*Diplodus*) and myliobatiformes (stingray) crushing plates, are found at Cosy Dell. The otolith faunas show considerable continuity with the extant marine fish fauna of New Zealand with 50% of species belonging to genera present in New Zealand waters today. Endemism in the Late Oligocene was high at ca. 45% including putative extinct endemics. Significant fossils include the first Southern Hemisphere representative of a basal gobioid family (Odontobutidae) now restricted to fresh- and brackish waters of eastern Asia. We compare and contrast the faunas of each site with one another and with the extant marine fauna of New Zealand and discuss their phylogenetic and biogeographic significance.

**COMPARISON OF GEOTECHNICAL
PROPERTIES OF TAUPO VOLCANIC ZONE
TEPHRA AND SURROUNDING SEDIMENTS OF
THE TAURANGA GROUP IN THE AUCKLAND
AREA**

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Tephra deposits originating from the Taupo Volcanic Zone (TVZ) are exposed as beds of variable thickness with fine-grained sedimentary sequences around the Auckland coast. These sequences, also of considerable thickness variability, are included in the Tauranga Group of sediments which overlie the Miocene East Coast Bays Formation. Cliff sections composed of the Tauranga Group are prone to rotational failures, with evidence of past landslides existing at Pohutukawa Bay and Sunkist Bay in the Beachlands area of East Auckland, and along the edges of the Tamaki Estuary. In January 2017, following an unusually large amount of rainfall, a landslide of significant size occurred at Sunkist Bay, resulting in the loss of a section of residential property. Given the unstable nature of these cliffs and the threat posed to infrastructure it is important that the geotechnical properties of the Tauranga Group sediments exposed at both Beachlands and the Tamaki estuary be determined to assess their influence on slope instability. Two tephra units from the Beachlands area, including one from the near the base of the 2017 Sunkist Bay landslide and the underlying fine-grained sediments were investigated. In addition, one tephra and a sample of underlying sediment from a coastal exposure near Saint Kentigerns School were investigated. Undisturbed intact block samples were taken for shear strength testing and scanning electron microscopy analysis. Each sample was also tested for a variety of index tests including laser particle size

analysis, *in-situ* moisture content, and skeletal and bulk density. Initial results suggest that fundamental differences exist in the geotechnical index and shear strength properties between the tephra and surrounding sediment which are contributing factors causing instability at the two sites.

**MODELLING BALLISTIC HAZARD AT NEW
ZEALAND'S MOST VISITED ACTIVE
VOLCANOES; WHITE ISLAND AND RED
CRATER, TONGARIRO.**

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Volcanic ballistics are a major hazard in areas proximal to volcanic eruptions. The high kinetic energy of volcanic ballistics constitutes a significant threat to life and property within the ballistic hazard zone. New Zealand has a large volcano-tourism industry with the country's two most visited active volcanoes, White Island and Tongariro, attracting a combined total of >150,000 tourists annually. Visitors to these volcanoes walk within volcanic ballistic fields emplaced during recent phreatic and phreato-magmatic eruptions. Ballistic hazard assessments of White Island and Red Crater, Tongariro are needed due to their rising popularity and histories of ballistic producing phreatic eruptions, which occur with little, if any, warning.

An unheralded, phreatic eruption at White Island on the night of the 13th of April 2016 produced ballistics and a surge. The ballistics heavily impacted the path used by tourism operators. Had the eruption occurred during operational hours, casualties would have been likely. Red Crater is an active vent of Tongariro

Volcano which has erupted at least 16 times within the last 300 years in Strombolian and phreatic styles. It lies directly adjacent to the Tongariro Alpine Crossing (TAC), which hosts >140, 000 visitors annually. Recent fieldwork has elucidated the extent of a composite ballistic field surrounding Red Crater and the Emerald Lake, which the TAC passes through.

We present phreatic ballistic hazard maps and insights into eruption source parameters at each volcano, informed by field mapping and 3D modelling. Detailed field mapping of White Island's April 2016 ballistic field and Red Crater's remnant ballistic field, following UAV image collection, is used to inform model inputs. Ballista, a semi-probabilistic 3D volcanic trajectory model, is calibrated using field data to determine eruption source parameters. This study is the first step towards production of probabilistic ballistic hazard maps for White Island and Red Crater, Tongariro.

PLIOCENE MACRO- AND MICROFOSSIL PLANTS AND FUNGI OF AUCKLAND

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Well-preserved fossil plants, fungi and arthropods are frequently recovered from

Tauranga Group sediments exposed around coastal southern Auckland. Fluvial, estuarine and near shore sediments yield organically preserved fossil fruits (and stones, seeds and cones), vascular and non-vascular leaves, wood, amber, pollen, spores, bracket fungus basidiocarps, mites and other arthropod fragments.

The fossil fruit and leaf assemblages are indicative of a diverse vascular plant flora. A high proportion of the currently identified fossil fruit morphotypes belong to locally extinct groups, such as Vitaceae, Menispermaceae, Casuarinaceae, *Brassospora*-type *Nothofagus* and locally extinct species of Cupressaceae and *Elaeocarpus*. In contrast, a few fossil fruit morphotypes including *Prumnopitys*, *Passiflora* and another *Elaeocarpus* species share possible affinities with extant taxa.

Non-vascular plant fossils, such as moss (Bryophyta) stems and leaves are an exciting addition to the list of fossils known from these localities. Mosses are only encountered or reported rarely in the fossil record and few moss fossils are known from New Zealand. The fossil mosses of the Tauranga Group sediments form a diverse assemblage with more than 15 taxa recognised to date. The preservation of the mosses is excellent and leaves retain fine cellular structure. One fossil moss morphotype is indistinguishable from an extant species, *Calyptrochaeta cristata*. Other specimens belong to extant genera/families, such as Hypnodendraceae, Neckeraceae, Sematophyllaceae, *Pyrrhobryum* and *Ptychomnion*. Some fossil mosses represent locally or globally extinct species, such as a morphotype attributable to *Rhizogonium*.

The sediments yielding these fossils are not yet dated precisely, but a macro-mollusc fauna suggests that sediments at one locality are Pliocene (Waipipian) in age. These plant

fossils provide unique insights into relatively recent, northern New Zealand ecosystems and highlight some plant taxa that have only become extinct in New Zealand since the Pliocene.

**MORPHOTECTONIC EVIDENCE OF BLIND
ACTIVE FAULTS IN THE MOUTERE
DEPRESSION (SOUTH ISLAND, NEW
ZEALAND)**

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Active, but undetected “blind” faults pose significant hazard because active fault inventories and seismic codes do not account for their presence. The Darfield fault which started the 2010-2011 Canterbury earthquake sequence is a recent example, so two questions arise: (1) how many faults capable of a $M > 6$ earthquake are still unaccounted for in New Zealand, and (2) are there cases where the geologists are blind rather than the faults?

The case made here concerns the Moutere depression, described in the past as an “aseismic corridor”, though bounded by the active Alpine-Wairau Fault to the south and the Waimea-Flaxmore reverse Fault to the east.

The structural geometry of the Moutere region is indeed poorly understood, given its subdued topography and the infilling of > 2 km thick Pliocene-Quaternary clastic cover. Seismic lines of the Survey MD87, together with magnetic and gravity surveys hint at the presence of a N-S elongated, Intra-Moutere

Structural High (IMSH), buried below the gravel cover, but penetrated by the Ruby Bay-1 exploration well, close to the coastline. However, a reconstruction of the IMSH has never been attempted. This structure can be linked to the Surville reverse fault offshore, and is continuous along-strike to the south for > 60 km. Evidence for surface faulting is not preserved in the unconsolidated cover sequence, but there is arguably a strong control exerted by the IMSH on a domal bulge in the surface topography, the development of an intra-basin divide, the deflected hydrographic network, and the aggradational vs. erosional pattern along the major river valleys.

All these elements point to a growing blind anticline connected to a set of reverse faults sub-parallel to the Waimea fault system, potentially posing significant hazard for the wider Nelson-Motueka urban area if reactivated with a $M \geq 6$ earthquake.

**AN UNUSUALLY COARSE BASALTIC LAVA
WITH EXTREMELY COARSE SEGREGATION
STRUCTURES, SWINBURN, WAIPIATA
VOLCANIC FIELD, OTAGO, NEW ZEALAND**

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The Miocene Waipiata Volcanic Field, South Island, New Zealand, is an eroded Miocene volcanic field (c. 25 – 9 Ma), belonging to the broader Dunedin Volcanic Group. The largest Waipiata volcano is represented by the little-known Swinburn Volcanic Complex, in Central Otago. Here we present new petrographic and geochemical results of an unusually coarse type of lava common at Swinburn and its extremely coarsely crystalline segregation

structures. Lava flows at Swinburn are underlain by bedded, bomb-bearing scoriaceous pyroclastic rocks. Highly vesicular basalt at the basal contact and equivalent-aged sediment depositionally overlying it, confirm an effusive origin. Swinburn lava has crystals of augite and olivine that enclose random plagioclase laths. Crystal sizes average 0.5 – 1 mm, with some bigger crystals reaching 2 mm. Centimetric domains crystallised from residual liquid and metre-scale pegmatitic segregation veins have been found at the bottom and at different heights inside the lava flow, respectively. They show the same mineralogy and ophitic texture of their host basalt but are much more coarsely crystalline (crystals 0.5 – 2 cm long). Inside the segregations, plagioclase compositions are more sodic, also olivine and augite crystals have enriched FeO and depleted MgO and CaO compared to host basalt crystals. There is also an enrichment in incompatible elements such as Ba, REE, Zr, Nb, Th and a depletion in compatible ones (e.g. Cr, Ni). Field and textural observations along with geochemical features of the Swinburn lavas suggest that they had an effusive emplacement. During cooling, within the partially solidified lava, a slighter more evolved and less dense residual liquid moves from the bottom to upward, through the flow, forming segregation veins and domains. A higher water content inside the residual melt and destruction of the majority of crystal nuclei during the ascent, could explain the extremely coarse crystals forming the segregation structures.

PRELIMINARY ANALYSIS OF SEISMIC ANISOTROPY CHANGES ASSOCIATED THE KAIKOURA EARTHQUAKES IN NEW ZEALAND

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The M7.8 Kaikōura Earthquake, occurred in a complex tectonic regime. It is the largest and most complex earthquake recorded on land since the digital seismological age. A remarkable number (more than 20) shallow crustal fault segments ruptured. It ruptured the surface over a distance of 150 km. The main shock was followed by more than 20,000 aftershocks clustered with three unique spatial patterns. The Kaikōura earthquakes provide a unique dataset to test the use of shear wave splitting (SWS) for measuring variations in stress, because clusters of closely-spaced earthquakes occurred both before and after the main shock. The study aims to measure any appreciable changes in stress, before and after the Kaikōura earthquake. We determine SWS, during the period of 2015 to August 2017, for over 5,000 crustal earthquakes which were located close to each other and near the previous Seddon earthquake sequence. We used the automatic, objective splitting analysis code MFAST and an automatic S-phase picker to speed the processing and to minimize observer bias. We made preliminary SWS measurement for two GeoNet stations around the Cape Campbell (CMWZ) and Seddon region (BSWZ) which released the most energy during the earthquake (Hamling et al., 2017). The mean fast orientation at both stations for events before the Kaikōura earthquake are parallel to NE-SW tectonic structures of the area. Station BSWZ showed similar NE-SW orientation after the earthquake. For station

CMWZ, there is bimodal fast orientation after the earthquake, with a NE–SW mode and a NW-SE mode, which could be an indication of stress changes. These changes may be related to crack opening and closing and to the fluids contained in the cracks. Further analysis is planned for stations around the Marlborough region, particularly in areas where most of the surface ruptures occurred.

A MODEL OF DEEP HYDROTHERMAL CIRCULATION ON A PERMEABLE ALPINE FAULT

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Drilling into the hanging wall of the Alpine Fault in the Whataroa Valley by the DFDP-2 borehole has revealed an unusually high geothermal gradient and pore fluids in excess of hydrostatic pressure. A recently presented thermal model (Sutherland et al. 2017) considered convection of groundwater within the hanging wall and tectonic uplift of hanging wall rocks to account for the high fluid temperatures. However, this model did not consider fault parallel fluid flow within a high permeability damage zone, nor periodic shear heating due to great (M 8) earthquakes every ~300 years.

We have constructed an alternative thermal model of the Alpine Fault to extend our understanding of the physical processes that contribute to such high temperatures. Incorporating fluid flow driven by local topography, uplift of hanging wall rock, and periodic shear heating, we find that the thermal anomaly can be accounted for as the product of cold downwelling in the hanging wall far from the fault and focused hot upflow in and around the fault damage zone.

Meteoric fluids circulate and are heated throughout the seismogenic zone in the hanging wall, while the higher permeability of a damage zone near the fault allows upwelling of hot fluid parallel to the fault. Upwelling fluid flows preferentially into valleys due to a higher water table height in the mountains of the Southern Alps. The presence of the low permeability fault gouge and the difference in water table height across the fault results in the elevated pressures observed in the hanging wall. Uplift of rock and shear heating contribute to the heat budget but are insufficient to explain the high temperatures on their own.

PRELIMINARY INVESTIGATION INTO LIQUEFACTION OF THE MANUKAU LOWLANDS, AUCKLAND, USING SETTLE3D MODELLING

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It is often assumed that Auckland has a low seismic hazard compared with the rest of New Zealand, but there is the possibility of large earthquakes from mapped and unmapped faults. The near-surface stratigraphy of the Manukau Lowlands is typically mapped as Puketoka Formation, a range of soil types including volcanic deposits, soft alluvial and swamp deposits, as well as reclaimed land. Despite the liquefaction potential of these soils, under the Auckland Unitary Plan the area will be developed, in-part, as greenfield sites. This study carries out a preliminary investigation into potential liquefaction at three sites within the Manukau Lowlands located at Kingseat, Drury and Takanini, by using site-specific standard penetration test (SPT) data and liquefaction analysis software, Settle3D. Two seismic scenarios adapted from

the National Seismic Hazard Model for New Zealand are modelled for each site with estimated return periods of 500 and 2,500 years. A further hypothetical seismic scenario is modelled with an estimated return period of 10,000 to 20,000 years.

The investigation reveals the uncertain nature of liquefaction occurrence subject to the complex relationship between earthquake magnitude and peak ground acceleration (PGA) with localised geological conditions. This uncertainty is amplified by a lack of standardised protocols for liquefaction modelling. Following the methods established by Idriss and Boulanger (2008), results show that there is a likelihood of liquefaction occurring at the Takanini site for the 500 year return period scenario. At both the Takanini and Drury sites, there is a likelihood of liquefaction for the 2,500 year return period scenario, and a likelihood of liquefaction occurring across all sites under the 10,000 to 20,000 year return period. This study also highlights the need for detailed engineering classification of sites in the Auckland region logged as “Puketoka Formation”, as well as detailed dynamic site characterisation.

Reference: Idriss, I., & Boulanger, R. W. (2008). *Soil liquefaction during earthquakes*: Earthquake Engineering Research Institute.

INSIGHTS INTO SUBSURFACE STRESS AND STRUCTURE IN THE SOUTHERN EAST COAST BASIN, NEW ZEALAND

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In 2011-2012, New Zealand Energy Corp drilled the Orui-1A, Te Mai-2, and Ranui-2 stratigraphic holes, to determine the

suitability of the Waipawa and Whangai formations as unconventional shale oil/gas plays in the onshore part of the southern East Coast Basin. Drillcores and borehole image logs (acoustic and resistivity) were acquired in the wells. These datasets provide a unique opportunity to directly calibrate image logs to observations in the core, allowing us to enhance our understanding of the fractures and *in-situ* stress in the boreholes, and relate these to outcrop at a regional scale.

Structural data obtained from image logs show that the fracture strike orientations vary between formations within the wells, and between the wells themselves. The Paleocene–Eocene Wanstead Formation has a general NW–SE fracture strike direction in Orui-1A, whereas in Te Mai-2 the fracture strike direction is more N–S. The Late Paleocene Waipawa Formation was intersected by Orui-1A and Te Mai-2, and has a similar fracture strike direction of NE–SW in both wells. Late Cretaceous–Paleocene Whangai Formation was imaged in both Ranui-2 and Te Mai-2, with approximate NE–SW and variable fracture strike directions, respectively.

The image logs show that *in-situ* stress varies between the same formations encountered in different wells, and between the three wells. Orui-1A has an overall SH_{max} of approximately N-S for the entire imaged interval, whereas Te Mai-2 has a low confidence SH_{max} of NE-SW. Ranui-2 has two directions of SH_{max} , NW–SE and W–E. When comparing these *in-situ* stress trends to the regional stress regime, other factors such as faults and topography need to be considered.

VARIATIONS WITHIN THE FOSSILISED SILICEOUS SINTERS OF THE COROMANDEL VOLCANIC ZONE

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The Coromandel Volcanic Zone (CVZ) hosts 19 fossilised siliceous sinters or hot spring deposits. Siliceous sinters are surface expressions of geothermal systems where fluids up to 100 °C are expelled at the intersection of the water table with the Earth's surface from deep reservoirs with temperatures >175 °C. Upon cooling, these fluids, oversaturated in silica, depositing non-crystalline opal-A precipitates onto biotic and abiotic surfaces. Overtime this silica diagenetically matures to quartz, to form erosion-resistant sinter mounds and sheet deposits with identifiable textures, which are produced by extremophiles and diagnostic taxa that live within the sinter during formation. The CVZ is a Miocene-Pliocene sub-aerial calc-alkaline volcanic arc, overlying Jurassic meta-sedimentary basement. Within the CVZ the Hauraki Goldfield consisting of 50 known epithermal veins, also produced by geothermal activity within the upper parts of the Earth's crust, some of which are directly associated with siliceous sinters. Analysis of lithological, textural and geochemical variation within the CVZ siliceous sinters show similarities to deposits in the Recent and actively forming Taupo Volcanic Zone deposits and the siliceous sinters of the Jurassic Deseado Massif, Argentina. Comparisons of these 19 siliceous sinter deposits to the modern and fossilised hot spring deposits reveals proximal, middle and distal facies assemblages, allowing inferences of paleo

fluid temperature, volume, pH and change in the system over time.

TRACE METALS IN CRUSTACEA: BIOMONITORING OF THE MARINE ENVIRONMENT

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The state and health of New Zealand's marine environment is paramount to our societal and economic wellbeing. An important factor in being able to preserve our unique marine estate is understanding the chemistry of our marine environment in order to monitor any change that might occur, such as changes in levels of metals resulting from offshore mining activities, urban development, or ocean acidification. Crustaceans, such as crabs and amphipods, take up potentially toxic trace metals into their tissue and carapace, and hence become recorders of their chemical environment.

We will present preliminary trace element data for marine amphipod and decapod specimens from several New Zealand locations, as a first stage in developing geochemical analysis of crustacea as a biomonitoring tool for tracing chemical change in the marine environment. Thirty trace elements have been analysed in four amphipod species (*Ampelisca chiltoni*, *Podocerus* sp., *Ischyrocerus* sp., *Apothyale* sp.) and in the decapod species *Jasus edwardsii* (crayfish). The trace element data allow us to evaluate natural variations among specimens from single localities, compare uptake of elements among different amphipod families

from the same environment, compare uptake of elements into decapod tissue versus shell, and between decapod and amphipod species from the same general locality.

These results are the first of a 3-year Endeavour funded programme to measure trace element contents in crustaceans throughout New Zealand's waters. The data will provide baseline values of trace elements from which any future changes in the marine environment can be assessed. The data also provide a means to test the quality of kaimoana, as any increase in toxic elements above natural values will affect the quality and health of the food chain ultimately consumed by us.

**MULTIPLE VENT ERUPTIONS AT
MONOGENETIC VOLCANOES: WAITOMOKIA
VOLCANO, AUCKLAND VOLCANIC FIELD,
NEW ZEALAND**

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Waitomokia volcano is a basaltic tuff ring and scoria cone complex located in the southern lowlands of the Auckland Volcanic Field (AVF). Extensive quarrying and urban developments have resulted in the near-complete removal of three intra-tuff ring scoria cones, incision of the tuff ring rim and some degree of infilling of the crater floor, hindering a full understanding of the volcano's formation. In this work, historical records are combined with detailed field studies of the remaining pyroclastic deposits to reconstruct the formation and evolution of Waitomokia, with special reference to the nature of explosive magma

and groundwater interactions.

The proximal sequence of the tuff ring consists of a coarse massive-to-weakly bedded pyroclastic breccia and lapilli tuff that alternates with a well-bedded, cross- and/or dune-bedded tuff. The clast-supported nature of juvenile lapilli layers and the presence of scoriaceous bombs within the tuff ring deposits suggest repeated magma discharge through an open but slurry-laden vent. The irregular and flame-like boundaries of lithic clasts within magmatic bombs indicate that coarse mixing occurred between intruding magma and water-saturated sediments (e.g., peperitic domain). Juvenile scoria fall and spatter deposits within the tuff ring crater provide evidence for a more sustained magmatic phase towards the end of Waitomokia's eruption leading to a scoria cone building phase. Several lines of evidence suggest that the tuff ring was formed by volcanic activity at multiple, closely-spaced vents with some aspect of vent migration through time.

This eruption model is in good concert with inferred eruptive histories of other large tuff ring complexes from the AVF, especially those formed in the low-lying coastal areas of the field, suggesting the influence of the external environment on volcano growth and the potential volcanic hazards involved in such type of evolution can be associated with vent migration and unstable vent/crater and conduit conditions.

SEDIMENTARY GEOLOGY OF A PORTION OF THE EAST COAST BASIN, WEBER TO AKITIO, NEW ZEALAND

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Geological mapping of the East Coast Basin has tended to be at a broad scale with detailed mapping confined to a few specific areas of interest. East Coast Basin is a petroliferous region and therefore of interest for petroleum exploration, however, further detailed mapping and sedimentological research is needed to have a better appreciation of the reservoir potential of the basin. The Weber district, 35km southeast of Dannevirke, has received minimal attention. Mapped geological boundaries are inferred based on broad tectonic features and structures and little sedimentology has been undertaken. The current geological understanding is that this area contains a succession of Late Cretaceous (66ma) to Late Miocene (10ma) sandstone, limestone, marl, flysch and mudstone facies. Few potential reservoir units are mapped or received detailed analysis and source rock has been an ongoing enigma.

The purpose of this research is to produce a high- resolution 1:25 000 geological map and undertake sedimentological, biostratigraphical, petrological, structural and paleo-environmental studies to help better understand the petroleum potential of the area.

Initial findings indicate the area is structurally complex with numerous faults, folds, including the Akitio Syncline, and local unconformities. Within the stratigraphic sequences identified both macro and micro fauna provide

depositional environment and age control. Sedimentological and petrographic analysis of major units also indicate variability in depositional environments such as abyssal to shallow marine. Key sections have been identified to provide accurate ages throughout the depositional sequence. This project will contribute to current research on the petroleum reservoir potential of the East Coast Basin.

DARWIN'S GEOLOGICAL OBSERVATIONS IN NEW ZEALAND, 1835

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Charles Darwin, arguably the world's best known geologist, visited the Bay of Islands, New Zealand, on HMS Beagle in December 1835, 22 years before the arrival of the fathers of New Zealand geology Ferdinand von Hochstetter and Julius von Haast. During his visit Darwin wrote nine pages of geological notes in his unpublished geological diary. Until recently these were relatively inaccessible in the Cambridge University archives but now the original diary and transcript are available on the web at Darwin on-line. Thus New Zealand geologists (including Hochstetter) have been mostly unaware that Darwin was the first to make substantive geological observations in New Zealand. His notes include descriptions of the puzzling weathered Waipapa Terrane greywacke that forms the Bay of Islands coast and the young basalt volcanoes of the Kaikohe Volcanic Field. He described Oligocene Whangarei Limestone and some of the rocks that we now recognise as having been displaced by the Northland Allochthon. He also documented discussions with the local missionaries on the lack of earthquakes in Northland compared with

further south; the active volcanoes of the central North Island, White Island, Mt Egmont and Rangitoto; and lignite, conglomerate and glauconitic marl from Northland's west coast. He uses some of his observations to affirm his growing conviction that most lands had been uplifted by earthquakes; that New Zealand was at the southwestern end of the Pacific Ring of Fire; and that coal existed because of a favourable environment for accumulation and not because of its age.

DRIVERS, DYNAMICS AND HAZARDS OF THE LARGEST ERUPTIONS OF MT. TONGARIRO

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Mt. Tongariro is an unusual composite volcanic complex made up of many widely dispersed vents, associated along fault-zone lineaments within the Tongariro graben. The eruptive history of Mt Tongariro is characterized by a bimodal distribution in eruption size and frequency. Small-scale eruptions of $<0.01 \text{ km}^3$ are regular, but very large eruptions ($0.5\text{-}1 \text{ km}^3$) are also documented. These large events were attributed to tectonic drivers, but firm evidence for this is lacking. In this study we examine in detail an unusual flare-up of activity at $\sim 11\,000$ years ago when Mt. Tongariro produced at least 4 Plinian eruptions, (mapped within the Mangamate Formation). In less than 400 years 5.3 km^3 of pyroclastic material was deposited over many hundreds of square kilometers around the volcano. In the first phase textures of the juvenile lapilli were examined. Bubble-growth in the rising magma foam drive the magma to rise either by increasing buoyancy or by increasing magma chamber overpressure. The resulting magma ascent is controlled by the

ability of the gas to separate from the magma and travel through connected bubbles. Data will be presented from 2D and 3D visualizations for several of the Mangamate lapilli units. Unusually fine-vesicle textures observed are suggestive of a late-stage bubble nucleation event, followed by rapid rise to eruption. This contrasts with the textures and eruptive processes identified in the neighbouring Ruapehu Plinian eruptions. The Mangamate textures seem consistent with the sudden rise of a deeply stored and gas-poor magma to eruption. This work will be extended alongside geochemical and petrological studies to delve further into the triggering mechanisms and dynamic properties of the maximum likely eruption scenarios at Mt. Tongariro.

VAPOUR PHASE ALTERATION AND COOLING OF COMPOUND IGNIMBRITE SHEETS: THE SILICA STORY

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Many welded ignimbrites show vapour-phase alteration, overprinting initial crystallisation of the formerly glassy matrix. We present data on silica polymorphs formed during glass crystallization accompanying cooling of compound ignimbrites. Previous work has indicated that ignimbrites can record a change in silica polymorphs and associated groundmass textures consistent with cooling profiles from numerical modelling. X-ray diffraction and SEM imaging is used to examine changes in groundmass texture and

mineralogy through selected sections in the Bishop Tuff (USA) and Whakamaru ignimbrite (New Zealand). Two transects through the Bishop Tuff, linked to documented stratigraphic packages and welding zones, provide a basis for comparison to the Whakamaru ignimbrite at Maraetai Dam on the Waikato River. Samples from both localities generally contain only 10-30% amorphous material, consistent with their welded nature. Silica polymorphs reflect a change from cristobalite to tridymite at, and just above, the contact between the major flow packages for two of the three sections investigated. No tridymite is observed within the Bishop section containing a fall deposit intercalation. A density profile through the Whakamaru section shows no significant variation in the presence of tridymite. In contrast, for the Bishop, there is a significant variation in density at the contact between ignimbrite packages. The systematic stratigraphic location of the tridymite at package boundaries suggests that the presence of tridymite is not related to cooling rate. For Whakamaru, the presence of tridymite corresponds to a distinctive horizontal fracture pattern. We propose that groundmass tridymite is related to localised vapour phase alteration under a cap of the less permeable upper flow materials, resulting in tridymite formation only where the two sheets are in contact. Correlations between compound ignimbrite structures and silica polymorphs may help mapping of hydrothermal fluid flow pathways in ignimbrite hosts.

URBAN MAPPING IN SOUTH AUCKLAND

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The current rate of city expansion means better understanding of urban geology, such as landforms, subsurface geology, hazards and resources, has become increasingly important. A GNS Science geological mapping project has commenced in South Auckland and extends from the Waikato River in the south to the Manukau Harbour in the north. This map is the start of our urban geological research in the Auckland region; our future intent is to continue mapping north through the city. Initial compilation of published and unpublished geological data in the region and an evaluation of the stratigraphy and volcanic evolution has been completed. South Auckland is particularly data-rich and includes many university mapping studies; aeromagnetic and radiometric geophysical data; LiDAR digital elevation models (DEMs); and several thousand borehole records. We have compiled ca. 28,000 lithological descriptions from more than 2,000 boreholes in the region that provides an extensive database of subsurface geological information. Aeromagnetic data has been used to create inversion models of areas with magnetic anomalies that represent volcanic intrusions, and these enhance our understanding of the subsurface volcanology. Using a 1 m LiDAR DTM we are mapping geomorphic features, many of which constrain the location of geological boundaries, and along with subsurface data and historic geological observations, will provide a robust foundation for our urban geological map. In addition to a surface geological map, the wealth of subsurface information allows the

construction of a 3D geological model that will provide constraints on the distribution of volcanic rocks, sedimentary formations and groundwater systems.

GEOMECHANICAL CHARACTERISATION OF RESERVOIR AND SEAL ROCKS IN THE TARANAKI BASIN

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Around the world, extensive work has been undertaken to understand the geomechanical properties of sands and shales, for application to the modelling of petroleum reservoirs. Geomechanics provides vital information on the *in-situ* stresses within a basin and how they impact the flow of fluids through reservoirs and movement of geological structures. This information is pivotal when considering petroleum migration, reservoir compaction, sealing quality of cap rocks, hydraulic fracturing, and fault reactivation; all considerations that need to be accounted for when considering the overall condition and viability of a petroleum play.

This study focused on the Maui and Maari Fields in the Southern Taranaki Basin, which contain substantial petroleum reserves for New Zealand. Despite development and interest in the resources hosted here, industry relies on non-site specific geomechanical properties of reservoir and seal rocks which has downstream implications for any decisions that need to be made on well design and field planning, as these rock properties impact stress field calculations needed for well

stability studies, and the calculations of vital data such as porosity and permeability from wireline logging.

We aim to quantify the geomechanical properties of key reservoir and seal horizons in the Maari and Maui Fields, including porosity, permeability, ultrasonic wave velocities (V_p/V_s), and uniaxial compressive strength (UCS). Laboratory testing is undertaken on samples of drill core and outcrop analogues to generate this data, which will then be used to refine stress data inputs into field geomechanical and migration models. Furthermore, following a practical approach, empirical relations will be determined between the rock properties, specific to the region, allowing for correlation between laboratory, wireline, and possibly field wide geophysics scales which open up enhanced analysis of existing and future exploration and development data in the Taranaki Basin.

FILLING THE GREAT BLANK WEDGE OF ZEALANDIA: CRETACEOUS TO PALEOGENE PALINSPASTIC RECONSTRUCTION OF THE EAST COAST BASIN

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The East Coast Basin is a Cretaceous-Cenozoic sedimentary basin that originally formed within a late Cretaceous–Oligocene passive margin setting, and has subsequently developed within a convergent margin setting throughout the Neogene. The position of the East Coast Basin prior to the inception of the modern boundary between the Pacific and Australian plates has, for many decades, been a contentious issue in palinspastic and

paleogeographic reconstructions of Zealandia and the broader southwest Pacific region. Many previous reconstructions of Zealandia either omit the region entirely, or depict it as a broad wedge-shaped zone of unconstrained and unspecified deformation.

Applying recently developed rigid-plate reconstructions for Zealandia, we have used geological and geophysical datasets to emplace constraints on the deformation, horizontal movement, and paleogeography of the East Coast Basin. The outcome is a series of palinspastic reconstructions. These palinspastic reconstructions are then translated into a suite of paleoenvironmental maps through the integration of various datasets, including stratigraphic and sedimentological measurements, fossil record data from the fossil record electronic database (FRED), and heavy mineral and detrital grain studies. These data provide insight into paleo-slope and current directions, paleo-water depth, and sediment provenance. Maps have been developed for several key time-slices through the late Cretaceous to late Eocene, namely the Ngaterian, Piripauan, Haumurian, K-Pg boundary, Teurian, Heretaungan and Runangan stages.

Information derived from these palinspastic maps has implications not only for the better understanding the petroleum prospectivity of the Raukumara-East Coast-Pegasus basins, but also has broader applicability to paleotectonic, paleoclimate, and paleoceanographic research. In addition to providing basin-wide temporal and spatial perspectives of ancient depositional environments, they can be presented in tandem with correlative time-slice maps from the Reinga-Northland-Deepwater Taranaki-Taranaki, and Canterbury-Great South basins to provide regional context for the Zealandia region in a consistent and reproducible format.

SEISMIC INVESTIGATIONS OF FLUID FLOW RELATED STRUCTURES ON THE SOUTH CANTERBURY SLOPE

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Crescent shaped pockmarks are abundant on the marginal extent of the Otago canyon system in water depths between 500 and 1100 m. Fluids seeping through the seabed, potentially forming pockmarks, play a crucial role in seabed ecological systems and can be used to investigate the distribution of hydrocarbons in underlying geological units. Buried pockmarks revealed by 3D seismic datasets indicate repeated fluid expulsion along the Canterbury slope triggered by different processes. Recent and buried seafloor depressions along the shelf exhibit the same north-eastward facing crescent form that we associate with water current modification. High-resolution seismic investigations near the Waitaki Canyon combined with recently acquired 3D seismic data give the first evidence of shallow gas accumulations in the region. No active fluid seepage was observed in water column imaging data above the shallow gas but pockmarks on the seafloor indicate past fluid flow. Analysis of the amplitude variation with angle (AVA) in seismic common depth point gathers reveals a class 3 AVA anomaly around bright spots and a near vertical structure beneath them. We assume this vertical structure to be a recent or ancient fluid migration pathway feeding the shallow gas pockets beneath the seafloor. Continuous reflections in the seismic section around the vertical structure visible in the AVA attribute suggests that fluid migration causes only minor modifications of the original sedimentary fabric. In a succession of dense

polygonal faulting, two near vertical faults create slightly uplifted cylindrical shapes with diameters of 4 and 6 km, respectively. Polygonal faults around these cylindrical features create structures less than 500 m in diameter. Seismic sections through these circular features reveal upward-bent reflections in their centres that we interpret as ancient fluid migration pathways. They are confined to strata below the Marshall paraconformity where they terminate and create a mound and a depression, respectively.

**COSMOGENIC NUCLIDE DATING OF THE
SEDIMENTS OF BULMER CAVERN:
IMPLICATIONS FOR THE UPLIFT HISTORY OF
SOUTHERN NORTHWEST NELSON, NEW
ZEALAND**

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Not much is known about the timing of the tectonic history of the Northwest Nelson area since the early Miocene inception of the Alpine fault, which lies to the south. Radioactive cosmogenic nuclides such as ^{10}Be and ^{26}Al which have half-lives of 1.34 Ma and 0.72 Ma respectively accumulate in minerals such as quartz on the Earth's surface. In karst terranes, these minerals can be transported by fluvial processes into cave systems and preserved in sediments that infill cave passages. After deposition in the cave, sediments are shielded from cosmic rays by the overlying rock, and the difference in decay rates of the cosmogenic nuclides allows the calculation of the age of burial.

Bulmer Cavern is an extensive multi-level cave system located within the Mt. Owen massif, which is located approximately 30km north of

the Alpine Fault in the southeast corner of Northwest Nelson. Progressive truncation of cave passages by faults in the upper levels of the cave suggests the system is of at least Miocene age.

Cosmogenic nuclide burial dating of cave sediments can be used to infer the age of abandonment of cave stream passages, and in multi-level cave systems these abandonment ages can be used to reconstruct the rate of the lowering of hydrologic base level and hence regional uplift.

Initial results of applying $^{10}\text{Be}/^{26}\text{Al}$ burial dating to quartz in sediments in Bulmer Cavern suggests that Eye in the Sky passage, which is located approximately 250m above the present day cave stream level was abandoned by 2.9Ma. This suggests a regional uplift rate of 0.1mm/yr since the late Pliocene. The abandonment age is supported by the observation that the sediments infilling Eye in the Sky passage are similar to the upper parts of the Glenhope Formation, which are also of late Pliocene age.

**THE VERY PECULIAR CONDITIONS THAT
CREATED THE WAIPAWA FORMATION, ~59
MILLION YEARS AGO**

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The Waipawa Formation is an organic-rich marine mudstone that is a proven source of petroleum. Total organic carbon (TOC) content is commonly 1–3% and ranges up to 12%. The unit and facies equivalents are widely distributed in the southwest Pacific but their thickness and distribution within individual basins is highly variable. Biostratigraphic studies indicate that the

formation was deposited within a relatively short period of time (0.5 to 1.0 million years) about 59 Ma, at varying depths from outer shelf to upper slope. Palynofacies and biomarker studies reveal that, despite the marine setting, the bulk of the organic matter (OM) is derived from land plants. The conditions that led to a massive influx of terrestrial OM into widely separated sedimentary basins are a matter of much conjecture and debate. A possible answer lies in the strongly positive $\delta^{13}\text{C}$ signature of the terrestrial OM: a mean value of -17.5 ‰, which is ~10 ‰ heavier than associated marine OM. We suggest that this excursion signals a major decrease in atmospheric CO_2 , linked to global cooling and a eustatic fall in sea level. Erosion of well-vegetated coastal regions, led to the accumulation of abundant terrestrial plant matter in marginal basins of Zealandia, eastern Australia and perhaps further afield. This short-lived event marks the termination of long-term Paleocene cooling in which deep sea temperatures cooled by 3°C over 4 million years. Within the event itself, local sea surface temperatures cooled by a further 4°C. This peculiar event was followed by a global warming trend of similar magnitude and duration that culminated in the Paleocene-Eocene thermal maximum.

VEGETATION CHANGE, CLIMATE AND VOLCANISM IN TARANAKI OVER THE LAST THREE GLACIAL/INTERGLACIAL CYCLES – A MULTI-PROXY APPROACH

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Previous studies of past vegetation patterns in Taranaki over the past ~250,000 years have concentrated almost entirely on palynology. While this has given considerable insight into

regional vegetation patterns, particularly since the last glacial maximum, there are still some unresolved questions. We report some preliminary results from an ongoing study in which we seek to integrate pollen records with plant macrofossils to help resolve some of these problems.

Three sites in north Taranaki form the basis of the first stage of this study. Two coastal sections, at Bell Block and Airedale Reef include seams of dirty lignite that have yielded pollen, macrofossils, tephra and charcoal. Together with a third, inland section at Colson Road, sampled for pollen alone they will allow comparison with other sites, both onshore and offshore. Initial results from this integrated approach suggest that during both MIS 7 and MIS 5, the coastal plain of northern Taranaki was covered by a complex of dunes backed by swampy podocarp/broadleaf forests, lakes and more open areas of swamp and oligotrophic restiad bog. Both volcanicity and fire seem to have affected the vegetation rather more than previous authors have suggested.

MICROSEISMIC RESPONSE TO DEEP INJECTION AT NGATAMARIKI GEOTHERMAL FIELD, NEW ZEALAND

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Fluid-induced seismicity (FIS) is a useful indicator of thermal and pressure changes within a geothermal reservoir. Given the difficulty of making measurements in the

space between wells, FIS provides one of the only direct observations of fluid-related reservoir processes. Understanding exactly why and how these microearthquakes occur helps us unravel the interaction between the movement of fluid and heat at depth and could allow for a better understanding of the creation and destruction of permeability in the reservoir. We begin with an earthquake catalogue of 1171 events which occurred between May 2012 and November 2015 at the Mercury geothermal field at Ngatamariki. We expand this catalog using matched filter detection to include ~77,000 microearthquakes. Earthquakes at the field are densely clustered in areas of active fluid injection and the rate of seismicity is highly correlated with injection rate. We present high-precision locations as well as frequency-magnitude distributions and source mechanisms for significant events and discuss their relation to injection and production rates at the fields. In particular, we focus on specific periods of interest including the stimulations of well NM08, NM09 and NM10 in June 2012 and the Ngatamariki plant start-up in April 2013.

USING MULTIPLE ATMOSPHERIC MODELS TO ASSESS AND DISPLAY UNCERTAINTIES IN VOLCANIC ASH FORECASTS FROM HYSPLIT

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Since the 1995 eruption of Ruapehu, GNS Science runs daily forecasts of where volcanic ash would be likely to land if there was a volcanic eruption. When a volcano is erupting, ashfall forecasts for that volcano are distributed to relevant organisations and the public; at times these daily forecasts are also published for volcanoes in heightened unrest.

A major source of error in volcanic ash forecasting is the wind pattern above and around the volcano. Our current operational forecasts are produced by the program ASHFALL (Hurst 1994), which uses a 1-dimensional model wind profile, and neglects horizontal variation in the wind field. Given New Zealand's dynamic meteorology, this is a major limitation. GNS Science, in conjunction with New Zealand's MetService, is working to move its operational ash forecasts to HYSPLIT, which uses a full 4-D atmospheric model. We are now routinely using HYSPLIT to produce forecasts of where ash would be deposited if a given volcano erupted.

Because of the simple 1-D wind assumption, and the way ash diffusion is treated, ash contours produced by ASHFALL are ellipses which usually cover a much wider area than more sophisticated models forecast. Conversely, HYSPLIT sometimes forecasts narrower deposited ash distributions with detailed contours with small scale features, so minor errors in input wind conditions cause precise but inaccurate forecasts. This higher level of detail can give a false impression of accuracy. This problem is apparent in hindcasting ash deposition from the 6 August 2012 Te Maari eruption from Tongariro volcano (Hurst & Davis, 2017).

Prior to making these new forecasts operational, we will explore ways of displaying the uncertainty in the atmospheric modelling to avoid inappropriate reliance on deposit forecast details. This includes using multiple atmospheric models to make our ash forecasts take better account of the uncertainties in the atmospheric modelling.

PRELIMINARY INSIGHTS INTO THE FAULT GEOMETRIES AND KINEMATICS OF THE SURFACE RUPTURE ALONG THE SOUTH LEADER FAULT DURING THE MW 7.8 KAIKOURA EARTHQUAKE

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The South Leader Fault (SLF) ruptured the ground surface during the Mw 7.8 Kaikoura earthquake. Part of the SLF had been previously mapped in bedrock, although the fault was not known to be active prior to the earthquake, and does not have a strong topographic expression. The fault is a NNE trending oblique left lateral fault that links the predominantly right lateral 'The Humps' and Conway-Charwell faults. Field mapping and terrestrial LIDAR at 0.5m resolution have been used to assess the factors influencing the surface geometries and kinematics of the SLF ruptures at the ground surface. The SLF deformation zone is up to 2km wide, and comprises a series of en echelon NE-striking thrusts linked by steeply dipping (65° west-85° east) N-S striking faults. The thrusts are generally upthrown to the west by up to 1 m and dip 35-45°. Thrusts are parallel with Cretaceous-Cenozoic bedding in the Greta Siltstone, Waikairi, Motunau and Amuri Limestone formations. These displacements may reflect flexural slip folding and off-fault deformation during the earthquake. By contrast, the northerly striking faults accommodate up to 3m of oblique left lateral displacement at the surface and displace Cenozoic bedding. The surface expression of both steep oblique slip and thrust faults is particularly complicated in the north of study area where they intersect with the right-lateral Humps to form a ~2 km widely zone of

fault-traces with left-lateral and right-lateral strike slip. Similar distributed fault intersection zones are widely documented in the literature, but in this case would be difficult to assess in the absence of the earthquake.

GEOLOGICAL STRESS EVOLUTION OF WEST JAVA, INDONESIA

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Block collision, amalgamation and rotation have affected all parts of Sundaland, including West Java, which is situated at a bend on the Sunda-Banda Subduction Margin (SBSM). This 'corner' marks the transition between oblique and orthogonal convergence along the margin and coincides with the Sunda Strait between West Java and Sumatra. The opening of Sunda Strait suggests a possible counter clockwise rotation of West Java relative to Sumatra. We tested this notion by analysing the temporal evolution of regional stress orientations, SHmax in particular, using available geological data and the World Stress Map. For this analysis, the direction of paleo- SHmax is defined by the orientation of igneous dikes and the elliptical shape of constructional volcanic edifices, based on the assumption that magma propagation through the brittle crust is sensitive to regional stress. The Cenozoic magmatic intrusions and edifices in West Java range from Middle Oligocene to Early Holocene in age. Those that have a clearly preferred orientation have been digitised from 19 map sheets at a scale of 1:

100,000. For the volcanic edifices, the SHmax trend is parallel to the major axis of each ellipse. The ellipses of 544 Cenozoic intrusions depict two major maxima trends at NW-SE and NE-SW. The SHmax trend analysis based on age clustering indicates 3 major groups: 1) NW-SE trend from Middle Oligocene to Middle Miocene, 2) NW-SE and NE-SW trend from Late Miocene to Pliocene; and 3) NE-SW trend from Pleistocene to Early Holocene. The bimodal trend from Late Miocene to Pliocene reflects a transitional period contemporaneous with opening of Sunda Strait at 10 Ma and associated counter-clockwise rotation of West Java.

WATER QUALITY AND GEOCHEMISTRY OF HISTORIC CASCADE MINE DISCHARGE ON THE DENNISTON PLATEAU, NEW ZEALAND

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New Zealand's largest coal resources are located on the West Coast of the South Island. One particular coal measure of interest is the pyritic Eocene Brunner Coal Measures due to their high acid producing potential. This is attributed to their pyritic nature, allowing the production of pH 3 acid mine runoff on interaction with meteoric water. Historic mining on the Denniston Plateau in the 1900s has caused an increase in the surface area of the pyritic coal. This allows the discharge of acid mine drainage (AMD) through a series of adits located above the current mine's high wall. These adits drain into the Cascade Creek, allowing the acidic water to mix with an unimpacted tributary, enabling partial neutralisation producing waters of pH ca. 5.5. Iron and aluminium oxide precipitates are present in this Cascade Creek mixing zone.

Analysis of the water chemistry of the AMD, including trace elements and major ions has been undertaken to allow quantification of the dilution occurring during mixing of waters in Cascade Creek catchment. Determination of dissolved loads in the AMD runoff is being quantified using a data-logger attached to a V-notch in a runoff stream. Correlation with pH and specific conductance measurements through flood events has been undertaken to allow the determination of the flux of acidic waters during these flood events. Preliminary results show a minor increase in pH during flood events coupled with a decrease in specific conductance correlating to a decrease in metals. The ultimate aim of the project is to define the parameters for dilution and/or passive treatment of the AMD to ensure enhanced environmental outcomes in the impacted streams.

DETAILED LITHOFACIES ANALYSIS OF THE LATE CRETACEOUS NORTH CAPE FORMATION, SOUTHERN TARANAKI BASIN

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The Whanganui Inlet, northwest Nelson, provides a unique opportunity for sedimentary analysis of onshore expressions of Late Cretaceous units of the southern Taranaki Basin. Previous sedimentary investigations of the North Cape Formation have assigned 3 lithofacies associations that represent estuarine, fluvial and swamp successions. These investigations have focussed on interpretation of depositional settings providing the framework for this detailed investigation of lithofacies and their lateral variability in order to define reservoir characteristics.

**GEOCHEMISTRY OF BIOLOGICALLY-
MEDIATED GOLD MOBILISATION
IN A SEMIARID CLIMATE, SOUTHERN NEW
ZEALAND**

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Detailed sedimentological assessment of 8 new stratigraphic sections in addition to those previously investigated has identified 9 key lithofacies that comprise the depositional environments of the North Cape Formation. Conglomerate lithofacies are limited to northern outcrops, while the remaining lithofacies can be observed throughout the area. Lithofacies range from high-energy, tidally influenced distributary systems in the northwest, to low-energy inter- and supra-tidal environments in central portions, to mixed-fluvial and tidal environments the southern areas. The recognition of cyclical shifts from supra- to intra-tidal environments within the central and southern regions suggests influence from base-level fluctuations over the Late Cretaceous, this may be the result of local subsidence variations within the basin and/or sea level changes. Tidal signatures such as ripple forms and rhythmic interbedded sandstones, in addition to unique bioturbation from both marine fauna and large herbivorous dinosaurs are present throughout the study area. These structures and their relationships with surrounding lithofacies have aided paleogeographic reconstruction.

Our analysis has established distinct tidally-influenced depositional modes that vary laterally and stratigraphically across the region. Further analysis will enable the interpretation of the reservoir quality in the onshore facies. Ultimately, it is hoped this research could be used to inform the petroleum reservoir potential of the offshore North Cape Formation.

Alluvial gold in Quaternary placers has undergone mobilisation and re-deposition at the micron scale during biologically-mediated interactions within groundwater. These processes have been occurring in a tectonically active semiarid region of southern New Zealand and are likely to be representative of this environment elsewhere in the world. The geochemical environment is dominated by authigenic sulphur minerals such as pyrite. Detrital and authigenic pyrite commonly occur below the water table, and evaporative sulphate minerals are common above the fluctuating water table. Oxidation of pyrite is widespread but any acid generated is rapidly neutralised by abundant calcite in sediments, and pH remains circumneutral except in highly localised (centimetre scale) zones around pyritic material. Pyrite oxidation produces metastable thiosulphate ions, enhanced by bacterial mediation. This bacterial mediation also forms authigenic pyrite in reducing conditions below the water table. Gold has been mobilised chemically in this groundwater environment as Au-thiosulphate complexes. Subsequent deposition of this mobilised gold resulted from localised variations in redox and/or pH near to the fluctuating sulphide-sulphate redox boundary.

VOLATILE EXCHANGE DURING MAGMA MIXING: INVESTIGATING THE VERY SHORT TIMESCALES BEFORE ERUPTION

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Significant evidence shows that magma mixing occurs throughout the lifespan of a magma reservoir; in some cases, this process has been used to explain the triggering of an eruption. To constrain the timing of these events, a growing number of studies have analysed the outer rims of zoned crystals to determine the time between magma interactions and ascent to eruption. This often requires a good understanding of the major and minor element transfer between two magmas. While such element transfer has been well studied and applied over a range of magmatic compositions, very little work has explored the transfer of volatiles (H₂O, CO₂, F, Cl, S) between two magmas. This is important because one of the first and least equivocal signs of an impending eruption are derived from active fumaroles. Therefore, we must understand the effect of mixing on degassing, which in turn will significantly aid in eruption forecasting.

To examine the transfer of volatiles between magmas, we analyse a sample from the 1976-2000 eruption episode at White Island where there is clear evidence of mixing between a basalt and the volumetrically dominant dacite magma. Using a novel SIMS measurement approach that scans across an area of ~ 30 μm², we measure the volatile content of each major volatile element across many disparate mingled glass patches. We then use these data

to show the variability of volatiles within and across these zones to investigate the heterogeneous nature of silicate glasses.

We then use a physically constrained model to calculate the time required to achieve complete homogenisation. This independent method provides a maximum time between magma mixing and eruption. Our combined results show that magmatic processes can be very rapid and through careful petrological analysis and modelling, we can quantify processes that are directly relevant to near-real time volcano monitoring.

SPELEOTHEM RECORDS OF NEW ZEALAND'S EARTHQUAKE HISTORY

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A record of past large earthquakes in NZ is essential for robust forecasting of future events. Current records are limited to the recent past (last few thousand years) due to imperfect preservation of paleoearthquake evidence in NZ's dynamic landscape. Many uncertainties remain around long-term earthquake recurrence intervals, as well as temporal sub-centennial clustering of large earthquakes. We will develop a new tool for detecting and dating paleo-earthquakes that should extend records back in time by more than an order of magnitude, and to places of

low modern-day seismicity, where the likelihood of large earthquakes remain unknown. The tool is based on field, geochronological, and geochemical investigations of cave deposits (i.e., speleothems) found throughout NZ. We hypothesize that speleothems will record large earthquakes by: (1) strong shaking either causing speleothems to break, fall to the cave floor and cease growth, or alternatively preserve irregularities in their columnar growth structure; (2) disruption of the cave's hydrological system and water flow/chemistry. Dating of the tips of broken or irregularly grown speleothems and abrupt geochemical anomalies in them may be able to greatly refine and extend NZ paleo-seismic records, over timescales up to hundreds of thousands of years. We will ground-truth this methodology by documenting the effects caused by the 2016 Mw 7.8 Kaikoura earthquake on nearby caves, and search for similar "damage" in other cave sites throughout NZ that can be compared with older, conventional paleo-earthquake records at those sites. Ultimately, this method may make it possible to greatly extend the paleo-seismic history of much of NZ and assess if and how often large earthquakes occur, for example, in the upper North Island.

DETRITAL THERMOCHRONOLOGY IN THE SOUTHERN ALPS: NEW INTERPRETATIONS OF SEDIMENT DYNAMICS AND EXHUMATION HISTORY

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Detrital thermochronology is a novel approach to interpret the pace, pattern and history of rock exhumation in sedimentary source areas from the cooling history of detrital minerals in sedimentary samples. Extensive thermochronologic analyses of bedrock terranes make the Southern Alps an ideal setting to apply detrital thermochronology in exciting new ways. We present two applications of detrital thermochronology to explore the evolution of this unique New Zealand landscape.

Our first application exploits a predictable relationship between apatite fission-track cooling age and southeastward distance across the Southern Alps to trace sediment provenance in six east-draining river catchments. In all six rivers, apatite fission-track cooling ages do not reflect a provenance consistent with long-term ($\sim 10^6$ yr) patterns of rock exhumation. Instead, cooling age distributions are better explained by storage and destruction of apatite grains within the river network. This observation contrasts with similar "tracer" thermochronology of late Pleistocene offshore glacial deposits, suggesting that intermontane sediment dynamics may vary with high frequency climate signals like Quaternary glacial cycles.

Our second example reconstructs the exhumation history of the Southern Alps from proximal basin deposits. We present new detrital fission-track results from Miocene-Pleistocene units in Mackenzie and Canterbury basins along with ~ 9 -1 Ma samples from Waiho-1 borehole cuttings. The absence of reset detrital apatite fission-track cooling ages in eastern exposures of the Pliocene Kowai Formation constrain a maximum ~ 2 -4 km pre-Quaternary exhumation east of the drainage divide, suggesting that Quaternary glaciation may account for 50-85% of the total exhumation of the eastern mountain flanks. Preliminary detrital zircon fission-track

analyses from the Waiho-1 borehole suggest that exhumation of the zircon partial annealing zone occurred between ~9 and 4 Ma, prior to the earliest observations of Haast schist fragments. Ongoing analyses will continue to paint a more detailed picture of an evolving Southern Alps landscape.

**THE ROLE OF SURFACE-RUPTURING FAULTS
IN THE 'WAIAUTOA MICRO-BLOCK',
CLARENCE VALLEY, DURING THE M_w 7.8 2016
KAIKOURA EARTHQUAKE**

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Post-seismic geodetic models highlighted the intersection and roles of the transpressive Jordan, Kekerengu and Papatea faults, which form a high angle fault intersection in association with the largest fault slips in the 2016 M_w 7.8 Kaikōura Earthquake. The 'Waiautoa triangle' refers to the intersection area between these faults and is further defined by minor ruptures of the Fidget and Waiautoa faults. These faults define a cluster of micro-blocks that transfer >10 m slip across from the Seaward and Kekerengu blocks to the Papatea Block, over an area of 2.5 km². Detailed field observations and post-earthquake LiDAR mapping indicate that these five faults that ruptured to the ground surface

and almost certainly link in a complex fashion. From SW to NE, i.e. following the propagation of these ruptures, the Jordan Thrust (dextral-normal in 2016) overlaps the dextral-reverse slip Kekerengu Fault near George Stream. In this same area, surface slip on the reverse-sinistral Papatea Fault approaches and almost intersects the Jordan Thrust at a high angle. To close the triangle, the reverse-sinistral Waiautoa Fault links the Papatea with the Kekerengu Fault. The Waiautoa Fault is partially concealed as it is followed by the Clarence River. Assessment of piercing line markers indicates that co-seismic surface slip increases to the NE along the Jordan, and is largely conserved north of George Stream across the Waiautoa triangle as the Jordan, Kekerengu and Waiautoa faults share and exchange 8-10 m of surface slip. Seismological data indicates that rupture of the Papatea Fault lagged those of the Jordan-Kekerengu faults which provides some indication of the role of the Papatea Fault and Waiautoa triangle in the Kaikōura Earthquake

**ELEMENTAL VARIATIONS IDENTIFIED IN
WELL POHOKURA SOUTH-1, TARANAKI
BASIN, USING A PORTABLE X-RAY
FLUORESCENCE DEVICE (pXRF)**

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Chemostratigraphy is a technique that has been used relatively commonly overseas in petroleum wells to characterize monotonous sandstone or mudstone successions that lack biostratigraphic or seismic markers. Normally, relatively time-consuming and potentially expensive laboratory-based ICPMS or XRF analyses are used. This study is a preliminary determination of the applicability of the comparatively quick and inexpensive pXRF for

chemostratigraphy. Well Pohokura South-1 was chosen as a case study as it contains good quality wireline logs including borehole images, 94 m of core, and a full suite of cuttings. All the washed cuttings were analysed, and the conventional core was analysed at approximately 1 m intervals using pXRF. Repeat analysis of a selection of samples and two NIST standards indicated good precision, with accuracy increasing for heavier elements. Detection limits meant a number of potentially useful elements (e.g. Cr, Cd, Ta) were not detected. Initial results show good agreement between cuttings and core acquired over the same depth interval. Geochemical trends with depth for several elements (e.g. Si, Ti, Ca, Mg, Fe, K, V, Rb, Nb, Y, Zr) matched some known stratigraphic boundaries, but also indicated heterogeneity within formations, probably reflecting factors such as weathering, provenance and diagenesis. Identification of geochemical variations indicates the possibility for subdivision of some stratigraphic zones resulting in higher resolution correlations between wells. In addition, results could aid in the characterization of heterogeneity in reservoirs and seals. Results to date support use of the pXRF for fast and relatively precise acquisition of geochemical data. Such data could be obtained shortly after core or cuttings acquisition, and be used as input for ongoing drilling operations.

A 70 M.Y. LONG RECORD OF ARAUCARIAN FORESTS IN ZEALANDIA: WOOD, LEAVES, POLLEN, AND INCLUSIONS

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Araucarian forest trees have a continuous record in from the Late Cretaceous through the Cenozoic to the living *Agathis australis* forests of northern North Island Araucarian wood with anatomical preservation is present at several localities of Paleocene, Eocene, Oligocene and Miocene age. Araucarian foliage is known from several Late Cretaceous sites, and leaves of *Agathis* with cuticle occur at some Oligocene-Miocene sites. The earliest sites with amber are Late Cretaceous and droplets, layers and blocks of amber occur in lignite, sandstone and mudstone from Cenozoic sites throughout New Zealand. Commonly bubble-filled and opaque, the amber was considered devoid of fossils. However, methodical screening of several thousand samples, combined with new preparation techniques, has revealed many three-dimensionally-preserved organisms and considerable biological and ecological complexity. Most inclusions represent new species and some represent the first global fossil records at genus and subfamily level. There is an impressive diversity of arthropod fossils, including species from the arachnid orders Acari, Araneae and Pseudoscorpiones and at least 14 families of Hexapoda in the orders Collembola, Hemiptera, Psocoptera, Hymenoptera, Coleoptera, Lepidoptera, and Diptera, together with nematodes (soft-bodied soil and litter metazoans) and a variety of mould fungi. Ecologically, the organisms include predators such as spiders (including web remains with prey), tiny carnivores such as pseudoscorpions, diverse soil-dwelling mites, detritivores such as springtails, biting and gall midges, fungus gnats and chironomids, parasitoid and other wasps, ants, carpet and other beetles, bark lice and

lepidopteran wing scales. This is the first major amber deposit with an abundance of biological inclusions from the Southern Hemisphere and the first of confirmed araucarian origin. These fossils expand the global record and evolutionary history of many arthropod and fungal groups, providing new insights into antecedents of the modern New Zealand terrestrial biota.

**THE LIFE AND TIMES OF CENTRAL TVZ:
15 YEARS OF MAPPING AND
GEOCHRONOLOGY ILLUMINATE
EARTH'S MOST PRODUCTIVE SILICIC SYSTEM**

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Central Taupo Volcanic Zone represents (in its overall evolution) a single rhyolitic caldera complex of comparable longevity and scale to Yellowstone volcanic system. It also has the largest time-averaged rhyolite eruption rate on Earth over the last ~25 ka. We present an overview of results and discoveries obtained from 120 new ⁴⁰Ar/³⁹Ar ages combined with a decade of regional mapping for the QMAP

programme. These data shed new light on the tempo, style and hazards of eruptions from the four supereruptions (Ongatiti, Kidnappers, Whakamaru, Oruanui) and the smaller but more frequent magmatic (millennial) and hydrothermal (decadal) eruptions.

We have identified periods of caldera-forming flare-ups, most recently from ~350 ka for >70 kyrs. In addition, previously unrecognised eruptive units have been identified and dated from geothermal fields, and fitted into the regional stratigraphic system. There appears to be both spatial and temporal clustering of smaller explosive and effusive eruptions, both following and apparently unrelated to caldera events. There is a spatial link of some Holocene vents with current shallow (~5km depth) areas of possible magma accumulation (e.g. Rotokawa), and yet other areas of similar low resistivity and high heat flow (e.g. Kapenga) are apparently un-associated with young eruptions. There is clear temporal variability in faulting of the Taupo Rift, including episodic narrowing, and sudden step-overs linked to caldera flare-ups. The rates of post-caldera volcanic and sedimentary infilling are remarkably rapid (kilometres thickness in tens of thousands of years) and the distal landscape responses to convulsive volcanic-induced sedimentation have been equally dramatic.

Substantial multi-agency planning of responses and communication during future eruptive activity is underway but preparedness is challenging because of the extremely diverse behaviour shown within this unique area. Future hazards are not confined to past caldera locations, but the modern caldera volcanoes dominate questions from both public and emergency managers.

UNCOVERING LONG-RUNOUT PYROCLASTIC FLOWS USING PALAEO-MAGNETISM AT MT TARANAKI

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Knowing the spatial distribution of different hazards at stratovolcanoes is vital for understanding which hazards represent a threat to different areas surrounding the volcano. An important part of this is understanding the conditions under which deposits from the volcano were emplaced. The coherence of paleomagnetic directions in different parts of the blocking temperature spectrum between the clasts of mass flow deposits has proven to be a useful tool for ascertaining emplacement temperatures. These temperature estimates can help in distinguishing between hot pyroclastic density currents (PDCs) and cold lahars, which cannot always be done definitively by field observation. In the case of more clast-poor distal deposits, however, it can be difficult to obtain sufficient clast material for effective paleomagnetic study. In this study, the problem was remedied by using oriented and strengthened samples of matrix material from mass flow deposits in the ~11,500 BP Warea Formation from Mt. Taranaki, New Zealand. Paleomagnetic data from matrix samples was used to supplement the limited data obtained from the traditional clast analysis in order to determine the emplacement temperature of the deposits. Comparison of paleomagnetic directions obtained from clast and matrix samples at several sites within the Warea Formation revealed it as a PDC with matrix temperatures over 200°C and clasts reaching temperatures of up to 410°C at their time of deposition. This discovery of hot PDC deposits

at distances >20 km from the summit of the volcano extends their known range at Mt Taranaki by at least 5 km. These findings could have a significant impact on hazard mapping and emergency planning for the Taranaki region.

20 YEARS OF CAMPAIGN AND CONTINUOUS GPS ACROSS THE CENTRAL SOUTHERN ALPS – TIME-SERIES AND MODELLING

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Previously published profiles of velocity and strain spanning the Alpine Fault have been used to examine the fault's geometry and to model the kinematics of the plate boundary zone. As part of a BSc (Hons) study, we are analysing data from a profile extending from Methven to Hokitika and crossing the Alpine Fault just south of the Hope Fault intersect. This profile provides an opportunity to compare along-strike changes in the fault's geometry and kinematics, and to examine how the current distribution of geodetic stations constrains fault slip inversions: are we taking measurements in the right places? Data from three continuous GPS sites were used to constrain the displacement of ten campaign GPS sites measured between 1997 and 2017. GPS processing was completed using Gamit/Globk processing flows. Annual and semi-annual signals were removed from the data and corrections made for co-seismic and post-seismic displacements. The fault-parallel (shear) and fault-normal (shortening) components of the velocity field have been calculated in both absolute and relative reference frames. This study has produced horizontal and vertical inter-seismic velocity fields to be used to evaluate the fault's

geometry and slip rate. A 2D elastic half-space dislocation model will be used to describe the fault plane, locking depth where the profile crosses the Alpine Fault.

TEN YEARS OF DETERMINING VOLCANIC RISK IN AUCKLAND

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The Determining Volcanic Risk in Auckland (DEVORA) research programme was launched in 2008 as a multi-agency, transdisciplinary effort with a mandate to investigate the Auckland Volcanic Field (AVF), a (mostly) monogenetic volcanic field that spatially coincides with Auckland, New Zealand's most populous city. With DEVORA approaching its tenth anniversary, it is timely to reflect back on the impacts of its research, its challenges and lessons learned over the last decade. 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 emergency managers and policy and decision makers to prepare the city for a future volcanic eruption. We describe how the DEVORA team is developing and populating a suite of volcanic fragility functions quantifying damage, loss of functionality, and clean up from basaltic eruptions expected in Auckland. We explain how these, along with hazard intensity maps, are being used to evaluate impacts from a range of scenarios, and how we are moving towards probabilistic risk

assessment. Beyond the science itself, over the years DEVORA has supported tens of postgraduate students and researchers in New Zealand, and has forged strong relationships, not only between scientists across disciplines, but across the scientist-stakeholder divide. In particular, its stakeholder-based governance structure ensures DEVORA research findings continue to strengthen the foundation for key decision-making in any preparation for and response to a future AVF eruption or ash fall event from distal volcanic eruptions.

GLACIAL-INTERGLACIAL PRODUCTIVITY AT THE POLAR FRONT, SOUTHWEST PACIFIC SECTOR OF THE SOUTHERN OCEAN

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The Southern Ocean plays a major role in global climate through redistributing heat and nutrients into all the major oceanic basins and regulating ocean-atmosphere CO₂ exchange. Previous research from the Southern Ocean has shown evidence of changes in biological productivity, the so called "biological pump", over glacial-interglacial timescales. It has been suggested that this change in productivity, along with changes in ocean circulation, has a significant influence on modulating atmospheric CO₂ draw-down, and thus represents a key component in facilitating glacial-interglacial global climate change.

Two marine sediment cores collected from the Polar Front, south-west of New Zealand, have

provided a new high resolution elemental record measured by XRF. These are combined with stable isotopes, radiocarbon dates, carbonate and opal content, ice-rafted debris (IRD) counts and diatom assemblage analysis. Preliminary age modelling suggests these marine records extend back to Marine Isotope Stage 8 (~275ky). The data show a progression of abrupt elemental changes, which agree with peaks in IRD and shifts in plankton. This data will be compared with previous work from the Southern Ocean to understand reorganisations of biological productivity and ocean circulation, and their relationship to glacial-interglacial climate change.

RECONNAISSANCE AND DETECTION OF CRYPTOTEPHRAS IN ~20,000-YR-OLD LAKE SEDIMENTS, WAIKATO REGION, USING CT SCANNING

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The study of cryptotephra (volcanic glass shard and/or crystal deposits insufficiently concentrated or numerous to be visible as a layer to the naked eye) is complicated by difficulties in finding time-efficient, cost-effective, non-destructive methods of

detection. Whole (unopened) lake sediment cores totalling 34.7 m in length from three Waikato lakes (Kainui, Ngaroto, and Rotokauri) formed c. 21,000–23,000 cal. years ago were scanned in one afternoon using a medical X-ray computed tomography (CT) scanner at Hamilton Radiology. Volume reconstructions and image analyses using the Fiji package of ImageJ software revealed numerous cryptotephra deposits, significantly increasing the number of observable deposits compared with findings from descriptive logs and associated photographs of the same cores when opened. The use of X-ray CT scanning and image analyses can be used to inform a more targeted approach to core sampling in cryptotephra studies, ultimately aiding the construction of more detailed histories of ashfall events. Together with spatial information, these enhanced frequency records enable probabilistic modelling for future events to be evaluated more realistically, thereby supporting the development of appropriate management strategies for ashfall hazards and potential impacts in the region.

CT AND MICRO-CT SCANNING OF LIQUEFIED TEPHRA DEPOSITS IN ~20,000-YR-OLD LAKE SEDIMENTS, WAIKATO REGION

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Soft-sediment deformation structures (SSDS) can record evidence of the liquefaction and fluidisation of deposits. The use of X-ray computed tomography (CT) and micro-CT to scan unopened lake sediment cores offers a way to reconstruct the volume of the disrupted tephra deposits within, capturing structural features which may not be readily observable in a cut core. Cores from three Waikato lakes (Ngaroto, Kainui, Rotokauri) formed ~21,000–23,000 cal. BP were scanned using medical CT at Hamilton Radiology, and a segment of core from Lake Rotokauri was scanned using the micro-CT facility at Swansea University. 3D-volume reconstruction of the cores using Fiji/ImageJ revealed that multiple tephra deposits (not the enclosing organic lake sediment) display SSDS, including injection structures, dish structures, voids, and disrupted internal bedding. Disrupted tephra ('tephra seismites') include Tuhua (7641 ± 102 cal. BP), Mamaku (7992 ± 58 cal. BP), Waiohau ($14,018 \pm 91$ cal. BP), Rotorua ($15,738 \pm 263$ cal. BP), and Rerewhakaaitu ($17,209 \pm 249$ cal. BP). The presence of non-disrupted tephra deposits in the same cores gives temporal constraints to the SDSS. The SDSS therefore are probably the result of episodic seismic shaking on one or more hidden faults identified near the lakes in the Hamilton Basin, or on faults associated with the distant Kerepehi Fault system in the Hauraki Basin, or both. CT analysis of the tephra seismites in the lake cores provides a new tool for palaeoseismology. The CT results, together with historical core records for a further 9 lakes, suggest that at least five palaeoseismic events have occurred in the Hamilton Basin since c. 17,000 cal. BP. After ~7600 cal. BP, tephra occur in the lakes as layers only a few

millimetres thick, hence possible local seismic events have not been recorded in the form of SDSS because these tephra lack the required physical properties.

**PRE- AND SYN-ERUPTIVE PROCESSES
VISUALIZED THROUGH SEMI-AUTOMATIC
CRYSTAL SIZE DISTRIBUTION ANALYSIS OF
MICROLITES FROM TONGARIRO VOLCANIC
CENTRE TEPHRAS, NEW ZEALAND**

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Crystal Size Distributions (CSDs) of microlites in volcanic rocks have become a useful tool to assess and estimate timescales of pre- and syn-eruptive processes such as nucleation, growth and ascent at the onset of explosive eruptions. So far, a time-consuming manual method is used to outline crystals, and thus generate CSDs, from back-scattered-electron (BSE) images. The Tongariro Volcanic Centre (TgVC), which includes Ruapehu, Ngauruhoe and Tongariro volcanoes, has produced historical explosive eruptions of different eruptive styles. A semi-automatic method for selecting microlites based on BSE images using a tool combining machine learning and image segmentation was employed on four tephra formations from TgVC. CSDs of plagioclase and pyroxene microlites from individual glass shards of each tephra are computed, compared, and combined to obtain total tephra CSDs. Manual and semi-automatic CSDs for the same grains overlap, and the

method used in this study acquires CSD considerably faster than the classic one. A hundred and seventy nine CSDs were generated, and CSDs from the same tephra were combined. All combined CSDs exhibit concave-up shape, similar intercepts and slopes at the smallest sizes and thus similar growth durations: from 22 ± 15 (2σ) to 68 ± 48 (2σ) hours for plagioclase and from 13 ± 9 (2σ) to 29 ± 20 (2σ) hours for pyroxenes. The semi-automatic method used in this study provides for fast-computing of CSDs. Also, the short timescales of microlite growth obtained appear to overlap for both plagioclase and pyroxene regardless the eruptive style or source. We conclude that volcanic eruption style within the TgVC is independent of magma ascent time in the conduit prior to eruption. If more explosive eruptions are due to more rapidly ascending magmas, they are sourced from greater depth in the plumbing system. Comparison with experimental petrological data may provide additional constraints on physical parameters such as decompression rate and depth of crystallization.

**ARE NUMERICAL AND STATISTICAL
METHODS THE PANACEA FOR CORRELATING
TEPHRAS OR CRYPTOTEPHRAS USING
COMPOSITIONAL DATA?**

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Correlations between tephra or cryptotephra deposits are testable hypotheses, subject to continual revision with expanded datasets. Consequently, the strongest correlations are those that show concordance between multiple independent datasets, including lithostratigraphic, palaeoenvironmental or archaeological data, chronological data, and mineralogical and geochemical evidence. In effect, prior correlations proposed on the basis of age equivalence are tested by examining potential correlatives suggested by mineralogical variations or by compositional variation within the glass or crystal/phenocryst phases of tephra deposits, or by dating materials associated with the tephra. Statistical methods provide a less subjective means of dealing with data pertaining to tephra components than alternative methods. They enable a better understanding of relationships among the data to be developed from multiple viewpoints, and help to quantify the degree of uncertainty in establishing correlations. In applying statistical methods to establish sample equivalence or difference, however, all methods have some degree of limitation. Furthermore, using statistical analysis of compositional data, it is easier to prove a difference between two samples than it is to prove they are the same. A two-stage approach to statistical correlation has been useful in recent times, the first stage being to identify the main data structure via simple but useful scatterplot matrices (bivariate plots) before undertaking statistical distance measures, SCs, hierarchical cluster analysis, and PCA. Some of these methods are also called machine learning. The second stage typically examines sample variance and the degree of compositional similarity. This stage

may involve DFA, CVA, and analysis of variance (ANOVA) or MANOVA (or its two-sample special case, the Hotelling two-sample T^2 test). Various transformations and scalings may be applied to compositional data prior to subjecting them to multivariate statistical procedures such as the calculation of distance matrices, hierarchical cluster analysis, and PCA. Such transformations may make the assumption of multivariate normality more appropriate.

RE-DATING TUHUA TEPHRA, A KEY MID-HOLOCENE MARKER BED IN NORTHERN NEW ZEALAND, USING AN ISOCHRON-INFORMED BAYESIAN AGE MODELLING APPROACH

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Tuhua Tephra, a distinctive peralkaline eruptive from Mayor Island, forms a unique chronostratigraphic marker bed for the Holocene of North Island and offshore. Its deposition coincided with the Holocene relative sea-level highstand ~8000–7000 cal. BP when present sea-level was first attained. Deriving an accurate age for Tuhua Tephra is therefore a priority for palaeoenvironmental applications and volcanology. Bayesian age-modelling of the Kaipo bog sequence in eastern North Island generated contradictory

and imprecise ages on Tuhua from ~7100 to ~6600 cal. BP. Here we use a new approach to dating it by applying a key principle of tephrochronology to Bayesian modelling: tephras are erupted and deposited effectively instantaneously forming isochrons so that a primary tephra has an identical age everywhere it occurs. We modelled ~50 ¹⁴C dates, together with ages on nine interbedded tephras, in three peat cores from each of Kopouatai and Moanatuatua bogs in Waikato to attain an age for Tuhua Tephra, which occurs in all six cores. In applying the Bayesian *P_sequence* routine of OxCal, the Tuhua Tephra was cross-referenced (set as being the same event) in each of the cores, thus modelling was ‘isochron informed’. Using SHCal13, the isochron-informed modelling yielded a new age for Tuhua Tephra of 7641 ± 100 cal. BP (2-sigma), older and more precise than previous estimates. A similar age (~7630 cal. BP) was obtained using *P_sequence* modelling whereby independent ages on Tuhua were estimated for each core without cross-referencing and then amalgamated using *Combine*. Finally, using the independently-modelled age distributions, we defined Tuhua deposition as a ‘Phase’ set between start and end ‘Boundaries’, and then used OxCal’s *Difference* function to estimate the ‘Phase’ duration across cores (it should be zero years based on tephrochronology): it ranged from 0–730 years (95.4% confidence-interval), mean 277 years, but reassuringly was markedly skewed towards zero (instantaneous).

TEREBRATULIDE BRACHIOPODS FROM THE EARLY JURASSIC OF ZEALANDIA

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New Zealand and New Caledonian Early Jurassic terebratulides have received little attention from palaeontologists, with only two species described to date. In this study, a total of seven genera and ten species are recognised.

Most of the material belongs to four genera. *Lobothyris* is present throughout the Aratauran and Ururoan. *Loboidothyris* is common in the late Aratauran and early Ururoan of the Hokonui Hills. *Zeilleria* first appears with *Zeilleria spiculata* in the narrow zone along the Otapirian-Aratauran boundary in the Hokonui Hills. A further species is found throughout the later Aratauran and Ururoan, and two more species have restricted stratigraphic and geographic ranges. The sulcate *Aulacothyris* is represented by one Aratauran form, known from Ben Bolt in the Hokonui Hills and the coast north of Marokopa. *Loboidothyris*, *Zeilleria* and *Aulacothyris* are also found in the Middle and Late Jurassic.

The other three genera are known from a few localities in New Zealand and New Caledonia. *Linguithyris agerorum* was described from a single specimen from near Port Waikato. Three further specimens from New Caledonia have now been found. Two genera are recorded for the first time in Zealandia. The Tethyan *Tegulithyris* is known from the late Aratauran and Ururoan of Kawhia, and *Rugithyris* from two Ururoan localities in the Awakino area.

Lobothyris, *Aulacothyris* and *Zeilleria* are

cosmopolitan and widely distributed. *Loboidothyris* is also cosmopolitan, but has a Tethyan aspect. *Tegulithyris* and *Rugithyris* are Tethyan, but less widely distributed. *Linguithyris* is also known from southern Europe, North Africa and western Asia.

The fauna in general is cosmopolitan or weakly Tethyan. It follows the distinctive endemic faunas that preceded the end-Triassic extinctions, and is replaced after the Toarcian event by a more strongly Tethyan fauna.

TECTONIC EVOLUTION OF THE LATE CRETACEOUS TO EARLY PALAEOCENE GREYMOUTH BASIN, WEST COAST

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The Greymouth Basin, in which the thick sequence of Paparoa Coal Measures (PCM) was deposited, is part of the same Late Cretaceous to Early Palaeocene rift-tectonics along the West Coast that produced the Taranaki Basin. The goal of this paper is to understand the subsidence history and basin evolution through time as recorded in the facies in the PCM. Isopach maps, a basal PCM unit map and a fence diagram of detailed facies correlations have been used in this research.

The fence diagram indicates the half graben geometry of the Greymouth Basin and illustrates three alternating fluvio-lacustrine sequences from Late Cretaceous to Early Paleocene. Braided river conglomerates are restricted to the north-west. The deposition of meandering fluvial systems with scattered abandoned channel coals indicates a slow to moderate subsidence rate across the basin.

These are overlain by raised mire coals and then by lacustrine mudstones in a transgressive sequence suggesting an increase in subsidence rate rather than an increase in rainfall since palaeontology studies indicate no climate change during that time. Lacustrine mudstones onlap braided river conglomerates as well as thicken and widen upsection. Isopach maps of the lacustrine units show that older units comprise several isolated smaller lakes which later connect and become wider through time expanding toward the west. The basal PCM unit map shows that the conglomerates step westward through time with ever younger PCM members sitting directly on basement.

The results suggest that the Greymouth basin evolved from small sub-basins that widened and deepened through time via small-displacement normal fault segments which became progressively more connected until they formed a major border fault. This fault gave rise to the large half graben basin and was responsible for the lateral and vertical facies changes across the basin.

A GEOCHEMICAL BASELINE SOIL SURVEY OVER OTAGO-NORTHERN SOUTHLAND

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A regional, 8-km spaced soil geochemistry survey covering c. 20,000 km² was undertaken over Otago and northern Southland. It uses include environmental assessment, mineral exploration, groundwater quality and regional geological interpretation. The survey extends north of Mossburn to Lake Hawea and from the east coast near Hampden to Lake Wakatipu/Mavora Lakes in the west. Three

hundred and sixteen sites were sampled at three depths: O-depth (0-2 cm), A-depth (2-20 cm) and B-depth (50-70 cm). A modified aqua regia digest on the sub-180 µm fraction was analysed by inductively coupled mass spectrometry (ICPMS), X-ray fluorescence and LECO Analyser methods. Two additional, infill surveys were conducted. One targeted West Dome and the other the Shotover area. The former took samples from an additional 83 sites on a 2 km spaced grid from the north of Mossburn to the Mararoa River. It targeted ultramafic, mafic igneous and sedimentary rocks of the Dun Mountain-Maitai Terrane which are perspective for platinum group metals. The Shotover survey took samples from 63 additional sites on a 4 km spaced grid covering the area between Glenorchy in the west through the Cardrona valley in the east including large parts of the Shotover, Motutapu and Arrow river catchments and the Richardson and Harris Mountains. The survey area is underlain by Otago Schist, particularly by the Aspiring Lithologic Association of the Rakaia Terrane and is prospective for Au, Sb and W mineralisation. Together with the Southland-southern Otago survey (completed 2015), this constitutes the single largest, systematic soil survey in New Zealand and forms the template for completing other, regional surveys (e.g. Westland) and the template for a survey of national coverage.

A SPATTER-RICH PYROCLASTIC DENISTY CURRENT DEPOSIT FROM A NEOGENE VOLCANO, MASON SPUR, ANTARCTICA, SUGGESTS SIMULTANEOUS MULTI-VENT ERUPTION

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Well exposed caldera interiors are uncommon but a remarkable section through the heart of a volcanic island, Mason Spur, in the south-western Ross Sea, Antarctica, is helping help to elucidate interpretations of other, less well exposed pyroclastic density current deposits elsewhere in Antarctica and globally. Near-continuous exposure, 10 km laterally and >1 km vertically, at Mason Spur cuts through Cenozoic alkalic volcanic rocks of the Erebus volcanic province (McMurdo Volcanic Group). The caldera filling sequence includes an unusual trachytic spatter-rich lapilli tuff (ignimbrite) facies that is particularly striking because of the presence of abundant fluidal, juvenile spatter clasts of trachytic obsidian up to 2m long supported in a pumiceous lapilli tuff matrix. New field mapping indicates that the deposit is an ignimbrite and, together with petrological considerations, it is suggested that mixing of spatter and lapilli tuff in the investigated deposit occurred during emplacement, not necessarily in the same vent, with the mixed fragmental material emplaced as a pyroclastic density current. Liquid water was not initially present but a steam phase was probably generated during transport and may represent water ingested during passage of the current as it passed over either wet ground (possibly puddled), a stream or a shallow lake. Mapping at Mason Spur permits the study of an ancient volcanic succession that is rarely available due to subsequent burial or erosion and is helping understand eruption dynamics associated with a complex large island volcano.

ANCIENT PENGUINS OF NEW ZEALAND: HOW MANY SPECIES OF *PLATYDYPTES*?

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Penguins are uniquely adapted to aquatic life. Their dense, ballasting, bones predispose penguins to fossilise readily, contributing to New Zealand's excellent fossil record. The Oligocene *Platydyptes*, first described by B.J. Marples, is one of the most crownward of the stem (basal) penguins and one of few described Late Oligocene genera. Currently there are three described species, *P. novazealandiae*, *P. amesi* and *P. marplei*. *Platydyptes* penguins are robust; there is some variation in size, but generally *Platydyptes* can be considered a medium sized ancient penguin (the smallest described species closer in size to a king penguin than to a crested). Due to its position in penguin phylogeny, the genus needs redescription; there is also scope for functional and ecological studies. New *Platydyptes* penguins from Hakataramea will be used in reviewing the genus.

A key new specimen, OU 22804, is a semi-articulated partial skeleton from the Otekaikē Limestone (Waitakian, latest Oligocene). The fossil also includes several rarer elements such as the quadrate, mandible, and a semi-complete sternum. The bone preservation is good; for example, both coracoids are present with much of the extremities preserved. The taxonomically diagnostic humerus shows characteristics typical of *Platydyptes*, including a small dorsal tubercle with clear separation from the articular surface of the humerus head. The new humerus is more robust and slightly broader than in other *Platydyptes* species, with a midshaft length/width ratio of 0.25 (all three named

species share a ratio of 0.24). Study of OU 22804 will elucidate the structure, systematics and lifestyle of New Zealand's *Platydyptes* penguins.

MAGMA INCEPTION AND THE BIRTH OF A SUPERVOLCANO

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Many aspects of the post-350 ka magma systems (including those at Maroa) that erupted within the Whakamaru Caldera, prior to the Oruanui 25.4ka eruption from Taupo have previously been examined in detail. However, to resolve questions on magma evolution post-Whakamaru, including development of the Oruanui super volcano system, there is a need for glass and mineral chemistry as well as precise ages on rhyolite lavas and pyroclastic deposits.

The study outlined here will use this data to discriminate between grouped or individual magma batches and reconstruct the configuration both temporally and spatially of the magma system or systems responsible for the chemically and isotopically distinct domes and pyroclastic deposits that outcrop on the Northern, West and Southwest margins of Lake Taupo. This study will also establish the relationship of the magmatic systems between Whakamaru and Maroa to understand how they behave and have evolved over time.

We aim to achieve this by focusing on three aspects. The major aspect builds on existing Ar⁴⁰/Ar³⁹ data and existing geochemistry by providing new age data, new glass and mineral chemistry and new Sr isotope analyses of dome complexes including Whakaroa,

Western Dome Belt, Southwest Domes and North East Dome Complex. An additional aspect will focus on identification and analysis of pyroclastic deposits within an initial time slice starting from Oruanui at 26.5 ka to the Rotoehu/Rotoiti eruptions of ~61 ka, building on the existing tephratigraphic framework. To provide a more comprehensive picture of magmatic processes and evolution, this time slice may extend further back in time to ~305 ka and correlate with existing studies on formations from drillholes in the geothermal fields of the northern Taupo area (e.g. Wairakei-Tauhara).

This study has implications for understanding the very earliest phases of assembling magma for the Oruanui eruption of the Taupo super volcano and the tempo of these caldera producing rhyolitic magma systems.

SUBMARINE ERUPTIVE PROCESSES IN THE BROOK STREET TERRANE

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A sequence of volcanic and volcanoclastic rocks of the Brook Street terrane crops out along the Southland coast from Howells Point, Riverton, into Colac Bay. This sequence includes pillow lavas, dikes, hydroclastic breccias, tuffs and lapilli tuffs. It is well-exposed for 8 km along strike in a section 220 m thick that reveals lateral variations in deposits of an oceanic island arc; such sequences are rarely studied, and provide different constraints on arc volcanism than the more common vertical sequences.

Detailed mapping, lithofacies analysis, and geochemical analysis were undertaken in order to ascertain the eruptive processes of

the succession, the environment of deposition and emplacement, the magmatic conditions, and the sequence of events. Tuffs and lapilli tuffs exhibit sedimentary structures that suggest subaqueous deposition by mass flows, and bear angular pillow clasts suggesting fragmentation of pillow lavas. Pillow lava piles are small (4-20 m high and up to 600 m across) and closely spaced (50-600 m) with the exception of one large pile (up to 120 m in height and 2.5 km across), indicating one main eruptive centre extending fingers of lava, and possibly several smaller vents. Pillow lavas are less common toward the western end of the section, and tuff grain size decreases in the same direction, supporting this hypothesis.

The whole sequence is hydrothermally altered and metamorphosed to prehnite-pumpellyite facies, so major and trace element analyses were conducted on the freshest augite phenocrysts wherein the magmatic signal is likely to be preserved. These data indicate variable primitive island arc to MORB-like magma sources. The latter suggest involvement of decompression melting under regions of thin lithosphere possibly attributable to back-arc spreading.

THE IMPACT OF CASCADING HAZARDS ON RURAL LAND USE- A HURUNUI-KAIKŌURA EARTHQUAKE SEQUENCE CASE STUDY

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On November 14th, 2016, a M7.8 earthquake occurred near Waiau, Hurunui District. This earthquake, its aftershocks and related seismicity triggered cascading co-seismic hazards. These cascading hazards caused a range of direct and indirect impacts to farms throughout the affected region. In particular,

on-farm infrastructure (e.g. irrigation systems, dairy sheds and woolsheds) and essential services provided by distributed infrastructure networks (e.g. road, electrical power, etc.) were severely impacted. As a result, farms throughout the Hurunui District have experienced substantial on-going land use impacts since the initial earthquake. Earthquake disaster impact studies on rural areas, in particular on farms, are less common compared to studies on urban areas. 'Cascading hazards' are often mistakenly included under 'multi-hazards' in current literature. This interpretation over-simplifies the complexity of the interdependent networks involved. This project defines cascading hazards as a series of hazard events that interlink through various triggering mechanisms. The concept currently lacks a standardised definition, data collection approach and impact assessment methodology. Using examples from the Hurunui District, the effects of cascading hazards on land use are explored, highlighting the ongoing geohazard issues faced by rural communities both during and following major earthquakes.

UNDERSTANDING THE PHYSICAL SEDIMENTOLOGY OF THE MADDEN CONTINENTAL SLOPE DISTRIBUTARY SYSTEM

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The Hikurangi Subduction Margin (HSM) is arguably New Zealand's largest earthquake and tsunami hazard, though the uncertainty around these hazards is great. To increase understanding around the potential hazards of the HSM it is vital to gain a greater understanding of the earthquake history. In

order to gain a better understanding of the history of the area, it is essential to investigate and analyse the sedimentology of the area, this will give a basis for further studies required in order to create more accurate hazard analysis models.

Focussing on the Madden Complex, on the east coast of New Zealand, paleoseismic sediments are going to be investigated using six piston cores. Sediment characteristics and flow dynamics will be analysed and used to understand the Madden continental slope distributary system. Some of the aims of this study are to determine whether there are any drastic changes across the Madden system, and whether any of the turbidites can be correlated to a specific event. Triggers for turbidity currents will also be investigated along with sediment provenance, and sediment accumulation rates.

Data which will be used to carry out this research includes CT scans, high quality imagery, p-wave velocity, gamma and, multibeam bathymetry. Further analysis to be carried out includes grain size, carbonate content, microscopic and possibly foraminifera analysis, and dating using tephra data and C^{14} if further information is required.

STRATIGRAPHIC ARCHITECTURE AND VOLCANIC PROCESSES OF THE PLIO- PLEISTOCENE PIRONGIA VOLCANIC SUCCESSION, WAIKATO.

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Mt Pirongia (959 m above sea level) is a prominent composite-shield volcano situated within the Alexandra Volcanic Group, Waikato – the most voluminous (55 km³) basaltic field

of the North Island. Volcanic activity spanned from the late Pliocene to early Pleistocene (2.74 – 1.60 Ma) over which time a regionally significant basaltic to andesitic volcano was constructed from numerous vents. This study documents the spatial distribution of volcanic deposits associated with the Pirongia volcanic succession, in order to understand how the volcanic edifice was constructed over time. An extensive field campaign across ~240 km² was conducted to map and sample volcanics deposits, and this was incorporated with GIS data (aerial photographs, digital elevation models at 15 m and 1 m resolution) and petrographic correlation to define the volcanic succession. The lowermost parts of the edifice are constructed from thinly layered lava flows of basalt and basaltic-andesite (0.5-2 m thickness), including large volumes of augite megacryst-rich (ankaramitic) basalt. The upper edifice is dominated by thick, localised extrusions of hornblende-andesite (up to 70 m thick) interspersed with basaltic sub-aerial deposits. Pyroclastic successions are rare and occur mostly around vent areas, where they record evidence of strombolian basaltic eruptions and block and ash flows. Volcaniclastic heterolithological breccias are widespread on the southern flanks and originate from vigorous pyroclastic and laharc activity that deposited material up to 15 km away from the summit. Prominent flank vents occur on the southwestern and eastern sides of Pirongia and are associated with extensive lava fields up to 3 km long. Intense fluvial erosion and mass wasting over the last 2 Ma has produced inversed topography across the mountain, whereby valley filling lavas now form resistant ridges. Material deposited by lahars and flank collapse has formed a thin ringplain that overlies the gently-dipping, distal basaltic lavas of Pirongia.

**INSIGHTS FROM PROXIMAL DEPOSITS OF
THE 1995-1996 SUBPLINIAN ERUPTIONS OF
MT. RUAPEHU**

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Subplinian eruptions during 1995-1996 activity at Ruapehu deposited tephra falls and lahars on the North-Eastern flanks of the volcano. Proximal deposits sampled 20 years after the eruptions were compared to the observed dynamics of the largest eruptive phases on the 11th and 14th of October 1995. Textural properties of the deposits provide new insights into the gas-expansion, environmental influences and conduit processes during the eruption. These deposits, from a relatively small eruption, were compared and contrasted to well-studied deposits from the largest subplinian eruptions known from this volcano. The results of this study show that external water influenced various stages of this eruption, contributing to phreatomagmatic fragmentation, alongside that driven by gas-expansion/bubble growth. The most sustained eruptions led to “dry” phases once water had been expelled from the Crater Lake basin and a clear conduit established through the upper hydrothermal system. There were sufficient pauses in between the main eruption phases (11 to 14 October) to allow re-accumulation of meteoric water in the crater and re-saturation of the conduit from the lateral margins of the vent-hosted hydrothermal system. This allowed for the generation of further small phreatomagmatic eruptions as well as phreatomagmatic phases at the start of the 14 October event. Along with the water influence on fragmentation and particle-size distribution, the internal texture of lapilli clasts of the main eruption phases show two

main phases of bubble nucleation. The pumice has 60-85% bulk porosity, with a population of large coalesced bubbles (0.06-2.5 mm²), along with a modal population of small isolated vesicles (0.02 mm²). These data show that magma rose to shallow levels to slow, vesiculate and bubbles coalesced. Once magma rose into the vent hydrothermal system, explosive magma-water interaction led to top-down magma excavation and decompression, triggering a second phase of bubble nucleation and sub-plinian eruption.

**MICROSTRUCTURE AND STRENGTH
CHARACTERISTICS OF HALLOYSITE-RICH
SENSITIVE SOILS FROM THE BAY OF PLENTY**

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Weathered rhyolitic pyroclastic materials are associated with many landslides in the Bay of Plenty, including a large number (> 20) of new and reactivated landslides that occurred during and following the passage of ex-Tropical Cyclones Cook and Debbie in April 2017. Both translational landslides and flow slides occur, but the ones causing significant damage to infrastructure are the flow slides that exhibit very long runout and several phases of landsliding that cause slow retrogression of the headscarp. These are characteristics of sensitive soil behaviour.

Undrained, consolidated static triaxial tests of a sensitive soil layer at the base of one such landslide at Bramley Drive, Omokoroa, show contractive p'-q' plots, shear band localization, and strain-softening behaviour coupled with rising pore water pressures post-

failure. Cyclic triaxial tests confirm brittle failure and extensive softening of the soil. Pore pressure gradients developed during shearing are inferred to initiate collapse of clay microstructures into shear zones; further excess pore pressure generation following collapse of structure in the shear zone leads to progressive fracture development.

Halloysite, a low-activity clay mineral, is associated with sensitive layers within these pyroclastic sequences. Mushroom cap-shaped spheroidal halloysite is a newly described morphology for halloysite. We postulate that the surface charge distribution on the mushroom-caps results in weak short-range interactions between exposed clay surfaces. This weak bonding allows disassociation of clay aggregates during slope failure, leading to strain softening and a very low remoulded strength. Hence, long runout debris flows are characteristic.

USING A MINERAL SYSTEMS APPROACH TO MAP RARE EARTH ELEMENT DISTRIBUTION IN IGNEOUS INTRUSIONS OF THE SOUTH ISLAND, NEW ZEALAND

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Global demand for rare earth elements (REEs) is on the rise due to unprecedented technological advances and a shift in societal attitudes towards cleaner and more efficient renewable energy. A key component of these innovative technologies are the REEs, whose many applications include magnets in wind turbines and batteries in hybrid cars. Primary sources of REEs are from alkaline igneous

complexes and carbonatites, and although we have occurrences of these rock types in the South Island of New Zealand, no REE deposits have yet been found here. We 1) propose an intrusion-related REE mineral systems model to help us understand the transport and concentration of REEs in igneous fluids; 2) identify the mappable components of that system to aid exploration for and protection of potential REE resources; and 3) use the Petlab, REGCHEM, GERM and QMAP databases to map the distribution of these components on a regional scale. The minerals system approach identifies the source of energy, metals and ligands, the migration of REE-rich fluids into mineral and structural traps, and the modern surface expression of REE mineralisation. Our mapping of these components of the mineral system includes geochemical maps such as alumina saturation index, igneous fractionation, Nd isotopes and REE distribution, that characterise the intrusive suites of the South Island. By identifying areas where the mineral system components overlap and results are favourable for mineralisation, or alternatively, where sample coverage is poor, REE concentrations can be explored for in more detail or further sampling and mapping acquisition programmes planned.

CHATHAM RISE, CHATHAM SCHIST

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The Chatham Rise is a broad, straight, east-west trending, 1500 km-long bathymetric feature of southern Zealandia. Schist basement on the Chatham Islands has been described by Haast (1868), Hay et al. (1970) and Adams and Robinson (1977). Chatham Schist protolith is Permian and Triassic

Torlesse Rakaia Terrane, based on U-Pb ages of zircons (Adams et al. 2008).

In 2013 we re-examined Chatham Schist structure on well-exposed shore platforms. Earlier work is largely confirmed. However, we clarify that Robinson's 4750 m thick stratigraphy is a structural (flattened) section, Matarakau Greywacke is a semischist, and Kaingaroa Volcanics are 99% psammitic and pelitic schist. The maximum textural grade of Chatham Schist is TZ3 chlorite zone greenschist facies. Thin sections show that schists previously dated at 198-180 Ma by Rb-Sr and K-Ar methods contain relict detrital micas, so true metamorphic K-Ar ages lie in the range 171-157 Ma. Chatham Schist was exhumed at 108 +/- 11 Ma, based on He ages of zircons (Mortimer et al. 2016).

Structurally and lithologically, Chatham Schist on Chatham Island resembles TZ2A to 3 Otago Schist around Lindis Pass and Danseys Pass. TZ4 garnet-biotite-albite schist has been sampled in a xenolith on Mangere Island 60 km SE, and amphibolite facies schist in a dredge 300 km SE from the Chathams, thus indicating a broad southward increase in metamorphic grade. Chatham Rise and Chatham Schist provide excellent long baseline, linear markers with which to track oroclinal bending across Zealandia.

**UNCERTAINTIES IN REGIONAL TSUNAMI
FORECASTING
DUE TO UNKNOWN DISTRIBUTION OF
EARTHQUAKE SLIP**

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Since the 2004 Indian Ocean tsunami, there has been a major increase globally in tsunami

propagation modelling for use in tsunami forecasting and warning. Forecasting and warning systems for distant sources, defined by travel times well over one hour, are existing now and forecasts are refined by tsunami source inversion based on DART buoy information. These systems are also used for regional tsunami forecasting and warning purposes. However, there is typically a period of about 30 minutes or sometimes longer before enough information can be gathered to refine tsunami source information sufficiently. If the area under tsunami threat falls within this travel time boundary, uncertainties remain until the tsunami arrives.

We propose to include uncertainties into the forecast in such circumstances, by using ensemble simulations which vary tsunami propagation and source parameters. To be useful, such forecasts require the calculation of ensemble scenarios in faster than real-time within the early development stages of the tsunami. This requirement can typically not be achieved by using pre-calculated scenario databases.

This study investigates the sensitivity of forecasting products to uncertainties in the tsunami source process, by using examples like threat level maps and near shore tsunami wave height forecasts. The study focuses on the effect of uncertainty in the distribution of earthquake slip considering sources on the Tonga-Kermadec trench and effects on New Zealand coastal areas. Uncertainty due to non-uniform slip follows tsunami ray paths, is a complex function of distance and bathymetry, does not decay with distance, and has considerable effect on shoreline forecasts.

UNUSUAL FLUID BEHAVIOR OF A SILICIC MELT DURING FRAGMENTATION IN A DEEP SUBAQUEOUS ERUPTION, HAVRE SEAMOUNT 2012

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Magma can respond to applied stresses in either a viscous or elastic manner, dependent on the system chemistry, temperature, and deformation rate. The rheological response of magma to stress is of importance in determining eruption processes. The higher silica content and lower temperature of silicic magmas vs mafic magmas leads to elastic deformation during eruption. This generates high bubble overpressures and stores more energy in the melt, leading to brittle fragmentation and highly explosive eruptions.

In 2012, a submarine rhyodacitic eruption occurred at Havre Seamount from a depth of 700-900 mbsl, producing four primary seafloor ash deposits. Subunit 1 (S1), the basal layer of these, is composed of glassy vesicular ash with <5% crystal content. Particle shape analyses, shows that up to 30% of grains in S1 display features implicate of viscous deformation syn- or post-fragmentation. These 'fluidal grains' exhibit evidence of surface tension rounding, particle-particle welding, post fragmentation vesicle inflation and Pele's Tear like particles.

The glass of S1 ash shows 72-75 wt% SiO₂ and water contents of 0.5-0.8 wt%. Using the GRD model this gives a calculated melt viscosity of 10⁷-10⁸ Pa s.

The high calculated viscosity and the high strain rates generated during ash fragmentation suggests elastic deformation

and brittle fracture of the Havre melt during eruption. Syn- or post-fragmentation viscous deformation of the magma, is therefore, extremely unusual, and implies high eruption temperatures.

Here we discuss possible mechanisms to account for increased magmatic temperatures, including volcanic lightning, viscous dissipation, and a hot source magma. The formation mechanisms of the fluidal particles and their implications for submarine eruption processes at Havre will also be examined. The presence of fluidal grains alongside brittlely produced ash suggests a duality in fragmentation mechanisms at Havre, indicating strong, local gradients in eruption temperature.

EARLY MASS FLOW SEDIMENTATION PROCESSES IN THREE MAAR CRATERS, HINDON MAAR COMPLEX, OTAGO

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The Hindon Maar Complex, located near Hindon, 25.0 km NW of Dunedin, consists of four volcanic craters infilled by lake sediments and mass flow deposits. The maars form part of the Waipiata volcanic group, which was active from 25-9 Ma. Drilling of Maar 1, Maar 3 and a sediment-filled depression between Maar 2 and Maar 3 revealed up to 10 m of laminated biogenic lake sediments underlain by siliciclastic mass flow deposits. This project describes the siliciclastic deposits from these drill-cores and from limited outcrops of Maar 2. Physical properties, stratigraphic logs, X-ray fluorescence spectrometry and optical petrography are used to create a facies analysis and infer the processes of initial sedimentation into the maar craters following

the maar-forming eruptions.

Initial results have indicated that the mass flow deposits from Maar 1, Maar 2 and the sediment-filled depression consist mostly of unconsolidated well-sorted fine to medium sand. The sand is sub-angular to sub-rounded, bluish grey, and highly micaceous, being composed primarily of quartz and schist fragments. Structures include laminations, soft sediment deformation and massive intervals. Intervals of semi-consolidated matrix-supported breccia occur in several cores. These breccia intervals are of similar composition to the sandy intervals, but with the addition of volcanic glass and 0.5 mm-2 cm voids with clay linings. These voids appear with varying frequency throughout the breccia intervals. Maar 3 is infilled with unconsolidated, well-sorted fine sand with extensive iron staining. Based on the mineralogy, we infer a basaltic source rock. Here we present more detailed mineralogical and geochemical data from these sedimentary and volcanoclastic deposits, along with preliminary interpretations of their origins.

**TEPHRASTRATIGRAPHY AND
TEPHROCHRONOLOGY OF THE SHIKOTSU-
TOYA VOLCANIC FIELD, HOKKAIDO JAPAN:
BEGINNING AND DEVELOPMENT OF SILICIC
VOLCANISM AT AN ARC-ARC JUNCTION**

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The Shikotsu-Toya volcanic field (STVF) is located at an arc-arc junction of Kuril and NE Japan arcs, and consists of three caldera volcanoes, Toya, Kuttara and Shikotsu, and a large stratovolcano, Yotei. These volcanoes had sequentially started their eruptive activity since late Pleistocene, and have continued the activity until now. Although eruptive rocks

range from basalt to rhyolite, major eruptive magma is silicic. Many tephra layers from these volcanoes are widely distributed eastward. Tephrastatigraphy and tephrochronology at proximal to distal region of these volcanoes could reveal not only the eruptive history of each volcano but also the sequence of each larger eruptive episode. To identify the source volcano for these tephra layers, chemical analysis of volcanic glasses was quite useful. We clarify that three volcanoes started their activity at nearly the same time after long quiet period in southwestern Hokkaido for ca. 400 ky. At first, Toya and Yotei volcanoes, located at the western region, started the activity 130 ka and occurred largest caldera-forming eruption (VEI=7) forming Toya caldera 110 ka. After the eruption, Kuttara and Shikotsu volcanoes started their eruptive activity ca.95 and 85 ka, respectively, suggesting that the activity had developed eastward and toward the arc-arc junction. The activity of the STVF had been vigorous during the period from 60 to 40 ka. Large eruptions with VEI=5 – 7 had repeated at Kuttara and Shikotsu volcanoes. The largest caldera-forming eruption occurred at Shikotsu volcano 42 ka. After the eruption, post-caldera volcanoes of the three calderas and Yotei volcano have been active until now. It should be noted that episodic and strong silicic eruptive activity at the STVF since 130 ka could be possibly affected by the change of tectonic stress at the arc-arc junction.

**QUANTITATIVE PALEOENVIRONMENTS
FROM SPELEOTHEMS (QUEST): CAVE
MONITORING AS A KEY TO
RECONSTRUCTING PAST ENVIRONMENT
FROM WAITOMO SPELEOTHEMS**

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Waipuna cave is located in Waitomo Region, North Island, NZ, which in turn is situated at the southwestern fringe of the Pacific Ocean, an area highly sensitive to El Niño-Southern Oscillation (ENSO) and the southern westerlies. This work is part of the multidisciplinary project Quantitative PalaeoEnvironments from SpeleoThems (QUEST), which employs speleothems as paleoclimatic archives to investigate ENSO dynamics and associated teleconnections across the Pacific during the Holocene. In order to understand the processes that control calcite precipitation during the last 10 ka, cave monitoring is an essential component. Knowledge of the present-day surface environment and the microclimatic parameters inside the cave will allow us to construct robust proxies of past climate.

Drip discharge rates are one key parameter controlling speleothem growth, affecting the delivery of calcium and CO₂ degassing rates. Drip response to rainfall provides information about flow path, storage, mixing and ultimately, signal transfer time into the cave. Measurements of on-site water chemistry such as electrical conductivity, pH, and total alkalinity are necessary to estimate the equilibrium pCO₂ and calcite saturation. An understanding of the meteorology around the

cave is required to calibrate the geochemical information. We have been monitoring four strategic drip sites inside Waipuna Cave over the last year to gather information about drip rate; the pH, alkalinity and stable isotopes (δD and $\delta^{18}O$) of drip water; air temperature; humidity; and pCO₂. Temperature and precipitation information has also been collected from a meteorological station outside the cave.

Here we present preliminary results of monitoring of both external climate and internal cave conditions. Waipuna Cave reacts very quickly to precipitation events, and therefore we expect the speleothems to represent very highly (sub- to multi-annually) resolved climate archives, which will provide valuable information about local and regional climate dynamics, such as the frequency of strong El Niño events.

**VOLCANIC GEOSITE SELECTION AND THEIR
GEOHERITAGE VALUE ASSESSMENT:
METHODOLOGY REVIEW**

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The protection of cultural and natural heritage is institutionalised and in New Zealand become the domain of a few Government agencies. In New Zealand, conservation values have generally focused on biodiversity tending to ignore other values such as geology and landscape conservation. There is very limited public awareness of any need to protect geological sites let alone recognising concepts such as geoheritage or geoconservation.

A geoconservation strategy is based on several successive steps: inventory, quantitative or qualitative assessment, interpretation,

visualisation, promotion and monitoring. This study proposes to provide an overview of methods available to identify, select, evaluate and classify the geoheritage sites and find an appropriate method that can be easily adapted to any geological site.

Different methodologies have been developed in geoconservation. Their characteristics depend on the choice of methods and techniques associated with evaluation using qualitative and/or quantitative systems of classification. These methods however are also not consistent as the main purpose for conservation (e.g. economical, educational, tourism) can differ. These objectives need to be considered when establishing the right assessment criteria as they are the key to answer the broad range of challenges associated to geoconservation. Statistical approaches available for the estimation of geoconservation/geoheritage values vary from the preliminary geosite assessment model (GAM) to loglinear, component analysis models. The complexity of the methods available could be overcome by combining them with spatial analysis in GIS to produce indicators such as the geomorphodiversity index.

As a first attempt to define geoheritage we will examine the Auckland Volcanic Field which displays a unique combination of young monogenetic volcanic landforms and archaeological remains of an indigenous culture through to European colonisation through to present day. It is envisaged that through further analysis, we will provide an opportunity for developing the first geopark in New Zealand that is part of the UNESCO Global Geopark Network.

THE UNDERUTILIZED VOLCANIC GEOHERITAGE VALUES OF UPOLU, WESTERN SAMOA - CHALLENGES TO DEVELOP SUSTAINABLE GEOTOURISM PROGRAMS INCORPORATING POLYNESIAN HERITAGE

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The two largest islands of Samoa (Savai'i & Upolu) contain ~400 young volcanic cones. In Savai'i, the most recent eruption (Matavanu: 1905-11) covered the N-E sector of the island with pahoehoe lava flows and littoral cones. In Savai'i, volcanic eruptions took place few times since the Polynesian migration ~3500 years ago. An inventory of these volcanic geosites is under development to promote geotourism (Samoa Geopark Project). Upolu received far less attention in spite that recent researches indicate the presence of young volcanic features along the dorsal ridge of the island. Fissure aligned vents are common with crater lakes in SE Upolu and large scoria cone complexes including Tafua Upolu in West Upolu among those volcanic landforms carry high geoheritage values that could be used more effectively for geotouristic purposes as well as geoeducational sites for local communities to understand volcanism in Samoa. As Upolu is the main gateway for visitors (most of them stays only in Upolu), and many of its prime resort sites are nearby those volcanic geosites, promoting them could develop sustainable tourism to the region. To develop a truly sustainable programs the local communities could also benefit from, volcanic geoheritage research needs to involve Samoan village communities through informal and formal participatory approaches to 1) assess their knowledge they have about

volcanism, 2) gather information from their cultural heritage associated with volcanism and 3) identify the best dissemination method of Western science that is conform with the Polynesian world view and everyday practices.

**TWO-STEP HUMAN-ENVIRONMENTAL
IMPACT PREHISTORY FOR AUCKLAND,
LINKED TO LATE HOLOCENE CLIMATE
CHANGE**

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Following resolution of a long-standing debate over the timing of the initial settlement of New Zealand from Polynesia (late 13th century), a prevailing paradigm has developed that invokes rapid transformation of the landscape, principally by fire, within a few decades of the first arrivals. This model has been constructed from evidence mostly from southern and eastern regions of New Zealand but a more complicated pattern may apply in the more humid western and northern regions where forests are more resilient to burning. We present a new pollen record from Lake Pupuke, Auckland, northern New Zealand, that charts the changing vegetation cover over the last thousand years, before and after the arrival of people. Previous results from this site concurred with the rapid transformation model, although sampling resolution, chronology and sediment disturbance make that interpretation equivocal. Our new record is dated principally by tephrochronology together with radiocarbon dating, and includes a cryptotephra deposit identified as Kaharoa tephra, a key marker for first settlement in northern New Zealand. Its

discovery and stratigraphic position below two Rangitoto-derived tephras enables a clearer picture of environmental change to be drawn. The new pollen record shows an early phase (step 1) of minor, localised forest clearance around the time of Kaharoa tephra (c. 1314 AD) followed by a later, more extensive deforestation phase (step 2) commencing at around the time of deposition of the Rangitoto tephras (c. 1400–1450 AD). This pattern, which needs to be corroborated from other well-resolved records from northern New Zealand, concurs with an emerging hypothesis that the Little Ice Age had a significant impact on pre-European Māori with the onset of harsher conditions causing a consolidation of populations and later environmental impact in northern New Zealand.

**ORGANIC CARBON TRANSFER TO THE DEEP
OCEAN BY A CO-SEISMIC TURBIDITY
CURRENT EVENT DURING THE KAIKŌURA
EARTHQUAKE**

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Significant ground-shaking events have the potential to transfer substantial organic carbon and other geological materials into deep-water environments via submarine mass transport processes along the continental margin. This carbon is effectively sequestered and restricted from further interaction with near-surface processes, thereby acting as a geological “sink” in the marine carbon cycle.

The November 2016 Kaikōura earthquake

sequence caused significant local and regional ground-shaking that resulted in submarine mass failure in the Kaikōura Canyon and the devastation of one of the world's most productive benthic ecosystems. This event also led to the initiation of a co-seismic turbidity current and the deposition of deep-ocean turbidite deposits, up to ~700 km from source. As part of the scientific response to the earthquake, a series of sediment cores were collected subsequently in Kaikōura Canyon itself, along the path of the turbidity current (Hikurangi Channel) and from adjacent submarine canyons along the Hikurangi subduction margin. Organic carbon measurements in these sediment cores and from previous samples in Kaikōura Canyon were undertaken and allowed a comparison to be made of the sedimentary composition of pre- and post-Kaikōura deposits, where these specific units could be determined. These data indicate that the inferred Kaikōura deep-sea turbidite contains higher average amounts of carbon (and nitrogen) than pre-turbidite sediments, suggesting greater carbon sequestration potential during such episodic events. Comparable $\delta^{13}\text{C}$ and molar C:N ratios between these units indicate that similar geological materials have been mobilised during the co-seismic event as were being deposited on the pre-turbidite "modern" seafloor.

SEISMIC TOMOGRAPHY IN THE NORTHERN SOUTH ISLAND AND THE 2016 KAIKOURA EARTHQUAKE

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The Mw 7.8 Kaikoura earthquake occurred on the 14th November 2016, in NE South Island. In order to investigate the cause of this earthquake we have undertaken seismic tomography in the region surrounding the focus of the Kaikoura earthquake. A key finding from this study is that fluids, inferred to have promoted the occurrence of the earthquake, could be detected as a seismic velocity anomaly.

Since the Canterbury earthquake sequence (2011) we have deployed a dense seismic array in the central and northern South Island. Data from both the temporary stations (51 stations) and GEONET stations (22 stations) were used. Data collection was from March 2011 to April 2015, with 4939 earthquakes located and identified by GEONET. The minimum magnitude of catalogued earthquakes in this study is about 1.0. Subsequently, we have added aftershocks from the 2016 Kaikoura earthquake and their arrival times from the GEONET catalogue. The

total number of located earthquakes (including the aftershocks) is 5389. We used the double-difference tomography method [Zhang and Thurber, 2003 and 2006] to determine hypocenter locations and three-dimensional velocity structure simultaneously. Grid intervals are 20 km in the horizontal plane. The Initial velocity structure adopted is from Eberhart-Phillips et al. [2010].

As a result, we located a region of low-Vp, low-Vs and high Vp/Vs surrounding the mainshock and aftershocks of the Kaikoura earthquake. We also have detected low-Vp, low-Vs and high Vp/Vs zones beneath other major faults in northern South Island. These low-Vp, low-Vs and high Vp/Vs zones are coincident with low electrical resistivity areas detected by MT soundings [Wannamaker et al., 2009] and can be interpreted as zones with overpressured fluids. These observations indicate that overpressured fluids, which are inferred to originate from slab dehydration, have acted to promote the occurrence of the Kaikoura earthquake.

NUMERICAL MODELLING OF GAS HYDRATE DISSOCIATION DURING THE GLACIAL-INTERGLACIAL CYCLES, CASE STUDY THE CHATHAM RISE, NEW ZEALAND.

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The Chatham Rise has been observed to have seafloor depressions, each 150m -11km in diameter, also covering an area >20,000 km², south east of New Zealand. These seafloor depressions have been interpreted as

pockmarks related to past fluid escape releases. 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 Plio-Pleistocene sea-level changes in the study area using thermodynamic modelling. Our models were constrained by stable isotopic data gathered from piston cores collected along the crest of the Chatham Rise (water ~550-1000m). 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 enabled us to assume constant bottom-water temperatures are constant. Our results show more gas is released at shallower water depth, which relates to the position of the large pockmarks in the Chatham Rise. However, the results from paleo-oceanographic 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.

CO-SEISMIC TURBIDITES TRIGGERED BY THE KAIKOURA EARTHQUAKE

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Long turbidite records of pre-historic earthquakes underpin our improved understanding of the pre-historic seismic behaviour and hazard represented by the Hikurangi subduction margin; New Zealand's largest yet most poorly constrained source of seismic hazard. Sediment cores allow the along-strike correlation of deep water turbidite deposits formed in response to earthquake strong ground motions. The large 2016 Mw7.8 Kaikōura Earthquake triggered a collapse in the outer-shelf rim of the Kaikōura canyon (Mountjoy, January 2017), and a co-seismic turbidite that traversed Hikurangi channel at least 300 km of the southern margin (Barnes et al., November 2016). This event provided an unprecedented opportunity to examine a modern analogue and calibrate the along-strike variability of deep water turbidite deposits formed in response to measured ground motions. This presentation will provide an overview of the range of co-seismic turbidites observed and images collected from the recently completed benthic survey of Kaikōura canyon.

Three voyages since the Kaikōura Earthquake have collected precision short cores from within the Kaikōura canyon head to as far north as the Poverty Bay margin 600 km to the north. Samples were taken for ²¹⁰Pb radioisotope analysis, sedimentology, CT

tomography, extracellular polymeric substance (EPS), organic carbon and meiofaunal analysis. Provisional data show that a number of slope-basin distributary systems along the southern Hikurangi margin have preserved a co-seismic event, characterised by a fluidised mud unit that is unbioturbated, faintly laminated and weakly graded. It immediately overlies a bioturbated and oxidised mud, interpreted to be the pre-earthquake seafloor. Some locations show coarse-grained material entrained in the turbidite base, with one example from Cook Strait having a very porous shell hash. Recent emplacement of the turbidite and burial of pre-earthquake seafloor are confirmed on the levee of the Hikurangi channel by the very-short lived radioisotope ²³⁴Th in concert with CT data. A compelling story that constrains the character and spatial extent of the co-seismic deposit is emerging. In addition, re-coring at critical sites is showing the progressive evolution of the event deposit and will inform our understanding of the preservation potential in the geologic record.

ENGINEERING GEOLOGICAL PROPERTIES AND SLOPE INSTABILITY OF TAURANGA GROUP SEDIMENTS IN THE BEACHLANDS LANDSLIDE ZONE (BLZ), AUCKLAND

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This study analyses a recent landslide initiated in the Beachlands Landslide Zone (BLZ), east Auckland. The BLZ is a region of coastal slope failures, occurring in suburban areas, creating substantial hazards for homeowners. We focus on the most recent slope failure in the area at Sunkist Bay, triggered on 5 April 2017. The landslide is characterized as rotational

slumping in the clay/silt cliffs, with retrogressive failure propagating an arcuate headscarp to within a few metres of the rear of houses on First View Avenue. Tension cracks extended laterally into neighbouring properties. The landslide was investigated using a combination of in situ testing and remote sensing techniques. Shear strength, penetration resistance and soil index properties were measured at various heights in the exposed headscarp, formed in Tauranga Group sediments. Structure-from-Motion photogrammetry of drone-acquired imagery allowed a detailed engineering geomorphological map to be constructed. Observations of the headscarp exposures suggest that perched water tables developed on impermeable tephra layers, increasing porewater pressure in overlying soils, and leading to rotational failure. Downslope, the slumping transitioned to an earthflow, which overtopped the seawall at the toe of the cliff, depositing a lobate fan of material on the beach below. The slope failure on 5 April followed ex-Tropical Cyclone Debbie delivering Auckland its normal April rainfall (84.6 mm) in 14 hours on 4/5 April. Preceding this, the 'Tasman Tempest' delivered a 1 in a 100-year rainfall event at nearby Hunua on 7 March (225 mm of rain in 12 hours). Hence, prior to failure, high antecedent porewater pressures had prevailed for some time.

TIMING OF SEDIMENTATION AND DEFORMATION IN PLIO-PLEISTOCENE WHANGANUI BASIN, NEW ZEALAND

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Pliocene to Recent sedimentary succession of Whanganui Basin is one of the most complete Quaternary stratigraphic records in the world. The thickest succession, which lies offshore, has not been drilled. Onshore, four exploration wells drilled in Whanganui – Manawatu region between 1942 and 1964, encountered basement at 2400m or less. Each well was located on one of a number of growing folds in the area. Farther east faulting and associated folding occur along the North Island dextral fault zone and blind active faults to the west. These are uplifting the axial ranges forming piercement structures as deformed Mesozoic basement is elevated and stripped of its late Neogene coverbeds. This tectonism is part of the deformation associated with crustal shortening along the present day North Island subduction margin.

Pumice units present in the coverbeds provide basinwide chronostratigraphic horizons that constrain the timing of uplift in the main axial range and formation of actively deforming anticlinal structures, such as Pohangina Anticline. Rhyolitic pumice (primary airfall (tephra) and reworked pumice) provide a high resolution chronostratigraphic framework for sedimentary and bio- facies preserved in the coverbeds. Thus constraining the timing of syn- and post-depositional deformation in the Whanganui Basin.

A study by Melhuish et al. (1996) suggested folding associated with the active anticlines had been going on for at least 3My. However,

tephrostratigraphy of southern Ruahine Range indicates the area was experiencing estuarine and shallow marine conditions 1My ago and that piercement of the greywacke has occurred largely since this time. Prior to the uplift of the ranges the Whanganui Basin extended east of the present Ruahine Range. The uplift of the ranges is gradually dissecting the basin cutting the central part of the basin off from its eastern counterpart.

Reference:

Melhuish, A., van Dissen, R., Berrryman, K., 1996. Mount Stewart-Halcombe Anticline: a look inside a growing fold in the Manawatu region, New Zealand. *New Zealand Journal of Geology and Geophysics*, 39(1): 123-133.

FINGERPRINTING RHYOLITIC TEPHRA LAYERS WITH NON-DESTRUCTIVE RAPID μ -XRF CORE SCANNING

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Tephra layers are the backbone of chronology development in New Zealand due to their (near) simultaneous deposition in the sedimentary archive over a wide area. Their identification is crucial for the robust chronological control of climate change events discerned in Auckland maar lake sediment cores, as well as for determination of the frequency and magnitude of the volcanic eruptions they are the product of.

Tephra layers are identified based on their mineralogy and fingerprint of major and trace elements since each volcanic centre, and most eruptions, contain a unique geochemical signature. However, traditional fingerprinting of tephra is a slow, expensive and destructive process unlike μ -XRF core scanning that is

becoming widely applied to the rapid and non-destructive chemical analysis of sediment cores.

Although μ -XRF core scanning techniques are increasingly used to locate crypto-tephra in sediment cores, no attempt to fingerprint and identify tephra layers using μ -XRF core scanning techniques has been published to date. We test the ability of this approach on numerous thick, easy to see rhyolitic tephra in continuous, organic-rich and well-laminated lake sediment cores from maar craters in Auckland spanning the period ca. 7 to 46 ka.

μ -XRF derived elemental ratios and magnetic susceptibility scans, quickly and non-destructively obtained with the Itrax[®] core scanner, yield the highest information value for identifying and fingerprinting tephra layers. Calibration of the μ -XRF scan data with conventional XRF and comparison to EMPA glass shard allowed: (1) characterization of discrete tephra, (2) a test of the ability of Itrax[®] scans to rapidly and reliably fingerprint tephra from macroscopic to crypto-scale, and (3) the proposal of optimal μ -XRF scanning conditions for tephra fingerprinting.

COMPOSITE STRATIGRAPHY AND PRELIMINARY AGE-MODEL OF 80 m MAAR LAKE SEDIMENT FROM ORAKEI BASIN (AUCKLAND CITY)

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The Orakei Maar Crater Lake (Auckland Volcanic Field) provides a well preserved, finely laminated, high-resolution record of palaeoenvironmental change over the last glacial cycle. One core of ca. 80 m length was drilled in 2006 followed by two cores to depths

of ca. 100 m below sediment surface with nearly 100% recovery. The two longer cores reach into volcanic ejecta interpreted to be the primary deposit of the maar forming eruption and further into the Waitemata sandstone basement. Here we describe the Orakei Maar Crater Lake composite stratigraphy established based on these three cores. Large intervals of the record show fine sub-mm laminations which allow visual correlation between the overlapping cores. In other intervals where correlation is not as straightforward statistically more robust methods based on magnetic susceptibility measurements, μ -XRF core scanning (Itrax) results and X-ray density have been employed to obtain a composite stratigraphy. The accuracy and strength of applied methods could be tested in the overlapping finely laminated intervals of the core. The entire sedimentary record of Orakei Maar Crater Lake below the marine/freshwater transition caused by the crater rim breach due to the post-glacial sea-level rise at ca. 9 ka comprises ca. 80 m.

A preliminary age-model could be established based on the composite stratigraphy and the preliminary identification of known and dated volcanic ash (tephra) layers. The average sedimentation rate for this crater lake below the Rotoehu tephra (ca. 45 ka) is approximately 0.4-0.5 m/ka and by extrapolation of the latter an Orakei eruption age of approx. 135 ka is estimated.

GEODETTIC RESULTS FROM THE HAURAKI RIFT: SLOW CONTINENTAL RIFTING OBLIQUE TO SUBDUCTION, NORTH ISLAND

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The Hauraki Rift, an active but slow-deforming (<1mm/yr) narrow intra-continental rift in northern New Zealand paradoxically strikes nearly normal to the Pacific-Australian oblique subduction boundary 300+ km to the southeast. Both the driving mechanism and quantitative details of the rift's current activity are unknown. A three year, ~40 station GNSS geodetic campaign beginning in 2015 has now completed, producing new velocity solutions throughout northern North Island. Preliminary vectors show that the Hauraki Rift may be discontinuous and accommodated not only by the active Kerepehi fault serving as its presumed median axis, but also by the active Wairoa North fault striking parallel 20 km to the west. The northern continuation of the Wairoa North fault may continue further than previously supposed, possibly extending into Auckland harbour. Additionally, an eastern extension of the presumed-inactive, rift perpendicular Waikato fault delineates a visible velocity discontinuity between geodetic stations and may serve as an active transform fault/transfer zone between these. We also determine lateral offsets resulting from the November 2016 Kaikoura Earthquake at continuous GPS reference stations (KTIA, CHTI, MAC1) over 800 km away from source.

THE CENOMANIAN–TURONIAN $\delta^{13}\text{C}$ RECORD OF THE CHATHAM ISLANDS: IMPLICATIONS FOR TERRESTRIAL STABLE CARBON CHEMOSTRATIGRAPHY

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Global hothouse climatic conditions prevailed during the Cretaceous (Cenomanian-Turonian) amidst the tectonic separation of southeastern Gondwana and poleward radiation of angiosperms. The fossilised remnants of the highest southern palaeolatitude (~70–80°S) forest studied to date from this important time interval are preserved within the Tupurangi Formation located on Pitt Island, Chatham Islands, New Zealand. Analysis of the preserved spore-pollen record of this fluviio-deltaic succession has enabled correlation to the Ngaterian, Arowhanan and Mangaotanean stages of the New Zealand chronostratigraphic scheme. In the absence of absolute dating, this study applied a new method of chemostratigraphic correlation in order to constrain these biostratigraphic stage boundaries, primarily the Arowhanan-Mangaotanean boundary which has previously been correlated with the Cenomanian-Turonian boundary (CTB). Global type sections of the CTB (93.9 Ma) preserve a distinct signature within the ratio of stable carbon isotopes ($\delta^{13}\text{C}$), specifically an increase in $\text{C}^{13}:\text{C}^{12}$, attributed to Cretaceous Oceanic Anoxic Event 2 (OAE-2). This study aimed to identify this characteristic $\delta^{13}\text{C}$ signal by analysing the stable carbon ratios preserved by coalified leaf compressions of two of the dominant taxa collected at semi-regular stratigraphic intervals (3–8m) across an approximately 400m thick section of the Tupurangi Formation. These leaves were isolated via manual preparation techniques and sieving from bulk samples. Following the

removal of adhering carbon contaminants with hydrochloric acid, the fossilised material was dried and $\delta^{13}\text{C}$ levels were analysed using elemental analysis isotope ratio mass spectrometry (EA-IRMS). The values obtained range between -23‰ and -28‰, which are typical of those acquired for extinct and extant C_3 plants. Statistical analyses of these data were performed to assess the inter- and intra-species variation in $\delta^{13}\text{C}$ values obtained for this first taxonomically controlled profile of terrestrial carbon, facilitating comparisons with global type sections. Subsequently, this study established the benefits and limitations of taxonomically-controlled terrestrial carbon chemostratigraphy.

ANALYSIS OF FLUID FLOW SYSTEMS AND LINKS TO POTENTIAL GAS HYDRATE DEPOSITS IN THE NORTHERN TARANAKI BASIN

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In this study we provide evidence for gas hydrates in the Taranaki Basin occurring off the continental margin. Modelling of the gas hydrate stability zone (GHSZ) suggest that pressure and temperature conditions for hydrate formations exist at water depths of 500 m and greater. Interpretation of high-resolution 2D and 3D seismic data reveal the presence of large deep seated faulting, polygonal faulting, seismic chimneys/pipes, mounds, pockmarks and high amplitude anomalies here interpreted as free gas. These features are linked to evidence suggesting upward migrating fluids (liquids and gas) from Late Cretaceous deposits into the shallow

sediments where hydrate deposits may be expected. Subsequently, the observation of patchy, polarity-reversed, high amplitude reflections (HARs) at the base and in the regional GHSZ are interpreted as bottom simulating reflectors (BSRs) indicating the presence of free gas below a layer of hydrates, which exist at the base of gas hydrate stability (BGHS). These reflections appear predominantly on the down-dip side of canyon incisions that are commonly located on the continental slope. It is proposed here that these lower the extent of the BGHS and consequently trap up dip migrating, which may then facilitate the formation of gas hydrates in these regions. The patchy nature of these reflections is believed to be characterised by areas of focussed fluid flow into heterogeneous deposits in the shallow sediments. This suggests that sources of gas may be derived from thermogenic origins associated with the Late Cretaceous source rocks in the basin. The lack of any strong HARs observed in the deeper regions of the basin suggests that upward fluid migration in these areas may be trapped well below the BGHS and subsequently migrate laterally into the continental slope regions. However, a number of moderate amplitude reflections in the GHSZ are observed, suggest that more diffuse gas emissions here may be at play, resulting in possibly weak BSR reflections.

TERRESTRIAL CLIMATE EVOLUTION IN THE SOUTHWEST PACIFIC OVER THE PAST 30 MILLION YEARS

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A reconstruction of terrestrial temperature and precipitation for the New Zealand landmass over the past ~30 million years is produced using pollen data from >2000 samples lodged in the New Zealand Fossil Record Electronic Database and modern climate data of nearest living relatives. The reconstruction reveals a warming trend through the late Oligocene to early Miocene, peak warmth in the middle Miocene, and stepwise cooling through the late Neogene. Whereas the regional signal in our reconstruction includes a ~5-10° northward tectonic drift, as well as an increase in high altitude biomes due to late Neogene and Pliocene uplift of the Southern Alps, the pattern mimics inferred changes in global ice extent, which suggests that global drivers played a major role in shaping local vegetation. Importantly seasonal temperature estimates indicate low seasonality during the middle Miocene, and that subsequent Neogene cooling was largely due to cooler winters. We suggest that this may reflect increased Sub-Antarctic influence on New Zealand vegetation as the climate cooled.

**VOLCANISM AT MAUNGATAUTARI
COMPOSITE CONE VOLCANO, CENTRAL
WAIKATO**

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Maungatautari is an extinct andesitic-dacitic composite cone volcano, situated 35 km southeast of Hamilton that rises prominently in the Waikato region. A single radiometric age of 1.8 Ma indicates volcanic activity here was contemporaneous with subduction-related volcanism of the nearby Alexandra Volcanics and the early Taupo Volcanic Zone. The volcanic history of Maungatautari has been reassessed using field and desktop geomorphic analysis, volcanic stratigraphy and facies analysis, petrographic and mineralogical studies, and elemental and isotopic geochemical analysis, which has provided new insights into how Maungatautari relates to volcanism elsewhere in the Waikato Region around 2 Ma.

This study is the first to document a record of explosive volcanism at Maungatautari. Track development by Maungatautari Ecological Island Trust (MEIT) exposed two pyroclastic successions located near the summit and on the southern flank. Activity at the now-eroded summit vent included complex, multiple phase eruptions with cycles of dome growth and collapse, whereas deposits on the flank show repeated production of eruption columns from associated vulcanian to subplinian style activity which created numerous pyroclastic density currents.

Lavas at Maungatautari consist of non-vesicular labradorite, pyroxene and hornblende andesites and hornblende dacites. Olivine basalt is found at the small Kairangi cone ~7 km to the northwest. Whole rock

geochemical and strontium and neodymium isotope analyses demonstrate these lavas were derived from at least three distinct mantle-melt sources: subduction-related, deep, garnet-bearing, depleted mantle (most andesites and dacites); a shallower, garnet-free, upper mantle (low SiO₂ hornblende andesites) and an area of deeper enriched mantle (Kairangi olivine basalt). Activity at Maungatautari is interpreted to reflect andesitic volcanism occurring along the edge of the continental tip of the Colville volcanic arc c. 2 Ma. The olivine basalt at Kairangi is more reflective of intraplate over subduction-related melts and is unrelated to magmatism at Maungatautari.

**GEOCHEMISTRY AND STRUCTURE OF BACK-
ARC BASINS IN THE HAVRE TROUGH,
SOUTHWEST PACIFIC**

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Magmatism at subduction zone systems represents one of the principal forms of volcanic activity on earth, and is the main foci for significant mass and chemical transfer between the crust, mantle, hydrosphere and atmosphere. The Havre Trough back-arc system located behind the Kermadec arc, in the southwest Pacific Ocean, is associated with the subduction of the Pacific plate beneath the Australian plate and is a classic example of an intra-oceanic back-arc system.

The location of back-arc basins can provide a wealth of information in understanding key structural and geochemical dynamics of

subduction systems. Previous Kermadec arc research has focussed on active arc front volcanoes yet the back-arc basins in the Havre Trough remain poorly understood. Therefore, significant gaps exist in our understanding of the nature of magmatism, and onset of rifting in the Havre Trough.

Extensive seafloor sampling and high resolution acoustic surveying of back-arc basins in the Havre Trough was undertaken during several marine voyages of the RV *Tangaroa* between 2012 and 2015 to investigate the formation of the back-arc basins. Dredge sampling recovered fresh back arc basin basalts (BABB) from depths up to ~4000 mbsl, and 30 kHz multibeam echosounder (MBES) data reveal a range of different morphological features such as elongated ridges oriented at 45° and small volcanic cones.

We present MBES and whole rock geochemical data of BABB from these previously unexplored basins. The samples are from the southern sector of the Havre Trough between 33.7° S and 36.6° S (with one northern location at -30.3° S) and span the breadth of the Havre Trough. The results show variable modification of ambient back-arc mantle by subducting plate derived components across the Havre Trough, and combined with digital terrain models give new insights into the tectono-magmatic evolution of the Havre Trough.

TIME-COMPOSITION TRENDS IN A COMPREHENSIVE SUITE OF LAVAS FROM TONGARIRO VOLCANO

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At stratovolcanoes, time-resolved eruptive stratigraphies provide the essential framework for reconstructing the evolution of magmatic systems. For systems that produce infrequent and low volume explosive eruptions, records of sequential magma evolution are best preserved in lava flows for timescales exceeding tens of millennia (because small volume unconsolidated tephra layers are highly susceptible to erosion or bioturbation where thin). Tongariro volcano in New Zealand has an edifice constructed dominantly by andesitic lavas that date from ~270 ka to present. This edifice history provides a framework for examining time-composition relationships of Tongariro's past and present magmatic systems.

We here present 25 new ⁴⁰Ar/³⁹Ar age determinations on lavas, principally from undersampled sectors of Tongariro's edifice (NW, NE, E) and peripheral vents, to augment existing K/Ar ages. These combined age data are coupled with new and existing whole rock geochemical analyses to interrogate time-composition relationships. The data show that consistent incompatible element concentrations (e.g., 0.9-1.5 wt% K₂O; 90-120 ppm Zr) persist from ~270-120 ka and 80 ka-present, interrupted by a series of incompatible element-enriched lavas (1.6-2.1 wt% K₂O; 120-160 ppm Zr) from 120-80 ka. We

interpret Tongariro's higher incompatible element concentrations at 120-80 ka to reflect increased country-rock assimilation of incompatible-element fertile phases in the mid- to upper-crust (e.g., biotite in greywacke metasediments). This assimilation period was possibly triggered by increased mid-upper crustal temperatures from continued magma injection over Tongariro's lifespan that were incapable of triggering voluminous melting prior to 120 ka. From 80 ka-present, incompatible element concentrations returned to pre-120 ka levels, reflecting the exhaustion of accessible fertile material. Similar explanations have been proposed for an incompatible element spike at Ruapehu volcano, 20 km south of Tongariro, at ~45 ka. The separated timing of similar time-composition events at Tongariro and Ruapehu suggest that the petrogenetic processes in the southern TVZ arc are decoupled.

ADAPTIVE COMMUNICATION FOR A DYNAMIC LANDSCAPE

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New Zealand is a relatively young country situated astride an active margin. Change is certain; resilience a byword of our modern times. There is an upward trend in research aimed at building more resilient cities and developing more engaged and prepared communities. Drawing upon disaster risk research and hazard mitigation studies, this paper explores the divide between science research and local public response and questions whether there are other ways that scientific knowledge might be more effectively communicated. What are the ways perception and value systems influence awareness of risk and uncertainty? How is future change

presently communicated and to what effect? The paper presents a review of current literature and discusses the need for bridging between the various scientific communities and the public, and posits need for more responsive and representative communication models using a New Zealand context.

ENGINEERING GEOMORPHOLOGICAL AND GEOTECHNICAL CHARACTERIZATION OF TROPICAL CYCLONE WINSTON INDUCED SLOPE FAILURES IN VITI LEVU, FIJI

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Battering Fiji for nearly 24 hours from 2 am 20 February 2016, with wind gusts of up to 306 km/hr, Severe Tropical Cyclone (STC) Winston was the first category five cyclone to make a landfall in Fiji and one of the strongest cyclones to traverse the southern hemisphere. Affecting at least 80% of the country's population, STC Winton caused 44 fatalities and cost the Fijian economy US\$1.3 billion with at least 10% relating to road infrastructure. Slope failures resulting from tropical cyclones have caused a high number of fatalities and infrastructure damage in the past, particularly along the King's Road, one of the two major highway's spanning Fiji's largest island, Viti Levu. Despite the severe economic impacts and damage to road infrastructure experienced in Fiji by landslides triggered by tropical cyclones, they are rarely documented. Here, we report on engineering geomorphometric and geotechnical character of slope failures triggered by the STC Winston along the 35 km stretch of King's Road in northern Viti Levu, Fiji. At least 61 distinctive failures were identified all of which were small (min. 12 m², max. 1125 m², mean 81 m²) and

shallow in nature (<5 m in depth), occurring on gentle to steep slopes (min. 5°, max. 50°, mean 23°), and low to intermediate relief (min. 4 m, max. 89 m, mean 86 m). Most of failures were earth and debris-slides (rotational and translational) with minor flow components. Geotechnical analysis of the soils sampled from the erosive scarps of the slope failures revealed most the soils to be cohesive, stiff, plastic, sensitive silts. XRD analysis further confirmed the presence of Smectite and/or Halloysite contributed to the sensitive nature of the slope materials. The trigger for the slope failures was the ~258 mm of rainfall in 24 hours after 30-day antecedent rainfall of 482 mm which caused rapid increases in pore water pressures which together groundwater pathways caused loss in shear strength of the sensitive surficial soils within the highly weathered soil profiles.

SURFACE HARDNESS AND LITHOLOGICAL PROPERTIES OF WAITEMATA GROUP EAST COAST BAYS FORMATION, AUCKLAND

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The hardness of a rock can be defined as the elastic resistance to local compression. It is an important geomechanical property, which is often overlooked when characterizing the geotechnical properties of Miocene East Coast Bays Formation of the Auckland region. Hardness testing was undertaken on rock samples in order to characterize the rocks based on surface hardness, while the influence of microstructures on rock hardness was also examined. Five rock types (siltstone, mudstone, Parnell Grit, fine-grained sandstone, and coarse sandstone) of the East Coast Bays Formation were analysed in this study. The samples were acquired from drill

core from geotechnical drilling associated with Auckland CBD site investigations and excavations. Laboratory hardness tests were conducted using a model C-2 Shore Scleroscope. A total of 51 cylindrical specimens with an average volume of 56.55 cm³ were tested for a total of 5364 Shore Scleroscope Rebound Hardness (SSRH) values. Statistical analysis of the data show that the hardness varies with lithology. In particular, the mudstone showed the highest mean hardness values, while the coarse sandstone showed the lowest mean SSRH values. The Parnell Grit had the highest range of values, indicative of the its lithological variability often seen over short distances in outcrop. The microstructure of the samples were analysed using scanning electron microscope (SEM) to identify pre-existing defects and examine resulting fracture patterns as a result of the SSRH test, which may be scaled up to understand fracture propagation and permeability when undertaking civil engineering excavations.

THE AEROMAGNETIC EXPRESSION OF THE ALPINE FAULT: REGIONAL DISPLACEMENT AND ENTRAINMENT OF IGNEOUS ROCK

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The Alpine Fault is very well delineated by recent high resolution aeromagnetic datasets over much of its length in New Zealand's South Island. Aeromagnetic data acquired over the West Coast, Buller, Nelson and Marlborough regions for the New Zealand Government reveal many total magnetic intensity anomalies that truncate at the Alpine Fault surface trace or are truncated where the fault is interpreted to be at depth. Strongly positive anomalies occurring in the Alpine Fault zone

are generally associated with igneous rocks; notably Mesozoic mafic metavolcanic and ultramafic rocks, Late Cretaceous basalt and some Early Cretaceous intrusions. Greenschist bands within the Alpine Schist are well expressed magnetically and the Dun Mountain Ultramafic Group serpentinitised peridotite rocks and dikes have a very strong magnetic expression. Isolated anomalies parallel and within the Alpine Fault zone are attributed in part to ultramafic rocks incorporated into the fault zone. The strong anomalies associated with the Hohonu Range and some other foothills are caused by magnetic granitoids and dikes that are interpreted to persist at depth to the southeast in the footwall to the dipping Alpine Fault plane. The broad anomaly under the Mataketake Range in South Westland is attributed to numerous dipping metavolcanic layers in the Alpine Schist hanging wall to the fault. The very broad positive anomaly underneath Blenheim reflects a very deep source, potentially related to the subducting Pacific Plate.

PLIO-PLEISTOCENE GEOLOGY OF CENTRAL RANGITIKEI, WHANGANUI BASIN, NEW ZEALAND

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Central Rangitikei provides a cross section through the Plio-Pleistocene succession of eastern Whanganui Basin (WB), Lower North Island, New Zealand. Sedimentary units exposed in the cliffs and valley sides of the Rangitikei by ongoing regional uplift and erosion provide part of one of the most comprehensive onland Quaternary stratigraphic records in the world. Geologically young faunal assemblages and their associated lithofacies form the basis for

stratigraphic subdivision. Contemporary counterparts persisting around modern day New Zealand waters provide palaeoenvironmental analogues. The succession contains a Plio-Pleistocene volcanic record derived from early eruptive products of the Taupo Volcanic Zone (TVZ). The development and application of geochemical ‘fingerprinting’ techniques to primary tephra and reworked volcanoclastic deposits in the Whanganui Basin has led to a revolution in mapping, allowing for identification of chronostratigraphic horizons and basin wide correlation. New research presented here continues the ongoing stratigraphic subdivision of early work by New Zealand’s pioneering geologists, presenting one sheet of a 1:25 000 geological map series encompassing the Central Rangitikei area. This work draws from over 50 years of research within the Whanganui Basin and Rangitikei District. Tephrochronology, biostratigraphy and lithostratigraphy are implemented to define sedimentary units and map them across the landscape. The aim of this project is to inform territorial authorities, landowners, developers and industry by providing information on the geology of the district. Particular emphasis is placed on the water bearing properties of sedimentary units, with the goal of investigating chemical and physical properties, which are relevant to environmental issues being faced in central Rangitikei today.

THE ALPINE FAULT – A TECTONOPHYSICS PERSPECTIVE

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The Alpine Fault has traditionally been interpreted as a plate boundary through continental lithosphere, with attendant widespread deformation. But recent 3-D imaging of deep crustal structure has shown that the habitat of the fault is dominated by strong, large igneous province (Hikurangi Plateau) lithosphere, producing a much narrower deformation zone. The fault formed at ca. 23 Ma as a subduction-transform edge propagator (STEP fault), when the subduction zone to the north rolled back by ripping oceanic crust seaward of the trench from the western edge of the strong Hikurangi Plateau. STEP fault propagation stopped at ca. 15 Ma, when the edge of the plateau became parallel to the strike of the subduction zone. Strike-slip motion on the fault renewed at ca. 7 Ma, when the fault linked with the Marlborough fault system. If the 480 km offset of geological terranes across the fault occurred only during these two episodes, this implies an average strike-slip rate of 32 mm/a, close to the relatively constant Late Quaternary strike-slip rate of 27 ± 5 mm/a. The current pattern of convergence along the fault is dominated by the 16° mismatch between the strike of the STEP fault and the strike of the converging plateau, which leads to the highest uplift and exhumation rates occurring in the Aorangi/Mt Cook region. The fault is weak on a lithospheric scale. Bending of geological terranes into the fault, previously ascribed to fault drag, can be explained by impact of the Hikurangi Plateau with subduction margins in the Cretaceous and Cenozoic, prior to STEP fault initiation. The current low level of seismicity near the fault is consistent with a characteristic model of large earthquake

ruptures, in agreement with recent geological studies.

A JUMBLE OF HOBBITS AND GIANTS: PENGUINS AND OTHER VERTEBRATES FROM THE LATE OLIGOCENE ROCKY SHORELINE AT COSY DELL, SOUTHLAND, NEW ZEALAND

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The Cosy Dell rocky shore deposit near Gore, Southland (Late Oligocene, Duntroonian - lower Waitakian) reveals much about the biota of Zealandia during a period of marine transgression and minimal emergent landmass. The vertebrate assemblage includes penguins, rays, sharks, bony fish, probable cetaceans (whales, dolphins), and a presumed sea bird and sea turtle. Specimens are isolated and generally fragmentary bones, worn due to the active wave-dominated depositional setting.

Bones from different-sized penguin species are present, but none are complete enough to be named to genus. No bones exhibit juvenile features. Some hindlimb elements are larger than emperor penguin (*Aptenodytes*). Fragmentary tibiotarsi and a radius are similar in size to the yellow-eyed penguin and medium-sized crested penguins (*Megadyptes*, *Eudyptes*). An ulna and coracoid are from tiny penguins comparable in size to little blue penguin (*Eudyptula*) and the smallest banded penguins (*Spheniscus*). Elsewhere, small *Eudyptula*-sized fossil penguins are rare; two Late Oligocene South Canterbury localities are the only New Zealand sites yielding associated bones from tiny specimens. Lone bones are known from Canterbury-Otago mid-Cenozoic

localities. Small Paleogene penguins are reported only from New Zealand and Seymour Island, Antarctica.

Cosy Dell has the richest Chatton Formation vertebrate biota, and one of the greatest size-ranges recorded for a fossil penguin assemblage. The Cosy Dell penguins probably nested in colonies along Southland's subtropical coastlines of sandy beaches, rocky shores and estuaries, festooned with rainforest and mangroves. Small ancient penguins, like their modern counterparts, probably had restricted foraging ranges, and likely exploited local marginal shallow seas. Larger penguins probably foraged in deeper continental shelf and slope waters further afield.

KINEMATIC PERMEABILITY INVERSION USING INDUCED SEISMICITY APPLIED TO THE PARALANA EGS STIMULATION

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In Enhanced Geothermal Systems (EGS) projects, in-situ permeability is artificially enhanced through high pressure injection of cold water. These stimulation operations typically induce large seismicity cloud. Earthquake triggering is assumed to be mainly a consequence of pore pressure increase through an existing fracture network, a mechanism called hydroshearing. It can potentially develop the overall permeability of the reservoir through mismatch of the rough surfaces of the shearing fractures. Thus, seismically active volume is commonly inferred to reflect the extent of the

engineered geothermal reservoir. Here, we challenge this assumption. We consider the case of the Paralana-2 EGS stimulation, undertaken in South Australia in 2011, where 4172 micro-earthquakes were detected and located. Injectivity, the ratio of injection rate to wellhead pressure, increased approximately linearly during the stimulation, implying permeability enhancement, and thus reservoir creation. To test whether permeability enhancement and seismicity triggering occurred concurrently, we develop an inversion procedure designed to obtain permeability spatio-temporal evolution, a process independent from assumptions on the mechanisms responsible for its increase. In order to do so, we use hypocentre density computed from the induced seismicity cloud as a proxy measure of pore pressure increase, a correlation established from a previous EGS experiment. The results indicate that permeability enhancement is limited to volumes close to the wellbore, and largely uncoupled from seismicity triggering occurring further away. The reservoir created at Paralana is thus much smaller than assumed by looking just at the seismicity cloud. Furthermore, it indicates that hydroshearing is not the mechanism primarily responsible for permeability enhancement in this case. Our study suggests that the success of hydraulic stimulations may be overestimated in other EGS settings.

DATING ALPINE SCHIST MYLONITISATION AND THE ROLE OF THE MID-CRUSTAL DECOLLEMENT

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We constrain the pressure-temperature (PT) conditions and the timing of mylonitisation of Alpine Schist directly above the central Alpine Fault for discussing the timing of transpressional crustal thickening and the role of the mid-crustal decollement in the Southern Alps. Crustal-thickening related thrusting reflects the direct response of the rocks to initiation of oblique plate convergence. A common concept is that the lithosphere of the incoming Pacific Plate delaminates along a mid-crustal decollement and lower crustal material is either added to the orogenic root or subducted with the Pacific lithospheric mantle. The fact that no rocks higher than amphibolite-facies grade are exhumed despite huge dip slip movement is compelling evidence for the mid-crustal decollement. Kinematic modelling suggests a ramping decollement between 15-25 km depth (Herman et al., 2009).

Three Rb-Sr multi-mineral isochrons yielded ages of 10.4 ± 0.5 and 8.9 ± 3.2 Ma for amphibolite-facies mylonitisation at Gaunt Creek and Harold Creek. PT conditions for mylonitisation were ~ 1 GPa and $\sim 565^\circ\text{C}$. The Rb-Sr age of 10.4 ± 0.5 Ma from Harold Creek is a maximum age for the end of ductile deformation and almost identical to an

$^{40}\text{Ar}/^{39}\text{Ar}$ illite/mica age of 11.46 ± 0.47 Ma from Harold Creek. Our ages of ~ 11 Ma are similar to the age for the onset of transpression by Cande and Stock (2006). We propose that the onset of transpression and associated thrusting/metamorphism started by ~ 11 Ma.

If current convergence rates were used to move the mylonite eastward back along the mid-crustal decollement to its 11 Ma position, the mylonite would end up outside the orogen. Furthermore, a decollement at 15-25 km is unlikely to sample rocks that formed at 35-40 km. We suggest that the Alpine Schist mylonite formed in the orogenic root and was slowly exhumed until the Southern Alps rainshadow developed and the current tectonic regime with the decollement was established.

ASSESSMENT OF DEBRIS FLOW/FLOOD HAZARD AT TE PURU TOWNSHIP, COROMANDEL, USING TITAN-2D AND RAMMS MODELLING

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Debris-flows can have peak discharges of c.40 times greater than that of anticipated flood flows due to the entrainment of sediment from stream beds and banks. Due to their velocity, and rapidity of development, they can have deadly consequences. The Melton Ratio, R (ratio of basin relief to the square root of basin area) is typically used to determine debris flow and debris flood hazard. The important threshold is $R=0.3$, below which conventional fluvial processes are assumed to be the dominant fan-forming processes. While many of the catchments around the Coromandel Peninsula on which townships

are built have Melton $R < 0.3$, geomorphic and historic evidence show that such townships may be vulnerable to debris flows and floods. For a recent comparison, the Matata event in 2005 developed from catchments with a Melton $R = 0.17$ and 0.25 . We focus on the Te Puru Stream fan-delta on the western side of the Coromandel Peninsula, on which Te Puru Township is located. Te Puru Stream now follows an engineered course on exiting the mountain front, diverted north within levees around the fan apex into the Firth of Thames. Landslide susceptibility mapping upstream of the Te Puru fan, both in-field and using GIS indicates the catchment is vulnerable to both shallow soil landslides, leading to debris flows. An assessment of debris flow hazard using the flow simulation programs Titan2D and RAMMS modelled the impacts of a series of discharge estimates from extratropical rainfall events. This modelling indicates that while the discharge reaching the fan apex is somewhat constrained by the channel bend as the river exits the mountain front, debris flows are likely to super-elevate prior to reaching the fan apex. This would lead to avulsion of the Te Puru Stream down the centre of the fan-delta through the township.

**THE GEOLOGICAL AND STRUCTURAL
CONSTRAINTS ON THE PRODUCTION OF
AGGREGATE, AT MATAKANA QUARRY,
RODNEY**

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Aggregate demand for infrastructure and building in Auckland is predicted to increase substantially as a result of increasing growth in population and wealth. In 2012 alone, the total value of industrial minerals mined was over \$388 million. The Matakana quarry is an

important site in the limited scale of quarries producing good quality aggregate to the Auckland area. Transport costs associated with aggregates are substantial as they double with every 30 kilometres transported away from the source. Therefore, maximising the safe production from quarries like Matakana is critical to economic development in the region, particularly with the new roading plans for north of Puhoi. Numerous factors impact on the safe production of aggregates, these include the scale of the excavation and the machinery/equipment being used. In particular, slope design is critical maximising in aggregate production, while ensuring hazard risks are minimised and yet still maintaining economically viability. An understanding of host rock stratigraphy and structure is integral to the decision making when designing slopes. This study used a combination of the conventional scanline surveying and computational digital photogrammetry mapping techniques to define the different geological and structural characteristics within the quarry. Both kinematic and limit equilibrium analysis geotechnical programmes were used to classify the different structural zones within the quarry and quantify their stability, which allowed for an interpretation of aggregate production at the Matakana quarry.

**POTENTIAL STABILISATION OF HALLOYSITE-
RICH SENSITIVE SOILS OF THE BAY OF
PLENTY BY CATION MANIPULATION**

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The aim of this study is to determine whether salt treatment of sensitive soils formed in halloysite rich soils of the Bay of Plenty provides a viable means of improving soil

behaviour. Soil collected from the base of the landslide at Bramley Drive, Omokoroa, was treated with 3 differing potassium based salts (KCl, KOH and K_2CO_3). Intact soil cores were soaked in K_2CO_3 solution for a period of three weeks before being subjected to static tri-axial testing; untreated soil cores were tested at the same stress conditions. Tri-axial testing showed a significant increase in the peak deviator stress measured when comparing the untreated and treated soils at its point of failure, with increases in peak deviator stress measured for the treated soils in the order of 124 - 227%. Strain softening for treated soil was also measured to be less than that of the untreated soil at all confining pressures, a trait reflected in pore pressures measured at point of failure also. Stress path plots indicated that untreated samples underwent contraction rapidly as deviator stress increased, with no clear failure point observed as would be expected from an over consolidated clay. In contrast, stress paths for the treated samples showed the soils dilating before reaching point of failure and undergoing contraction following failure. Differences in friction angle and cohesion were also measured between treated and untreated samples, with untreated soil indicating friction angle and cohesion of $\Phi'=19.3^\circ$, $C'=26.6$ kPa. Both friction angle and cohesion values increased in treated soils ($\Phi'=28.2$ and $C'=58.4$). These results indicate a real potential for slope remediation by cation manipulation in the Bay of Plenty.

DEVELOPING SEDIMENT FINGERPRINTING TECHNIQUES FOR THE WHANGANUI CATCHMENT, NEW ZEALAND

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Suspended sediment is an important component of the fluvial system, affecting water quality, chemistry, channel morphology and ecological character of streams and rivers. Due to the inherent geological and geomorphological character of the Whanganui catchment, anthropogenic influences such as land use change have greatly exacerbated rates of erosion leading to increased suspended sediment entering waterways. Understanding the spatial origin and movement of suspended sediment is an important step in guiding sustainable management of the natural resources within the Whanganui catchment.

Sediment fingerprinting is a tool for evaluating sediment provenance, capable of directly quantifying sediment supply through differentiating sediment sources based on inherent geochemical signatures. The preliminary approach for this research is to conduct a catchment-wide time-integrated sampling programme. Geochemical fingerprints will be established for major tributaries using statistical analysis and un-mixing models will be employed on samples collected lower in the catchment to elucidate sediment provenance. Further aims of this research are to develop techniques to analyse a wider spectrum of grain sizes and to provide insight into historical sediment flux regimes using flood deposits.

Māori have a long-standing relationship with the Whanganui Catchment and its waterways. More than a millennium of occupation has embedded this environment deep into the collective consciousness of Whanganui iwi. A substantial environmental knowledge base has accrued during this time and is contained in the forms of recitation of whakapapa, stories, proverbs, sayings, songs, cultural activities and tribal expressions. Incorporating these philosophies into this research presents an opportunity to study the catchment with a unique Maori perspective using methods that adhere to mātauranga ā-iwi principles and values. This indigenous knowledge base can provide holistic traditional and contemporary insights into the processes operating within the Whanganui catchment and will be a key component in developing effective research tools and management strategies.

APPLICATION OF THE RHENIUM-OSMIUM ISOTOPIC SYSTEM TO NEW ZEALAND SOURCE ROCKS AND OILS

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The application of the Rhenium-Osmium (Re-Os) isotope system in understanding the processes and elements of a petroleum system is a developing area of research with great potential. Re and Os are organophilic trace metals that become enriched in organic-rich sedimentary rocks. The resulting combination of high and variable Re and Os concentrations with variations in Os isotopic composition produced by the radioactive decay of ¹⁸⁷Re to ¹⁸⁷Os, means that these metals can be used to directly and precisely

date petroleum source rocks. Re-Os isotopic dating has also been extended to crude oils, potentially providing the timing of oil generation and/or expulsion from the source rocks. Further, it has been established that the Os isotopic composition of oils and bitumen faithfully reflects that of their main source units. The isotopic system can thus provide a potential means for tracing oils to their source rocks, showing particular promise for biodegraded oils where conventional biomarkers based on lighter oil components have been compromised. But while the Re-Os isotopic system shows excellent promise in dating and tracing source rocks and oils, there remain some fundamental questions. In particular, most published work has focused on sediments and oils of marine origin. How applicable is the Re-Os isotope system to terrestrial, coaly sourced systems such as typify most of New Zealand's petroleum basins? We aim to evaluate the behaviour of the Re-Os isotopic system in well characterised terrestrial source-oil systems from the Taranaki Basin, and assess its ability to trace and date such systems. We will present results from our preliminary analyses and the methodologies used.

CHARACTERIZING AMORPHOUS MATERIALS BY X-RAY DIFFRACTION: APPLICATIONS ON EARTH AND MARS

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Although classically used for determining mineral componentry in geologic samples, X-ray diffraction (XRD) also records important information on amorphous materials, such as volcanic glass, amorphous silica, and other

partially-amorphous materials. Recent studies have utilized XRD to determine crystallinity in volcanic materials related to a range of different processes including ignimbrite devitrification, volcanic dome emplacement, and determining basaltic eruption styles. In order to standardize the methodology, we present a new approach to processing XRD patterns, using Bayesian statistics. This is a new approach, in the program AMORPH, not only quantifies the crystallinity of geologic materials but it characterizes the shape of the amorphous component in terms of skewness, non-gaussianity, centre of mass, and width.

We see a significant improvement in reproducibility of crystallinity results using the statistical approach and AMORPH software, regardless of user, and the composition of the material. The methodology is best-suited for crystallinities between 10-90%. In addition, testing on compositionally diverse volcanic glasses (basalt and rhyolite) clearly indicates that we can independently assess changes in the XRD patterns associated with structural changes in the silicate glass. Compared to basaltic glass, the tested rhyolite has an increased positive skewness and a shift to lower two-theta values. Processing of XRD results of inferred basaltic and silicic Martian sediment samples produces similar changes in amorphous characteristics, particularly with a distinctive 4x increase in skewness in the silicic material. Overall, we see that regardless of instrumentation, characterization of amorphous materials produces systematic results with regard to glass composition and our new AMORPH program more accurately reproduces crystallinity results in a range of compositions and rock types.

HIGH RESOLUTION SIMS ANALYSIS OF $^{87}\text{SR}/^{86}\text{SR}$ IN PLAGIOCLASE: METHOD DEVELOPMENT AND INITIAL APPLICATION

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Plagioclase, a ubiquitous igneous mineral, responds readily to fluctuations in crystallization conditions and records variations in host magma composition. These qualities make plagioclase ideal for deciphering magma evolution and pre-eruptive changes, which are determined through combination of mineral textures, compositional zoning and isotopic ratios. The temporal scale at which we can determine changes in magmatic conditions is dependent on the spatial resolution of techniques used to obtain mineral compositions. Therefore by improving the resolution at which isotopic compositions can be determined, specifically Sr in plagioclase, we can improve our understanding of rates of magmatic change. Methods presently used are laser ablation multi-collector inductively-coupled plasma mass spectrometry (LA-MC-ICPMS) and thermal ionization mass spectrometry (TIMS). TIMS is the most precise, but necessary microdrilling and chemical separation make it a time-consuming technique. Although LA-MC-ICPMS offers in-situ analysis, the diameter of ablation spots (commonly 100 μm) limits the number of crystal domains that can be analysed. Additional issues for both methods include diffusion and averaging of Sr isotopes across the analysed region, and size limitation

on the crystals that can be analysed. Here we investigate the potential for MC-secondary ion mass spectrometry (SIMS) as a new method for obtaining $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in plagioclase. This was done using a CAMECA IMS 1280-HR at Hokkaido University. Run conditions include $^{16}\text{O}^-$ primary ion beam ($\sim 12\ \mu\text{m}$ diameter, 6 nA, 23 keV), mass resolving power ($M/\Delta M$) of 7,000, 400 s total count time per spot, and average external precision of ± 0.0005 (2σ). ^{85}Rb and $^{40}\text{Ca}_2$ were measured to determine contribution of interferences of ^{87}Rb and Ca dimers to $^{86}\text{Sr}^+$ and $^{87}\text{Sr}^+$. Crystals from three rhyolite Okataina volcano deposits were examined initially. Future work includes improving analytical precision, analysing plagioclase with variable An contents, and locating natural plagioclase with homogeneous $^{87}\text{Sr}/^{86}\text{Sr}$ and An_{70-30} as additional analytical standards.

SPATIO-TEMPORAL REGIONAL STRESS FIELD ASSOCIATED WITH THE MW 7.8 KAIKOURA EARTHQUAKE BY STRESS TENSOR INVERSION IN THE NORTHERN SOUTH ISLAND

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The Mw 7.8 earthquake occurred in the Kaikoura region of northern South Island on 14 November 2016 (UT), with rupturing of a complex network of right-lateral, left-lateral and oblique-reverse faults. We have

calculated the spatio-temporal variation of the crustal stress field by stress tensor inversion using focal mechanisms of the micro- to moderate-sized earthquakes in the area.

In the period before the Kaikoura earthquake, we analyzed seismic data acquired by a dense seismic array, which has been recording over 2 years, from 2013 to 2015. We determined focal mechanisms using the HASH program (Hardebeck, 2002; 2003) and estimated the crustal stress field using the SATSI algorithm (Hardebeck and Michael, 2006). In the period after the Kaikoura earthquake we analyzed the data acquired by a dense seismic array which recorded, from 13 November 2016 to 30 November 2016, to estimate the post-seismic stress field. We also used GeoNet CMTs calculated over the 7 month period from 14 November 2016 to 30 June 2017.

We compared the stress tensor solutions from before and after the Kaikoura earthquake. Using a $1^\circ \times 1^\circ$ regular grid inversion, we determined the orientation of the σ_1 axes as SE-NW, both before and after the earthquake. The orientations of σ_2 and σ_3 axes interchanged after the Kaikoura earthquake. Before the earthquake the σ_2 axis was vertical and the stress regime was one of strike-slip faulting, while after the earthquake the σ_3 axis is vertical and the stress regime is that of reverse faulting.

To consider the effect of irregularity of the aftershock distribution, we also group 157 focal mechanisms spatially into 6 clusters using k-means algorithm. The result from the 3D clustering inversion using the k-means method shows a similar result utilizing the regular gridding. We conclude that the observed temporal variation is robust using the different groupings.

**SEISMIC ANISOTROPY CHANGES
ASSOCIATED WITH THE 2016 KUMAMOTO
EARTHQUAKE, JAPAN**

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Seismic anisotropy, measured by shear-wave splitting, may be an indicator of stress in the crust due to the effects of stress on aligned cracks. However, the effects of mineral or structural alignment, and the difficulty of distinguishing between changes in anisotropy along an earthquake-station path from distinguishing changes in the path itself, have made such findings controversial.

The sequence of earthquakes related to the M=7.2 Japanese Kumamoto earthquake of 14 April 2016 includes both foreshocks, mainshocks and aftershocks. The sequence was recorded by the NIED permanent network, which already contributed background seismic anisotropy measurements in a previous study of anisotropy and stress in Kyushu. This provides a unique dataset to test the use of shear wave splitting for measuring variations in stress because clusters of closely-spaced earthquakes occurred both before and after a mainshock. We use the automatic, objective splitting analysis code MFAST to speed process and minimize unwitting observer bias when determining time variations.

Earthquakes in the region that occurred in 2016 yielded over 100,000 shear-wave splitting measurements. Results at some stations clearly differ from those of our earlier study. They also change between earthquakes recorded before and after the mainshock. For stations near the fault rupture, median delay

times increase after the foreshock and decrease with time afterwards, suggesting that cracks form with the rupture and then heal. Further work is under way to determine whether the changes in orientation are more likely due to changes in stress during the observation time, or due to spatial changes in anisotropy combined with changes in earthquake locations.

**GEOCHEMISTRY AND PARAGENESIS OF
SCHEELITE AT GLENORCHY, OTAGO, NEW
ZEALAND**

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Scheelite (CaWO_4) is an important tungsten ore mineral and has uses in both industrial and commercial settings. Scheelite-bearing quartz veins in the Glenorchy region have been mined intermittently since the 1880's but have had little investigation. We report a study of samples from the Glenorchy and Bonnie Jean lodes on Mt Judah that we have geochemically and isotopically characterised. Electron backscatter imaging shows the large scheelite masses in the veins are made up of numerous small grains with different crystallographic orientations. Cathodoluminescence (CL) imaging reveals that the grains within the scheelite masses to have slightly different responses, but all are Mo-poor and fluoresce bright blue under short wave UV light. Scheelite is a major host of REE, and REE variations within samples correspond to CL response. The scheelite grains show MREE variations that form three types, which we interpret to represent precipitation from a fluid that had undergone variable fractional of MREE. In-situ scheelite $^{87}\text{Sr}/^{86}\text{Sr}$ by LA-ICP-MS averages ~ 0.7070 . Since host rock samples have less radiogenic age-corrected whole rock

$^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.7046-0.7050 at 135 Ma, there must be a more radiogenic lithology at depth that has imparted its Sr isotopic signature on the mineralising fluid. This source is suggested to be the Aspiring Terrane. Paterson and Rankin (1979) showed that wallrock adjacent to mineralised veins is depleted in Sr, and so our results mean that the volume of fluid flowing through this hydrothermal system must have been large enough to overprint the Sr signature of the host rock. Carbonate is present in the veins, but it replaces scheelite and is therefore a later mineral. It takes on the scheelite isotopic composition where it replaces it but otherwise is more radiogenic. The geochemical and isotopic compositions of minerals in the Glenorchy W systems therefore require large scale redistribution of hydrothermal fluids from depth.

STABILITY ASSESSMENT OF THE CRATER LAKE OUTLET DAM AT MT. RUAPEHU VOLCANO

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Mt. Ruapehu volcano hosts a 10^6 m^3 lake in the active summit crater, making it prone to lahars due to the abundance of water stored at high elevation. Apart from eruptive periods, large lahar events can occur when portions of the crater rim fail and partially drain the lake; such lahars occurred in 1953 and 2007. Here, we investigate the potential of future dam-break lahars at the current outlet dam using detailed geotechnical assessments and numerical modeling. Prehistoric lavas and breccias

comprising the outlet dam were sampled and analysed using rock and soil physical and mechanical laboratory tests. These properties were used as input in finite element and limit equilibrium method-based groundwater and stability models. Groundwater models indicate that a layer of laminated ash deposited on the inside of the crater during past eruptions likely serves as a low-permeability barrier preventing water from seeping through a matrix-rich breccia unit of the outlet dam. The degradation or removal of this impermeable unit could result in undercutting and collapse of the outlet. Stability models suggest that the continued incision of a lava cap on top of the breccia unit, which is actively eroding due to the flow of water over time, could also result in water seepage into the breccia unit and subsequent failure. Ground acceleration from local and regional earthquake events sourced from nearby stations were additionally used in a Newmark stability analysis to determine critical slip surfaces and displacements for different sized earthquake events. These results indicate that major volcano-tectonic earthquakes could induce failure of the outlet dam, leading to drainage that could lower the crater lake up to 4 m. Engineering-focused studies such as these can reveal the influential variables in volcanic stability, useful for long-term hazard planning at Mt. Ruapehu.

STRUCTURAL EVOLUTION OF SOLANDER BASIN

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The Solander Basin is nestled between the Alpine Fault and Stewart Island at the foot of New Zealand. Since its inception in the mid-

Cretaceous, the basin has been translated 450 km south-westwards along the Alpine Fault from a location near the southern Taranaki Basin. Given its location, deformation in the Solander Basin provides a unique record of evidence for the timing and kinematics of tectonic events in southern Zealandia; including the Fiordland block and Emerald Basin.

The aim of this research is to determine the structural evolution of the Solander Basin by describing the geological structures and sedimentary sequences that can be identified on 2D seismic reflection lines. The data available for the analysis consists of 147 seismic reflection lines collected from 1971 to 2006. The Late Eocene to Recent sedimentary stratigraphy and age of seismic horizons in the basin have been mainly constrained by the Solander-1 and Parara-1 wells.

Preliminary seismic interpretation reveals mid- Cretaceous to early Cenozoic normal faults associated with half-grabens and Late Miocene to Recent reverse faults and associated folds. Most of the early normal faults are reactivated to produce inversion structures. Each of the two phases of faulting are followed by periods of uplift and erosion which produced regional angular unconformities of possible Late Eocene and Pliocene ages. Thus the tectonic history of the Solander Basin appears to be comparable to the Taranaki Basin. Based on interpretations of the Solander Basin to date we can neither conclusively demonstrate significant (e.g., kms to hundreds of kms) strike-slip movement on the Moonlight Fault nor see evidence for extension associated with Emerald Basin opening.

ARE GARNET PYROXENITES IN KAKANUI MINERAL BRECCIA PART OF HIKURANGI PLATEAU?

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The subducted extent of the Hikurangi Plateau beneath southern Zealandia remains debated. It has been suggested from seismic data that the southernmost limit of the Hikurangi Plateau is located somewhere between Dunedin and Timaru. We test this theory from a petrological view point by looking at garnet pyroxenite xenoliths in the Kakanui Mineral Breccia, since these could be metamorphosed components of the plateau. Petrographical and geochemical analysis has been applied to six garnet pyroxenite samples. Temperatures given by garnet-clinopyroxene thermometer range between 1081-1260°C and imply that last equilibration of the xenoliths occurred within the lithospheric mantle, which is appropriate for the plateau. Whole rock trace element and REE data show that Kakanui garnet pyroxenites have MORB-like chemistries, which are similar to the plateau. Whole rock Sr-Nd isotope data show significant differences between the garnet pyroxenites and the MORB-like Hikurangi Plateau, with the garnet pyroxenites being less radiogenic in Sr and more radiogenic in Nd. The garnet pyroxenites are instead chemically and isotopically similar to the intraplate basalts that have erupted throughout Zealandia, and we suggest that these rocks represent stalled basaltic melts in the lower lithosphere that were subsequently entrained by the nephelinite magma that formed the Kakanui Mineral Breccia. There remains an absence of petrological data that indicates the presence of the Hikurangi Plateau beneath Otago.

CRETACEOUS TO RECENT PLATE TECTONIC RECONSTRUCTIONS OF ZEALANDIA

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Reconstructions of the past relative positions of north (Lord Howe Rise and Challenger Plateau) and south Zealandia (Campbell Plateau and Chatham Rise) provide important constraints on the orientation and amount of strain accumulated between rigid plates separated by divergent, convergent and transform boundaries within the Australia-Pacific plate tectonic circuit. This configuration of plates ultimately determines how, where, and when sedimentary basins formed during and since continental breakup along the eastern margin of Gondwana.

While the first-order geometry of Zealandia is well established, uncertainty still remains regarding plate motions through the latest Cretaceous to Eocene. Recent reconstructions are, in some cases, inconsistent with geological observations at key time intervals, highlighting uncertainties inherent in plate reconstructions for the SW Pacific.

Building on previous tectonic reconstructions and incorporating published seafloor magnetic interpretations, paleomagnetic observations and geological constraints (e.g. Terrane geometry and distribution), we have developed a first-iteration tectonic framework to reconstruct Zealandia back through to the latest Cretaceous.

We have developed a consistent and accessible model with which to test hypotheses relating to the pre-breakup

configuration, the establishment of the modern plate boundary through Zealandia, and internal deformation of North and South islands during the Neogene.

Using GPlates, we use a simple double-hinge slat model to describe Neogene deformation within the New Zealand plate boundary zone, while the geometry of north and south Zealandia during the Eocene is modified from recently published models based on geologic considerations. This study ultimately highlights the need for integrated studies of the Zealandia plate circuit.

MICROSTRUCTURES AND ANISOTROPIES OF HARZBURGITE AND LHERZOLITE XENOLITHS FROM EAST OTAGO

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Mantle xenoliths, entrained in volcanic rocks, provide constraints on mantle geodynamics. We have examined spinel-facies peridotites, from Trig L, East Otago, that occur as xenoliths in alkaline basalt volcanics, erupted during the late Oligocene-Miocene (24-9 Ma). Ten xenoliths were selected for quantitative microstructural analysis using Electron Backscattered Diffraction (EBSD). The samples comprise harzburgites and lherzolites. Mineral chemistry constrains the harzburgites to have equilibrated at lower temperatures (748-849 °C) than the lherzolites (827-960 °C). Crystallographic preferred orientations (CPO) of olivine in all samples are characterised by mutually perpendicular single maxima clusters of [100] and [010] with [001] less strongly aligned. Olivine CPOs are stronger in harzburgite than lherzolite. The shape of harzburgite and lherzolite olivine CPOs overlap but the tendency is for [010]

alignment to be better developed in harzburgite and [100] in lherzolite. In the harzburgites, the orthopyroxene [001] aligns in a cluster parallel or sub parallel to olivine [100], with orthopyroxene [100] and [010] less strongly aligned with olivine [100], [010]. In lherzolites the orthopyroxene CPOs do not correspond so well with the olivine CPOs, but clinopyroxene (100) is broadly aligned in a cluster parallel to olivine [100]. The CPO data suggest that the operating deformation mechanisms and potentially the mantle rheology of the harzburgites and lherzolites were different. Calculated elastic properties for average harzburgite and lherzolite samples would give rise to shear wave splitting in steeply inclined teleseismic data if the olivine [100] were orientated horizontally. 80km thickness of harzburgites or 150km thickness of lherzolites, or some combination in a layered mantle structure, can explain the ~1s of shear wave splitting in data related to the present day mantle.

FAULT FRICTION IN THE SEISMOGENIC UPPER CRUST

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Seismic activity is largely restricted to the upper 15 ± 5 km of deforming continental crust where $T < 350^\circ\text{C}$. Within this seismogenic zone, frictional shear strength of faults is governed by: $\tau_f = C_f + \mu_s(\sigma_n - P_f)$, where σ_n is normal stress across the fault, P_f is pore-fluid pressure, C_f is residual cohesion, and μ_s is the friction coefficient. Laboratory determinations generally show $0.6 < \mu_s < 0.85$ (Byerlee, 1978), but application to natural faults has been questioned because of small displacements and specimen size in laboratory experiments, and possible clay mineral alteration in natural

fault rocks.

M > 5.5 fault ruptures 'sample' substantial portions of the seismogenic upper crust. Global dip compilations have been made for near-pure dip-slip ruptures in continental crust where the rupture plane is positively discriminated. 2-D reactivation analysis shows that for faults containing σ_2 and oriented at θ_r to σ_1 , *optimal reactivation* occurs when $\theta_r^* = \frac{1}{2}\tan^{-1}(1/\mu_s)$, and *frictional lock-up* occurs when $\theta = 2\theta_r^* = \tan^{-1}(1/\mu_s)$. Assuming 'Andersonian' horizontal σ_1 trajectories for pure reverse-slip faulting, θ_r corresponds to the fault dip, δ , but for normal faulting with vertical σ_1 , $\theta_r = (90^\circ - \delta)$. In the case of reverse-slip faulting, a well-defined peak in the dip histogram at $30 \pm 5^\circ$ is flanked by two subordinate peaks at $50 \pm 5^\circ$ and $10 \pm 5^\circ$ with no dips above 60° . For normal fault ruptures, the dip range extends from 65° down to 30° . Thus $\theta_r = 60^\circ$ to inferred σ_1 (twice the optimal angle, $\theta_r = 30^\circ$, for reshear of reverse faults) appears to represent the angle of frictional 'lock-up'. This is consistent with $\mu_s \approx 0.6$, at the base of Byerlee's (1978) range for hard-rock friction.

Fault weakening by fluid overpressuring, especially in the lower seismogenic zone, remains a possibility.

MULTI-PARAMETER STUDIES OF A PERSISTENTLY ACTIVE VOLCANO, YASUR, VANUATU

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Yasur is a globally rare persistently active volcano that has been in eruption for at least 800 years. It produces sustained, small Strombolian explosions from several summit vents. The processes that sustain such consistent activity over such long timescales are currently poorly understood, as are the mechanisms that drive changes in eruptive style, vigour and power. Whilst small on a global scale, the spectacular explosions can change suddenly to endanger lives of tourists and guides that visit its crater rim on a daily basis. Furthermore, the regularity of eruptions can cause a false degree of safety for visitors. Sudden changes, even minor ones, may send explosive ballistics at low angles or farther than their normal range. It is these small-scale variations from the regular eruption processes that are deadly, and understanding the processes that precede them is a major focus of our research.

An effective approach to gaining a holistic understanding of the dynamics of explosive volcanoes is through synergy of multiple data sets. Each data set provides different pieces of information about the physical processes that drive the activity. In bringing together these diverse sets of data, it is possible to build a unified model of the factors that control explosive vigour and consequent hazard.

Observations were carried out during an extended field campaign from September to

November 2016. Results are used to identify magmatic, as well as external (e.g. environmental) processes that affect eruption behaviour and consequent hazard. A multi-component dataset has been produced using a variety of instrumentation and analytical methods, including seismometers, infrared thermal cameras, UV gas spectrometers, visual observations and statistical records, meteorological observations, as well as ash and plume-rain-fallout sampling. These combined data sets comprise a particularly powerful group of tools for parameterizing and understanding volcanic activity over both long and short time-scales.

EXPLORING THE SUBDUCTED PACIFIC PLATE WITH LEAKY MODES

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Observations of earthquakes originating from the Kermadec subduction zone contain low amplitude, high frequency (2-6 Hz) P-wave phases arriving before the main P-wave phase at seismometers in New Zealand. Previous studies suggest a continuous thin high velocity eclogite layer within the subducting Pacific plate is the structure responsible for 'trapping' fast waves called leaky modes. This research has identified leaky modes arriving at seismometers across New Zealand, and the seismograms have been analysed for frequency content and dispersion. We are exploring to extract inter-station information about the subducting plate that hosts the leaky mode via seismic interferometry.

NORTHERN HEMISPHERE INFLUENCE ON THE SPCZ POSITION DURING MIS3: A HIGH RESOLUTION GLACIAL RAINFALL RECORD FROM A NIUEAN SPELEOTHEM

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Here we present a high-resolution glacial paleorainfall record from the heart of the South Pacific Convergence Zone (SPCZ) extracted from a stalagmite from the remote island of Niue (19°03'S 169°52'W). The record spans much of MIS3 (25-45 ka) and captures rapid rainfall changes associated with shifts in the SPCZ.

It is clear that rapid climate shifts in the Northern Hemisphere have a strong influence on the SPCZ. All of the warm Dansgaard-Oeschger ('D-O') interstadials across this period are represented by rainfall increases, with D-O Events 9-11 particularly strongly represented. Since Niue lies south of the core of the SPCZ, this implies that rather than shifting northwards (as the ITCZ does), the SPCZ instead rotates clockwise in response to northern Hemisphere warming (analogous to a shift between modern El Niño and La Niña states). We propose that changes to surface ocean temperature gradients in the Eastern Pacific modulate the strength of the Wind Evaporation SST feedback, changing the size and westward penetration of the eastern Pacific dry zone, resulting in changes to the

diagonality of the SPCZ.

Our record also captures a response to strong northern Hemisphere cooling. The 25-45 ka record is bounded by large hiatuses (inferred dry conditions) coincident with cold Heinrich Stadials (HS) 2 and 5, while HS3 and HS4 are captured as distinct reductions in speleothem growth rate and proxy evidence for declining rainfall. This is consistent with a counter-clockwise rotation of the SPCZ during Northern cooling, supporting our proposed mechanism. Interestingly, our record also captures several other (non-Heinrich) cooling events, including a strong 500-year dry interval at ~26ka that is captured in Chinese and Brazilian speleothems and coincides with a strong cooling over Asia (inferred from Greenland dust records). We note the (possibly coincidental) timing between this event and the Oruanui super-eruption at 25.6 ka.

MIXED THOLEIITIC AND CALC-ALKALINE PALEOVOLCANOLOGY OF THE MERCURY BASALTS, COROMANDEL VOLCANIC ZONE (CVZ)

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The "Mercury Basalts", erupted within, but aligned mostly perpendicular to, the NNW-trending, andesitic-dacitic-rhyolitic, Neogene CVZ of northern New Zealand. K/Ar dating defines two broad periods of activity at c. 9 to 8 Ma and c. 6 to 3.8 Ma, each corresponding to major eruptions of caldera-associated rhyolites and ignimbrites.

The older group erupted on northern Great Mercury Island and along the ENE-trending Kuaotunu Peninsula as stacked lava flows with

interlayered breccias and tuffs, some of which include sanidine-bearing rhyolitic material. Other features are relict scoria spatter mounds, agglomerate-filled rifts, dike swarms, a composite lava dome, rarely pillow lavas, and plugs with doleritic to microgabbroic textures. The rocks consist of ol-hy, hy-ol and Q-hy normative basalts and Q-hy normative basaltic andesites, within a range of 50-55% SiO₂.

The younger group occurs east of the Kuaotunu Peninsular on the Mercury Islands, but is also associated onshore with the rhyolites and ignimbrites of the Kapowai Caldera in the eastern CVZ (Woody Hill). The two largest occurrences (Red Mercury Island-Whakau and Stanley Island-Atiu) are remnants of small shield volcanoes that consist of stacked and ponded lava flows, with intercalated breccias and tuff breccias that include sanidine-bearing rhyolitic pumice and crystal tuffs. There are also scoria cone and lava neck volcano residuals, scoriaceous tephra layers, welded agglomerate and spatter-filled vent residuals, sills, dikes and doleritic to microgabbroic plugs, and rarely pillow lavas. The rocks consist of hy-ol normative picritic basalt and basalt, and Q-hy basalt, basaltic andesite and low SiO₂ andesite, within a range of 48-58% SiO₂.

Tholeiitic attributes are shown by zoned olivine and augite with reaction coronas of Fe-Ti oxides, pigeonitic augite, pigeonite, inverted pigeonite, and hypersthene, and phenocrystic and poikilitic to ophitic hypersthene. Spidergrams normalised to NMORB show typical LILE-HFS elemental patterns of arc lavas of continental affinity, with low Nb and elevated Pb.

SEARCHING FOR SUBDUCTION: INFLUENCES ON MAGMA CHEMISTRY IN THE AUCKLAND VOLCANIC FIELD, NEW ZEALAND

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Small-scale volcanism, where a single batch of magma ascends from the mantle and erupts once, is the most common type of subaerial volcanism on Earth. However, the cause for this type of volcanism, particularly in intraplate settings, is not as well-understood as it is for volcanism at mid-ocean ridges, rift zones, subduction-related arcs, or above deep-seated mantle plumes.

The 53 volcanic centres in the dormant, intraplate, basaltic Auckland Volcanic Field (AVF), New Zealand, were formed from this kind of small-scale activity. The Auckland region has had a complex tectonic history, including active subduction off of the coast of the North Island c. 20 Mya, which will have contributed metasomatising fluids to the lithosphere. Current major North Island tectonic activity includes extension at the Hauraki Rift (located ~75 km to the southeast), and subduction at the Hikurangi Trench (located ~400 km southeast of the field).

Our ongoing study is using olivine-hosted melt inclusion compositions from key centres in the AVF to identify possible tectonic influences on magma chemistry. We will present new AVF data in comparison to typical arc, mid-ocean ridge basalt (MORB), and ocean island basalt (OIB) chemistry. Results thus far reveal that AVF magmas are consistently most similar to OIBs, although a subset of samples have higher H₂O/Ce ratios than would be expected (up to 600; above ~300 usually indicates a subduction influence).

MANTLE FLOW AND THE LATE CENOZOIC BASALT FIELDS OF NORTHERN NEW ZEALAND

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As convergent tectonics and associated subduction-related magmatism in northern New Zealand migrated southward during the late Cenozoic, fields of basalt volcanoes on small spatial and short to medium but variable temporal scales and with characteristic intraplate chemical compositions developed behind the active arcs; these are the Auckland province (Ngatutura, South Auckland and Auckland) and the Northland province (Kaikohe-Bay of Islands and Whangarei) volcano fields. Differences between these volcanic systems are in longevity and, in detail, their chemistry, indicating subtly differing conditions of magma generation and of mantle source regions. The Northland fields have characteristic trace element and isotopic signatures that are clearly different from those of the Auckland fields. Interpretation of selected trace element ratios indicates that their source area is within the spinel lherzolite facies of the upper mantle whereas the Auckland fields originated in the asthenosphere at greater depth. Further, some Northland basalts show compositional features indicating a subduction modified source.

A possible explanation for the intraplate volcano fields in northern New Zealand is edge driven convection where the boundary between thick and thin lithosphere focuses upwelling that brings hot material from under thicker lithosphere to shallower levels. The asymmetry and the discontinuity in the thickness of the lithosphere is provided by the juxtaposition of Paleozoic and Mesozoic crust.

Mantle flow beneath this junction led to small-scale decompression melting in stratified and heterogeneous mantle sources producing the magmas that rose to produce the volcanism of the northern New Zealand fields. An as yet unresolved question is why the location of intraplate volcanism has been stationary in Northland over the past 10 my but has migrated systematically northward during the last 3 my in the Auckland province.

PROVENANCE OF LATE CRETACEOUS AND PALEOCENE SEDIMENTS IN THE SOUTHERN TARANAKI BASIN, NORTHWEST NELSON

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The northwest Nelson region has excellent outcrop of the Late Cretaceous Rakopi and North Cape formations and the Paleocene Farewell Formation, which extend north through much of the Taranaki Basin. During their deposition, uplift of sediment source rocks and sediment transport was controlled by the northeast striking Wakamarama and Kahurangi faults. These bound the Pakawau sub-basin. Potential sediment sources include intraformational clasts, the Buller and Takaka terranes, and Tuhua Intrusives (Separation Point Suite and Karamea Suite). The aim of this research is to examine the changes in sediment provenance through these three formations using conglomerate clast counts, sandstone point counts and geochemical analysis of siltstones. This will contribute to a better understanding of the paleogeography of the southern Taranaki Basin.

The conglomerates in the North Cape and Farewell formations are dominated by fine-

grained metasedimentary clasts, likely sourced from the Buller Terrane. Granitoid clasts are another significant component, and become increasingly weathered up-section. The petrography of these clasts suggest a Separation Point Suite source, although XRF analyses are inconclusive. Volcanic clasts are a minor constituent, most likely derived from the Takaka Terrane. Other minor clasts are vein quartz, schist, and siltstone. Rakopi, North Cape, and Farewell formation sandstones are dominantly lithic feldsarenites. Lithic types include siltstones, plutonic rock fragments, volcanics, schist, and chert. Towards the top of the Farewell Formation in the northeast, the sandstones become more quartzose, and the lithics dominated by quartz siltstone.

The increasing quartz content and weathering of clasts through the Farewell Formation likely indicates increased transport time and reworking. The prevalence of Buller and Takaka Terrane clasts suggests there was a significant component of axial drainage along the Pakawau sub-basin. The Separation Point Suite clasts show sediment was also supplied from uplifted granitoids to the southeast of the Wakamarama Fault, continuing into Farewell Formation time.

PROGRESS ON UNDERSTANDING FAULT STRUCTURE IN THE HAMILTON BASIN

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The Hamilton Basin is considered an area of low seismic risk, partly due to the lack of any mapped active fault traces within the basin. Recent geological and geomorphological mapping provides evidence for at least three

complex fault zones striking approximately SW-NE through and near Hamilton City. Geomorphological signatures including rectangular drainage patterns, stream knickpoints, and linear ridge and drainage systems which all point to structural control on the path of the Waikato River and its tributary gullies. Several fault traces are accessible, including one very complex fault zone at Kay Rd in northern Hamilton which was exposed during earthworks for the Hamilton Section of the Waikato Expressway. These exposed fault traces indicate significant splintering of fault planes on encountering the soft sediments and tephras infilling the basin; hence fault zones are wide and characterised by multiple traces forming a complex ridge geomorphology. Steeply dipping normal faults are typical, with relative uplift to the north, indicating a north-south extensional environment. While several geomorphic lines of evidence suggest fault movement has displaced the < 20 ka Hinuera Surface, no definitive evidence for movement more recent than 350 ka has yet been identified.

PROVENANCE AND POROSITY ANALYSIS OF THE LATE CRETACEOUS GREYMOUTH BASIN, NEW ZEALAND

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The coal and lacustrine deposits of the Greymouth Basin have been explored for their economic potential. However, the associated coarse clastic sediments have not been as thoroughly investigated. Thus there is continuing uncertainty about the provenance of the sediments and tectonic setting of the basin. This study uses conglomerate clast counts, sandstone point counts and geochemical analyses of clasts to examine the

provenance of the Paparoa Group.

Results show a dramatic eastern vs western lithological difference with conglomerates primarily on the west side of the basin, sandstones on the east, and mudstones inter-fingering both. Most of the clasts encountered were granite, hornfels, and metasedimentary with rare unusual volcanic clasts. Aplite was recorded in the lowermost conglomerates and faded out with the introduction of granitic clasts in the middle Paparoa Group. Trace element geochemistry on basaltic clasts in a conglomerate associated with a fault on the eastern side of the basin shows typical rift signature. Geochemistry analysis of the granites was consistent with the Karamea Suite. The sandstone porosity was variable with grain size, location and stratigraphic position in the basin. The degree of weathering in the sandstones was also variable from minor to major feldspar alteration to clays.

Provenance and geochemistry analysis show that the sediment sources of the basin changed throughout time with results showing two main sources, the eastern granitic Karamea suite and the western Greenland Group metasedimentary sources. This contradicts some previous interpretations. Clast counts also show evidence for the un-roofing of a granitic source with the presence of aplite clasts lower in the basin conglomerates replaced by granite clasts stratigraphically higher. The volcanic clasts are evidence of active volcanism in the area which could be attributed to the rift setting. Porosity in the sandstones was variable spatially and stratigraphically making them a poor option for hydrocarbon reservoirs.

SPELEOTHEM RECORDS OF VOLCANIC ERUPTIONS

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Explosive (super)volcanic eruptions can have a profound effect on climate. For example, at the Permian–Triassic boundary almost 95% of life became extinct at the same time as the Siberian Traps flood basalt eruptions took place. Volcanic eruptions have repeatedly altered conditions on Earth in recent history and have been proposed to account for many of the coldest periods over the past 2500 years. However, our understanding of the actual volcanic impacts on our environmental system remain poorly understood, partly due to challenges in linking different geological records of volcanic eruptions with archives of paleo-environmental data. Research to-date has focused on polar ice cores to identify the chemical signatures of volcanic eruptions. Typically, the environmental effects of these eruptions are examined using dendrochronology (tree ring widths). However, it is challenging to directly correlate between the ice core and tree ring chronologies. This study aims to identify different elements peaks and geochemical fingerprint for different type of volcanic eruption using speleothems. Having identified volcanic spikes we will then, in the same archive, geochemically quantify the magnitude and longevity of regional and global post-eruptive environmental changes.

This research will yield fundamental advances in identifying and quantifying environmental changes from local and global volcanic eruptions of varying sizes and magma compositions.

A MAGMA CARTA: HOW THE HUCKLEBERRY RIDGE TUFF (YELLOWSTONE) REWRITES THE POSSIBILITIES FOR LARGE SILICIC MAGMATIC SYSTEMS

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Large silicic caldera-forming eruptions are conventionally viewed as representing the runaway evacuation of a single, unitary, melt-dominant body. Here we summarise compositional data from the 2.08 Ma, 2,500 km³ Huckleberry Ridge Tuff, the first and largest caldera-forming eruption from Yellowstone. The tuff comprises an initial fall deposit, three ignimbrite members (A, B and C), with another fall deposit separating members B and C. Pumice/fiamme, mineral and matrix glass elemental and isotopic data reveal an extraordinary degree of intra- and inter-member diversities and hence complexities in the magmatic system. Pyroclasts from ignimbrite members A and B are dominated by a rhyodacitic to high-silica rhyolite suite (69-77 wt% SiO₂, 3500-45 ppm Ba) that is mirrored in glass chemistries. A subordinate rhyolitic compositional suite in the initial fall deposits and member A (but missing in member B) is characterised by low Ba concentrations in pumice and glass (<250 ppm). Moderately radiogenic isotopic compositions (⁸⁷Sr/⁸⁶Sr_i = 0.70958-0.71146) in pyroclasts and their constancy with indices of geochemical evolution indicate a dominant fractional crystallisation control on the felsic

chemistries. Minor volumes of mafic compositions also occur (Wilson et al., poster). Renewal of activity for member C after some decades evacuated regenerated and newly formed melt-dominant bodies. The low Ba (<230 ppm) rhyolite suite reappears, chemically similar to those in member A but with markedly different physical characteristics. In addition, juvenile materials defining a dacitic trend (66-71 wt% SiO₂, 670-1200 ppm Ba) and a high-silica rhyolite trend (76-78 wt% SiO₂, 2300-400 ppm Ba) were also erupted. These wholly new suites, despite their diverse elemental chemical characteristics, have overlapping, highly radiogenic isotopic signatures (⁸⁷Sr/⁸⁶Sr_i = 0.72463-0.72962), indicative of a high degree of crustal assimilation. The Huckleberry Ridge Tuff is unique in its complexity and diversity of magmatic compositions, all of which are linked within a single geological event.

NEW INSIGHTS INTO GLACIO-LACUSTRINE SEDIMENTATION IN SOUTH WESTLAND

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Recent work has revealed the presence of numerous, previously unmapped glacio-lacustrine sedimentary sequences exposed in South Westland. Outcrops in the Waitangitaona and Arahura rivers provide new opportunities to understand landscape response to deglaciation at these locations. Outcrop exposures were described in detail using field mapping, sampling and structure from motion photography. These descriptions are then utilised to understand the unique depositional setting of each outcrop, as well as

the lateral and vertical variance observed. Collectively, the outcrop exposures are used to develop a facies model for glacio-lacustrine sedimentation in high erosion-high precipitation environments.

This model is then applied to interpret the glacio-lacustrine sedimentary sequence recovered by Deep Fault Drilling Project 2 (DFDP-2). Drilled in the Whataroa Valley in late 2014, initial findings suggest the formation of a large pro-glacial lake in response to deglaciation, extending across the Westland piedmont. Radiocarbon dating has shown the ~180m post-glacial sequence accumulated in 655 ± 200 years, suggesting the extremely rapid sedimentation rate of ~27 cm/yr.

Comparison between the DFDP-2 sedimentary record with outcrop exposures and modern analogues suggests a transition from an ice-contact to ice-distal depositional setting at the drill site. This is related to rapid glacial retreat and high post-glacial sediment flux promoting rapid lake infill and delta progradation. The developed facies model also allows the dominant modes of deposition into the pro-glacial lake to be examined in detail, and linked to processes controlling sedimentation at the drill site.

Future work will aim to develop a chronology for the Arahura and Waitangitona outcrop sequences, to relate them temporally with the DFDP-2 sequence.

GEOTRIPS WEBSITE – AN UPDATE

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GeoTrips (www.geotrips.org.nz) is the website that informs non-specialists in New Zealand about where to go to investigate interesting geological outcrops and landforms.

The website has been live since March 2017, and we are continuing to add content and to improve usability. The aim for the end of 2017 has been to achieve more widespread coverage of locations around NZ, with a focus on population centres and tourist hot spots, prior to a more targeted and widespread promotional campaign in the early summer.

This presentation will include an update on progress of the website design, content creation by participating scientists, and user analytics. It will also include a look at possibilities for further development of GeoTrips so that it can become a popular and comprehensive platform that enables the public to explore New Zealand’s dynamic history and rich geological environment.

SUBMARINE GEOMORPHOLOGY IN THE SUB-ANTARCTIC AUCKLAND ISLANDS

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At about 50.7S, the sub-Antarctic Auckland Islands/Maungahuka are located near the northern limit of the subantarctic front, a boundary across which southern high- and mid-latitude atmospheres influence each

other. Understanding the paleoclimate of these islands may therefore improve understanding of climate processes and climate change in the southern hemisphere more broadly. While these low-elevation islands are not currently glaciated, terrestrial morphological features including cirques and steep-sided fjords, indicate that they were glaciated during past, colder, conditions. Marine bathymetric observations can extend the record beyond the shoreline by providing evidence of glacier terminus extent and characteristics. This supports additional details regarding glacial history, in particular the conditions associated with retreat from the most recent glacial advance. Here, we report on submarine features observed using high-resolution multibeam swath bathymetry, and the events they imply.

The new bathymetric model of the sea floor used for this work was created using data collected on recent hydrographic charting and research voyages (LINZ, University of Otago). Modern multibeam swath technology collects spatially dense and highly accurate data allowing analysis of previously unknown submarine geomorphic features. Depth of sea floor can also be analysed to highlight aspect, rugosity and other morphometric characteristics, while intensity of the acoustic return to indicate sediment type and biotic environments. Glacial morphology is of particular interest here, and we combine this with estimates of past sea level change to infer conditions at glacial termini (sub-aerial, submarine) prior to retreat.

THE EPISODIC EXPLOSIVE PHASE OF THE AD 1314 KAHAROA ERUPTION (TARAWERA VOLCANO, NEW ZEALAND): NEW INSIGHTS FROM TEPHRA DEPOSITS

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Mid- to large-intensity explosive eruptions are commonly fed by intermediate- to-silicic magmas, and they are characterized by the generation of sustained and quasi-steady eruptive plumes, dispersing large volumes of tephra fallout in the areas nearby. Such eruptions may include a sustained phase of constant activity but they typically consist of a complex succession of volcanic pulses with quasi-steady, convective plumes that alternate and overlap with explosions of different styles and intensities. This makes the time-variant evolution of eruptive behaviour hard to constrain. Detailed field studies of tephra deposits, together with sedimentological and textural characterization of the erupted, deposited material can provide a dataset to understand complex eruptive sequences associated with these eruptions. In this context we investigate the AD 1314 Kaharoa eruption, the youngest, rhyolite-dominated eruption of Tarawera volcano. The eruption developed from multiple vents along an 8 km linear zone and exhibited a complex succession of different eruptive events, including initial sub-Plinian to Plinian explosions with associated pyroclastic density currents (PDCs), and extrusions of lava domes with associated block-and-ash flows (Nairn et al. 2001, Sahetapy-Engel et al. 2014). This study focuses on the explosive phase recorded in the tephra deposits dispersed toward the SE. Preliminary results from field observations, grain-size and componentry

analyses indicate that the Kaharoa eruption was an episodic (occurrence of time breaks) and unsteady (fluctuations in mass discharge rate) eruption. At least seven lapilli-bearing, fallout-dominated units record the deposition from convective columns, each associated to an individual eruptive episode throughout the eruption. The sedimentological features of the tephra units suggest a slightly different evolution for each eruptive episode, characterized by changes in eruption intensity. Ash layers at the top of lapilli-bearing units mark the cessation of each episode. In proximal areas, the fallout-dominated sequence is capped by PDC and block-and-ash flow deposits.

WHAT DO THE MAGNITUDE-FREQUENCY CHARACTERISTICS OF EARTHQUAKES DETECTED BY CROSS-CORRELATION TELL US ABOUT FAULT SOURCE SCALING?

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Methods of earthquake detection based on cross-correlation are now in widespread use and provide a means of greatly expanding earthquake catalogues and mitigating the effects of noise and low-magnitudes. As the earthquakes detected with such approaches have similar waveforms to the template with which they correlate, they have (by design) similar hypocentres and focal mechanisms. Intriguingly, the magnitudes of earthquakes detected by such methods exhibit Gutenberg-Richter magnitude-frequency characteristics

with exponents of ~ 1 that are similar to those of seismicity occurring in much larger crustal volumes and with a range of focal mechanisms. Using examples from seismotectonically distinct parts of New Zealand (Taupo Volcanic Zone, central Alpine Fault, Southern Lakes) and magnitudes calculated using singular value decomposition, we consider the extent to which Gutenberg-Richter (power-law) scaling characterises individual faults. We suggest that the magnitude-frequency scaling of earthquakes detected with specific templates pertains to both a geographically (x, y, z) and a geometrically (ϕ, δ, λ) restricted set of sources, providing a means of studying low-magnitude seismogenesis on a fault-by-fault basis.

CAN ALONG STRIKE VARIATIONS IN THE ALPINE FAULT GEOTHERMAL GRADIENT AFFECT DEFORMATION MECHANISMS AND FAULT STRENGTH AT THE BRITTLE-CREEP TRANSITION?

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A characteristic feature of Alpine Fault (AF) mylonites with dislocation creep microstructures is a coarse recrystallized quartz grain size (40-70 μm). This suggests maximum creep stresses of 35 MPa at minimum temperatures of 500°C, which could be explained by a stepped exhumation temperature trajectory related to extremely rapid cooling when meteoric fluids are able to penetrate into the mylonites at the base of the seismogenic zone.

Ultramylonites with finer grain sizes (<10 μm) are also locally preserved as clasts within cataclastic rocks. These are of two types: (i)

lacking crystallographic preferred orientations (CPOs) and in aggregates with greenschist facies minerals; (ii) with single girdle CPOs, in monomineralic layers with GSI creep microstructures. Type (i) probably deformed by solution-accommodated GSS creep at fairly low stress or fast strain rate, while type (ii) reflect GSI creep at high stresses (>100 MPa). This suggests that in places rocks at the brittle-creep transition are strong and dry, and elsewhere they are damp and weak. The former may represent asperities that are likely sources for earthquake nucleation.

Similar variation in microstructures observed in the Hatagawa Fault Zone, Japan, occurs on a 5-10km length scale (Shigematsu et al., 2009). A surprisingly high geothermal gradient measured in DFDP-2B has been attributed to advection of heat in meteoric-derived fluids circulating between high ridges and deep Quaternary sediment-filled valleys that strike perpendicular to the fault (Sutherland et al., 2017), yielding along-strike variation in the thermal gradient and the fluid pressure at the 5-20km length scale. *Valley vs. ridge geotherms* of 120°C km⁻¹ and 40°C km⁻¹ yield brittle-creep transitions at 4km vs. 8km, and shear stresses of 50MPa vs. 140MPa; solution-accommodated creep further reduces the maximum supported stresses.

It seems likely that topographically-driven variations in thermal structure and fluid availability persist to sufficient depths to affect the deformation mechanisms at the base of the AF seismogenic zone.

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A RECORD OF HOLOCENE PALEOCLIMATE EVOLUTION FROM ROBERTSON BAY, VICTORIA LAND, ANTARCTICA

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Regionally representative records of how Antarctica responded to the transition from the Last Glacial Maximum into the Holocene are an essential component of understanding the processes by which the Antarctic cryosphere responds to a changing climate. Here, we present a high-resolution record of Holocene Antarctic paleoclimate evolution from a previously unstudied section of the Victoria Land margin. In 2015 the Korea Polar Research Institute collected a 571 cm sediment core, GC57, from Robertson Bay, a protected embayment west of Cape Adare and adjacent to the outlet glaciers of the Transantarctic Mountains. Using diatom assemblages, bulk sediment geochemistry, and the magnetic properties of GC57, we reconstruct the response of the East Antarctic Ice Sheet to warming associated with deglaciation at the interface between the Ross Sea and the Southern Ocean. Our multiproxy approach allows us to study sea ice extent, terrigenous input, seasonality, ocean stratification and circulation, and primary productivity from the mid-Holocene (7,400 ¹⁴C year BP) to the present.

A sea-ice associated diatom assemblage indicative of summer sea surface temperatures below 0°C and a high concentration of magnetic minerals demarcate a lower unit in GC57. A rapid transition at 4600 ¹⁴C yr BP is identified by a steep increase in wt% BSi (average 9% to average 13%), a decrease in magnetic minerals, and a subtle assemblage change towards sea-ice associated diatoms with warmer temperature tolerances.

The novel ramped pyrolysis ¹⁴C dating methodology allows us to date the carbon fixed concurrent with deposition and generate a robust age model for GC57 with an accuracy previously difficult to achieve given the uncertainties associated with dating bulk acid insoluble organic matter in Antarctic sediments. When complete, this study will contribute to the larger project of identifying drivers of Antarctic climate dynamics during intervals of rapid change.

THERMAL GRADIENTS IN SUBSTRATES BENEATH LAVA FLOWS: A LABORATORY APPROACH

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Lava flows are generally considered a hazard with binary impacts: anything not in direct contact with a lava flow is assumed to be

unaffected. However, lava flow crises (e.g. Pāhoā, Hawaii 2014-2015) have demonstrated lava flow impacts to critical infrastructure networks can have non-binary consequences. When lava flows have threatened buried infrastructure networks, engineers responsible for these networks have still implemented, and potentially benefited from, lava flow mitigation measures: lava flows are estimated to heat anywhere between 2 cm and 3 m of the substrate beneath them. This is a particularly relevant issue for Auckland, where the vast majority of buried infrastructure is less than 3 m from the surface.

We present results from a series of lava pour experiments measuring thermal profiles in substrates beneath basaltic lava flows. The experiments involved pouring molten lava onto a surface in a controlled environment and were designed to simulate a'a and pāhoehoe lava flows. The first set of lava pours focused on developing a depth-temperature-time relationship in a dry soil substrate. The second set of lava pours used the same set-up, but the substrate was saturated with water. These first two sets of experiments use molten basalt to simulate pāhoehoe lava flows; the third set of lava pours focused on differentiating temperature-depth-time relationships of pāhoehoe flows from a'a flows. To simulate the rubbly base of a'a-type lava flows, we heated volcanic scoria and then poured the molten basalt over it. Finally, we poured lava onto concrete and asphalt, representing footpaths and roads respectively. Together, the results of these experiments create a temperature intensity model to assess the vulnerability of buried infrastructure to lava flows. This will enable engineers at infrastructure companies to make informed decisions about lava flow protection measures when their systems are threatened by lava flows.

THE CAMPBELL MAFIC COMPLEX OF SOUTH ZEALANDIA

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South Zealandia (1.5M km²) offers only five islands/groups, five drill holes, four dredge sites and one volcano to directly determine the nature of its basement crust. A major feature with no exposed source on the Campbell Plateau is the Campbell Magnetic Anomaly System (CMAS). First reported by Davey and Christoffel (1978), they and others explained it as being caused by the same basement terranes and batholiths that caused the onland Stokes Magnetic Anomaly System (SMAS). The CMAS=SMAS interpretation required a putative Campbell Fault or 330km dextral displacement. Others including Beggs et al. (1990) have pointed out various problems with this interpretation.

We have thresholded recent magnetic maps of South Zealandia and find that the main Campbell anomaly has a predominant WSW-ENE trend that is accompanied by a NNW-SSE grain, producing an orthogonal pattern. The orthogonal ENE and NNW striking pattern parallels Southern Ocean mid-ocean ridge spreading magnetic anomalies and transform fracture zones, respectively, to the SE. To the NW of the CMAS the low angle Sisters detachment fault of southern Stewart Island strikes ENE and is offset by at least three NNW km-scale transfer faults. Rapid extensional exhumation of footwall mid crust occurred from 89-82 Ma. Three smaller orthogonal anomalies also occur SE of Chatham Is where one of them can be associated with 86 Ma alkali basalts and trachytes, the only location where the orthogonal magnetic anomalies are exposed onshore. On the basis of orthogonal alignments with known extensional

structures, and the coincidence with Late Cretaceous Chatham Island lavas, we interpret that the CMAS is not caused by terranes or batholiths. Instead, we conclude that the CMAS represents alkalic, predominantly mafic, magmatism associated with a failed rift, some of it at least, only slightly older than final 84 Ma breakup along the Campbell margin.

DETRITAL ZIRCON EVIDENCE FOR THE PROVENANCE OF CRETACEOUS–PALEOGENE SANDSTONES IN THE GREAT SOUTH BASIN

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The Great South Basin (GSB) lies mostly offshore southeast of South Island and straddles several Paleozoic–Mesozoic basement terranes and batholiths. The GSB initially formed as a series of fault-bound terrestrial depocenters during mid-Cretaceous (~105 Ma) extension that preceded Zealandia–Gondwana separation. Basin-wide subsidence began during the Late Cretaceous (~80 Ma) with opening of the Tasman Sea, leading to progressive marine incursion from the east. By Eocene time, the entire basin was submerged.

To investigate the provenance of Cretaceous–Eocene sandstones within the GSB, U–Pb dates were acquired for detrital zircons from 12 samples in six petroleum wells (Tara-1, Rakiura-1, Toroa-1, Pukaki-1, Kawau-1A and Hoiho-1C). The majority of zircon grains (80%) are <400 Ma and define a broadly bi-modal age spectrum with peaks in (1) the Early

Cretaceous (~132–105 Ma) and (2) mid-Paleozoic (~370–350) Ma. This indicates two main sediment sources: (1) the Early Cretaceous Separation Point Suite (~132–105 Ma), and (2) the mid-Paleozoic Ridge (~350 Ma) and Karamea (~370 Ma) suites. Western Province metasedimentary rocks (>400 Ma), Brook Street Terrane (~300–270 Ma) and Darran–Longwood suites (~270–133 Ma) were subordinate. However, the proportion of Western Province zircons (~20%) is significantly greater than age-equivalent Taranaki Basin sandstones. Rift volcanism associated with extension is represented by ~102–84 Ma zircons.

In general, the proportions of zircons from the Karamea, Ridge and Darran suites, and Western Province rocks increase from the Cretaceous to Eocene, while those from the rift volcanics and Separation Point Suite decrease over the same period. We infer that the dominance of Separation Point Suite sources in the Cretaceous was due to tectonic exhumation of proximal source areas, whereas N–S longshore drift and emergent land to the west provided more distal and varied local (e.g., Darran Suite) sediment sources during the Eocene.

NEW ZEALAND'S GONDWANA MARGIN AND ITS NEMESIS

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New Zealand's basement developed as part of the Gondwana margin over a considerable period. Rocks ranging from Paleozoic to late Mesozoic ages form the substrate within, and on which, later units were deposited. In recent years, seismic reflection data, mostly acquired for petroleum exploration, have imaged the latest stages of the development of this margin and its abandonment as a subduction

zone. The abandoned margin extends along the north Chatham Rise and through the Raukumara Basin. Between these two regions, the East Coast of North Island has been so overprinted by modern subduction along the Hikurangi Trough that no indications of the older margin can be seen on seismic data. However, outcrops of the Torlesse Supergroup are widespread along the East Coast and document development just inboard of the abandoned margin.

Subduction ceased along the New Zealand Gondwana margin about 105 Ma after the Hikurangi Plateau collided. Seismic data reveal some of the internal structure of the Plateau and guide speculation about its geology. The advent of modern seismic data has answered some geological questions and has given rise to more. Now we can see the Gondwana margin preserved offshore and we have information about the structure of the Hikurangi Plateau, we can start to ask further questions, such as: where is the Gondwana margin beyond the Raukumara Peninsula? How far does the Hikurangi Plateau extend? Why is it subducting under the East Coast now, when it stopped subduction along the Gondwana margin? Did the collision of the Plateau cause obduction of the Dun Mountain ophiolite and folding of the Murihiku Basin? While this paper cannot offer answers to all these questions, it does suggest some future discoveries that marine researchers may make.

CENOZOIC FOSSIL WOOD FROM SOUTHERN ZEALANDIA

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Cenozoic fossil wood (branches, logs and *in situ* tree stumps) preserved in lignite, conglomerate, sandstone, mudstone and silcrete at 14 sites from the southern South Island is investigated. Both angiosperms and gymnosperms are present, but gymnosperm wood is more abundant. Specimens were collected from south Canterbury (Lake Aviemore and Waihao River), Central Otago (Idaburn, Roxburgh and upper Manuherikia River) and Southland (Bennett's Pit, Cosy Dell Coal Pit, Cosy Dell Lime Pit, Gold Sandpit, Landslip Hill, Mataura Coal Mine, Newvale Coal Mine, Orepuki and Pikopiko). Except for the Eocene-aged Waihao River and Pikopiko Fossil Forest and Pliocene-aged Gold Sandpit and Orepuki locations, all sites are Late Oligocene to Early Miocene in age. Less compressed and silicified samples were selected for rock thin-sectioning and SEM imaging, while softer lignified material was charcoalified. SEM imaging did not produce good results, but sectioning of wood using traditional orientations for wood anatomy, combined with cellular structure keys was used to determine modern affinities for the fossilised wood samples.

Araucariaceae were identified at three sites: Waihao River, Roxburgh and Newvale. Podocarpaceae were present at Pikopiko (*Podocarpus*), Idaburn (*Podocarpus* and *Prumnopitys*), Roxburgh (*Dacrycarpus/Dacrydium*), Cosy Dell Coal Pit (*Lagarostrobos* and *Podocarpus*), Mataura

(*Lepidothamnus* and *Podocarpus*), Newvale and Gold Sandpit (*Phyllocladus*). Cupressaceae (*Libocedrus*) were identified at Idaburn, Mataura and Newvale. A number of sites (Cosy Dell Lime Pit, Bennett's Pit and Mataura) had samples that could represent either *Libocedrus* or *Podocarpus*. Lake Aviemore has angiospermous wood that resembles Casuarinaceae, Myrtaceae or Picrodendraceae, while Idaburn and Landslip Hill produced Casuarinaceae wood (*Allocasuarina* and *Gymnostoma*, respectively). Angiosperms recovered from Pikopiko included *Ixerba* and Elaeocarpaceae. *Nestegis* was found at Orepuki. Identification of samples of fossil wood provides new data that can be used to reconstruct the forest vegetation that grew in southern Zealandia during the Cenozoic.

SEISMIC IMAGING AND GEODYNAMIC MODELING OF THE AUCKLAND VOLCANIC FIELD

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The city of Auckland, New Zealand, sits atop a young and active volcanic field, whose earlier eruptions stem from a series of small yet violent volcanic episodes. Despite the obvious hazard beneath Aucklanders' feet, the origin and mechanisms of the Auckland Volcanic Field (AVF) remain largely unknown.

While plate tectonic theory successfully explains many of Earth's geological features,

an important class of volcanism occurs within plates. The AVF is a prime example of such intra-plate -- and active -- volcanism, and it is widely accepted that the AVF is not an expression of a mantle plume.

The AVF is monitored with a network of seismometers, as part of New Zealand's national GeoNet project. Here, we report our latest 3D subsurface model of the AVF, based on seismic ambient noise tomography (ANT) of the crust and seismic P-wave tomography that extends well into the mantle.

Initial ANT differentiates areas of the AVF crust with continental and oceanic features, which extend deep into the AVF crust. To infer the origin and dynamics of the AVF, we are optimizing ANT models and adding P-wave tomography to constrain structural information of the lithosphere and asthenosphere. These models then serve as inputs for geodynamic modeling efforts, aiming to understand the how and why of the AVF.

ERUPTION DYNAMICS OF SURTSEYAN VOLCANOES: STUDY CASES FROM BLACK POINT AND PAHVANT BUTTE, WESTERN USA

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Surtseyan eruptions are shallow underwater to emergent explosive eruptions that involve contact between magma and surface water (e.g. lakes or oceans). They have potential to threaten shoreline communities and affect the local fauna, both at the onset of the eruption (i.e. subaqueous eruption) and/or as the eruption proceeds and reaches the water surface (subaerial eruptive material transported by winds or remobilised).

One of the most common methods to study volcanic eruptions is to analyse their deposits. Modern subaqueous deposits are, however, expensive to study and typically lack cross-sectional exposures, whereas older uplifted ones have commonly suffered alteration and/or tectonic deformation. Here we report results from two relatively young (~15 ka), partly dissected, Surtseyan volcanoes, Black Point, California and Pahvant Butte, Utah. These volcanoes formed in now-drained Pleistocene lakes and are ideal examples of well-preserved shallow to emergent explosive basaltic volcanoes.

Some past works have confined the "Surtseyan style" of such eruptions to activity visible at the surface, but we aim to infer the eruption dynamics of Surtseyan eruptions from their onset, including both subaqueous and subaerial deposits, correlated through geochemical variations and textural ones. For Black Point and Pahvant Butte, we assess whether the subaqueous parts of the eruptions are represented in distal lake-deposited ash, or whether that ash was initially distributed only during subaerial phases of eruption.

Energy-dispersive X-ray spectroscopy has been carried out on samples from different stratigraphic sequences for Black Point and Pahvant Butte to analyse sideromelane glass for samples from proximal, medial and relatively distal deposits. We find that the geochemistry differs for subaqueous proximal versus subaqueous distal deposits for Black Point and Pahvant Butte. This suggests that the distal ash was not formed during the same part of the eruption as was the main subaqueous-to-emergent deposits forming the volcanic edifices.

DETAILED TEPHROSTRATIGRAPHY AS A TOOL TO DEVELOP A MULTI-HAZARD MODEL FOR MT. RUAPEHU, NEW ZEALAND

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Volcanic hazards are among the most lethal natural hazards in the world and can potentially pose enormous threat to life and economy. Traditionally, volcanic hazards and their underlying physical processes are studied in isolation. However, recently observed eruptive episodes have shown that a wide range of eruption scales and styles can occur throughout a multi-stage multi-hazard eruption. Frequently active andesitic composite volcanoes such as Mt. Ruapehu in New Zealand are particularly notorious for sudden changes in eruptive behaviour and dynamics. This leads to a broad spectrum of related hazards and may result in a high degree of unpreparedness. Despite extensive studies on Ruapehu's eruptive history, the dynamic evolution within an eruption episode and thus the relationships between hazards are not entirely understood yet.

This research aims at providing a high-resolution multi-hazard record for the late Holocene eruptive record of Ruapehu. This will be achieved by creating a framework of proximal-medial tephra sequences which can be related to other concurrent deposits, both explosive and effusive in origin. Here, we will show how a detailed characterisation of depositional units can be used to distinguish between single eruptive events and multi-stage eruptions and how to define sequence, number, magnitude and style of eruptions within an episode. Our preliminary results suggest that the eruptive history of the past few thousand years is much more complex

than previously thought. Earlier defined nineteen tephra fall members represent multi-stage eruption episodes rather than previously assumed single events. At least ten additional multi-stage eruption episodes have been identified, increasing the existing eruption frequency by nearly an order of magnitude. These multi-stage eruptions involve a broad range of phreatomagmatic to dry magmatic eruption styles and slightly different groundmass glass compositions. These patterns form the basis for on-going analyses that aim at better constraining the dynamics of Ruapehu's source-conduit-vent system.

CAUSAL LINKS BETWEEN GEOLOGY AND THE SUBSURFACE GEOMETRY OF A GEOTHERMAL RESERVOIR

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The geometry of a geothermal reservoir dictates the exploitable resource volume and therefore influences the scale of sustainable power development. That geometry is typically illustrated by a conceptual model and is primarily defined using a pattern of natural state isotherms. Prior to drilling, surface exploration sets out to constrain the reservoir geometry even though the shape is highly uncertain. Subsequently, it is useful to develop a range of alternative models that fit the available data and to use well-defined reservoirs as analogues. The uncertainty associated with reservoir geometry will, however, remain significant until it is

extensively drilled, so considering alternative geometries is also an aspect of ongoing resource capacity assessment and makeup well targeting.

We present initial results of research that uses case histories to define the geometry of reservoir permeability in relationship to the geologic architecture. The results are presented as a continuum that may be used as a practical tool for developing alternative conceptual models. This work highlights causal links between the geologic architecture and geothermal reservoir permeability, and we discuss two examples in detail: structures (faults & fractures) and intrusive rocks. These links highlight the value of investing in quality local and regional geologic mapping during exploration, as well as clearly communicating geologic model uncertainty during all development stages.

IMPROVED FOCAL MECHANISMS OF SEISMICITY PERTAINING TO SHALLOW SLOW SLIP IN THE NORTHERN HIKURANGI

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Slow slip events (SSEs) on the northern Hikurangi are commonly associated with increased seismicity rates, yet limited network azimuthal coverage for offshore earthquakes means source properties, such as focal mechanisms, are difficult to constrain. Here,

we utilize >20 ocean-bottom seismometers and pressure sensors deployed as part of the Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip (HOBITSS) experiment (May 2014 – June 2015), to offer improved constraints on focal mechanisms of earthquakes during the deployment. This network recorded a shallow M_w 6.8 SSE in September-October 2014, and hence allows analysis of both microseismicity and earthquakes $M > 4$ pertaining to the onset, development and shutdown of slow slip.

Specifically, we focus on 14 well-constrained events of magnitude > 3 to demonstrate the improved coverage provided by OBS stations, and to optimise a non-linear location procedure using a 3D velocity model. We then implement a Bayesian method to constrain focal mechanisms using improved take off angles, and compare our results with other approaches. We extend the workflow to re-locate many more microearthquakes, and estimate focal mechanisms for events as small as $\sim M_{1.5}$ occurring within the network. Earthquakes exhibit a range of mechanism types, dominated by dip-slip events in the subducting Pacific plate, with strike-slip events occurring in both the Australian and Pacific plates. Preliminary coarse stress inversions of focal mechanisms indicate large-scale margin-parallel contraction consistent with previous Hikurangi and global subduction zone studies.

VARIABLE PARTIAL MELTING AS A CONTROL ON THE FORMATION OF ANOMALOUS BASALTIC ACHONDRITES

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Meteorites are an invaluable archive of

geochemical information. Generated in Solar System forming environments, meteorites preserve a direct record of planetary accretion and differentiation. 4 Vesta is a rocky protoplanet and the second largest body in our Solar System's asteroid belt. Vesta generates a vast number of meteorite fragments – the Howardite-Eucrite-Diogenite (HED) suite – through which its formation has been extensively studied. In this study, analysis of five eucritic meteorite samples has revealed the role of partial melting as a control on their formation. Of particular interest was an anomalous eucrite-like sample, the genesis of which and relationship to the HED parent body has remained inconclusive. The trace element composition of the five basaltic achondrites samples was investigated using LA-ICP-MS. Trace element data was used to aid in interpretations of asteroidal magmatism. Preliminary results suggest that the genesis of the full suite of meteorites analysed within this study can be explained by variable degrees of partial melting on the HED parent body Vesta. These results have implications for current differentiation models that have been proposed for the asteroid. Previous works have suggested that the presence of the anomalous samples can only be explained by the involvement of another parent body. These results challenge that assumption.

VARIATIONS IN FAULT-ZONE ARCHITECTURE IN A WELL-BEDDED SEQUENCE

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Fault zones comprise clay-rich fault rock and associated minor faults. The widths of fault zones and fault rock generally increase with displacement, but often display significant variation. Here we quantify variations in fault-zone geometry and examine the controlling factors in a well-bedded turbidite sequence. The research was conducted on normal faults with displacements of 0.001 – 70 m that disrupt Miocene (~7.5-11 Ma) interbedded sandstones and mudstones of the Mount Messenger Formation in Taranaki, New Zealand. These rocks are poorly lithified, with a maximum burial of ~1500m, and sand-sized particles dominated by ~55-80% lithic grains.

Fault analysis was conducted using a combination of outcrop-scale measurements along faults at spacings as small as 5 cm, thin sections, SEM images and laser sizer analysis. These data provide information on fault processes from individual grains (~0.1-350 μm) to cliff scale (10-20 m). Fault-rock and fault-zone thicknesses vary by up to three orders of magnitude for a given displacement and at short distances (2-10 m). These variations partly reflect the role of stratigraphy on the generation of fault rock and minor faulting adjacent to the primary slip surface. Cataclasis of sandstones and smear of mudstones are the primary mechanisms for fault rock generation, with the dominant mechanism being dependent on bed grain-size and displacement. Fault zones are widest and have the highest densities at fault intersections, bends and segment boundaries, the location of which may be influenced by mechanical heterogeneities. With increasing displacement these asperities are continuously removed resulting in increases in fault rock thickness, the densities of minor faults and strain localisation.

**EVOLUTION OF MAGMATIC VOLATILES
DURING DRILLING INTO A MAGMA BODY,
KRAFLA ICELAND**

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In 2009, the Iceland Deep Drilling Project (IDDP-1) borehole unexpectedly intercepted a silicic (76.5% SiO₂) magma body at a depth of approximately 2.1 km. Glass samples quenched in the drilling mud were directly sampled at regular (~15 minute) intervals throughout the time the magma was intercepted, providing a unique opportunity to investigate the behaviour of magmatic volatiles and bubbles during rapid decompression and freezing of a magma body. During decompression, volatiles diffuse through the magma and exsolve into growing bubbles. Conversely, pressure increases or temperature decreases can cause volatile species to diffuse back from bubbles into the surrounding melt. These processes should create distinct diffusion gradients in magmatic glass surrounding the bubbles. Synchrotron radiation Fourier transform infrared spectroscopy (SR-FTIR) was used to generate maps of H₂O and CO₂ absorbance in each sample. Using these maps average H₂O and CO₂ concentrations were obtained allowing the evolution of H₂O and CO₂ after the magma had been intercepted to be examined. In addition, transects around bubbles will be extracted to examine whether H₂O and/or CO₂

diffusion profiles developed, and if so how they responded with time.

Preliminary results show that average H₂O contents in the glass samples increase with time from 1.58 to 2.57 wt%. This suggests variable degassing in response to the interception of the magma body by drilling and/or subsequent rise of magma up the drillhole. Detailed examination of the textures and volatile contents and their distribution in conjunction with pressure data recorded during drilling will be used to constrain this further.

**BEDROCK EROSION BY HYDRAULIC
PLUCKING: EXPERIMENTS AND
IMPLICATIONS**

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Bedrock channel erosion by plucking—the wholesale removal of bedrock blocks from a channel bed—is likely the dominant non-glacial driver of incision into topography over both short and long timescales. However, the process is poorly understood because it is difficult and often dangerous to observe and measure in the field. As such, plucking is mostly understood through engineering or physical/numerical modelling studies.

Results are presented from a study conducted in an experimental flume using Plaster of Paris model bedrock tiles, and from a field study in which a bedrock block was instrumented with pressure and motion sensors. The flume study, inspired by existing modelling studies, investigates the roles of block geometry, protrusion factor, and pressure fluctuations in the plucking process. The field study examines the influence of pressure pulse transmission through the joint network in fractured bedrock; engineering studies inform the influence of pressure pulse transmission through joint networks of concrete blocks from impinging jets, and it is likely that the same phenomenon contributes to plucking in natural channels with jointed bedrock.

Our flume experiments reveal that blocks can be plucked in the absence of protrusion, and that plucking of blocks is most likely to occur near the upstream end of a hydraulic jump. We propose that the mechanism driving block uplift is a pressure gradient in the sub-bed crack network generated by a hydraulic jump, and that transient pressure fluctuations from turbulence trigger plucking. This suggests that the presence of bedrock steps and step-pool systems, which cause hydraulic jumps at high flow rates, may increase the ability of the stream to incise bedrock when the entry Froude number is high enough that the jump lies above bedrock.

USING ITRAX ELEMENTAL DATA TO DETECT TSUNAMI PULSES IN THE LANDSCAPE: A CASE STUDY AT LITTLE PIGEON BAY, NEW ZEALAND

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High resolution ITRAX elemental data has previously been used in conjunction with other proxies (e.g. sedimentary, palaeontological, contextual) in tsunami sediment studies to identify potential palaeotsunami deposits in the geologic record. Raw ITRAX data has inherent uncertainties associated with organic dilution and matrix effects (e.g. grain size, moisture content, surface roughness). For sediments with large fluctuations in organic content, it is necessary to normalize the raw element data against a conservative element to account for organic dilution as well as assess changes in elemental inputs to the lithogenic fraction of the sediment. Previously presented ITRAX results in the tsunami deposit literature have not adequately accounted for organic dilution, resulting in potentially non-representative results. Here we use sediment cores containing high organic content variability as well as deposits of the 2016 Kaikōura Tsunami at Little Pigeon Bay, Banks Peninsula, to demonstrate that normalization of ITRAX element data against aluminium (Al) provides an effective filter for organic dilution in the dataset. This yields results that are more representative of the lithogenic component of the sediment and which are more reliable for tsunami interpretation compared with normalization against other elements. We show that the 2016 Kaikōura Tsunami deposit has a distinct elevated elemental pulse relative to pre-tsunami-inundation soil at this site. This provides a benchmark for identifying similar pulses in the geologic record which could be associated with older tsunami and/or other extreme coastal inundation events (e.g. storms). We discuss the implications of these findings as well as provide directions for further research.

**MAFIC INPUTS INTO THE RHYOLITIC
MAGMATIC SYSTEM OF THE
2.08 Ma HUCKLEBERRY RIDGE TUFF,
YELLOWSTONE**

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The Yellowstone Plateau volcanic field (YPVF) is the modern focus of the Yellowstone-Snake River Plain (YSRP) province. The bimodal YSRP has mantle-derived olivine tholeiites providing the thermal and volatile fluxes to generate the voluminous rhyolites. However, and in contrast, volumetrically minor trachybasalts and trachyandesites represent a contrasting Craters of the Moon (COM) suite. COM eruptives generally occur at the YSRP margins and are interpreted to represent small-volume magmas derived by mid-crustal extreme fractionation of a tholeiitic parent.

The ~2,500 km³ caldera-forming Huckleberry Ridge Tuff (HRT), the earliest voluminous rhyolitic YPVF product, consists of initial fall deposits, then three ignimbrite members (A, B, C), with fall deposits between B and C. The HRT was temporally bracketed by eruption of YSRP olivine tholeiites from an area spanning the subsequent caldera. Previously identified scoria in ignimbrite B, and newly identified juvenile mafic material in ignimbrite A are compositionally overlapping, with 49.3-63.3 wt% SiO₂, Ba to 3500 ppm and Zr to 1850 ppm. These HRT materials define a third mafic suite, parallel to but offset to higher Ba from that defined by the younger surficial COM lavas west of the HRT caldera. We present major, trace and isotopic data from all three mafic suites, which temporally bracket the HRT eruption. We compare our data with those from other COM lavas and evaluate published models for their petrogenesis. We propose

that the HRT mafic suite, despite being erupted in close spatial and/or temporal proximity to olivine tholeiites, is sourced from contrasting, heterogeneously enriched portions of the sub-continental lithospheric mantle. The enrichment was by solute-rich fluids/partial melts derived from the underlying Farallon slab in a Cretaceous high temperature, high pressure regime. Our data highlight the magmatic complexities of the mafic roots beneath the voluminous Huckleberry Ridge rhyolitic magma system during the initiation of the YPVF.

**HYDRO-ACOUSTIC AND SHALLOW SEISMIC
REFLECTION DATA FROM THE
CANTERBURY SHELF – THE MARCAN
PROJECT**

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The MARCAN project is a 5-year project funded by the European Research Council that addresses the hypothesis that topographically-driven meteoric groundwater plays a key role in the geomorphic development of passive continental margins. The objectives of the project are a) to define the characteristics and dynamics of topographically-driven meteoric groundwater systems in passive continental margins and b) to test the hypothesis that topographically-driven meteoric groundwater is an important geomorphic agent in passive continental margin.

One of the project's two study areas is the

Canterbury margin, offshore the eastern South Island of New Zealand. This site has been selected because it is representative of siliclastic margins (the most prevalent type of passive continental margins worldwide) and because it is thought to host the shallowest offshore freshwater reservoir.

On *R.V. Tangaroa's* voyage TAN1703 in April 2017, a vast amount of data was collected in the shallow part of the Canterbury Bight. The data set comprises of multi-channel seismic reflection data (MCS), sub-bottom chirp data (SBP), multibeam echosounder bathymetry (MB), backscatter data (BS) and water column data (WCL), controlled-source electromagnetic data (CSEM), CTD profiles, seafloor imagery from CoastCam (CC), and sediment cores. These data will be used to investigate potential offshore aquifers on the Canterbury Shelf. In particular, we will characterise the geometry and distribution of the offshore groundwater reservoir using the CSEM data and generate a 3D model of the shelf stratigraphy and structure using MCS and SBP data. Sites of groundwater seepage will be identified from MB, BS, WCL, CTD data, imagery, and pore water chemistry. Sedimentological, geotechnical and hydraulic properties of seabed sediment will be determined using the sediment cores.

Here we will present data and first results from the hydro-acoustic and shallow seismic reflection data acquired during TAN1703.

MINERAL CHEMISTRY OF PRE-CALDERA MAGMA SYSTEMS IN JEMEZ MOUNTAINS VOLCANIC FIELD, NEW MEXICO, USA

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Caldera-forming eruptions are the largest types of volcanism known. This study concentrates on understanding how such large volumes of magma accumulate to cause such events. We use the example of the Jemez Mountains volcanic field in the USA, which produced two enormous eruptions resulting in ~780 km³ of deposits at 1.6 Ma and 1.2 Ma. Prior to these caldera-forming eruptions, the volcanic field experienced a long period of smaller eruptions in two phases from >13-7 million years and 5-2.7 million years. Mineral chemistry is used to estimate the physical conditions and processes of magma accumulation in the crust in build up to the major eruptions.

Electron microprobe analysis was used to investigate the in-situ chemistry of plagioclase and amphibole mineral grains. Amphibole thermobarometry (Ridolfi and Renzulli, 2012) indicates that there were three major magma reservoirs at different crustal depths in the 5-2.7 million year system (i.e., Reservoir 1 at 16-18 km, Reservoir 2 at 7-14 km, and Reservoir 3 at 3-5 km). Mixing of amphiboles crystallized in Reservoir 2 and 3 is commonly observed, suggesting that Reservoir 2 was feeding the shallower Reservoir 3. Reservoir 1 and 2 hosted magma mixing as additionally revealed by compositional variation (mafic enclaves within dacitic hosts). The older 13-7 million year system extended up to a depth of 8 km and was subsequently overlapped by

Reservoir 1 and 2 of the younger phase. Diversity in plagioclase textures further reflects a range of complex magma processes occurring in reservoirs of both magma systems. Disequilibrium textures may represent a range of processes including mineral migration between reservoirs and potentially magma recharge episodes.

The first results of this work are already showing how the development of magmas to feed very large caldera-forming eruptions may involve the amalgamation and rejuvenation of older diverse and spatially separated magma systems.

VOLCANISM IN THE OFFSHORE TAUPO VOLCANIC ZONE

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The Taupo Volcanic Zone (TVZ) is one of the most active silicic volcanic systems on Earth, yet the geology and volcanic history of its offshore continuation (OTVZ), remains virtually unknown. This lack of knowledge is a fundamental gap in our understanding of the origins and architecture of the TVZ, its northern continuation into the Kermadec arc, and its evolution from the Miocene-Pliocene

arc structure. This knowledge gap also applies to any potential volcanic hazard that this region may pose to continental New Zealand.

To ascertain the extent and style of volcanism in the OTVZ (which accounts for nearly half the areal extent of the TVZ) an extensive sampling and acoustic survey of the OTVZ was conducted in October 2015 during a research voyage (SAMSARA) of the RV *Tangaroa*. The survey was focussed on knolls and depressions northwest of White Island, and included seismic and magnetic surveys along the length of the Motiti Graben and the Tauranga Trough.

Dredge sampling recovered a diverse range of volcanic samples, from mafic to silicic. The region centred on Matatara Knoll, between 700 and 2000 mbsl, is characterized by dense rhyodacite/rhyolitic material and pumice, a large dome (Matatara) composed of dome-building dacite overlain by pumice deposits up to 100 m thick, three mafic cones up to 500 m high and a potentially extensive hydrothermal deposit. To the southeast lies a 2-km-wide caldera-related structure (Mahina knoll) composed of porphyritic felsic lava and altered pumice, and a number of volcanic domes, composed mostly of silicic material, although at least one is mafic.

We present geochemical, seismic and magnetic data of this previously little-surveyed region. Together the data show the OTVZ to consist of dominantly silicic volcanic products, but with minor mafic and hydrothermal material, that collectively highlight the extensive recent volcanic activity that this region has seen.

THE PIGROOT DUALITY: AN EXPERIMENTAL ANALYSIS OF THE PIGROOT PHONOLITE

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Phonolite is a type of alkaline magma occurring in intraplate volcanic settings. Despite its SiO₂ and alkalis (Na + K) rich nature, which implies some degree of chemical evolution, some occurrences host mantle xenoliths. This is contrary to genetic models that assume phonolite evolution at shallow crustal depths. This project aims to characterise the dynamic conditions of magma evolution of the peridotite xenolith-hosting Pigroot phonolite within the Miocene Waipiata Volcanic Field, New Zealand. This volcanic centre consists of a basal tuff layer, pillow lava and overlying lava flows. The eruption products range compositionally from tephrite to *sensu stricto* phonolite, with peridotite xenoliths being present in all rocks. Analysed samples find that mineralogy consists of a variety of K-feldspars including microcline and anorthoclase, as well as olivine and volcanic glass.

A piston cylinder experimental apparatus will be utilised to simulate the pre-eruptive magma storage conditions that generated the chemical variation in the Pigroot phonolite. The project aims to determine the sequence of crystallisation at a variety of pressures and temperatures to investigate phase relations in the host magma. These will be compared to those in the natural samples to gain greater understanding of mechanisms controlling alkaline magma evolution to phonolite composition and magma genesis in intraplate settings.

MONITORING TEMPORAL VELOCITY CHANGES AT WHITE ISLAND VOLCANO USING SEISMIC AMBIENT NOISE

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Forecasting volcanic eruptions is a fundamental aim of volcanology. Crucial to this is the ability to detect rising magma or the disturbance of a pre-existing shallow chamber. Over the past decade, significant improvements have been made towards detecting small velocity changes around volcanoes by cross-correlating ambient seismic noise. This involves measuring fluctuations in the travel time of repeatedly-generated seismic energy along a path between two receivers. Such temporal variations carry information about the stresses and fluids present within hydrothermal and magmatic systems. Additionally, the approach benefits from the production of continuous data, offering application towards real-time monitoring. In this study, we further test the technique at White Island, using noise recorded between 2007 – 2017. The volcano represents an excellent case study, where a new stage of eruptive activity began in 2012 following a decade of inactivity. Thus we are able to investigate velocity changes during quiescent, inter-eruptive and eruptive periods. Ten station-pairs are used, consisting of five onshore broadband stations around the Bay of Plenty region and two located on White Island. This provided an opportunity to assess the capability of resolving coherent noise between onshore and offshore stations, with implications for global monitoring of volcanic islands. Preliminary results show clear decreases in velocity of 0.1 – 0.2 % during the two-to-three weeks prior to three eruptions,

recorded by the majority of station-pairs. In addition, long-term velocity trends are identified in the four-to-five months leading up to and following two eruptions in 2016. Further work will therefore focus on identifying why not all eruptions exhibit the same precursory signals and investigating the characteristic differences between active and inactive periods at White Island.

THE STRAIN SEGMENTATION AT THE SUMATRA SUBDUCTION ZONE BASED ON GPS-DERIVED INTERSEISMIC COUPLING

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A total of 164 continuous GPS position time series from 142 unique GPS locations in six different countries were combined to examine changes to fault segmentation during a series of earthquakes that occurred on the Sumatra trench between 2004 and 2012. These events include the 2004 M_w 9.0 Aceh, the 2005 M_w 8.6 Nias, the 2007 M_w 8.5 Bengkulu and the 2012 M_w 8.6 Wharton Basin earthquakes. For the first time, the far-field GPS sites (more than 500 km) are used to examine the elastic strain from stress build up on the thrust-type subduction zone. The inversion of GPS velocity along the western margin of the Sundaland plate is used to estimate the interseismic coupling distribution on the subduction zone interface underneath the Sunda trench, as well as the kinematics of the tectonic block rotations. The analysis agrees with previous studies that the Sunda megathrust is segmented, whereby this characteristic will lead to the potential of multiple earthquake cycles. The comparison of three sets of velocity fields: prior-2004, between 2005.2-2012.2, and after 2012.2; indicates a change of state from partially to fully coupled (prior-

2004), followed by freely slipping in a different part of fault segment. The latest interseismic velocity suggests that both segments ruptured during the 2005 and 2007 earthquakes are now partially coupled to freely slipping. However, the best fitting model shows that the Siberut segment of the megathrust (0.5–2.0°S) remains fully coupled throughout three interseismic periods. Hence, the results of this study support the present-day understanding of the interseismic coupling of the subduction zone where it varies with time.

TEMPORAL VARIATIONS IN SEISMIC ANISOTROPY DURING THE 2014 GISBORNE SSE, NEW ZEALAND

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In October 2014, a 2-week long slow slip event (SSE) occurred near Gisborne at the northern Hikurangi Margin, New Zealand. It was recorded by offshore instruments, deployed by the Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip (HOBITSS) project. This study uses data compiled from May 2014 to July 2015, recorded on 15 HOBITSS ocean bottom seismometers as well as 12 Geonet stations around the time of this uniquely recorded SSE. We use the S-wave splitting technique to detect stress and fluid changes associated with slow slip. The shear wave splitting fast polarization direction is often

inferred to represent the maximum horizontal stress directions (SHmax) in crustal studies and has been shown to vary temporally at volcanoes and in association with large earthquakes. Using Multiple Filter Automatic Splitting Technique (MFAST) we analyse more than 3000 local earthquakes to look for temporal changes in S-wave fast polarization directions and delay times during the Gisborne 2014 SSE. Because S-wave splitting results are sensitive to variations in earthquake locations, we also analyse results from individual spatial earthquake clusters to test the robustness of temporal changes and to better indicate where the measured anisotropy originates. The mean fast directions in the area show a NE-SW trending fast polarization direction similar to local SHmax directions mapped by previous studies and to local fault trends. Preliminary SWS results at LOBS stations show approximately 5-10 degrees of change in fast polarization direction from before to after the SSE. We also observe increased delay times (~ 0.5 seconds) occurring around the time of the SSE with a slow decrease in delay time in the following months. We hypothesize an initial movement of fluids in cracks due to changes in stress during the SSE, followed by a relaxation period where cracks slowly return to their previous state.

**INSIGHTS INTO THE PETROGENESIS OF
TAUPO VOLCANIC ZONE BASALTS FROM U-
SERIES ISOTOPE ANALYSIS OF WHOLE
ROCKS, GROUNDMASSSES, AND MINERALS**

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The Taupo Volcanic Zone (TVZ) is a back-arc continental rift zone within the North Island of New Zealand, and extends from White Island in the Bay of Plenty southwards to the Tongariro Volcanic Centre. Extension rates vary from >12 mm yr⁻¹ in the North to < 7 mm yr⁻¹ within the Tongariro graben in the south. The central TVZ is characterized by high magma production rates (> 10,000 km³ since c. 2 Ma), with 95% erupted as rhyolites and less than 1% as basalts. However, mafic magmas are thought to be the heat source for the extensive crustal melting that produces felsic eruptives, and thus the rates and processes of mafic magma production are critical in our understanding of all magmatism within the TVZ. We have sampled 7 Late Pleistocene to Holocene basaltic eruption products from Rotokawau in the North to Waimarino in the South, and have separated groundmass, olivine, pyroxene, and plagioclase, for U-series (²³⁸U-²³⁴U-²³²Th-²³⁰Th) isotope work, targeting the timescales of crystallisation and how these may or may not vary with extension rates within the TVZ. Preliminary U-series data provides some insights into the complex petrogenetic processes operating in the genesis of these basaltic magmas, indicating the uptake of hydrothermally altered crystal cargo in ²³⁴U-²³⁸U disequilibrium into ascending basaltic arc melts prior to their eruption. Ultimately, our work will provide important insights into the timescales of mafic melt ascent from mantle source to surface within the TVZ.

EXPLORING THE GEOCHEMICAL SIGNATURES OF GROWTH AND COLLAPSE OF TARANAKI VOLCANO

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New Zealand's long-lived stratovolcanoes such as Taranaki, Tongariro and Ruapehu, exhibit some of the best long-term record of growth and destruction. This research attempts to find answers for one of the interesting questions of volcanic hazards by finding the relationship between magmatic behaviour prior and after volcano destruction and growth phases. Geochemical techniques could lead us to understand more the magmatic response to the pressure releases and changes pre- and post-debris avalanche events. Residence times can be determined by modelling and examining the diffusive equilibrium of major, minor and trace elements using several geochemical measurements, such as ICP-MS, Ion Probe and Sr - Mg diffusion patterns across selected crystals.

The ring plain deposits of Taranaki/Egmont Volcano contains volcanoclastic deposits representing a continuous record of the evolution of the volcano's fourteen collapse and growth phases. Initial field investigations have focused on deposits in-between the Te Namu (29 ka) and Rama (>35 ka) debris avalanche deposits. This time range partially represents volcanoclastics associated with the Opunake Fm. The Opunake Fm provides a well preserved sequence of lahars (hyperconcentrated flows – debris flows) that represent a substantial growth phase of Taranaki. The hyperconcentrated flow deposits are unique in that they contain relatively well preserved pumice rich clasts (<5

cm in size) indicating eruptive material that has been rapidly remobilised after a significant eruptive phase.

After investigating the stratigraphy of the lahars of Opunake Formation, we intend to correlate tephras with these lahars in the area. Examining the petrology and chemistry of the pyroxene and plagioclases, that are abundant in these pumiceous clasts from the layers of lahars, may provide suitable candidates to determine crystal residence times between that may provide insights into the magma progression and eruptive phases of this growth phase.